



TOLANI MARITIME INSTITUTE, PUNE

Institute of Marine Engineers (India) Student Chapter, TMI, Pune

Institute of Marine Engineers (India), Pune Branch

and

In association with

and

The Institution of Engineers (India), Pune Local Centre

proudly presents All India Seminar

TRANSTECH'25

4 TO 6 MARCH 2025

A common platform for engineering students to present technical papers on

THEME

BLUE ECONOMY 4.0: HARNESSING INNOVATION FOR A SUSTAINABLE MARITIME FUTURE

SUB THEME

HUMAN FACTORS AND SKILL DEVELOPMENT



INNOVATIONS IN NAVIGATIONAL AIDS



DIGITALIZATION, IOT AND ML



ADVANCEMENTS IN LOGISTICS



SHIP DESIGN AND NAVAL ARCHITECTURE



**ENTREPRENEURSHIP DEVELOPMENT
IN SHIPPING**



**INNOVATIVE IDEAS FOR ENVIRONMENT
PROTECTION**



**RESEARCH AND DEVELOPMENTS IN
RENEWABLE ENERGY**



BOOK OF PROCEEDINGS

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MESSAGE

The metaphor of shipping, highlights the transportation of cargo safely, without any damage and without any delay. The context has an additional dimension of sustainability, which has three core concepts: economic, environmental, and social. This core objective of shipping is to be understood by every individual choosing the profession of shipping. All compliments on board directly contribute to meeting this objective. This objective shall be the prologue of any Maritime Training Institute.

The means to achieve these objectives have been honed with the advent of technology. Industrial revolution 4.0 aims to digitalise technology and further hone the objective. The shipping aspirants shall need to understand this objective and work towards it.

Transtech, over the last decade, has dealt with innovative topics and brought many students from different academic institutions across the country to come together and share their ideas. These ideas have evolved in technical paper presentations, demonstrating models and interaction with experts from the industry. Transtech 25 will introduce IOT based models and I am sure this will pave the way for the students to be familiar with digitalisation and understand the advantages of it.

The rock-steady support from the prestigious professional bodies, namely The Institution of Engineers (India), Pune Local Centre and The Institute of Marine Engineers (India) Pune Branch, is praiseworthy and multiplies the importance of the event. The Institute Innovation Council and TMIAN are the new path guiders for Transtech 25 and I welcome them on behalf of all at TMI.

I take this opportunity to extend my best wishes to Dr. Dhiren Dave and his organizing team for successfully organizing this 18th edition of Transtech.

Let us come together, think together and grow together!

Dr. Sanjeet Kanungo

Principal

The Institution of Engineers (India)

(Established: 1920 - Incorporated by Royal Charter: 1935)

"A Century of Service to the Nation"

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IEI-PLC Chairman's Message

It is a matter of immense pleasure to note that Tolani Maritime Institute, Induri in association with The Institution of Engineers (India), Pune Local Centre and The Institute of Marine Engineers (India), Pune Branch is organizing Annual Seminar for Students "TRANSTECH'25" on the Theme "Blue Economy 4.0: Harnessing Innovation for a Sustainable Maritime Future" during March 4 to 6 March, 2025. The theme of the seminar is very appropriate. Transtech presents a common platform for engineering students to present technical papers on varied topics of interest. It encourages the young generation of engineers to delve into numerous activities such as paper presentation and research work, thereby empowering them with a razor-sharp thinking ability.

Transtech aims at providing an apt forum for such laudable pupils to bring out the best in them, thus leading them towards reaching the top echelons of any industry. Shipping already has been experiencing the application of new technology by adapting Industry 5.0 revolution. Digitization is no exception in the world shipping. Automation, Artificial Intelligence (AI), Machine Learning (ML), use of robots and unmanned systems in the operations are the immediate future in shipping world. As a result, people are getting tuned to the concept of technology driven, environmentally friendly, challenging and Clean ecosystem-based shipping.

I am sure and confident that during the seminar numerous emerging technologies will be discussed which will be helpful in creating tangible understanding so as to achieve Efficient and Effective Shipping. I wish the Seminar a grand success and extend my greetings to all concerned.

With Best Wishes

Er. Vasant Pandarkar
Chairman IEI-PLC

Shri Sanjeev D. Ogale
Chairman, Pune Branch
The Institute of Marine Engineers (India)
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MESSAGE

It is indeed a matter of great pride that **Tolani Maritime Institute** in the 27th Year is consistently working in association with "The Institute of Marine Engineers (India) Pune Branch" and "The Institution of Engineers (India), Pune Local Centre" in hosting "**Transtech 2025**" as a part of its Annual Event.

Transtech 2025 this year's theme focuses on the "**Blue Economy 4.0: Harnessing Innovation for a Sustainable Maritime Future**". This Theme will further encourage the students to do research work and empowering them with thinking ability.

"The Blue Economy represents a vital shift towards a sustainable maritime future, harnessing innovation to balance economic growth with environmental stewardship.

By embracing cutting-edge technologies, renewable energy sources, and eco-friendly practices, we can:

- ❑ Reduce marine pollution and protect biodiversity
- ❑ Promote sustainable fishing and aquaculture
- ❑ Foster resilient coastal communities and economies
- ❑ Enhance maritime safety and efficiency

Let's work together to unlock the potential of the Blue Economy, ensuring a healthier ocean and a more prosperous future for all.

The Institute of Marine Engineers (India), established in 1980 is the professional body of marine engineers in the country. It aims to promote the scientific development of Marine Engineering with exchange of ideas and co-operates with all Marine Training Institutions for the furtherance of education in Marine Engineering.

I am confident the theme will give the students the right direction in his or her pursuit of making Innovation for a Sustainable Maritime Future.

I wish the seminar a grand success and my greetings and compliments to all the organizing team.

Sanjeev Ogale
Chairman, Pune Branch
The Institute of Marine Engineers (India)

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SELF-HEALING SMART PACKAGING IN LOGISTICS WITH IOT

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ABSTRACT

Logistics is the backbone of global trade, ensuring efficient transportation. However, cargo damage, environmental factors, and lack of real-time monitoring leads to financial losses. Traditional packaging lacks resilience, increasing waste and delays. This paper proposes Self-Healing Smart Packaging, integrating self-healing polymers and IoT sensors for autonomous damage repair and real-time tracking. AI-driven analytics enhance predictive maintenance and supply chain transparency. This type of packaging offers a transformative solution to reduce waste, lower costs, and optimize shipping logistics.

KEYWORDS

Logistics, Smart Packaging, Self-Healing, IoT Sensors, Supply Chain

1. INTRODUCTION

Logistics plays a critical role in the global economy, ensuring the seamless movement of goods, services, and information across supply chains. From the manufacturing stage to the final delivery to consumers, logistics operations involve complex coordination of transportation, warehousing, inventory management, and distribution. Traditionally, logistics relied heavily on manual processes, paper-based tracking, and planning models. However, in recent decades, rapid advancements in technology have revolutionized logistics, making it more efficient, transparent, and cost-effective.

The global logistics market was valued at approximately \$10.41 trillion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 6.8% from 2023 to 2030. This growth is primarily driven by increasing demand for faster delivery times, globalization of supply chains, and digital transformation initiatives adopted by companies worldwide. Emerging technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), blockchain, robotics, and automation are at the forefront of this transformation

Packaging plays a crucial role in logistics, particularly in shipping, as it ensures the safety, efficiency, and cost-effectiveness of transporting goods. It involves selecting appropriate materials, design, and techniques to protect products from damage, contamination, and external conditions during transit.

2. FUNCTIONS OF PACKAGING IN SHIPPING LOGISTICS

A. Protection

Shields goods from physical damage (impact, vibration, compression), environmental factors (humidity, temperature, corrosion), and contamination.

B. Handling & Storage

Packaging design enables easy handling with forklifts, conveyors, and automated systems while optimizing warehouse space.

C. Transportation Efficiency

Reduces weight and volume while ensuring structural integrity, leading to lower freight costs and optimized container space.

D. Regulatory Compliance

Adheres to international shipping regulations, including hazardous material packaging, labeling, and documentation.

E. Branding & Information

Provides necessary details like handling instructions, expiry dates, and barcodes for tracking, while also enhancing brand visibility.

3. CHALLENGES IN PACKAGING LOGISTICS

Cost vs. Protection Trade-off: Balancing durability with material costs and weight considerations.

Compliance with International Regulations: Meeting diverse country-specific packaging laws, such as IMO (International Maritime Organization) guidelines for hazardous goods.

Supply Chain Complexity: Managing packaging across different transportation modes (air, sea, land) while maintaining efficiency.

To address these challenges, we introduce **SELF-HEALING SMART PACKAGING**—an innovative solution that combines self-healing polymers with IoT-driven condition monitoring. This system autonomously repairs minor damage and provides real-time tracking, impact detection, and predictive analytics, offering a resilient and intelligent packaging system for modern logistics.

3.1 Related work

The development of self-healing smart packaging with IoT sensors is an interdisciplinary

approach integrating material science, wireless sensor networks (WSN), AI-driven logistics, and blockchain security. This section reviews significant contributions in these domains.

4. SELF-HEALING MATERIALS IN LOGISTICS

Self-healing materials have been widely explored in industries such as automotive, aerospace, and biomedical engineering.

4.1 Microencapsulation Method

Brown et al. (2019) developed polymer-based microcapsules that rupture upon impact, releasing healing agents that react with the surrounding polymer matrix. This method has been effective for repairing small cracks and punctures in materials.

4.2 Nano-Engineered Self-Healing Polymers

White et al. (2021) introduced nanoparticle-infused self-healing materials, improving durability and enabling multiple repair cycles. Martinez et al. (2022) further optimized these materials by embedding graphene-based nanofillers, which enhance mechanical strength and thermal resistance.

4.3 Hydrogel-Based Self-Healing Coatings

Kim et al. (2023) demonstrated hydrogel-based coatings that allow moisture-induced healing, beneficial for pharmaceutical packaging and perishable goods transport.

5. IOT-ENABLED SMART PACKAGING IN LOGISTICS

The integration of Internet of Things (IoT) sensors in packaging has improved tracking, environmental monitoring, and security.

5.1 Real-Time Damage Detection

Gupta & Singh (2021) designed RFID and NFC-based packaging to track temperature, humidity, and pressure changes.

Lee et al. (2020) introduced impact detection sensors that alert logistics providers about package damage, but lacked a self-repairing mechanism.

5.2 Wireless Sensor Networks (WSN) in Supply Chain Monitoring

Fernandez et al. (2022) explored low-power Bluetooth and LoRaWAN sensors, enabling continuous cargo tracking over long distances.

Kumar & Rao (2020) emphasized AI-driven analytics for data processing and anomaly detection, optimizing predictive maintenance.

6. AI-DRIVEN PREDICTIVE METHODS IN LOGISTICS

6.1 Machine Learning in Shipping Logistics

Zhang et al. (2023) implemented AI algorithms to predict package wear and tear, reducing damage-related losses. Wang et al. (2022) combined deep learning with IoT sensors to forecast temperature fluctuations, preventing spoilage in cold-chain logistics.

6.2 Blockchain for Secure Logistics Tracking

Li & Chen (2022) proposed blockchain-integrated smart contracts that store tamper-proof package data, ensuring supply chain transparency

7. PROPOSED METHOD/MAIN CONTRIBUTION

The proposed SHSP (Self-Healing Smart Package) system integrates advanced technologies to enhance logistics operations, especially in shipping. By combining self-healing materials, IoT-based sensor networks, AI analytics, and blockchain security, it offers a robust solution for improving the durability, security, and efficiency of shipping packages.

7.1 Self-Healing Mechanism

The SHSP system leverages advanced materials with a self-healing capability to address damage sustained during transit. The main features of this mechanism include:

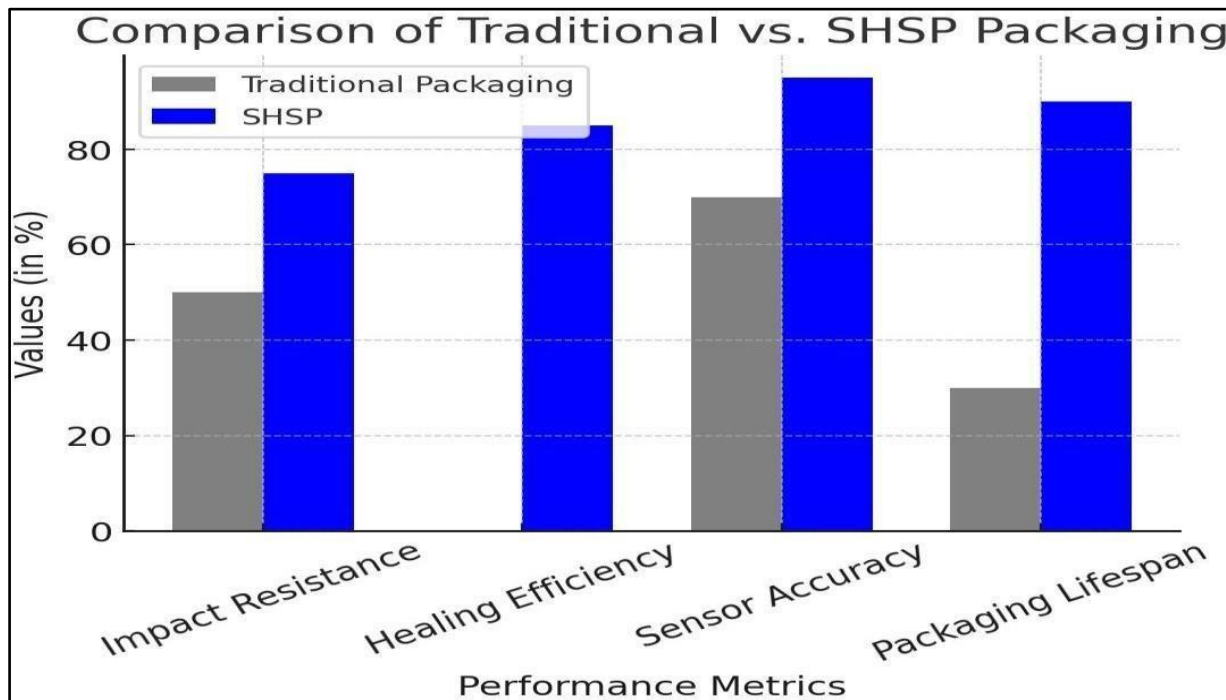
7.2 Microencapsulated Polymer-Based Healing Agents

Microcapsules embedded in the packaging contain healing agents, typically polymers or resins. When the package experiences external stress or impact, these microcapsules rupture, releasing the healing agents into the damaged area. This process effectively seals cracks or breaks in the package, restoring its integrity.

7.3 Hydrogel-Based Coatings

Hydrogel coatings on the surface of the packaging can also contribute to self-repair. These hydrogels are moisture-sensitive, meaning they activate in the presence of humidity or water, and can repair damage caused by environmental factors such as exposure to rain or humidity.

This self-healing mechanism significantly extends the lifespan of packaging, protecting sensitive goods from damage while in transit.



8. IOT SENSOR NETWORK

The SHSP system integrates a network of IoT sensors to monitor and report on various aspects of the package's condition during transit. These sensors collect real-time data to ensure the package is safe and handled correctly:

a. Impact Sensors

These sensors detect any sudden shocks or impacts that the package experiences, such as when it is dropped or mishandled. By detecting such events, the system can trigger an automatic response, such as activating the self-healing process.

b. Temperature & Humidity Sensors

These sensors track the environmental conditions that the package is exposed to, including temperature fluctuations and humidity levels. By monitoring these variables, the system can ensure that the goods inside the package are stored under optimal conditions and prevent any damage due to extreme temperatures or moisture.

8.2 RFID & GPS Modules

RFID (Radio Frequency Identification) tags and GPS modules are used to track the package's location in real

time. This enables precise monitoring of the package's journey throughout the supply chain and ensures it is routed efficiently. Additionally, this data can be used for inventory management and route optimization.

8.3 AI-Driven Analytics

The IoT sensors generate large volumes of data, which are processed using AI algorithms. The system can then analyze patterns to predict potential risks, such as excessive temperature changes or impacts, and generate alerts for maintenance or corrective actions. Predictive maintenance can be used to address issues proactively, reducing the likelihood of damage or delays.

9. SELF HEALING ACTIVATION MODEL

The self-healing process in the SHSP system follows an exponential growth model, which governs the healing efficiency over time. The healing efficiency at any time can be shown as:

$$H(t) = H_{\max} (1 - e^{-\lambda t})$$

Where:

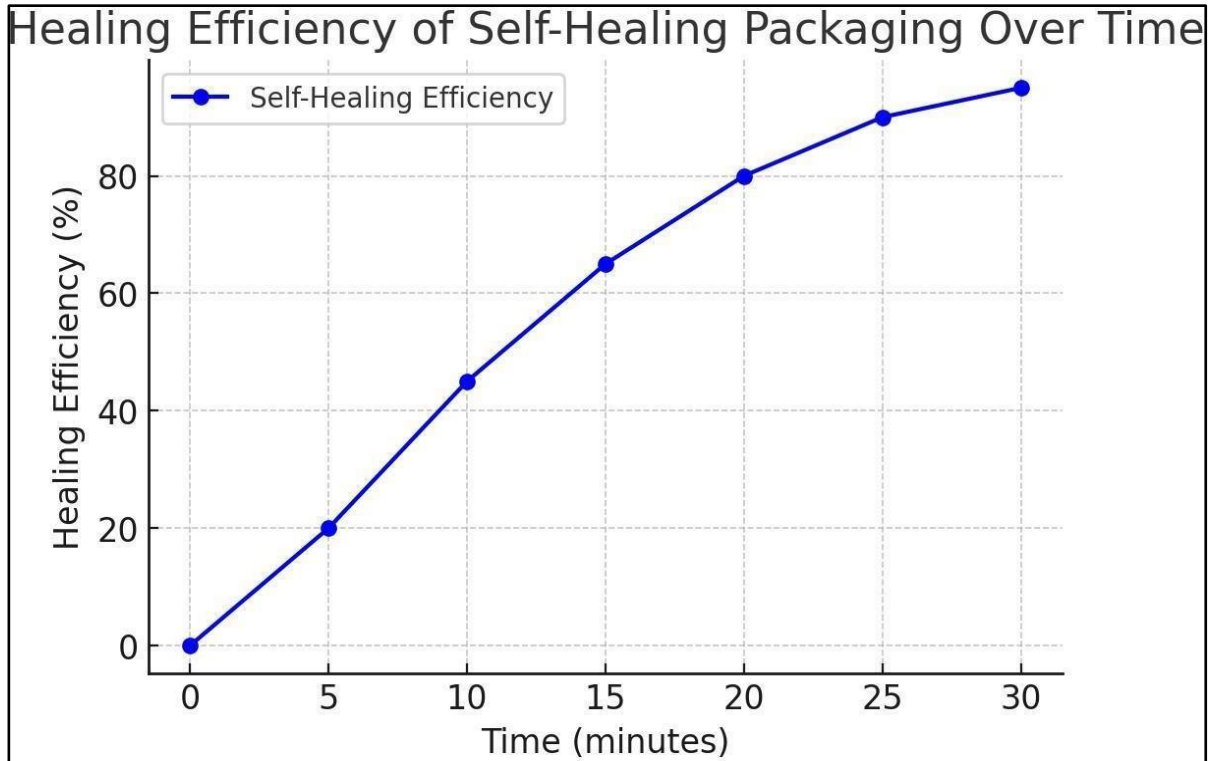
$H(t)$ is the healing efficiency at time

H_{\max} represents the maximum possible healing efficiency (the complete healing state),

λ is the healing rate constant (a parameter that determines how quickly the healing process takes place),

t is the time elapsed in minutes.

This model helps in predicting how effectively the self-healing process is progressing over time, ensuring that the damage is addressed quickly and efficiently as soon as it occurs.



10. BLOCKCHAIN AND SECURITY INTEGRATION

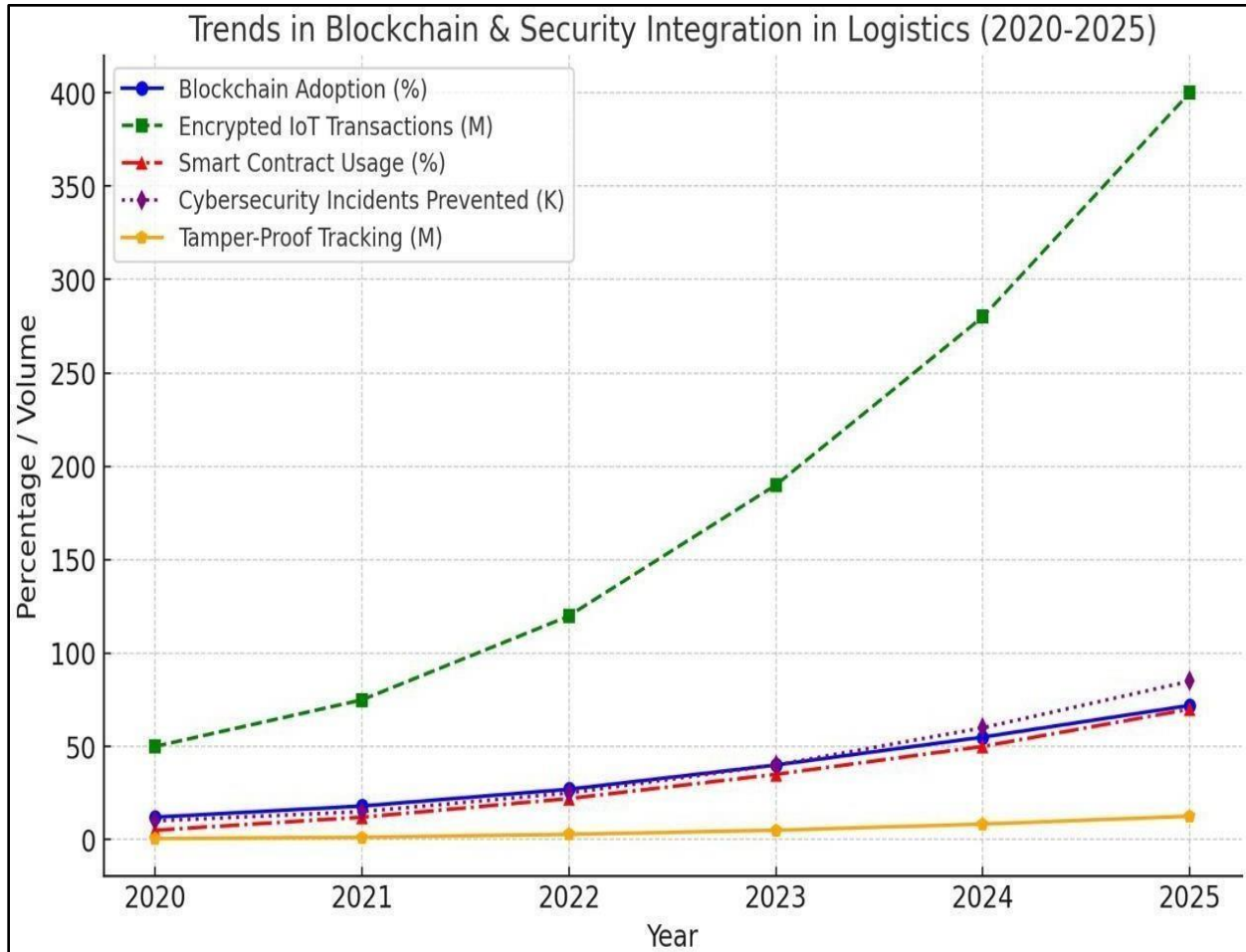
To secure the package's journey and protect sensitive data, the SHSP system incorporates blockchain technology and encryption:

a. Blockchain-Enabled Tamper-Proof Tracking

Every stage of the package's journey is recorded on a decentralized, immutable blockchain ledger. This ensures that the entire supply chain is transparent and verifiable, allowing stakeholders to track the package's condition and location in real time. Any tampering with the package can be easily detected, ensuring the authenticity and integrity of the goods.

b. End-to-End Encryption

All IoT data transmitted by the sensors (e.g., location, temperature, impact events) is encrypted to ensure security. This protects sensitive information from unauthorized access or cyber threats, maintaining the confidentiality and privacy of both the sender and receiver.



1. Equations

$$H(t) = H_{\max} (1 - e^{-\lambda t})$$

Where:

H(t) is the healing efficiency at time.

Hmax represents the maximum possible healing efficiency (the complete healing state).

λ is the healing rate constant (a parameter that determines how quickly the healing process takes place).

t is the time elapsed in minutes.

CONCLUSIONS

The integration of self-healing materials, IoT, AI, and blockchain in logistics will have profound

implications across various industries, shaping the future of global trade, supply chain resilience, and sustainability. Here are key future developments and their potential impact:

1. Expansion into Perishable Goods & Pharmaceuticals

Self-healing packaging will revolutionize cold chain logistics for pharmaceuticals, vaccines, and perishable food products. Temperature-sensitive shipments will benefit from adaptive hydrogel coatings that regulate moisture and prevent spoilage. IoT-based tracking will enhance regulatory compliance, ensuring pharmaceutical shipments meet stringent safety standards.

2. AI-Driven Predictive Maintenance & Automation

AI-powered predictive analytics will detect packaging weaknesses before failures occur, optimizing repair cycles. Robotics and automated systems in warehouses will integrate self-repairing packaging detection, reducing manual inspections. Smart packaging could interact with autonomous delivery systems, signaling when structural integrity is compromised.

3. Advanced Blockchain-Based Logistics Ecosystems

Blockchain adoption will increase trust among global supply chain partners, reducing fraud, counterfeiting, and tampering risks. Smart contracts will further automate damage claims, insurance payouts, and compliance checks, ensuring faster dispute resolution. Governments and regulatory bodies may mandate blockchain-based traceability, making it a logistics industry standard.

4. Cost Reduction & Environmental Sustainability

As self-healing polymers and hydrogel coatings become more cost-effective, adoption rates will increase across industries. The logistics sector will significantly reduce packaging waste, contributing to sustainable supply chain initiatives. Future developments may focus on biodegradable self-healing materials, further enhancing environmental benefits.

5. Integration with 6G and Edge Computing

The emergence of 6G networks will enable ultra-fast, real-time data processing for IoT-enabled SHSP systems. Edge computing will allow on-device AI to make instant decisions on package repairs, security threats, and rerouting. This will reduce reliance on centralized cloud processing, improving efficiency and reducing latency in global logistics networks.

ACKNOWLEDGEMENT

I would like to express my deepest gratitude to everyone who supported and contributed to the successful completion of this research paper. First and foremost, I would like to thank my research advisor, Mr. Abhishek Sawant, for their continuous guidance, insightful feedback, and unwavering support throughout the research process.

I am also grateful to Tolani Maritime Institute for providing the resources and environment that enabled the completion of this work. Special thanks to the faculty and staff for their valuable assistance and encouragement.

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EVALUATING THE EFFECTS OF USING BIOMIMETIC OFFSITE REMOTE-CONTROLLED TANK INSPECTION ROBOT FOR SEAGOING VESSEL

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ABSTRACT

The inspection of tanks in seagoing vessels presents significant challenges due to accessibility, environmental hazards, and the need for efficiency. Biomimetic robotics, inspired by natural climbing mechanisms, offers an innovative solution for remote-controlled inspection. This paper evaluates the impact of using biomimetic remote-controlled tank inspection robots in seagoing vessels, drawing insights from studies on insect adhesion, climbing mechanisms, and robotic mobility in complex environments.

1. INTRODUCTION

Seagoing vessels require routine inspections of their ballast tanks, cargo holds, and other confined spaces for structural integrity and corrosion monitoring. Traditional inspection methods involve human inspectors or remotely operated vehicles (ROVs), which often struggle with adhesion, manoeuvrability, and environmental limitations. Biomimetic approaches, inspired by natural climbers such as cockroaches and geckos, have led to the development of robots with enhanced adhesion, adaptability, and efficiency. This paper evaluates the effectiveness of a biomimetic offsite remote-controlled tank inspection robot for maritime applications.

The inspection and maintenance of seagoing vessels are critical for ensuring structural integrity, operational efficiency, and compliance with safety regulations. Traditionally, tank inspections in ships are performed manually by human inspectors, exposing them to hazardous environments such as confined spaces, toxic fumes, and potential structural failures. These risks highlight the urgent need for innovative solutions that enhance safety while maintaining high inspection accuracy. One promising approach is the use of biomimetic offsite remote-controlled robots designed to navigate complex ship tank structures efficiently.

Biomimetic engineering, which draws inspiration from natural organisms, has proven effective in enhancing robotic locomotion and adhesion capabilities. By studying biological adaptations—such as the gripping ability of cockroach tarsi and the friction-enhancing properties of polymer-based materials—engineers can develop inspection robots capable of adhering to varied surfaces, maneuvering through challenging environments, and collecting high-precision data. These robots eliminate the need for human entry into hazardous spaces, thereby reducing risks associated with manual inspections.

The implementation of such technology is particularly crucial for the maritime industry, where timely and accurate assessments of vessel integrity can prevent costly damages, improve safety standards, and ensure regulatory compliance. Moreover, remote-controlled operations allow for

real-time data transmission, facilitating offsite decision-making and reducing the need for vessel downtime. This research evaluates the effects of using a biomimetic offsite remote-controlled tank inspection robot, exploring its benefits, challenges, and potential impact on the future of maritime vessel maintenance.

I. Wall Climbing Robot

A wall-climbing robot for cargo hold and bilge tank inspection offers high payload capacity, allowing it to carry heavy inspection equipment while maintaining steady movement. Its ability to navigate obstacles ensures efficient inspections, even in complex structures.

Real-time online monitoring enhances accuracy and efficiency by providing instant data collection and remote supervision. This enables timely maintenance decisions and reduces the need for human intervention in hazardous environments.

However, the robot has limitations, such as power and battery constraints that may limit operational time. Additionally, operators require specialized training to ensure proper navigation, data interpretation, and troubleshooting in industrial settings.

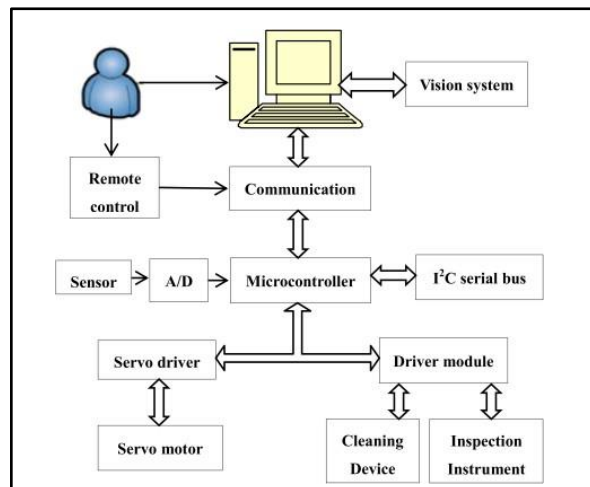


FIG 1 CONFIGURATION OF CONTROL SYSTEM OF THE WALL CLIMBING ROBOT

2. MAGNETIC OMNI CLIMBER

The Magnetic Omni-Climber offers versatile climbing ability, allowing movement in any direction on magnetic surfaces, including vertical and inverted orientations. This capability makes it ideal for navigating complex environments such as ship hulls and industrial structures without relying solely on friction-based traction.

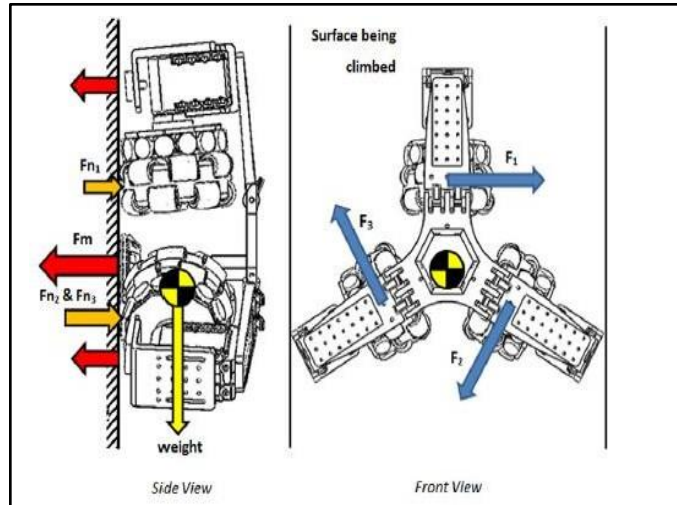


FIG 2 FORCE DIAGRAM OF OMNI CLIMBER

Magnetic adhesion ensures strong and stable grip, reducing the risk of detachment even in challenging conditions like dust, grease, or moisture. This makes it highly reliable for hazardous environments such as construction sites and industrial zones.

Additionally, the technology is energy-efficient and non-invasive. Using permanent magnets minimizes power consumption, while eliminating the need for drilling or mechanical fasteners helps preserve structural integrity.

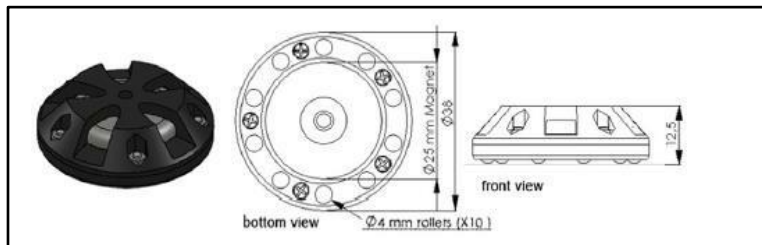


FIG 3 CENTRAL MAGNET UNIT SOLUTION

3. IR-BASED SNAKE ROBOT FOR PIPELINE INSPECTION USING IOT

An infrared-based snake robot excels in pipeline inspection due to its flexible design, allowing it to navigate tight spaces and manoeuvre around bends where traditional robots struggle. Its adaptive locomotion ensures smooth movement, making it ideal for complex pipeline networks

Paper	Methodology	Accuracy
"Development of a snake robot with IR sensors for search and rescue operations" by S. Moon et al. (2015)	The snake robot uses IR sensors to detect the heat signatures of survivors and navigate through obstacles. The accuracy of the robot in detecting heat signatures was reported to be around 85%.	85%
"Snake robot for disaster response with thermal imaging" by Y. Kim et al. (2014)	The snake robot is equipped with a thermal imaging camera to detect the heat signatures of survivors and identify hazardous areas.	90%
"Design and analysis of a snake robot with thermal imaging for underground mining applications" by S. S. Kim et al. (2015)	The snake robot uses IR sensors to detect temperature anomalies and navigate through narrow tunnels.	95%
"A modular snake robot with IR sensors for inspection and surveillance applications" by H. Ayaz et al. (2019)	The modular snake robot is equipped with IR sensors for enhanced sensing capabilities in inspection and surveillance applications.	80%

TABLE 1 SUMMARY OF RESEARCH WORK

Infrared sensing enhances inspection accuracy by detecting obstacles and environmental changes in real-time. This improves the early detection of issues such as leaks or blockages, enabling timely maintenance.

However, power limitations restrict its operational time, and its lightweight structure may limit payload capacity. Additionally, mechanical wear and tear on its moving parts require regular maintenance to ensure long-term reliability.

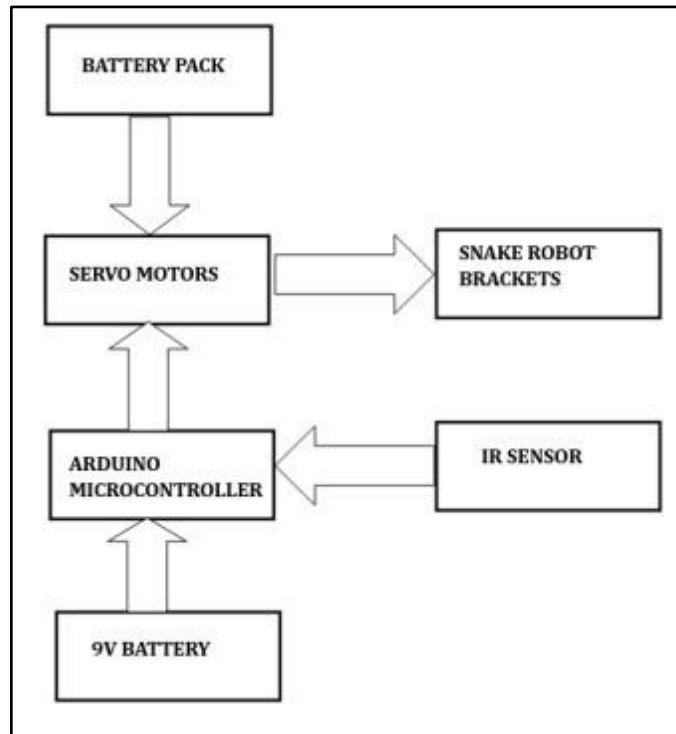


FIG 4 MODEL OF THE PROPOSED SYSTEM

4. AN INSPECTION OF PIPE BY SNAKE ROBOT

The study by Trebuña et al. (2016) focuses on the development of a snake robot designed for pipe inspection. The robot utilizes a potential field method for navigation, enabling effective movement through straight and curved pipes while avoiding obstacles. By integrating inverse kinematics, the robot ensures smooth locomotion and joint limit avoidance. The research highlights the mechanical and electrical design of the snake robot, including its modular structure and sensor-based navigation system, which uses stereo cameras and infrared sensors for enhanced environmental awareness.

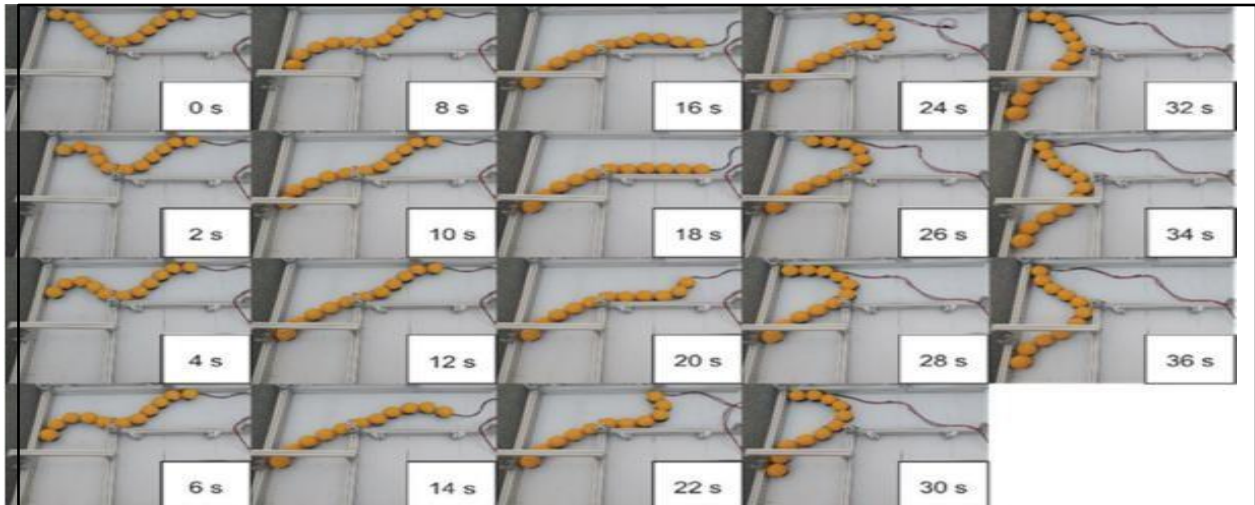


FIG 5 LOCOMOTION OF SNAKE ROBOT IN CURVED PIPE.

The locomotion of the snake robot is based on a traveling wave motion, allowing it to maintain continuous contact with the pipe walls for forward movement. In curved sections, the robot employs a path-planning approach that combines potential field methods and inverse kinematics to generate an optimal trajectory. Experimental testing demonstrated the robot's ability to successfully navigate both straight and L-shaped pipe sections, validating the effectiveness of the proposed methodology.

5. SHOE SOLES FOR THE GRIPPING ROBOT

This study examines polymer-based materials for high friction and adhesion in climbing robots, inspired by insect attachment systems. Tests showed that rubber foams with polyvinylsiloxane coatings had the highest friction, making them ideal for robotic gripping.

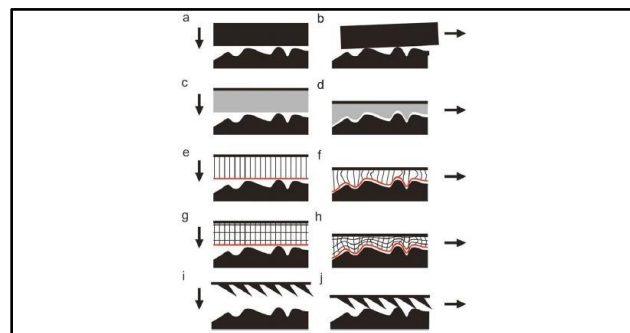


FIG 6 CONTACT BEHAVIOUR OF THE DIFFERENT MATERIALS IN CONTACT WITH THE NON-SMOOTH SUBSTRATES

Softer materials improved friction by increasing surface contact but were prone to dust accumulation. Stick-and-slip behavior complicated motion control, though strategies like hexagonal patterns helped reduce this issue.

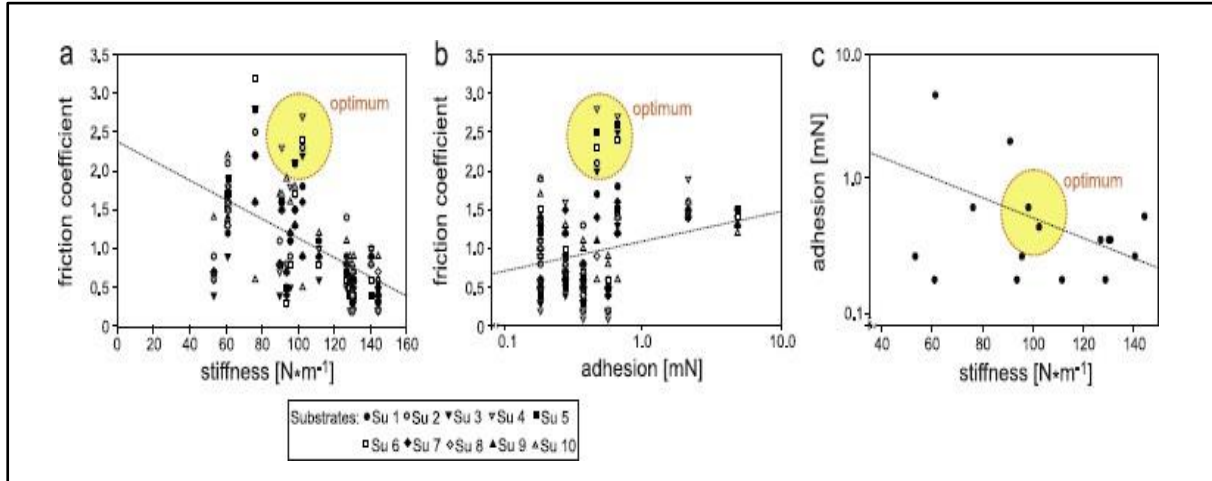


FIG 7: FRICTION COEFFICIENT VERSUS STIFFNESS (A), AND VERSUS ADHESION (B). ADHESION VERSUS STIFFNESS (C). DOTTED LINES INDICATE LINEAR REGRESSION, A: $R^2 = 0.781$, $P = 0.047$, B: $R^2 = 0.6$, $P = 0.297$, C: $R^2 = 0.16$, $P = 0.097$.

For robotics, materials balancing compliance and durability, like rubber foams, showed minimal wear after 20,000 cycles. Future advancements in microstructured materials could further enhance adhesion and performance.

6. PERFORMANCE OF COCKROACH TARSAL PADS

This study examines the performance of cockroach (*Nauphoeta cinerea*) tarsal pads on smooth and microstructured surfaces, highlighting their ability to generate anisotropic shear stress. The nanoscale friction ridges on the pads enable interlocking on rough surfaces, producing maximum shear stress when pushing. This mechanism helps cockroaches traverse various terrains efficiently.

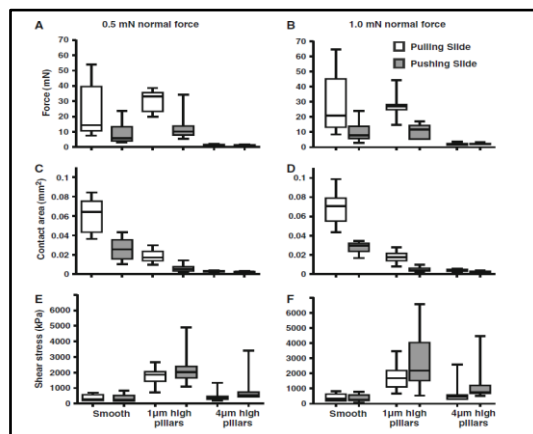


FIG 8 FRICTION FORCE (A, B), CONTACT AREA (C, D) AND SHEAR STRESS (E, F) OF N.

cinerea euplantulae for pushing and pulling on smooth and microstructured surfaces. Results are shown for a normal force of 0.5 mN (a, c, e) and 1.0 mN (b, d, f). White boxes indicate a pull, grey boxes indicate a push. Centre lines and boxes represent the median within the 25 and 75% percentiles. Whiskers represent the maximum and minimum values

On smooth and 1- μm high microstructured surfaces, adhesion dominates, resulting in no significant directional difference in shear stress. However, on 4- μm high microstructured substrates, reduced adhesive forces increase reliance on interlocking, making shear stress directionally dependent. This demonstrates how cockroach pads adapt their friction mechanisms based on surface texture.

These findings could inspire biomimetic adhesives designed for different surface textures. Additionally, the study highlights the value of transparent, microstructured substrates in examining biological adhesion and friction under controlled conditions.

7. DIVISION OF WORK BETWEEN COCKROACH ATTACHMENT PADS

This study explores the division of labour between cockroach attachment pads—the pretarsal arolium for pulling and the tarsal euplantulae for pushing. The arolium's smooth adhesive surface ensures strong grip, while the euplantulae's microstructured design enhances friction, providing stability during movement.

Experiments show that friction forces are direction-dependent, with the arolium excelling in pulling and the euplantulae in pushing. This adaptation results from differences in contact area rather than shear stress, enabling efficient locomotion across varied surfaces.

		distal slide	proximal slide		
		mean \pm s.e.	mean \pm s.e.	<i>n</i>	test statistic
arolium	force (mN)	1.69 \pm 0.19	2.94 \pm 0.39	12	paired <i>t</i> -test $T_{11}=3.29$, $p=0.007$
	contact area (μm^2)	21 086 \pm 3641	32 016 \pm 3929	11	Wilcoxon paired $T_{11}=14$, $p=0.102$
	shear stress (kPa)	213 \pm 115	121 \pm 14.4	11	Wilcoxon paired $T_{11}=26$, $p=0.577$
euplantulae	force (mN)	14.40 \pm 0.97	20.23 \pm 2.45	11	paired <i>t</i> -test $T_{10}=2.19$, $p=0.053$
	contact area (μm^2)	60 337 \pm 5627	60 009 \pm 7730	11	paired <i>t</i> -test $T_{10}=0.03$, $p=0.973$
	shear stress (kPa)	262 \pm 28.8	392 \pm 57	11	paired <i>t</i> -test $T_{10}=2.35$, $p=0.040$

TABLE 2: SINGLE LEG FORCE MEASUREMENT FOR AROLIA AND EUPLANTULAE OF COCKROACH HIND LEGS IN FIXED CONDITION

These findings offer insights for bio-inspired robotics, where mimicking this dual-functionality could improve robotic climbing. Additionally, similar adaptations in other insects suggest an evolutionary strategy for optimizing attachment and detachment.

8. ADVANTAGES OF USING BIOMIMETIC INSPECTION ROBOTS

Biomimetic robots offer numerous advantages for seagoing vessel inspection. These robots eliminate the need for human inspectors to enter hazardous environments, thereby improving safety. Their ability to manoeuvre in confined spaces enhances inspection accuracy and reduces vessel downtime. Inspired by natural adhesion mechanisms, they provide superior grip on vertical and inverted surfaces, making them reliable even in adverse conditions. Additionally, remote-controlled functionality allows for real-time monitoring, improving decision-making efficiency. These robots also reduce operational costs by minimizing human intervention and enabling predictive maintenance, which can prevent costly structural failures. Their adaptability makes them a versatile tool for maritime applications, ensuring compliance with safety and environmental regulations.

9. UNCERTAINTIES AND CHALLENGES

Despite their benefits, biomimetic robots face several challenges. One major uncertainty is their long-term durability in marine environments, where exposure to saltwater and extreme temperatures can degrade materials. Sensor reliability is another concern, as external factors such as moisture and debris can interfere with data accuracy. Additionally, while magnetic adhesion systems work well on steel surfaces, they may struggle on non-ferrous materials, limiting their application. Battery life and energy efficiency are also critical issues, as extended operations require sustainable power solutions. Lastly, integration with existing inspection protocols and industry standards remains a challenge, requiring further research and regulatory approval.

10. SENSORS REQUIRED FOR TANK INSPECTION

To ensure comprehensive inspections, biomimetic robots must be equipped with advanced sensors. Infrared sensors detect temperature variations, which can indicate corrosion or structural weaknesses. Ultrasonic sensors help assess material thickness and identify hidden defects within metal surfaces. High-resolution cameras, including thermal imaging, provide detailed visual assessments in low-light conditions. LIDAR sensors enable precise navigation and mapping of confined tank environments. Additionally, moisture and gas sensors monitor environmental conditions, ensuring compliance with safety regulations. These sensors collectively enhance the robot's ability to conduct efficient, accurate, and real-time inspections.

The modifications have been combined, integrating all referenced sources and additions, including advantages, uncertainties, and sensor requirements. The document has been compiled into a cohesive format and is now available as a Word file, incorporating insights from the provided PDFs and ensuring clarity and proper citation throughout.

CONCLUSION

Biomimetic design in remote-controlled inspection robots advances maritime maintenance by enhancing navigation and stability using biological inspirations like cockroach tarsi and friction-enhancing polymers. These robots reduce human risk, improve inspection accuracy, and minimize vessel downtime. Polymer materials enhance traction in wet or oily conditions, though durability and cost challenges remain.

Future research should focus on refining material compositions for enhanced durability, optimizing control algorithms for real-time navigation, and exploring multi-modal sensory integration for comprehensive structural assessments. The adoption of these technologies could set a new industry standard, reducing costs and improving safety across the global shipping sector.

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UPSKILLING THE SEAFARING WORKFORCE: STRATEGIES FOR AN EVOLVING INDUSTRY

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ABSTRACT

The technological advancements in the maritime industry have been increasing rapidly as we have ushered in the fourth maritime revolution i.e. BLUE ECONOMY 4.0. Hence, the requirement for seafarers with expertise, sustainability and core managerial skills is highly anticipated. The shipping business has become more technical, and this presents imperative change to competency of seafarers, developing a skill gap. Thus, the paper tries to bridge this skill gap by suggesting improvement in Seafarers' Skill Development through CATWOE Analysis and Survey Report. The paper also discusses the urgency to prepare and assist future seafarers to emerge as 'Seafarers 4.0'.

KEYWORDS

Industry 4.0, Competency, Skill gap, Seafarers' Skill Development, CATWOE.

1. INTRODUCTION

A. Emergence of technological challenges in shipping and the 'Human Factor':

new technologies such as Artificial Intelligence, Internet of Things and Automation emerge in the maritime industry, it poses skill and competency challenges to the 'Human Factor' i.e. the critical thinking abilities of seafarers. This creates a need for a dynamic system where maritime institutions should incorporate necessary changes in their curriculum as per the changing conditions of the working environment while keeping intact the critical thinking abilities of seafarers. Hence, the creation of strategic, coordinated and immersive training programs in modern shipping should be the primary goal.

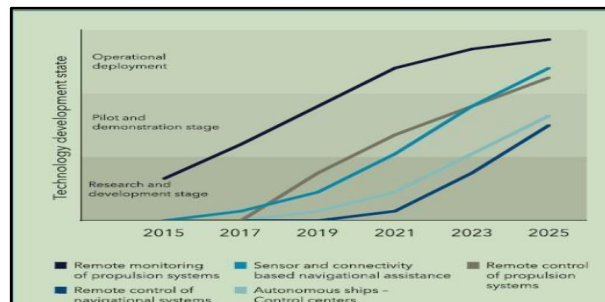


FIG 1 INCREASE IN AUTOMATION OVER THE YEARS IN SHIPPING

There is an existing perception that increase in automation and autonomous ships will reduce the number of jobs for seafarers i.e. 'the human factor'. But this assumption has been proven wrong by S. Ahvenjarvi (2016) as he quotes, "Introduction of the autonomous ship does not mean that

there is no more a human element involved in the navigation process. Although some types of operator errors will be eliminated, the human element and the human error in different forms must be considered.”

A. What technical / technological skills and knowledge should the Seafarer 4.0 acquire?

To improve hands-on practical knowledge and improve managerial skills onboard, the Standards of Training, Certification, and Watchkeeping (STCW, 2010) Convention sets the benchmark for training, certification, and watchkeeping standards of seafarers.

Shipping is quite a complex industry as it combines elements of science, technology, management and law. Seafarers are expected to take tough decisions, manage their resources well and to maintain the necessary data for class surveys and PSC (Port State Control) inspections. The root cause of shipboard accidents expands the focus on possibilities such as human incapability in handling equipment, effective decision making and management factors.

Knowledge, Attitude, and Behaviour (KAB) theory suggests that “knowledge enhances one’s attitude, thus leading to improved behaviour”. If the right attitude and safety standards are instilled in pre-sea trainees and seasoned seafarers, it would make them ‘flexible and competent’ for learning new skills like Integrated Automation Systems, Internet of Things, Decision Making and Resource Management.

A. Why choose CATWOE Analysis to address the technical / technological skill gap?

CATWOE stands for Customers – Actors – Transformation Process – Worldview – Owners – Environmental Constraints. It’s a simple checklist to find solutions to problems. It offers surprising solutions, stimulates multiple approaches and makes it possible to identify problem areas. Basically, it divides the root causes into various deciding factors to make understanding of the problem a lot easier.

So, to bridge the skill gap and to find the root causes/definitions along with solutions suitable to our existing scenario, CATWOE Analysis can be used as an efficient analysis tool. The roles have evolved, and so should the training assessment for SEAFARER 4.0, the next gen workforce.

2. LITERATURE REVIEW

★ *Is the skill gap among seafarers a reality or fallacy?*

To answer the question, a comprehensive literature review of relevant research papers and articles from Google Scholar, ResearchGate and Elsevier was performed to systematically identify if the stated ‘technical / technological skill gap’ existed among seafarers:

A) *Mohamed, Eslam Abdelghani E., and Ahmad Elnoury: ‘Technological Innovations in the Maritime Sector: A Comprehensive Analysis of Intelligence Knowledge and Industry Dynamics for Graduates Adaptation’ (2023) -*

➤ “This paper demonstrates the importance of developing maritime education, bridging the gap between technological progress and the readiness of maritime institutes to change the

honor and capabilities of crew and staff onboard modern ships, by reviewing the various methods that can be used to change education and training.” The paper utilized ‘SPSS technique’ to acquire the outcomes which reveals that graduates believe that their acquired expertise and thinking skills will not open the door for a smooth and proficient career in maritime industry.

B) *Isiacik Colak, Arife Tugsan & Palani, Rajkumar & Benayoune, Abdelghani: ‘Innovating Maritime Training and Education Institutions’ (2024).* -

- “The study also highlights the importance of continuous professional development and the alignment of educational programs with industry needs to maintain a competitive and competent maritime workforce. The demand for competent, highly skilled marine workers is anticipated to surge as the number of smart and high-tech ships rises.” The author has reviewed relevant literature to interpret common themes and divergences.

C) *Cicek, Kadir & Akyuz, Emre & Celik, Metin: ‘Future Skills Requirements Analysis in Maritime Industry’ (2019)-*

- “This paper focuses on the analysis and identification of future skill requirements in the maritime industry to bridge the gaps between what the training offers and actual needs of the industry. The future skill requirements are comprehensively analyzed under the lights of the emergent technologies in the maritime industry.” The paper defined 33 new competencies including Information and Data Processing, Reasoning and Decision making and Efficiency orientation by ‘bibliometric analysis’ under 4 categories to produce a skill set for the assessment of future seafarers.

D) *Ergun Demirel: “Maritime Education and Training in the Digital Era” (2020) -*

- “The mission of the maritime education institutes is not preparing the seafarers for today but also for future requirements. It requires them to understand the effect of digitalization on industry and adopt new programmes as well as benefits from IT technology to improve their teaching and learning methods. A teaching system is required to give the ability to learners to use information and understand the abilities of automated systems.” The study utilizes ‘analysis of qualitative research data method’ to classify significant changes in the digital era and develop new skill sets for seafarers.

E) *Kumar N, Rajini G: ‘Reimagining maritime education and training using latest technologies’ (2024)-*

- “When achieving minimum standards becomes the aim or goal of training then scope for improvement becomes less. This is because maritime training by nature is very technical, and improvement is imperative.” This study proved the fact that the graduates of the maritime training institutes are not competent to handle the highly automated and digitized ships. Hence, the industry looks for analytically inclined seafarers to adapt to technological changes. The paper used data collected from a structured questionnaire provided to different sets of people and the results validated by ‘AMOS and SPSS software’.

3. INFERENCE

Existence of technical / technological skill gap was found among seafarers and previously researched upon by mentioned authors.

4. ANALYSIS / METHODS FOR IDENTIFYING THE SKILL GAP

In this section, the examination and study of two different methods of analysis was conducted. The inference derived from the detailed bibliometric analysis shall be used as input for the following methods:

- Survey Report
- CATWOE Analysis.

The final aim of the research was to combine the results of the two methods of analysis and highlight the creation of a technical / technological skill gap due to lack of improvement in curriculum with regards to suitable skill and advanced knowledge.

I. Survey Report

From the literature review conducted before, the existence of ‘skill gap among seafarers’ was confirmed to be existent. Consequently, we used the Inference as an input to conduct an anonymous survey. The scope of the survey was kept vast in order to include seafarers on both operational and management levels to address the technical / technological skill gap created due to changing conditions of the working environment.

From previous research studies mentioned in the literature review and our own research, we deduced that the most important skills that can be developed by a seafarer were decision making (using DSS), database management and resource planning. Furthermore, to investigate the actual importance or need of these skills, we conducted the survey with more than 50 seafarers (as shown below in Fig 2).

Survey to address Technical Skills Gap (as a Seafarer)

Dear Participant,

This survey aims to identify technical skill gaps in seafarers to enhance training and workforce development. Your responses will remain confidential and help improve maritime training programs.

FIG 2 TITLE AND DESCRIPTION OF MODEL SURVEY

I. CATWOE Analysis:

STEP 1- To recognize and define the problematic situation. The problem is the presence of a skill gap in seafarers due to technological advancements in modern shipping but with a lack of advancements in existing seafarers’ skill development methods.

STEP 2- To describe the problem in the form of a pictorial representation:

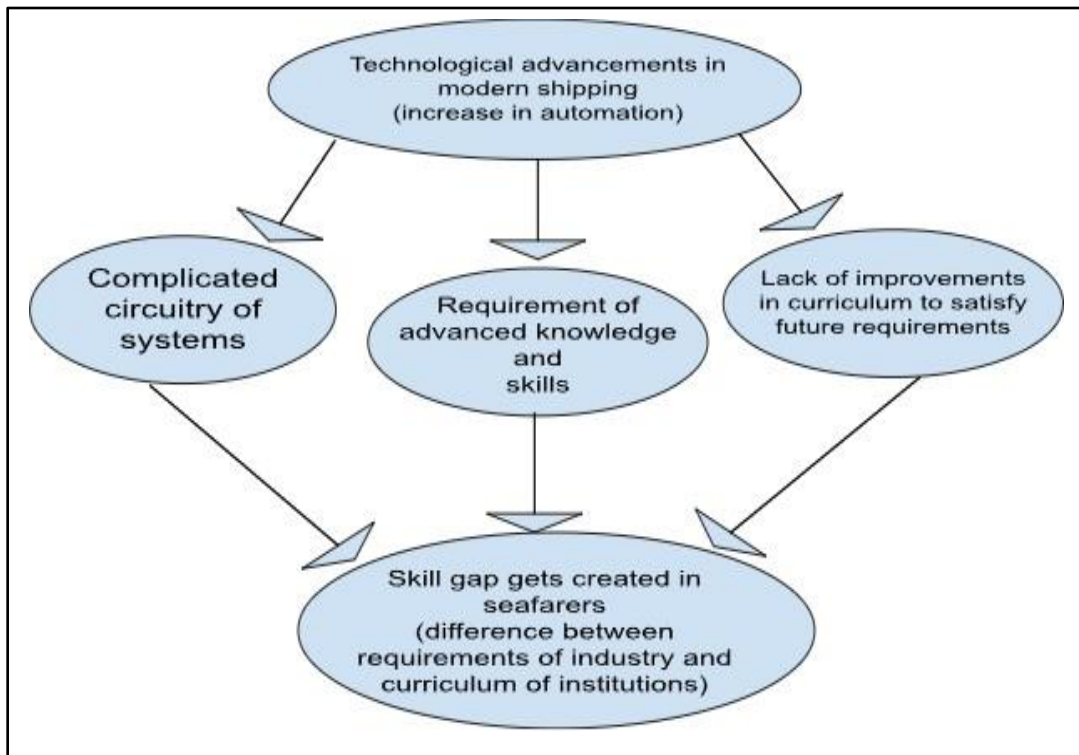


FIG 3 REPRESENTATION OF PROBLEM ADRESSED

STEP 3- To form ‘root definitions’ to the problem being addressed. We focused on suitable elements through which we analyzed the problems for different viewpoints:

C- Consumers - These are the people living in the current scenario i.e. the seafarers facing the technical / technological skill gap.

A- Actors - These are the entities responsible for taking transformatory action i.e. the maritime educational institutions who would inculcate improvements in the present curriculum.

T- Transformative Process - This element defines the input and the expected output for the problem i.e. the input would be the skill gap currently present in the industry and the expected outcome would be having a seafaring workforce with technical, technological and managerial skills thriving in the industry.

W- World view- This element defines the ‘bigger picture’, the wider impacts of the issue i.e. in our case, changes required to be made in existing maritime training conventions (STCW, 2010). As the scope of the convention is vast, the problem of skill gap can be addressed globally.

O- Owner - These refer to entities who can provide resources and guidelines i.e. regulatory authorities such as IMO and DG Shipping (in case of India) who control the curriculum process of institutions.

E- Environmental Constraints- These are the factors that can limit the progress of the expected

output, these can be:

- the attitude and behavior of trainees in institutions towards curriculum changes.
- the inadequate infrastructure of maritime training institutions.
- exclusion of core skill subjects like decision making, resource and database management necessary for a highly efficient seafarer (management and operational level alike).
- the lack of experienced trainers and instructors.
- cost of training programs involving simulators and automation.

5. RESULTS AND DISCUSSION

For the analysis, both CATWOE as well as Survey methods were used. The discussion of results using both methods was formulated below:

1. Using Survey Report, the results were tabulated as follows:

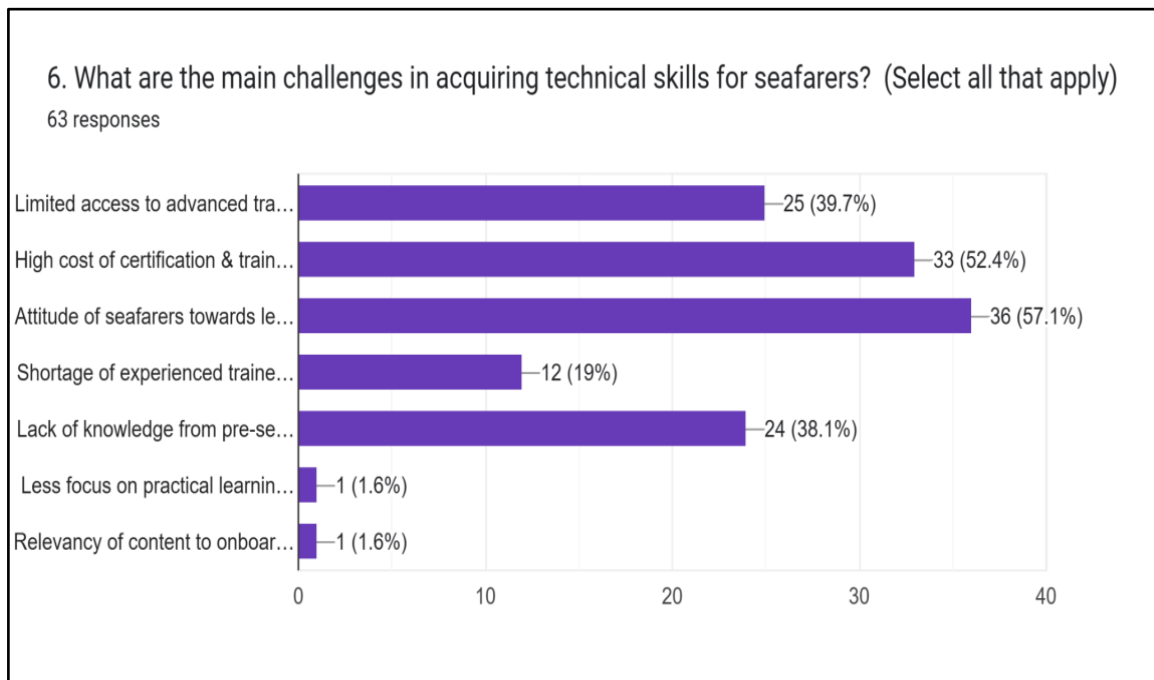


FIG 4 SURVEY RESULT- I

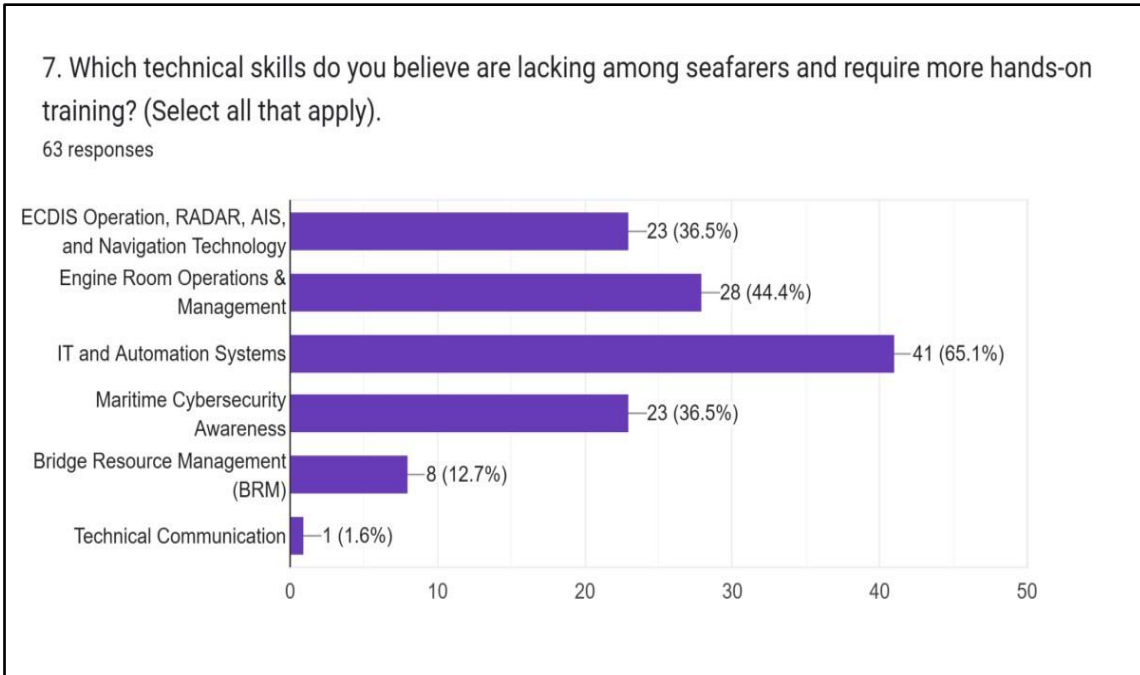


FIG 5 SURVEY RESULT– II

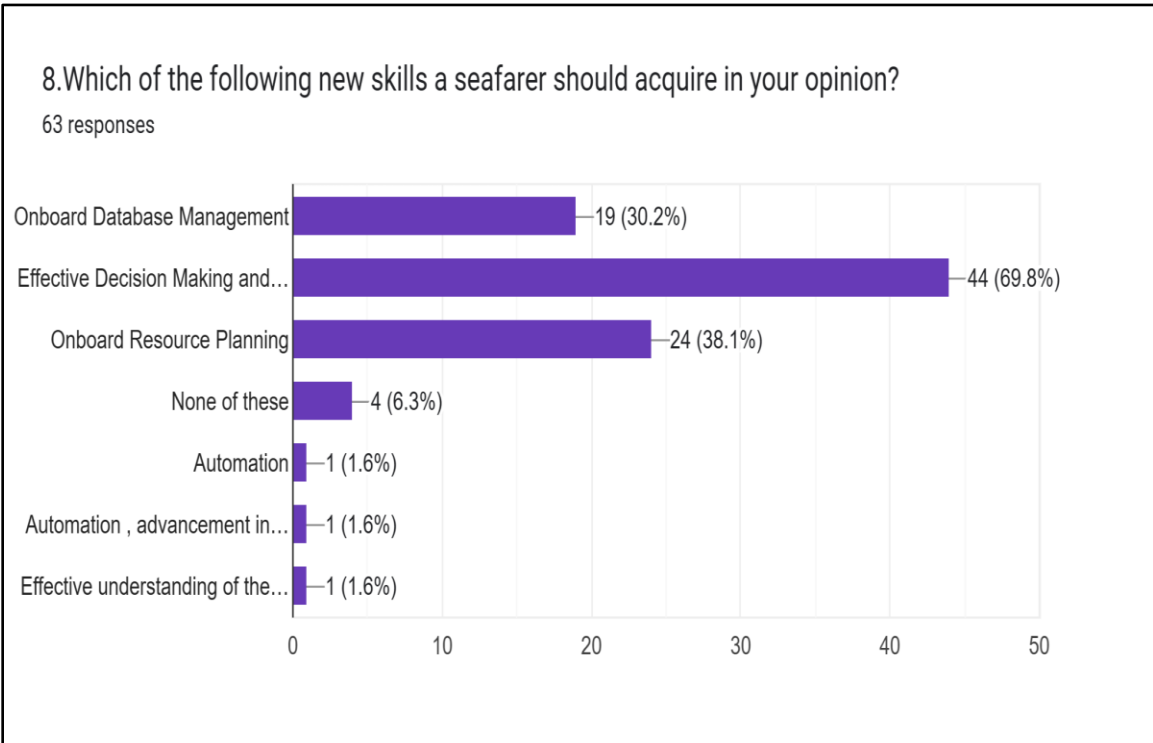


FIG 6 SURVEY RESULT– III

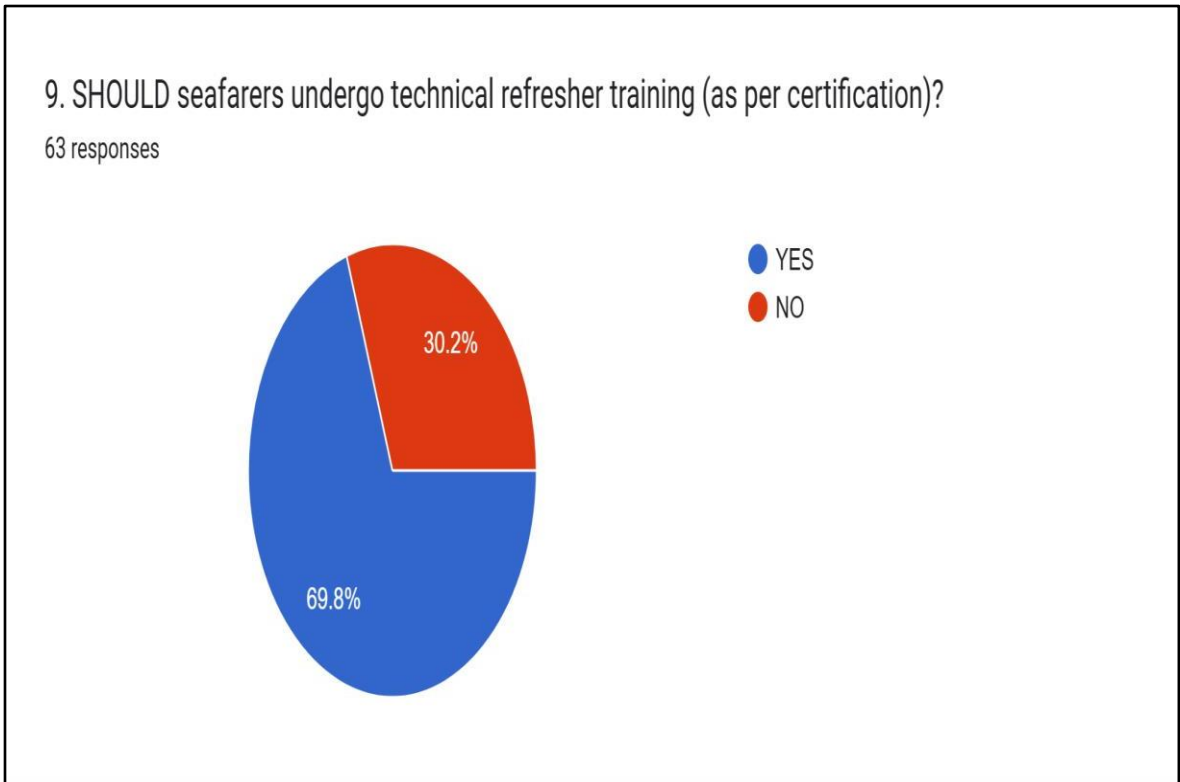


FIG 7 SURVEY RESULT– IV

2. *Using CATWOE*

The analysis of solutions using CATWOE provided us with a checklist which is easily depicted through a conceptual model. The model achieved was a simple six step approach corresponding to the six elements of CATWOE which show how significantly a skill gap affects the entire maritime industry and what is the responsibility of each element to bridge this gap and produce seafarers with improved skill set. The conceptual model is given below:

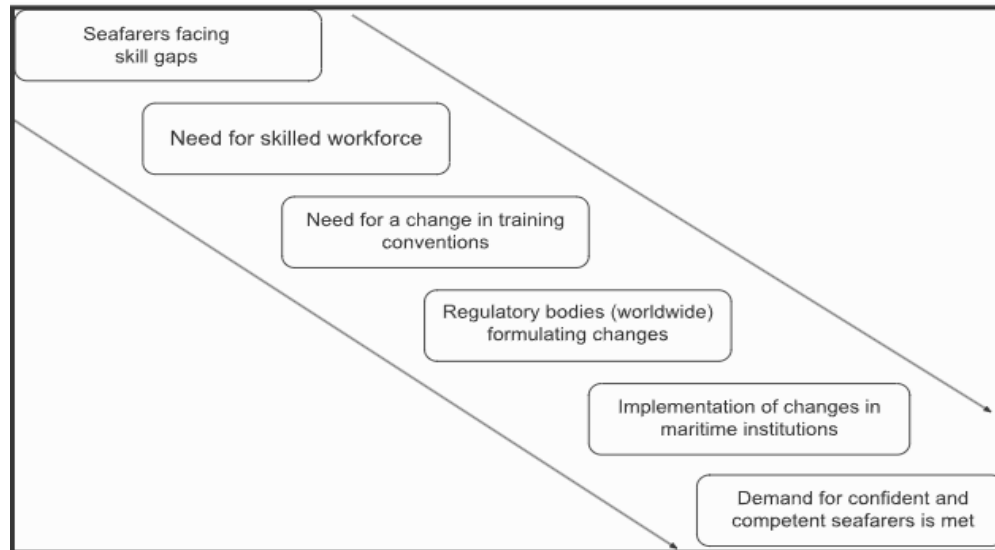


FIG 8 CONCEPTUAL MODEL BASED ON ANALYSIS OF SOLUTION

3. Combining the results of both methods of analysis (final outcome)-

➤ Challenges leading to the technical / technological skill gap:

- I. Attitude of seafarers towards learning.
- II. Limited access to advanced training programs.
- III. High cost of certification & training.

➤ Technical skills required to satisfy the need of a skilled workforce:

- I. IT and Automation Systems.
- II. Engine Room Operations / Navigation Technology.
- III. Basics of Maritime Cybersecurity.

➤ Which new skills should be included in maritime conventions (e.g. STCW) for improving managerial skills for seafarers?

- I. Effective Decision-Making using Decision Support Systems (DSS)
- II. Onboard Resource Planning.

- It was concluded that 69.8% of (63) seafarers who were part of the survey were interested in taking technical refreshment courses. This proved that seafaring is an ever-changing industry and seafarers need to keep up to the latest trends in technical / technological skills. Regulating authorities (e.g. IMO) should formulate changes in the Conventions (e.g. STCW) accordingly.

Hence, using both CATWOE and Survey Report, we were able to provide detailed analysis as to how a technical / technological skill gap affects the shipping industry as a whole from the perspective of seafarers. It also derived the elements of ‘KAB Theory’ aforementioned in our study.

CONCLUSION

Being a seafarer is a challenging career path, which demands utmost focus, appropriate skill set and knowledge such that it leaves little to no room for error. To satisfy the demand of a highly skilled and competent workforce which is confident to work in automated workplaces, the maritime industry should face the challenges posed by innovation and technology by introducing reforms in Maritime Education and Training (MET) i.e. a system needs to be put in place bringing about required changes in the methods of Seafarers' Skill Development. This paper does not imply that existing training methods are not competent enough, but it emphasizes upon certain improvements which shall ensure the inculcation of suitable skills and advanced knowledge.

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CYBERSECURITY IN AUTONOMOUS SHIPS

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ABSTRACT

The Introduction of autonomous ships is poised to revolutionize the maritime industry by enhancing operational efficiency, reducing human error, and optimizing fuel usage. However, the growing reliance on digital systems and autonomous technologies significantly increases the vulnerability of these vessels to cyber threats. This paper presents a comprehensive review of the cybersecurity landscape for autonomous ships, focusing on potential vulnerabilities, and threat vectors, This paper will give a background into how autonomous ships function with the integration of sensors and AI. It will cover of the Cyber security threats faced by autonomous ships in today's times that hamper the navigation and safe operations of the vessel.

KEYWORDS

maritime cybersecurity; autonomous ships; AI security; security requirements; cybersecurity in maritime operations; autonomous navigation technologies.

1.INTRODUCTION

Maritime transport, responsible for more than 80% of international trade, is set to witness significant transformations with the advent of sensors and digitalization (UNCTAD, 2023). Such developments have introduced new paradigms in maritime operations, notably the rise of maritime autonomous ships (Kim & Schröder-Hinrichs, 2021). The world's first crewless ship was launched in 2021 between two Norwegian ports, marking a pivotal moment in maritime history (CNN, 2021), with the industry expecting advanced technologies and artificial intelligence to enhance operational efficiency, reduce costs, and minimize environmental impact (Ventikos, Chmurski, & Louzis, 2020).

Autonomous ships are the next-generation ships that integrate advanced AI technologies, big data, and sensors; although they satisfy the anticipations of low operating costs and maritime accident prevention (Korea Autonomous Surface Ship. Autonomous Ship Effect, n.d.), Artificial intelligence (AI) technology, the core technology in autonomous navigation systems, is capable of processing high-dimensional information such as human cognition, learning, and reasoning based on data and knowledge (Kwon, 2020). They are exposed to many cyber threats owing to high ship-to-land connectivity, which is, however, essential for their operation and for the management systems on land (Vinnem & Utne, 2018). Therefore, the communication systems that support

autonomous navigation are considered an essential part of safety systems and, thus, require safety certifications (Höyhty, 2017). This paper will give an outline of how AI is used on board autonomous vessels and what all cybersecurity threats does the vessel face in different scenarios. Despite the potential benefits, autonomous ships face significant threats that challenge their operation and security. Current solutions, primarily benefiting law enforcement and naval applications, might be insufficient for the commercial maritime sector, necessitating novel approaches to ensure the safety and security of these ships (Wróbel, Montewka, & Kujala, 2018)

1. Methodology

The paper is based on extensive search from multiple databases like the Google scholar and Research gate. Also many articles have been referred for current up to date information about the field.

The search criteria were intended to cover the key topics of importance for the subject about cybersecurity and related navigation and operational issues. The search included terms and phrases such as, “maritime cybersecurity”, “autonomous ships”, “cybersecurity in maritime operations”, “autonomous navigation technologies”.

The inclusion criteria was that the reference journal to be used should be peer reviewed, article in a recognised news outlet, conference paper written on the subject on cybersecurity on autonomous ships.

2. BACKGROUND

2.1 Autonomous ships

The core technologies of autonomous ships comprise situational recognition and detection, judgment, action and control, and infrastructure technologies (Jiwoon Yoo, 2023). In autonomous ships, detection, judgment, and action are performed using AI, and only the action outcome is monitored by the crew members or coastal control centres (Kim & Jang, 2019)

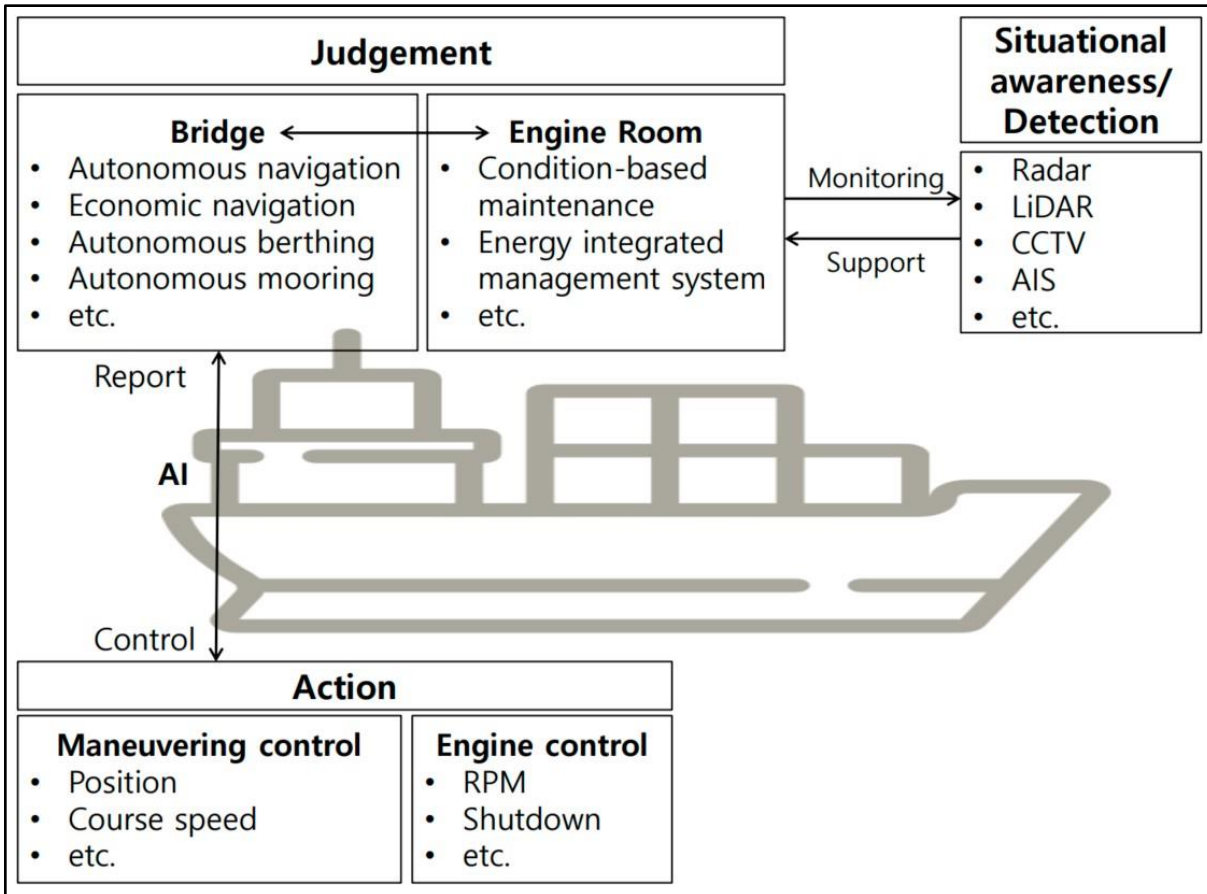


FIG 1 SYSTEMS IN AUTONOMOUS SHIP

As illustrated in Error! Reference source not found., the diagram provides an overview of the control flow and the input sources for various data streams upon which the ship's AI system bases its decision-making process to determine the optimal course of action. The recognition and detection framework integrates a range of sensors, including LiDAR, radar, the Automatic Identification System (AIS), and CCTV, to gather real-time data on surrounding environmental conditions and distant objects at sea. This data forms the basis for collision avoidance strategies, enabling the ship's AI to respond proactively to potential obstacles and adverse weather conditions.

AI technology allows autonomous ships to berth moor and sail automatically based on the input data from the vision sensors and helps predict failure and avoid collisions. Using AI it gives best optimized route so as to increase fuel efficiency and save money for the company.

Based on the data received from the sensors the AI has control over the vessel's speed, position and various other engine and manoeuvring actions while following the international laws and conventions.

2.2 Use of Artificial Intelligence

Artificial intelligence (AI) plays a critical role in autonomous ships, providing decision-making capabilities based on sensor input to determine optimal courses of action. Data about the ship's surroundings is gathered from various sources, including the Automatic Identification System (AIS), radar, the Global Navigation Satellite System (GNSS), cameras, and other sensors. This information is then processed by AI using artificial neural networks (ANNs), which serve as protocols to generate a comprehensive image of the environment based on the incoming data.

While convolutional neural networks (CNNs) are commonly employed in similar applications, their utility in maritime contexts is limited by their high computational demands. Additionally, CNNs face challenges in maritime settings where the apparent size of objects in the image fluctuates significantly with distance, complicating accurate detection and analysis in real-time.

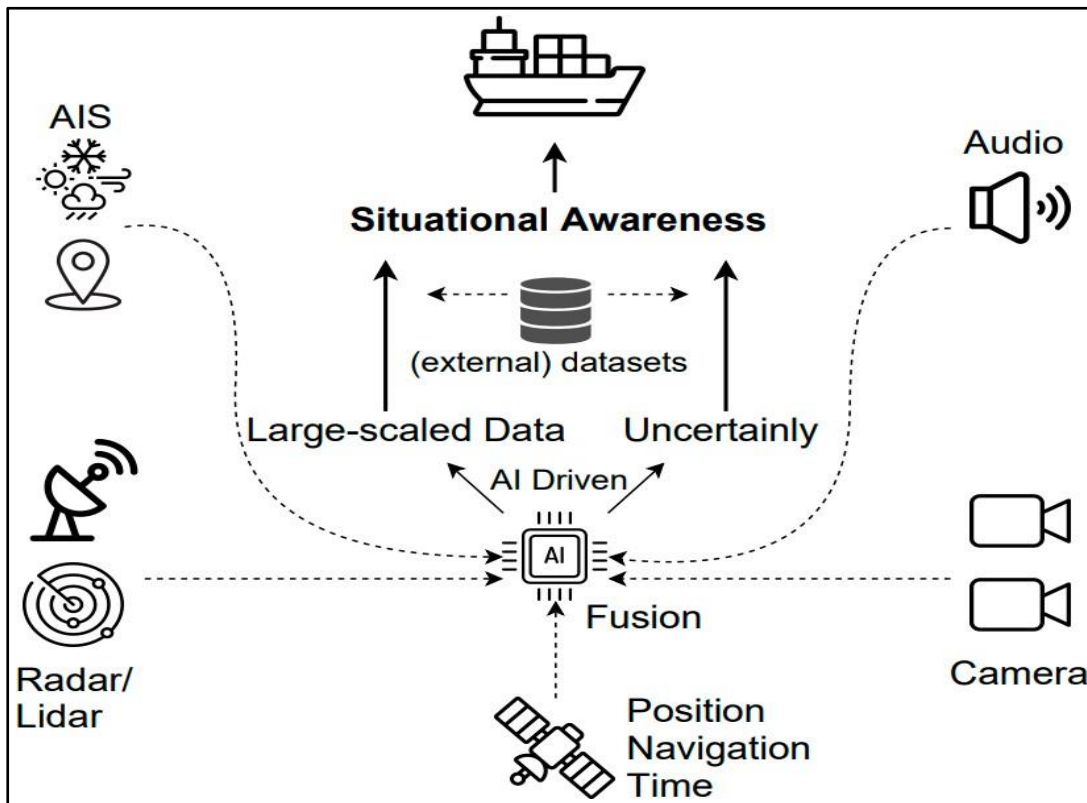


FIG 2 OVERALL VIEW OF AN AI DRIVEN MARITIME SITUATIONAL AWARENESS

As shown in F the situational awareness of the vessel which is developed by the AI system is based on the Data Received from the various sensory devices.

A major cybersecurity threat to AI in autonomous ships arises from the risk of false data input, which may result from malware or other forms of cyber attacks. Such compromised data can impair the AI's decision-making processes, adversely affecting navigational accuracy and potentially

leading to collisions. This vulnerability underscores the critical need for robust cybersecurity measures to ensure data integrity in AI-driven navigation systems.

2.3 Autonomous Navigation System

The autonomous operation of ships involves various AI technologies. Additionally, the structure of the automatic navigation system can be divided into four technical areas: situational awareness and detection technology via sensor data collection and analysis for autonomous operation without the intervention of human decisions; technology for making judgments such as automatic navigation, collision avoidance, and efficient route planning; technology for controlling the ship's activities and taking action on the situations based on the judgment; infrastructure technology for operating autonomous ships from outside the ship and remote monitoring and controlling. FIG 1 depicts the structure of an autonomous navigation system (Kim & Jang, 2019).

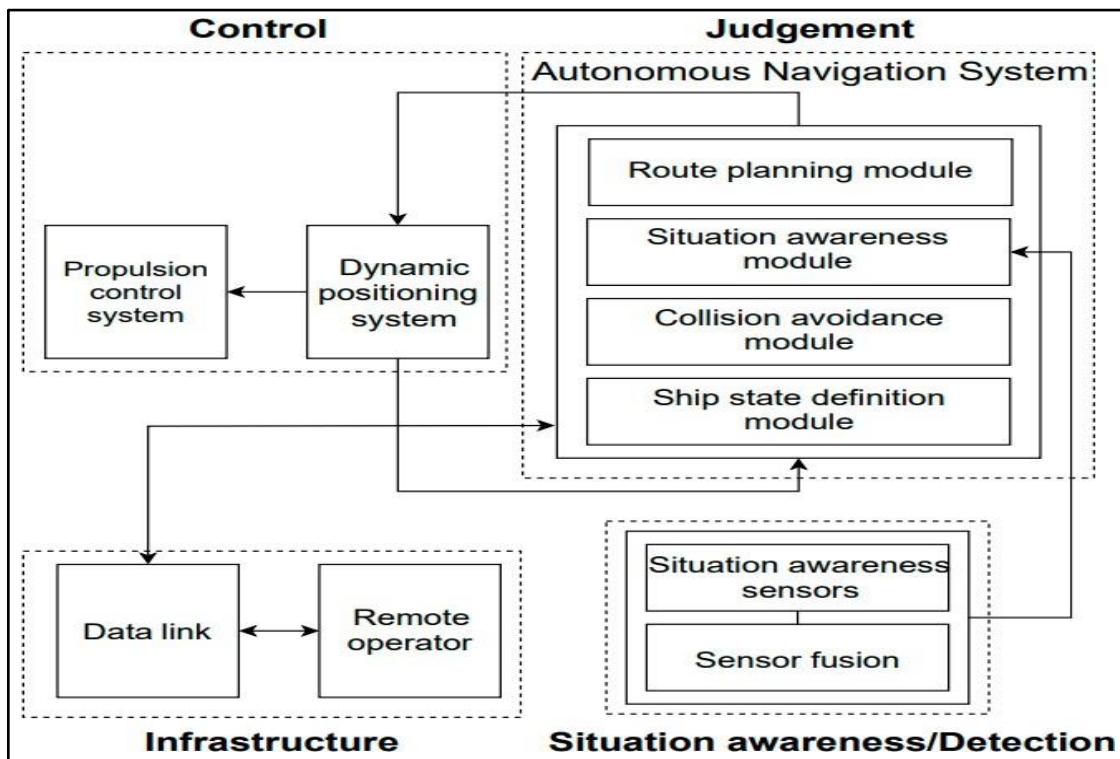


FIG 3 AUTONOMUS NAVIGATION SYSTEM (ANS) ARCITECTURE

Most ship collisions are caused by human accidents; they pose a major threat at sea (Perera, Ferrari, Santos, Hinostroza, & Soares, 2014). Ship collision avoidance is governed by the 1972 Convention on the Prevention of Collisions at Sea (COLREGs). Autonomous vessels benefit from the capability to evaluate multiple scenarios simultaneously, analysing both immediate surroundings and distant anomalies, typically represented by other vessels. By integrating situational awareness with maritime laws and COLREGs, autonomous systems can develop precise action plans to prevent collisions. This level of multi-scenario analysis surpasses human cognitive limits, offering enhanced safety and decision-making accuracy in complex maritime environments.

Route planning is one of the main parameters in autonomous ship systems. The purpose of route planning is to arrive at the destination with the optimal distance and time. Currently, methods such as neural networks and fuzzy and genetic algorithms are being studied for route planning in the fields of unmanned cars, mobile robots, and drones (Noel, Shreyanka, Kumar, Shameem, & Akshar, 2019). Traditional path-planning algorithms recycle historical data, resulting in poor algorithm accuracy and inefficient actual paths. As a result, research is being conducted on the routing models for autonomous unmanned ships, and improved route planning algorithms and models are under development (Guo, Zhang, Zheng, & Du, 2020)

3. CYBERSECURITY ON AUTONOMUS SHIPS

From August 2022 to March 2023, a total of 55 maritime cyber incidents were analysed, with 28 ransomware groups, 19 unknown attack groups, and 8 APT attack groups. The primary damage types are ransomware and service disruption, accounting for more than half of all damage types. Anticipated effects and estimates for autonomous ships do not take into account the potential threats associated with cyber and cyber physical attacks. This is because the untested combination of existing maritime system with new autonomous navigation technologies makes the comprehensive assessment of their risks and vulnerabilities impossible. Nevertheless, the interconnections among ships (and between ships and onshore infrastructure) are increasing, and as they increase, so do the potential cyber threats (Jones, Tam, & Papadaki, 2016)

AI in autonomous vessels relies on real-time data from sensors such as GNSS, AIS, and cameras to assess situations and make scenario-based judgments. However, the presence of malware during data transmission could alter or introduce erroneous input data, leading to various cybersecurity threats. Such compromised data can impair the AI's situational assessment capabilities, resulting in potential risks to navigational accuracy and overall system integrity.

Various attack scenarios are given as follows

3.1 Poisoning attack

An attack on a ship's autonomous system during its learning phase, which is foundational for its decision-making processes, could have severe implications for safe navigation. Such an attack could cause the system to misclassify potential threats as benign elements, undermining its ability to navigate safely and increasing the risk of collision. This type of attack, known as a poisoning attack, compromises the data received from the ship's sensors, leading to faulty input and subsequent errors in judgment.

A common example of a poisoning attack on autonomous ships involves the manipulation of visual data received by the AI from on board cameras. Under normal conditions, the AI receives an image

of a nearby vessel, classifies it accurately, and responds with appropriate navigational actions. However, in the case of a poisoning attack, the pixels in the image are intentionally distorted. This distortion can cause a significant lapse in judgment, leading to errors in the AI’s response. Research indicates that such attacks can reduce AI classification accuracy from 95% to as low as 33% (Jiang, Li, Liu, Luo, & Lu, 2020). While these alterations may be imperceptible to the human eye, the AI—relying on its specific training dataset—may interpret the image differently, leading to critical navigational errors.

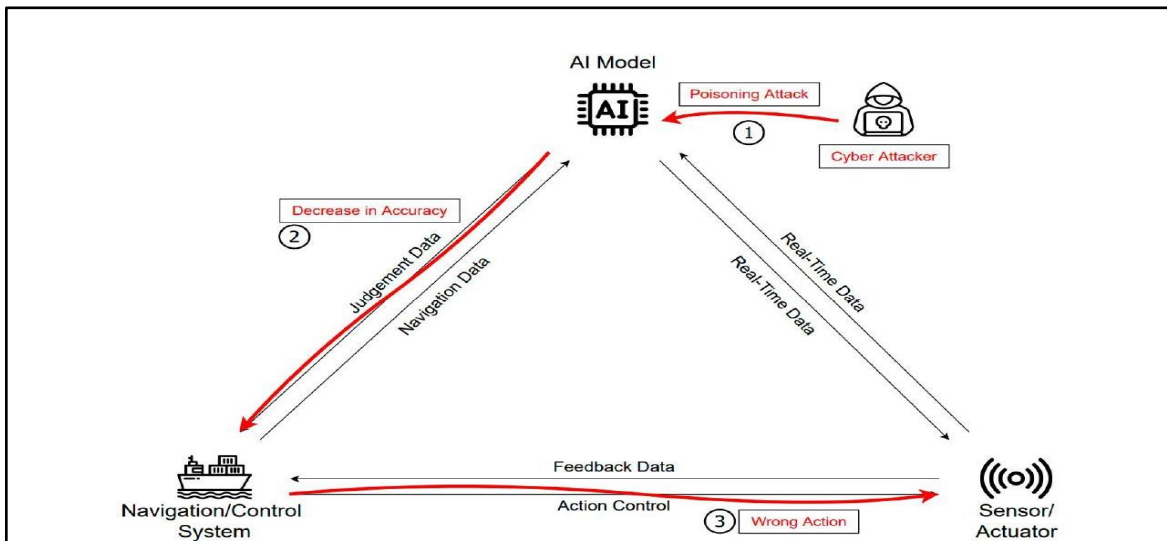


FIG 4 POISONING ATTACK SCENARIO

As shown in FIG 4. The Attacker attacks the AI at the learning stage which leads to decrease in accuracy. This lack of accuracy then leads to a wrong action being taken by the AI.

3.2 Attack on the sensor

Autonomous ships use many internal or external sensors, including AIS, radar, camera, SONAR, and LiDAR. Through these multiple ocean sensor data, the ship recognizes the situation and detects objects to make appropriate judgments such as course correction and collision avoidance (Thombre, et al., 2020).

AIS (Automatic Identification System) are mandatory for many large vessels; however, there are currently no protocols to safeguard AIS against cyber-attacks. The messages transmitted and received by AIS lack encryption, making them vulnerable to interception and manipulation. This lack of security allows potential attackers to exploit AIS, posing risks to the vessel’s critical operational functions.

If an attack is made on the sensor components then it leads to false data and thus error in navigation. Attacks using AIS vulnerabilities have been shown as possible in a number of

scenarios, including weather information manipulation, false collision warnings, and denial-of-service attacks (CyberKeel, 2014). Thus autonomous vessels are at a great risk from data tampering and disturbances.

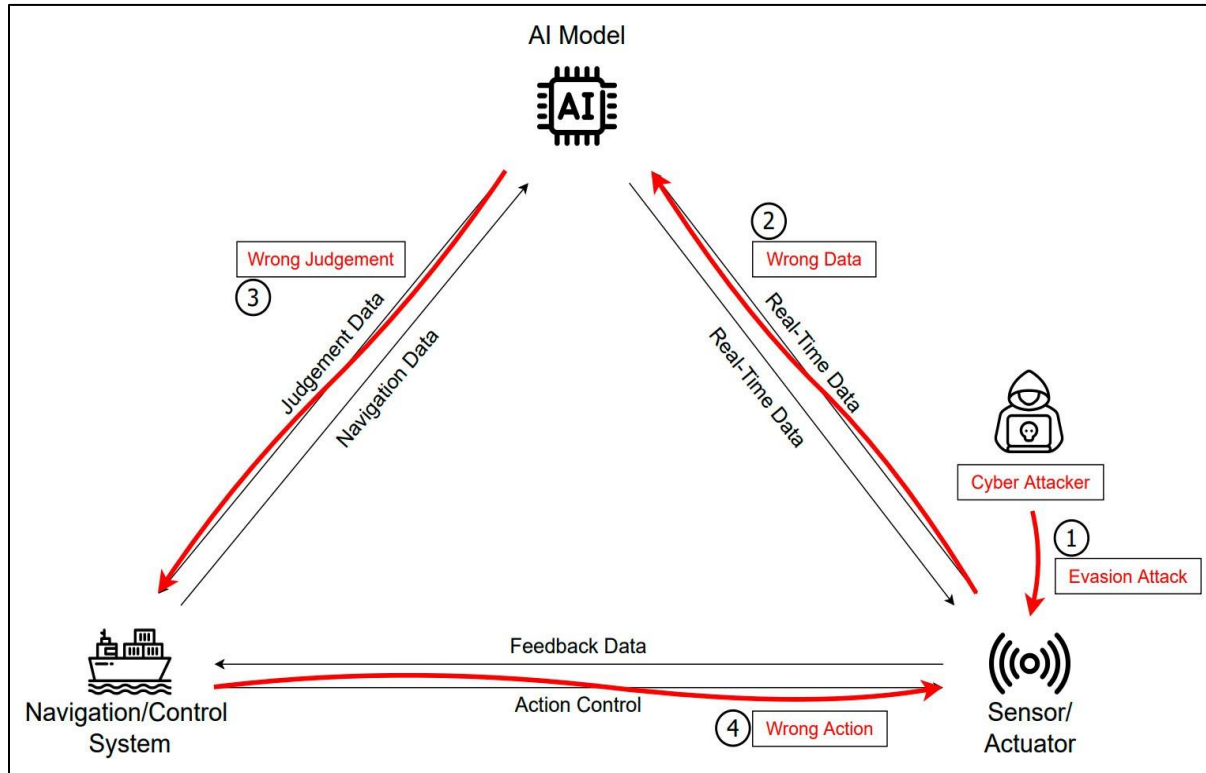


FIG 5 ATTACK SCENARIO TO DECIEVE OR DEGRADE SENSORS

As shown here in FIG 5. Data received from a damaged sensor can cause abnormal behaviour by the Ship or incorrect judgment making.

To counter this kind of an attack there has been some proposal. Software security framework, encryption, obfuscate signals, and (remote) attestation have been proposed as countermeasures in opposition to cyber threats to sensor data, such as AIS, GNSS, and LiDAR, which are essential for ships (Evtimov, et al., 2017)

3.3 Attack on the Communication Protocol

It has been observed that autonomous ship systems have the potential to provide complete control to the ship in cyberattacks owing to the high network connectivity for facilitating communication with land (Coffed, 2014)

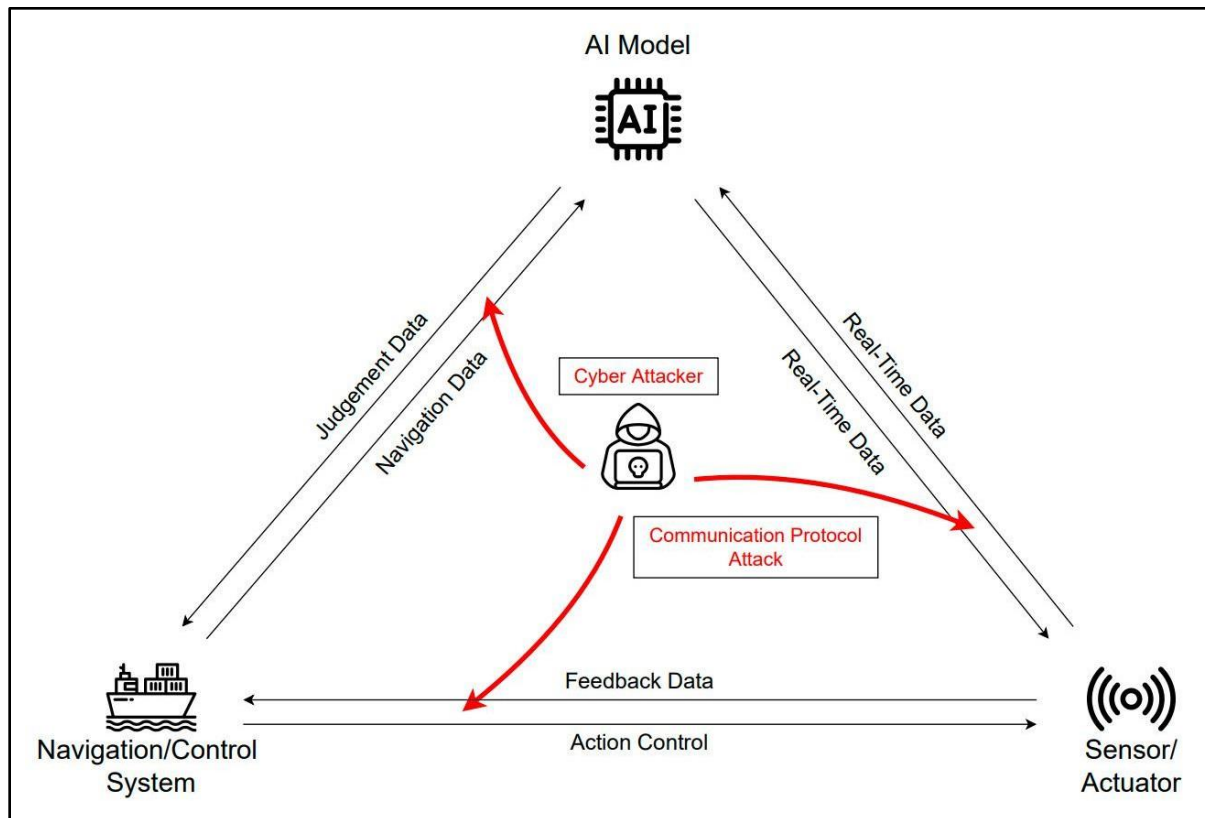


FIG 6 ATTACK ON THE COMMUNICATION PROTOCOL

In the case of an attack on the communication protocol of the ship, various communication protocols such as the 4G/5G protocol, NMEA (Used for transmission of sensor data to the AI system) are the one which would be attacked and thus can cause various security and safety issues on the ship. The NMEA protocol has no security features, meaning there is no encryption on the transmission of data on board the vessel thus they are the most vulnerable to a cyberattack.

As there are no authentication protocols set in place thus they are vulnerable to a man-in-the-middle attack where the attacker can insert error full data and alter with the collected data from the sensor. This case of an attack is not just in theory, Vulnerabilities in the satellite communications used by ships have also been reported, allowing attackers to gain access to the ship's network (Santamarta, 2014).

CONCLUSION

Many researchers agree that autonomous ships represent the future of the maritime industry. However, these vessels present significant cybersecurity risks, necessitating the implementation of advanced anti-cyber-hacking protocols, which current standards do not yet mandate. This paper aims to identify the various stages of decision-making processes within autonomous vessels where cyber-attacks could occur, potentially compromising the vessel's overall security. Autonomous systems onboard are highly interdependent, so a successful attack on one system can cascade to

others, compromising the entire network. Therefore, establishing protocols that isolate systems in the event of an attack is essential, as this would contain the impact to the initially targeted system, safeguarding the broader network integrity.

In response to these emerging threats, international regulatory bodies such as the International Maritime Organization (IMO) and the International Association of Classification Societies (IACS) have recently highlighted the cybersecurity risks posed by autonomous ships and are working toward standardized regulations for their safe operation in the commercial sector. Although existing research has explored numerous cyberattack scenarios, there remain potential attack vectors that may not yet be fully considered. This underscores the need for further research and on going deliberations in the field of maritime cybersecurity.

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IMPROVING ENGINE ROOM VENTILATION SYSTEM

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ABSTRACT

Enhancing ship energy efficiency is crucial for minimizing fuel consumption and reducing shipborne harmful emissions. The engine room houses numerous electric motors, which contribute significantly to overall energy usage. Optimizing the performance of these motors is essential when considering energy efficiency in relation to environmental impact and climate change. Implementing variable frequency drives (VFDs) can enhance the electrical, mechanical, and operational efficiency of these motors. This study examines the use of VFDs in engine room ventilation motors under two different ambient temperatures to improve overall ship energy efficiency. The energy consumption of ventilation fans is calculated, and efficiency variations based on air temperature are analysed. Using real data from crude oil tanker ships, the results are compared with conventional systems. Findings indicate that VFD-powered electric motors for engine room fans can achieve over 80% energy savings, reducing annual energy consumption from 613.116 kWh to 153.279 kWh.

KEYWORDS

Variable Frequency drive, Electric Motors, Ship Energy consumption, Engine Room Ventilation

1. INTRODUCTION

Maritime transportation is a vital component of global trade, accounting for approximately 90% of its share (Deniz & Zincir 2016; Inal & Deniz, 2020). The most important component of maritime trade is ships, which are powered by marine diesel engines. Therefore, considering its environmental effects, the amount of fossil fuel consumed becomes substantial. The maritime industry is facing increasing pressure of reducing ship-sourced harmful emissions, and enhance sustainability (IMO, 2020). From this perspective, energy efficiency plays a critical role for ships, and cannot be overstated with many benefits ranging from cost savings to sustainability. The International Maritime Organization (IMO), a United Nations agency responsible for the maritime industry, has implemented a series of rules and regulations aimed at addressing shipping emissions and promoting increased energy efficiency in ships (IMO, 2021). For instance, the Energy Efficiency Design Index (EEDI) sets energy efficiency requirements for new ships, while the Ship Energy Efficiency Management Plan (SEEMP) encourages ship operators to implement energy-saving measures. Adhering to these regulations is essential for ships to maintain compliance and ensure access to ports worldwide. Ships are responsible for significant global greenhouse gas

emissions and air pollutants (Dere & Deniz, 2019). By embracing energy-efficient practices, ships can minimize their carbon footprint, reduce harmful emissions, and contribute to the global fight against global warming and climate change. Energy-efficient practices can reduce emissions such as CO₂, SO_x, NO_x, or PM, helping meet international emission reduction targets and regulatory requirements.

The combustion and heat emission air-flow requirements of the / and auxiliary machinery at reduced speeds can be defined through modelling the vessel's / air ventilation system, which will reveal the maximum power-saving margin that can be obtained after the application of the proposed topology. The following results are provided specifically for the tanker vessel under study, assisting the design and implementation of the proposed process control scheme,

The easiest and most efficient way to reduce the power consumption is to install a VFD to control the cooling capacity when operating at less than extreme conditions. ABB provides specialized solutions and services to improve the energy efficiency in these processes. Average annual savings are 40-60%. Pumps and fans on board vessels are mainly of a centrifugal type, which means that a speed reduction of 10%, will give 27% power savings.

The onboard ship systems best suited to improving energy efficiency are systems with large pumps and fans, which are not required to run continuously or at full capacity. Where applicable, electric motors could be fitted with VFD to operate pumps and fans more efficiently at partial loads, for example during slower sailing speeds or with reduced ventilation requirements.

Energy Efficiency plays the most important role in CO₂ emission reductions, accounting for up to 53% of total CO₂ emission reductions. In pump and fan applications onboard vessels, using Variable Frequency Drives (VFD) can cut the energy consumption for these applications by as much as 60%.

2. RELATED WORK

The typical E/R ventilation system for a marine vessel is presented in Figure 1. Our axial flow fans are installed outside the engine casing and, through separate air ducts, provide combustion air to major E/R consumers, which include the M/E, D/Gs, and the oil-fired boiler. Two of them can also work in exhaust mode, used only on very hot days when the air needs to be evacuated from the E/R during hot work. It is noted that air ventilation ducts are placed near M/E and D/Gs turbochargers.

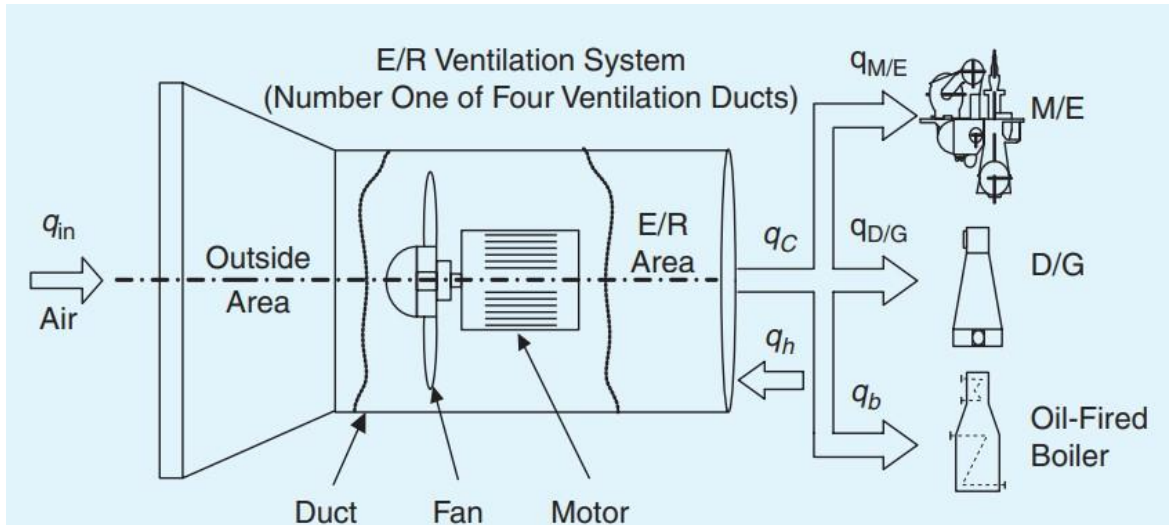


FIG 1 TYPICAL E/R VENTILATION SYSTEM

The image is a diagram of an E/R Ventilation System, specifically one of four ventilation ducts. The diagram shows how air is drawn in from the outside, passed through a fan and motor, and then distributed to different areas (M/E, D/G, and an oil-fired boiler), indicated by the arrows and flow rates (q)

3. PROPOSED METHOD

The proposed data-driven controller interface with the E/R air ventilation system process for the vessel under study is presented in Figure 2, using real-time measurement sets to regulate parameter set points and set fan motor speed.

1. HMI (Human-Machine Interface)

This allows operators or users to interact with the system, input commands, and receive feedback on the system's status.

2. Data-Driven Process Controller

This component takes in real-time data (such as temperature, pressure, etc.) and adjusts the system accordingly to meet set parameters. It manages the control of the system based on the information it receives.

3. VFD (Variable Frequency Drive)

This component controls the speed of the fans by adjusting their power based on inputs from the data-driven process controller. It helps optimize energy use while maintaining the necessary airflow.

4. *Fan Numbers 1-4*

These represent multiple fans in the system. Their speeds or operation could be controlled by the VFD to regulate airflow in the system.

5. *E/R Area (Exhaust/Return Area)*

This section refers to the area in the system where the air is either being returned or exhausted.

6. *Outside Area*

The external environment outside the system, which is influencing the conditions inside the system.

7. *Amb. Temp (Ambient Temperature)*

This represents the temperature of the surrounding environment, which is a factor in controlling the system's behaviour.

8. *Pdiff, E/R (Differential Pressure)*

This is a measure of the pressure difference across various sections of the system, which could help monitor airflow efficiency and identify any blockages or performance issues.

9. *Pout*

Output pressure, which could be used to assess the system's efficiency or the pressure level at the end of the airflow process.

10. *DP (Differential Pressure)*

This could refer to the pressure difference that the system is monitoring or maintaining to ensure proper airflow or ventilation.

An Adaptive Controller for a Ventilation Fan System Motor on a ship, operated via a Variable Frequency Drive (VFD), works by dynamically adjusting the motor speed based on real-time engine room conditions

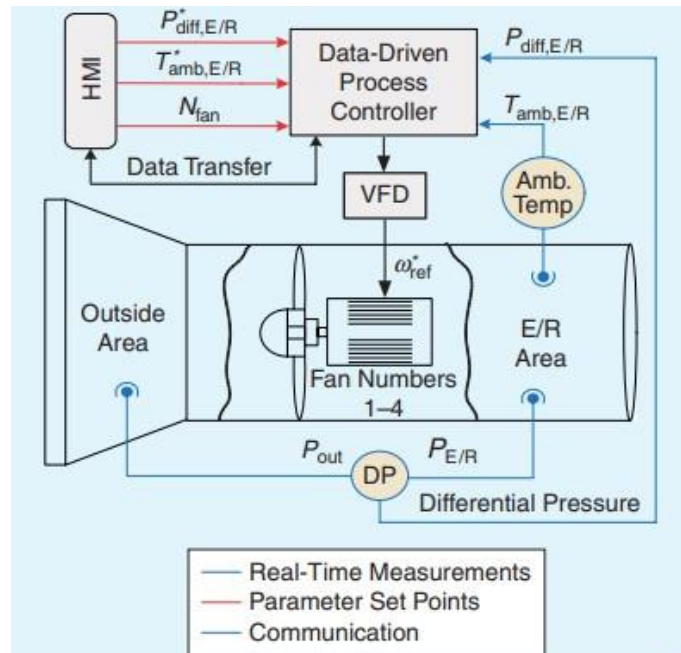


FIG 2 PROPOSED VENTILATION SYSTEM USING VFDs

4. INPUTS TO THE CONTROLLER

The controller continuously monitors two primary parameters: engine room temperature and pressure difference. Engine room temperature is measured using temperature sensors strategically placed inside the engine room, providing real-time data on the thermal conditions within this critical area. Additionally, pressure difference is assessed through sensors that compare the internal pressure of the engine room with the outside atmospheric pressure, ensuring that any deviations are promptly detected.

5. DECISION-MAKING PROCESS

The controller employs an adaptive algorithm that processes various inputs to determine the optimal fan speed for ventilation and temperature control. When the temperature is high, the controller responds by increasing the fan speed through a Variable Frequency Drive (VFD), which enhances ventilation and helps lower the temperature effectively. Conversely, if the temperature is low, the controller reduces the fan speed to conserve energy and prevent overcooling of the environment. Additionally, if the pressure inside the system is too high, the controller will increase the fan speed to balance this pressure with that of the outside environment. On the other hand, if it detects that the pressure inside is too low, it will reduce fan speed to avoid creating excessive negative pressure, which can adversely affect proper ventilation and engine performance.

6. HOW VFD HELPS IN CONTROLLING THE MOTOR

A Variable Frequency Drive (VFD) is an essential component in modern motor control systems, allowing for precise regulation of motor speed and torque by varying the frequency and voltage supplied to the motor. One of the primary benefits of using a VFD is energy efficiency; it adjusts power consumption based on the actual demand of the application, which can lead to significant energy savings compared to traditional constant-speed motors. By enabling motors to operate at lower speeds when full power is not required, VFDs help reduce overall energy usage.

7. POWER CONSUMPTION

The power consumption of an engine room ventilation system on a ship depends on factors such as fan size, number of fans, engine power, ship type, and operating conditions. Below is a general estimation:

A ship's engine room ventilation consists of:

- Main Engine Room Fans: 2-6 large fans (~50-150 kW each)
- Generator Room Fans: 2-4 medium fans (~20-50 kW each)
- Auxiliary Space Ventilation: (~5-20 kW per fan)

Load Condition	Typical System (DOL) – Constant Speed	System with VFD – Reduced Speed
100% Load (Full Speed)	50 kW	50 kW
75% Load	50 kW	≈ 26.4 kW (Using Affinity Laws: Power ∝ Speed³)
50% Load	50 kW	≈ 12.5 kW
25% Load	50 kW	≈ 3.1 kW

Table 1 POWER CONSUMPTION COMPARISON

Assume a 50kW motor running at different loads in both systems.

Load Condition	Typical System Energy Consumption (kWh/year)	VFD System Energy Consumption (kWh/year)
100% Load (10% time)	40,000 kWh	40,000 kWh
75% Load (30% time)	120,000 kWh	63,360 kWh
50% Load (40% time)	160,000 kWh	50,000 kWh
25% Load (20% time)	80,000 kWh	12,480 kWh
Total Energy (kWh/year)	400,000 kWh	165,840 kWh

TABLE 2 ENERGY SAVING ESTIMATION

Assume the fan operates 8,000 hours/year at different load levels

CONCLUSION

Modernizing your engine room ventilation system with a variable frequency drive (VFD) can significantly improve energy efficiency, reduce operational costs and improve overall system performance. Unlike traditional fixed speed fans, VFD-controlled ventilation adjusts airflow based on actual demand, reducing unnecessary energy consumption. The result is a significant reduction in energy consumption (often by more than 50%) and reduced maintenance needs due to reduced mechanical stress.

In addition, VFDs improve environmental conditions by maintaining optimal air circulation, reducing heat build-up, and improving humidity control. Though the initial investment is higher, the long-term savings in energy costs and maintenance result in a short payback period. Implementing VFDs in engine room ventilation systems enhances sustainability, extends equipment lifespan, and aligns with modern energy efficiency regulations. Therefore, integrating VFD technology is a highly beneficial upgrade for ship operators looking for cost-effective and environmentally friendly solutions.

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CHARTING A NEW AGE IN INLAND WATER TRANSPORT: A CASE STUDY ON KOCHI WATER METRO

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ABSTRACT

This paper indulges in the comparative study between the Kochi water Metro and other vehicles which are currently being used by the public to commute. This included studying the detailed project report by the Kerala Water Metro Limited (KWML), various research papers and articles along with the ground work done by the authors. The study was done mainly on ecological, economical, technology aspects using publicly accessible data and field work with water metro operators. The study concludes that meanwhile the advantages to the environment and the public is evident, the promised benefits can only be seen on the completion of the project. In our study, we found out that range from batteries are a concern requiring frequent recharging. To mitigate this, hydrogen fuel cells are in consideration for the next phases of the project, of which we also have collected data on for existing hydrogen powered ferries currently operational and servicing in Varanasi. The main aim of the study was to learn about an operational model of an eco-friendly transport system.

KEYWORDS

hydrogen, battery, CO₂, Comparative, solar

1. INTRODUCTION

Kochi is a city laced by islands and connected by roads and inland waterways. Being a major commercial hub in the state, congestion and long travel times has always been a hassle. To mitigate this the Kochi metro rail was introduced in 17th of June 2017. But the connectivity between islands and the mainland remained an issue where the bridges and diesel-powered ferries were the only option. The Kochi metro was envisioned as a part of an integrated transport system including the rail system, electric autos, buses, bicycles and our topic of interest- the water metro. [12] The project aimed at creating a link between the ten islands to the mainland with a fleet of 78 electric boats and 38 terminals covering more than 75 kilometres. But as of now 5 routes are operational with a compliment of 18 boats. The study aims to study the ecological impact the project has by comparing it with other modes of transport including motorcycles, cars and diesel-powered ferries operating in the same routes. Talking about the economic aspect, as the project as a whole is still in its infancy, it was decided that the overall profitability of the project to not be considered for now. As the project claims to be of service to the public by being an affordable and

environmentally friendly alternative, the study focuses on how this project holds up to that claim and how is it better compared to existing transport systems. The calculations were done with mostly data available in the public domain, but also data collected from more than a week of field work in Kochi and Alappuzha and also working with officials and staff of the Kochi water Metro Limited.

2. WATER METRO FERRY DETAILS

The water metro boat, built by Cochin Shipyard limited for the KMRL is 24-meter-long dual class catamaran classified by both the DNV and the IRS. The boats are equipped with advanced propulsion systems, featuring a fixed pitch propellor, a 2:1 ratio reduction gear for propulsion. The reversal of the vessel depends on gear box, which does not require the motor to turn in the opposite direction. The boat uses a hydraulic clutch. The lube oil serves as hydraulic fluid, with the lube oil pump acting as the hydraulic pump.

The boat has two 3 phase PPMC motors. The propulsion system was designed and manufactured by Siemens and Echandia. The pair gives a theoretical output of 55 KW, but operationally they give between 35 and 45 KW which are powered a LTO battery of 122KWh split into 2 hulls. They are accompanied by a pair of diesel generators (theoretical output: 108 KW) which gives the boat 3 modes: electric, diesel (8 knots) and hybrid (10 knots). According to the operators, the hybrid mode is used when additional power is required especially during berthing and passing through rougher waters.



FIG 1 WATER METRO FERRY

2.1 Safety Features of The Boat and Jetties

Automatic Boat locating system: The ABLS collects the real time information on the speed, position, battery SOC and other aspects. This allows for a fast response during an emergency using their fast response boat ‘Garuda’.

- Easily accessible lifejackets were also a plus point.
- In addition, floating pontoons used as jetties added to its operational capacity during higher or lower waters.



FIG 2 FLOATING PANTOONS UNDER CONSTRUCTION



FIG 3 PILLARS WITH ROLLERS SUPPORTING PANTOONS

- The KWML chose to go with a catamaran design over the traditional single hull design owing to its stability and resistance to rolling. However, pitching was observed during rougher waters.
- One of the major reasons for boat accidents in inland waters was observed to be overcrowding. This is a common tactic used by boat operators to increase the number of people transported per trip thereby increasing profits. To mitigate this is, PCS (passenger counting system) is deployed at each station which closes the gates at 96 passengers.
- The cabin doors for the passengers are closed before each trip starts and only opened after safely berthing at the destination. This is to prevent passengers from accessing the open deck during voyage and causing accidents.

3.COMPARATIVE STUDY

3.1 Diesel Ferry

The manuscript "Economics of ADITYA - India's First Solar Ferry" by Sandith Thandasherry offers insights into the fuel consumption of a 75-passenger ferry operating between Vaikom and Thavanakkadavu. The ferry covers a distance of 2.8 km per trip and completes 22 trips in a 12-hour period, consuming 100 litres of diesel. This gives a total distance covered of 61.6 km (22 trips × 2.8 km). From this, we calculate the ferry's average fuel efficiency to be 0.616 km per litre of diesel, although this doesn't account for idling times. This data provides a useful reference point for comparing the fuel efficiency of traditional diesel-powered ferries with electric propulsion systems used in modern alternatives like water metro boats, which aim to reduce fuel consumption and emissions.

- Route 1

Vytilla to Kakkanad: 24 trips (07:35 to 19:00) and return 24 trips (08:05 to 19:30) This sums up to 48 trips.

The distance between the two terminal is 5.1 km. Total distance covered: $48 \times 5.1 = 244.8$ km. From previous data it was found out that the ferry requires approximately 1.162 litres per kilometre

If the same route is covered using a diesel ferry, we would require $244.8 \times 1.162 = 285$ litres of diesel. At an average price of diesel in Kochi to be taken as 95.33 rupee, the amount to be spent on fuel: $285 \times 95.33 = 27,200$ rupee.

At a fuel expenditure of 285 litres of diesel,

Carbon emissions per day = $285 \times 2.7 = 770$ kg of CO₂.

This method was used to calculate emission for all routes.

This gives us the total distance covered by the boats per day = 650.48 km.

For a yearly operation of 365 days assuming no interruptions, the total covered would be 2,37,425.2km.

At an average of 1.162 litre/km, a conventional ferry would have used 2,76 lakh litres of diesel.

At an average emission of 2.7 kg of CO₂ /litre, it would have released 7.45 lakh kg of CO₂. (US EPA calculator)

3.2 Road Transport

To study about the average time required by using road, we take the starting and end points as the two terminals of the water metro. The sample space is taken as a period of 42 days. The average time required to cover the distance is take twice for everyday (once for a peak hour and a non-peak hour). This data is then calculated for finding average travelling times and speeds between these points. The calculated data gives an approximate value and can be used for finding cost effectiveness for

the end user and emission.

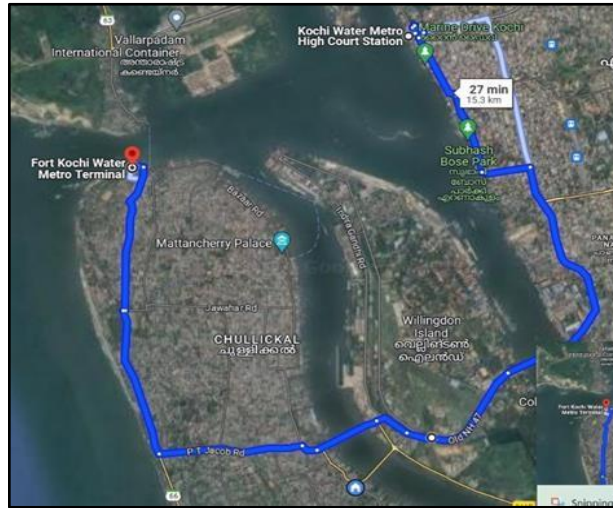


FIG 4 HIGH COURT AND FORT KOCHI ROUTE (GOOGLE MAPS)

Average time taken for car to cover the distance= 1.5 to 2 hrs.

Average time taken for the motorcycle to travel the distance= 1 hr.

Time taken by the water metro to travel=40 minutes

CO₂ emission from motorcycle if it travelled 30.6km= 1.26 kg (at 41.2 g/km)

CO₂ emission from car if it travelled 30.6 km= 4.23 kg (at 138 g/km)

Let us assume that a person travels every day for work between the two points, in a period of 30 days. Excluding holidays we can take 25 days. This would make him travel by road $15.3 \times 25 = 382.5$ km. Considering return journey= 765 km. CO₂ emission from car for a month= 105.6 kg CO₂ emission from bike for a month= 31.6 kg

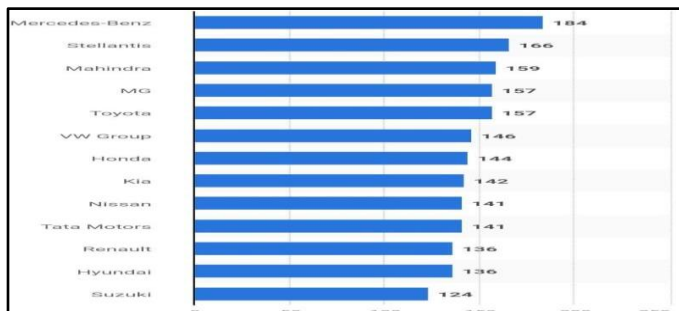


FIG 5 AVERAGE CO₂ EMISSION IN G/KM IN INDIAN CARS

DATE	PEAK HR 9AM (min)	AVG (min)	BIKE	AVG	NON-PEAK 6 PM (min)	AVG (min)
July						
12	30 to 55	42.5	23 to 32	27.5	40 to 70	55
11	30 to 55	42.5	22 to 32	27.5	40 to 70	55
10	30 to 55	42.5	23 to 32	27.5	40 to 70	55
9	30 to 55	42.5	23 to 32	27.5	40 to 70	55
8	30 to 55	42.5	23 to 33	28	40 to 70	55
7	28 to 50	39	23 to 32	27.5	35 to 65	50
6	30 to 55	42.5	23 to 32	27.5	40 to 70	55
5	30 to 55	42.5	23 to 32	27.5	40 to 70	55
4	30 to 55	42.5	22 to 32	27	40 to 70	55
3	30 to 55	42.5	22 to 32	27	40 to 70	55
2	30 to 55	42.5	23 to 32	27.5	40 to 70	55
1	30 to 55	42.5	23 to 33	27.5	40 to 70	55
June						
30	28 to 50	39	23 to 32	27.5	35 to 65	50
29	30 to 55	42.5	23 to 32	27.5	40 to 70	55
28	30 to 55	42.5	23 to 32	27.5	40 to 70	55
27	30 to 55	42.5	23 to 33	28	40 to 70	55
26	30 to 55	42.5	23 to 33	28	40 to 70	55
25	30 to 55	42.5	23 to 32	27.5	40 to 70	55
24	30 to 55	42.5	23 to 32	27.5	40 to 70	55
23	28 to 50	39	23 to 32	27.5	35 to 65	50
22	30 to 55	42.5	22 to 32	27.5	40 to 70	55
21	30 to 55	42.5	22 to 32	27.5	40 to 70	55
20	30 to 55	42.5	23 to 32	27.5	40 to 70	55
19	30 to 55	42.5	23 to 32	27.5	40 to 70	55
18	30 to 55	42.5	23 to 32	27.5	40 to 70	55
17	30 to 55	42.5	22 to 32	27.5	40 to 70	55
16	28 to 55	39	22 to 32	27.5	35 to 65	50
15	30 to 55	42.5	23 to 32	27.5	40 to 70	55
14	30 to 55	42.5	23 to 32	27.5	40 to 70	55
13	30 to 55	42.5	23 to 32	27.5	40 to 70	55
12	30 to 55	42.5	22 to 32	27.5	40 to 70	55
11	30 to 55	42.5	22 to 32	27.5	40 to 70	55
10	30 to 55	42.5	23 to 32	27.5	40 to 70	55
9	28 to 50	39	23 to 32	27.5	35 to 65	50
8	30 to 55	42.5	23 to 32	27.5	40 to 70	55
7	30 to 55	42.5	22 to 32	27.5	40 to 70	55
6	30 to 55	42.5	22 to 32	27.5	40 to 70	55
5	30 to 55	42.5	23 to 32	27.5	40 to 70	55
4	30 to 55	42.5	23 to 32	27.5	40 to 70	55
3	30 to 55	42.5	23 to 32	27.5	40 to 70	55
2	28 to 50	39	22 to 32	28	35 to 65	50
1	30 to 55	42.5	22 to 32	28	40 to 70	55
		AVG = 42		AVG = 27.537		AVG = 54.285

FIG 6 AVERAGE TIME TAKEN FOR ONE WAY TRAVEL

3.3. Emission From Charging of Batteries in The Water Metro Ferry [2]

As the ferry boats are still being charged using power from the grid, the emission from the production of electricity with the data from the Central electricity department, Ministry of Power, Government of India is calculated.

Total CO₂ emissions from production of electricity in 2021-22= 1002.02 million tonnes

Net electricity generation (considering renewables) = 1401.1 million MWh

Weighted average Factor= $\frac{1002.02}{1401.01}$ = 0.71 tCO₂/MWh.

In the same route take above (High Court and fort Kochi) for one round trip around 60% SOC is used: which is around 73.2 KWh per round trip. This is higher consumption compared to other routes as the route here is near the sea mouth and close to the Cochin Port. Strong cross currents and wake from other fishing boats, ferry and ships arriving in and departing from cochin port. Sometimes onboard generators are used to give more power concurrently with batteries (known as hybrid mode).

For a period of 25 days 73.2 x 25= 1830 Kwh= 1.83 MWh

Distance between the two stations by water= 3.9 km

The CO₂ emission from the boat for one round trip per day for 25 days= 1.83 MWh x 0.71tonnes/
Mwh= 1.2933 tonnes or 1.3 tonnes.

As this ferry carries 96 passengers, then per head CO₂ emission per month= 13.5 kg

This is higher compared to another route between Vytilla and Kakkanad

Distance between the two stations by water= 5.1 km

For one round trip around 60% SOC is used: which is around 73.2 KWh per round trip.

Even though battery consumption is same in both routes, the per km consumption is higher in one route due to several factors such as cross currents, wake from other vessels, slower running due to clogging of cooling water intake, locking of propellers from algae in the waters.

3.4. Cost, Time And CO₂ Comparison for Passengers for Every Transport Mode [4]

The cost to the consumer is of utmost importance in every transport system. This not only includes the per day or per month monetary cost to the consumer, but also the time for transport, and the carbon footprint they leave behind.

The cost per month for a consumer using a car= total distance travelled in Km x per Km
Cost

Per km cost of running a car= this includes the fuel cost, insurance, yearly maintenance, tires at an average for both diesel and petrol cars= 11 rupee/km

Monthly cost for the consumer for 765km= almost 8400 rupees

The CO₂ emission for a month by the consumer= 105.6 kg

The cost per month for a consumer using a motorcycle= total distance travelled in Km x per km Cost
Per km cost of running a motorcycle = this includes the fuel cost, insurance, yearly maintenance= 4.36 rupee/km

Monthly cost for the consumer for 765km= almost 3330 rupees

The CO₂ emission for a month by the consumer= 31.6 kg

Per month cost to a consumer using a diesel ferry= 300

Per head emission of CO₂ = 8.37 kg (this is for the best-case scenario and not the actual numbers, some sources say that the per km consumption is much higher due to the same reason the electric ferry achieves less efficiency).

Per month cost of consumer using water metro boat= 600 rupees

Per head emission of CO₂= 13.5 kg

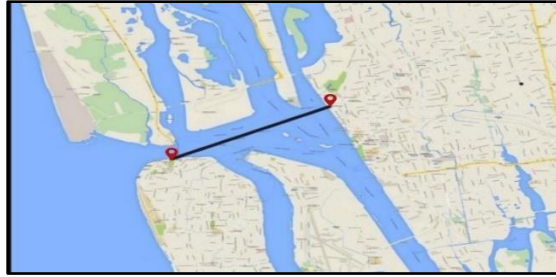


FIG 7 WATER ROUTE BETWEEN KOCHI FORT AND HIGH COURT

Mode of Transport	Distance Between Two points (round trip)	Time taken to travel (round trip)	Per month expenditure for the consumer	CO ₂ emission per head
1. Car	30.6 km	2-2.5 hrs	8400-rupee	105.6 kg
2. Motorcycle	30.6 km	1 hr	3300-rupee	31.6 kg
3. Dieel powered ferry	3.6 km	40 mins	300-rupee	8.4 kg
4. Water metro Ferry	4 km	30 mins	600-rupee	13.5 kg

TABLE 1: All the calculated data from above is tabulated below for easy comparison

4. SOLAR POWER TO ACHIEVE NET-ZERO [6]

As we have thought by now, the charging of batteries directly from the grid is causing the project to be a part of CO₂ emissions. To mitigate this a solar plant in Alappuzha as suggested by the operators is a viable option.

Estimating the Electricity Production of a 17 MWp Solar Plant in Alappuzha, Kerala

To estimate the annual electricity production of a 17 MWp (megawatt-peak) solar plant in Alappuzha, Kerala, we can use the following formula:

$$\text{Annual Energy Output (MWh)} = \text{Installed Capacity (MWp)} \times \text{Average Daily Energy Production (kWh/kW/day)} \times 365 \times \text{Performance Ratio (PR)}$$

Parameters

Installed Capacity: 17 MWp

Average Daily Energy Production (varies seasonally in Alappuzha):

- Summer: 5.22 kWh/kW/day
- Autumn: 4.77 kWh/kW/day
- Winter: 6.15 kWh/kW/day
- Spring: 6.28 kWh/kW/day

These values are derived from data specific to Alappuzha.

Performance Ratio (PR): A typical value of 0.80 (80%), accounting for system losses due to factors like temperature, dust, and inefficiencies.

Step 1

Calculate the Weighted Average Daily Energy Production

We calculate the weighted average daily energy production by multiplying each season's average

daily energy production by the number of days in the season and then dividing by the total number of days in the year.

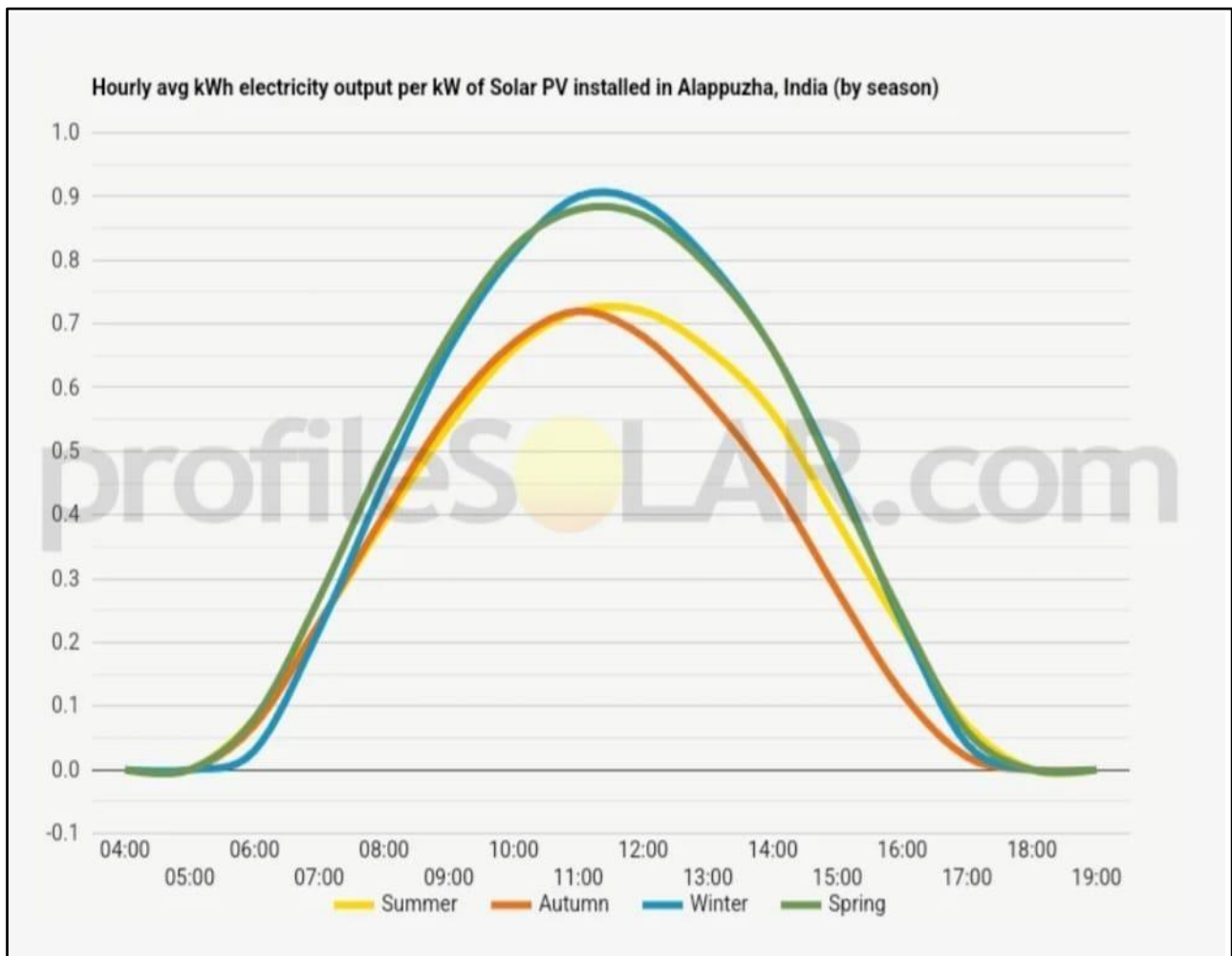
$$\text{Weighted Average} = \frac{(5.22 \times 92) + (4.77 \times 91) + (6.15 \times 90) + (6.28 \times 92)}{365}$$

Where the number of days in each season is approximated as:

- Summer: 92 days
- Autumn: 91 days
- Winter: 90 days
- Spring: 92 days

$$\text{Weighted Average} = \frac{(480.24) + (434.07) + (553.5) + (577.76)}{365}$$

≈ 5.66 kWh/kW/day



CONCLUSION

A 17 MWp solar plant in Alappuzha is estimated to produce approximately 28.1 GWh (gigawatt-hours) of electricity annually (or 32,222,222 KVAh at 0.9 pf). This estimate accounts for seasonal variations in solar irradiance and typical system performance losses.

Note: Actual energy production can vary based on specific site conditions, system design, maintenance, and unforeseen environmental factors.

If this is installed, the operators claim that they can meet the daily energy requirement for the entire fleet of 78 boats. The plant does not give power directly to the boats. As the plant is in Alappuzha, the energy is taken from the grid and supplying the plant's power directly to the grid. This gives net zero and maybe allow them to go carbon negative if the opt for an alternative fuel in the next phase of the project.

4.1 Emission from production of Solar Panels

The production of solar panels generates emissions primarily from mining, manufacturing, and transportation. Key sources include:

1. Raw Material Extraction: Mining and processing silicon, aluminium, and metals like silver.
2. Manufacturing: Energy-intensive processes like silicon purification and crystallization.
3. Transport: Shipping panels globally adds to emissions.

The carbon footprint of producing solar panels is around 20–80 kg CO_{2e} per m². However, the carbon footprint of solar energy is much lower at 20–50 g CO_{2e} per kWh over the panel's lifetime (25–30 years). This is significantly less than fossil fuels like coal (800–1,000 g CO_{2e}/kWh).

Solar energy's carbon footprint can be reduced by recycling, using renewable energy in manufacturing, and improving efficiency. Solar panels offset their production emissions in about 1–3 years of use.

5. ALTERNATIVE METHOD OF PROPULSION: HYDROGEN CELLS

India has made significant progress in hydrogen-powered maritime transportation, with Cochin Shipyard Limited developing the country's first hydrogen fuel cell ferry under the "Harit Nauka" initiative. The 24-meter catamaran ferry can carry 50 passengers and operates on a 50-kilowatt PEM fuel cell, supported by lithium-ion batteries and a 3-kW solar panel. It has a hydrogen storage capacity of 40 kg in 5 cylinders and can operate for up to eight hours with zero emissions and noise. Developed in collaboration with KPIT Technologies and CSIR, this ferry highlights India's commitment to sustainable transportation and achieving net-zero emissions by 2070.



FIG 8 THE HYDRGEN FERRY BUILT BY CSL(ENT NEWS)

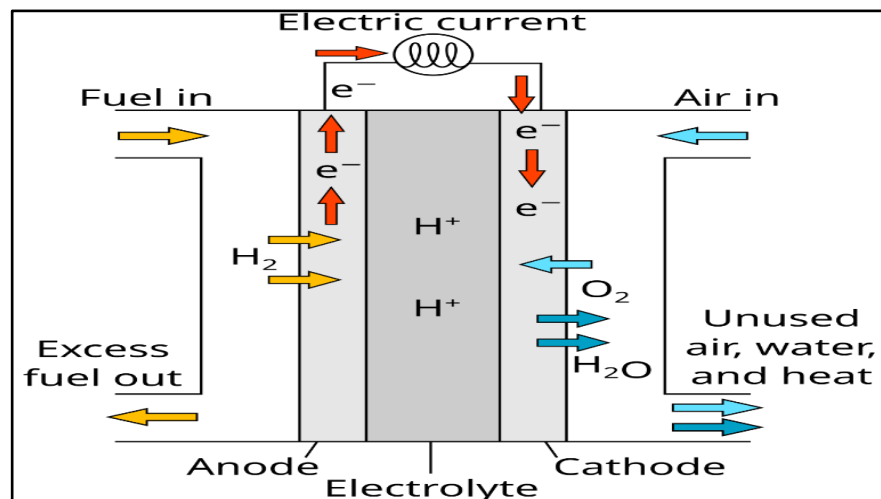


FIG 9 A PEMFC (WIKEPEDIA)

5.1 proton exchange membrane fuel cell (PEMFC)

Proton Exchange Membrane Fuel Cell (PEMFC) – Technical Details

A Proton Exchange Membrane Fuel Cell (PEMFC) is a type of hydrogen fuel cell that converts chemical energy into electricity using hydrogen and oxygen, producing only water and heat as byproducts.

5.2 Key Components of a PEMFC

1. Membrane Electrode Assembly (MEA):

Proton Exchange Membrane (PEM): Made of perfluoro sulfonic acid polymers like Nafion, allowing only protons to pass while blocking electrons and gases.

Electrodes (Anode & Cathode): Typically, carbon-supported platinum (Pt) catalysts where the electrochemical reactions occur.

2. Bipolar Plates:

Made of graphite, stainless steel, or composite materials, they distribute reactant gases, remove excess water, and conduct electricity between cells in a stack.

3. Gas Diffusion Layer (GDL):

Ensures even gas distribution and helps in water management within the cell.

4. Catalyst Layer:

Contains platinum-based nanoparticles that speed up the hydrogen oxidation reaction (HOR) and oxygen reduction reaction (ORR).

a. Advantages of PEM Fuel Cells

Zero Emissions: Only water and heat as byproducts.

High Power Density: More power in a compact size.

Quick Start-up: Unlike other fuel cells, PEMFCs start instantly.

Scalability: Can be used in vehicles, portable power, and grid applications.

1. Challenges & Limitations

Expensive Catalysts: Platinum is costly.

Hydrogen Storage Issues: Requires high-pressure tanks or cryogenic storage.

Water Management: Excess water can block airflow, while too little can dry out the membrane.

2. Output from the PEMFC

Energy content of hydrogen = 33.33 kWh/kg

So 40 kg = 1333.2 kWh

Efficiency of pemfc = 50% - 60%

Usable energy = $0.55 \times 1333.2 = 733.26$ kWh

RESULTS AND CONCLUSION

Kochi is considered 50th most congested city in the world and 8th most congested city in India. The water metro, has shown promising results with 18 operational boats catering to 6,000-7,000 passengers daily. Till date they have serviced more than 3.2 million people.

Key findings

A comfortable commute while being safer, cheaper and overall, a more sustainable option for passengers. Potential to reduce road congestion - Private vehicle usage dropped from 50% to 35% and public transport usage increased to 45%.

Our calculations show that this has a huge potential in reducing CO₂ while not breaking the bank for the consumer. AQI was low during lockdown and has worsened over last few years and this calls for

action. Otherwise, Kochi would be a future example like Delhi. To achieve true carbon emission neutrality, they should switch to a renewable source for charging the batteries and an alternative fuel like hydrogen for future phases. There is also scope for tourism.

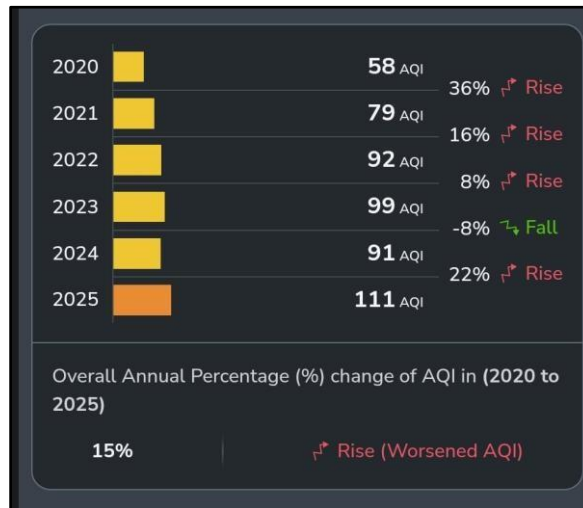


FIG 10 AQI OF KOCHI OVER THE YEARS (AQLIN)

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ADVANCING CARBON CAPTURE IN MARITIME INDUSTRY STRATEGIES FOR REDUCING THE CARBON FOOTPRINT OF MERCHANT VESSELS

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ABSTRACT

Carbon capture technologies, notably CCS and CCU, present effective strategies for lowering maritime CO₂ emissions, thereby enhancing air quality and mitigating ocean acidification. Although the initial investment is considerable, the long-term advantages—such as meeting stricter environmental regulations, generating new revenue streams, and improving overall operational efficiency—make these technologies economically attractive. By either securely storing or repurposing captured CO₂, these methods not only contribute to reducing the industry's carbon footprint but also support sustainable practices and a circular economy. Ultimately, investing in carbon capture is a forward-thinking approach that balances environmental responsibility with economic benefits for the maritime sector.

KEYWORDS

Carbon Capture and Storage, CCS (sequestration), Carbon Capture and Utilization (CCU), Maritime Decarbonization, Emission Reduction, Circular Economy

1. INTRODUCTION

The Merchant Marine industry, one of the oldest yet most vital sectors globally, is key to transporting passengers and bulk cargo. With ships requiring significantly less fuel per ton-mile than trucks or airplanes, the industry has experienced over 3% annual growth in both seaborne trade and capacity over the past 50 years. However, the heavy reliance on diesel engines—which are efficient but produce high emissions—has led to mounting environmental concerns. In response, international regulations aim to cut the maritime sector's carbon footprint by at least 50% by 2050.

1.1 Background and significance

Global agreements and national laws now focus on reducing the environmental impact of shipping by protecting marine ecosystems and lowering greenhouse gas emissions. Targets include reducing carbon intensity by 2% annually and cutting the emissions performance factor significantly compared to 2018 and 2008 levels. Calculating total annual emissions on vessels is complex, involving factors such as engine output, fuel consumption, auxiliary systems, and

variable operating conditions.

1.2 Scope and objectives

Despite its essential role in global trade, the maritime industry is a notable contributor to environmental degradation. This research examines carbon capture technologies as a promising solution to mitigate these emissions. It evaluates both onboard and offshore carbon capture methods in terms of technical feasibility, efficiency, and economic viability. Additionally, the study explores regulatory drivers—such as the International Maritime Organization’s (IMO) greenhouse gas strategy—and their impact on promoting carbon capture in shipping. The paper also identifies barriers like high costs, retrofitting challenges, and infrastructure needs, proposing potential strategies to overcome these obstacles.

Through this analysis, the study aims to deepen the understanding of decarbonization in maritime operations and underscore the potential of innovative carbon capture technologies to significantly reduce the industry’s environmental impact.

2. PROPOSED METHOD/MAIN CONTRIBUTION

2.1 CAUSES AND IMPACTS OF THE MARITIME CARBON FOOTPRINT

2.1.1 PRIMARY SOURCES OF EMISSIONS

At the heart of the maritime carbon footprint is the combustion of heavy fuel oil, which powers the majority of merchant vessels. The combustion process not only generates large volumes of CO₂ but also emits other harmful pollutants:

- *Co₂ emissions*: Directly linked to the burning of fossil fuels, CO₂ is the principal driver of climate change.
- *Sulphur oxides (so_x) and nitrogen oxides (no_x)*: These gases contribute to acid rain and respiratory problems, with severe impacts on human health and marine ecosystems.
- *Particulate matter (pm)*: Fine particles from combustion further deteriorate air quality, especially in coastal and port areas.
- *Black carbon (bc)*: This short-lived climate pollutant accelerates Arctic warming by darkening ice surfaces and enhancing melt rates.

The environmental consequences are multifaceted. Beyond global warming, the absorption of CO₂ by oceans leads to acidification, threatening marine biodiversity and the sustainability of coastal communities. Emissions are particularly concentrated along major shipping routes, compounding air quality issues in densely populated coastal regions.

2.1.2 Indirect environmental impacts

In addition to direct emissions from ship engines, maritime operations also produce indirect pollutants. For example, black carbon, although short-lived, significantly contributes to regional warming and impacts sensitive ecosystems like the Arctic. The cumulative effect of these

emissions not only exacerbates climate change but also imposes additional environmental burdens on coastal areas and port cities.

2.1.3 Regulations and international agreements

Recognizing the environmental challenges posed by shipping emissions, governments and international bodies have established rigorous regulatory frameworks and agreements to mitigate these impacts. The International Maritime Organization (IMO), a specialized agency of the United Nations, is at the forefront of these efforts.

2.2 Global regulatory frameworks

In 2018, the IMO adopted an ambitious greenhouse gas strategy aimed at reducing the annual GHG emissions from international shipping by at least 50% by 2050, relative to 2008 levels. This target is aligned with the Paris Agreement's objective of limiting global warming to well below 2°C. Key regulatory measures include:

- *Energy Efficiency Design Index (EEDI)*: Mandatory efficiency standards for new vessels, ensuring that each new ship built meets defined energy performance criteria.
- *Ship Energy Efficiency Management Plan (SEEMP)*: A voluntary yet strongly encouraged plan that promotes continuous operational improvements in energy usage for existing vessels.

2.3 Regional initiatives

In addition to IMO standards, regional regulations further drive emissions reductions. The European Union, for instance, has integrated shipping into its Emissions Trading Scheme (EU ETS), thereby imposing stricter emissions limits on vessels operating in EU waters. Shipowners must purchase carbon allowances for their emissions, creating a direct economic incentive to reduce their carbon output. Moreover, the EU's Monitoring, Reporting, and Verification (MRV) system mandates that all ships report their CO₂ emissions on voyages to, from, and within European ports, ensuring transparent and accountable tracking of emissions

2.4 Voluntary measures

Alongside mandatory regulations, industry stakeholders are increasingly adopting voluntary measures. These include switching to low-carbon alternatives such as liquefied natural gas (LNG), biofuels, and hydrogen; developing zero-emission vessels (ZEVs); and exploring onboard carbon capture technologies. These efforts, though not universally mandated, signal a growing commitment within the maritime industry to reduce environmental impact and comply with tightening regulatory timelines.

2.5 Carbon capture technologies

To address the sector's significant carbon footprint, emerging carbon capture technologies offer

promising solutions. These methods aim either to prevent CO₂ from reaching the atmosphere or to transform it into valuable products.

3. OVERVIEW OF CARBON CAPTURE METHODS

Carbon capture approaches for maritime applications can be broadly divided into three categories:

1. *Pre-combustion capture:*

In this method, fuel is processed prior to combustion, separating carbon components from the fuel. Typically applied in industries like power generation, this approach can be adapted for ships using alternative fuels (e.g., hydrogen or synthetic fuels). The fuel is transformed into a mixture of hydrogen and CO₂, with the latter being captured before the hydrogen is burned. Although this process is efficient, it requires substantial modifications to engine and fuel systems, making it more suitable for new builds or vessels already transitioning to alternative fuels.

2. *Post-combustion capture:*

This is the most researched method for maritime use. Post-combustion capture involves extracting CO₂ from exhaust gases after fuel combustion. Techniques such as chemical solvent absorption, membrane separation, or cryogenic processes are employed to isolate CO₂, which is then stored onboard temporarily until it can be offloaded or utilized. Post-combustion capture is attractive because it can be retrofitted to existing vessels, though challenges include energy demands, limited onboard space, and the need for specialized storage infrastructure.

3. *Direct air capture (dac):*

Still in its early stages for maritime applications, DAC involves removing CO₂ directly from ambient air using chemical processes. Although energy-intensive and not yet cost-effective for widespread use aboard ships, DAC holds promise for offsetting emissions in sectors where direct reductions are challenging.

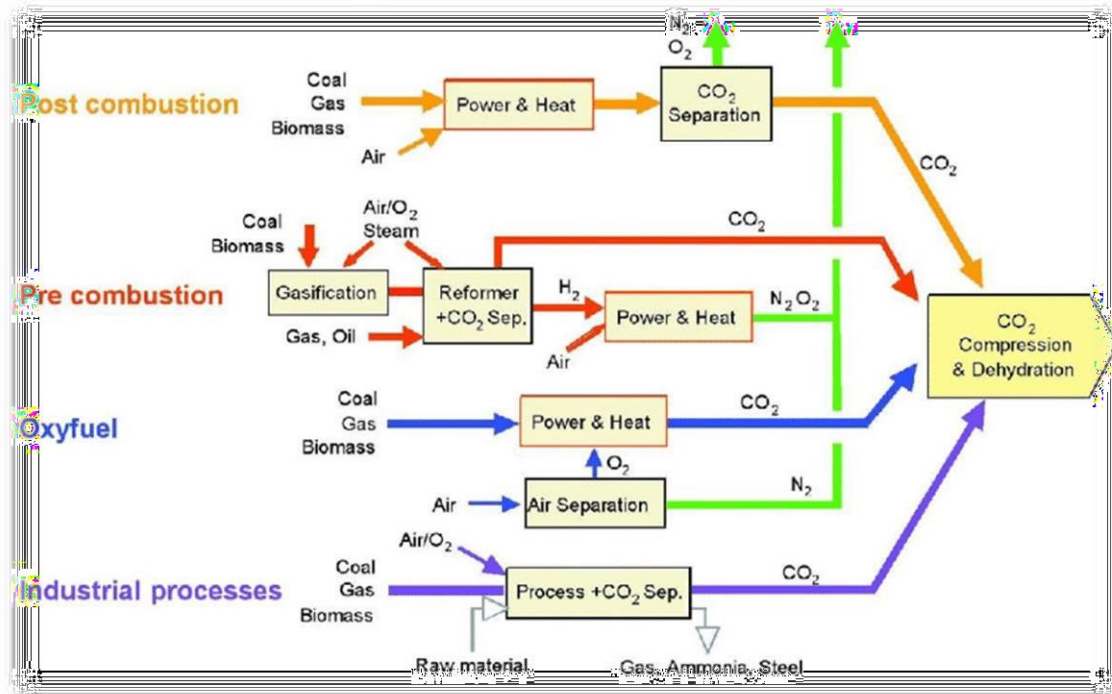


FIG 1 METHODS OF CO₂ CAPTURE SYSTEM

- *Carbon capture and storage (ccs)*

CCS IS A WELL-ESTABLISHED TECHNOLOGY IN OTHER INDUSTRIAL SECTORS, NOW BEING TAILORED TO MARITIME NEEDS. THE CCS PROCESS COMPRISES three STAGES:

- **Capture:** CO₂ is separated from exhaust gases using methods such as amine-based solvents, membrane filters, or cryogenic techniques. These systems can achieve up to 90% capture efficiency.
- **Transportation:** Once captured, CO₂ is compressed into a liquid or gaseous state and stored temporarily in pressurized tanks onboard. Following the voyage, the CO₂ is offloaded at specialized port facilities.
- **Storage:** Finally, CO₂ is sequestered in deep underground geological formations— such as saline aquifers or depleted oil and gas reservoirs—where it can be safely stored for millennia. Continuous monitoring ensures the integrity of these storage sites, preventing any leakage back into the atmosphere.

Despite its promise, CCS faces hurdles including high retrofit costs, the spatial demands of onboard storage, and the energy required for operation, which may reduce overall fuel efficiency. Nonetheless, ongoing technological advancements continue to improve its viability.

- *Carbon capture and utilization (ccu)*

CCU technologies take a different route by converting captured CO₂ into useful products rather than storing it underground. In maritime settings, CCU offers exciting opportunities to integrate environmental responsibility with economic benefit. Applications include:

- *Synthetic fuels:* By combining captured CO₂ with green hydrogen produced from renewable energy, synthetic fuels such as methanol can be manufactured. These fuels have a lower carbon footprint and can be used to power vessels, creating a closed-loop system where emissions are continuously recycled.
- *Building materials:* Captured CO₂ can be injected into concrete during curing, reducing the carbon intensity of construction materials. This not only provides a market for CO₂ but also helps offset the carbon emissions from infrastructure development.
- *Chemical production:* CO₂ can serve as a feedstock in the production of plastics, fertilizers, and other chemicals, opening new revenue streams for shipowners.

CCU, while promising, faces challenges such as high energy requirements for conversion processes and the need to establish viable markets for the end products. Achieving significant maritime emissions reductions through CCU will demand close collaboration between shipping companies, ports, and industrial partners.

- *Membrane technology for carbon capture*

Membrane technology offers a compact and efficient solution for CO₂ capture in the maritime sector, aligning with stricter emission regulations. It operates on the principle of differential permeability, acting as a selective barrier to separate CO₂ from exhaust gases like nitrogen and oxygen. This in-situ process not only reduces emissions but also enables the conversion of captured CO₂ into valuable products.

4. VARIOUS TYPES OF MEMBRANES

- *Polymeric membranes:* The thin, flexible plastic membranes made from synthetic polymers which happen to be the most common given their economics are made of materials of high tensile strength. They operate through the differences in gas permeability and gas dissolution.
- *Inorganic membranes:* These include membranes made out of stainless steel, ceramic, and silicon which are claimed to have high temperatures.
- *Hybrid matrix membrane:* It combines organic and inorganic materials and aims to improve performance by using the advantages of both materials.

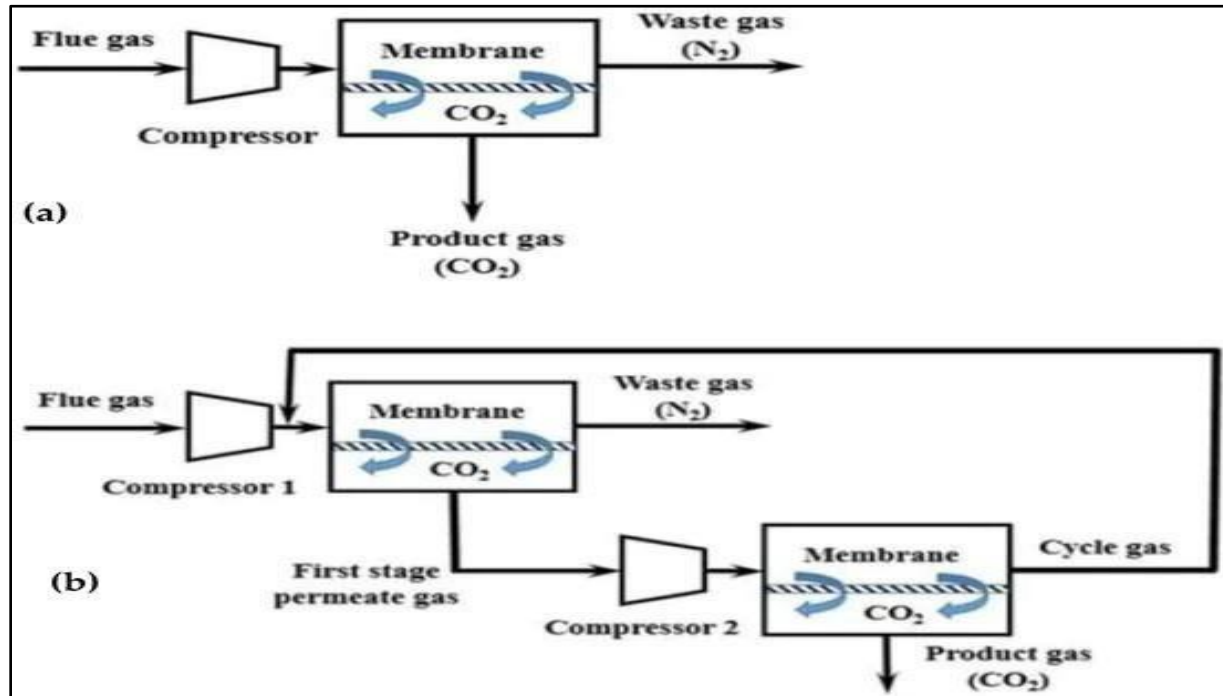


FIG 2 MEMBRANE CAPTURE SYSTEM

5. APPLICATION OF CARBON CAPTURE METHODS IN THE MARITIME INDUSTRY

The implementation of carbon capture technologies in the maritime sector presents a blend of significant challenges and exciting opportunities. These innovations have the potential to transform shipping into a more sustainable mode of transport while simultaneously complying with increasingly stringent environmental regulations.

- *Challenges*

Several technical, economic, and logistical obstacles must be overcome for widespread adoption of carbon capture in shipping:

- *Technical feasibility:*

Integrating carbon capture systems into existing ship designs is complex. Retrofitting vessels with CCS or CCU equipment requires considerable space for both the capture apparatus and CO₂ storage. These systems demand substantial energy input, potentially affecting vessel efficiency. Additionally, the added weight from equipment and stored CO₂ can impact stability and fuel consumption.

- *High costs:*

The capital investment and operational expenses for carbon capture technologies are high. Retrofitting existing fleets, maintaining advanced systems, and establishing port-based offloading infrastructure all contribute to significant costs. Without robust regulatory incentives or financial support, shipowners may be hesitant to commit to these expensive modifications.

- *Infrastructure and logistics:*
For carbon capture to be effective, a comprehensive infrastructure must be in place to handle, transport, and store CO₂. Many ports currently lack the facilities required to offload and process captured CO₂, necessitating large-scale investments in new logistics networks and storage solutions.
- *Regulatory uncertainty:*
While international bodies such as the IMO are pushing for decarbonization, specific guidelines for carbon capture remain underdeveloped. The absence of standardized, enforceable regulations creates uncertainty, making it difficult for shipowners to justify the financial risks involved in adopting these new technologies.

- *Opportunities*

Despite these challenges, the transition to carbon capture in the maritime industry also presents several compelling opportunities:

- *Regulatory drivers and incentives:*
Increasingly stringent international and regional regulations, such as the IMO's emission reduction targets and the EU's carbon market mechanisms, create strong economic and legal incentives for adopting carbon capture. Government subsidies, tax credits, and funding programs can help offset high initial costs, encouraging more rapid adoption of these technologies.
- *Technological innovation:*
The push for a greener shipping industry is spurring significant research and development. Advances in materials science, digital control systems, and energy-efficient capture methods promise to reduce the size, energy consumption, and cost of carbon capture systems, making them more suitable for maritime applications.
- *New business models and revenue streams:*
CCU technologies, in particular, open up new revenue possibilities by transforming waste CO₂ into marketable products, such as synthetic fuels, building materials, and chemicals. This circular economy approach not only helps offset the costs of implementation but also provides shipowners with diversified income streams.
- *Early adoption and competitive advantage:*
Shipowners and operators who invest early in carbon capture technologies can gain a competitive edge by positioning themselves as industry leaders in sustainability. Early adopters stand to benefit from lower future regulatory compliance costs, improved market reputation, and preferential access to environmentally conscious clients and investors.
- *Enhanced corporate sustainability:*
Embracing carbon capture not only aids in regulatory compliance but also improves a company's overall sustainability profile. This can attract investment, foster customer loyalty, and build long-term resilience in a market that increasingly values environmental responsibility.

6. BEST PRACTICES COLLABORATION

Successful carbon capture projects in maritime settings rely on strong partnerships among governments, research institutions, and private companies. Collaborative efforts allow for sharing expertise and spreading financial and technological risks, accelerating innovation and easing early adoption challenges. [International CCS pilot programs exemplify how cross-border collaboration can serve as a model for future initiatives.]

7. INTEGRATION WITH OTHER DECARBONIZATION STRATEGIES

Carbon capture should be part of a broader approach that includes alternative fuels—such as LNG, biofuels, and hydrogen—as well as energy efficiency measures and digital monitoring tools. This multi-faceted strategy enhances overall emissions reduction and improves operational performance. [Hybrid propulsion systems that combine conventional engines with carbon capture and renewable energy sources are an emerging trend.]

8. PILOT PROJECTS AND GRADUAL SCALE-UP

Small-scale pilot projects allow companies to test carbon capture technologies under real maritime conditions. Gathering performance data on energy use, maintenance, and system efficiency helps optimize these technologies before they are scaled up fleet-wide. [A phased rollout minimizes risks and reduces implementation costs over time.] These practices show that despite technical challenges, coordinated efforts and strategic partnerships can significantly reduce shipping's carbon footprint.

9. ECONOMIC AND ENVIRONMENTAL BENEFITS

- *Cost analysis and return on investment*

Implementing carbon capture systems requires considerable upfront investments for retrofitting vessels, installing onboard capture and storage equipment, and developing port infrastructure. However, these costs must be balanced against long-term benefits:

1. *Upfront capital costs:*

Retrofitting ships with carbon capture and storage (CCS) or carbon capture and utilization (CCU) systems involves installing specialized hardware like exhaust gas scrubbers, chemical solvents, and high-pressure storage tanks. Structural modifications to accommodate the new equipment add further expense.

[The development of modular systems is expected to lower installation complexity and costs.]

2. *Operating and maintenance costs:*

Additional energy is required to operate capture systems, slightly reducing fuel efficiency. Regular maintenance and solvent replacement contribute to ongoing expenses, though future technological advancements should help reduce these costs.

3. *Infrastructure costs:*

Developing port infrastructure for offloading and processing captured CO₂—including

storage facilities, pipelines, and transport networks—is a significant investment. Regional projects, such as Norway’s Northern Lights, could help achieve economies of scale and lower costs per vessel.

[Shared infrastructure models between companies may also reduce costs.]

4. *Potential revenue streams:*

Carbon capture opens new revenue avenues. Participation in carbon credit markets allows shipowners to sell surplus captured CO₂, and CCU technologies can convert CO₂ into marketable products like synthetic fuels, building materials, or chemicals. These opportunities can offset initial investments.

5. *Return on investment (ROI):*

While initial costs are high, the long-term ROI is promising. Benefits include lower future compliance costs, reduced exposure to carbon taxes, and enhanced competitiveness in sustainability-conscious markets. As technologies mature and scale, unit costs are expected to decline, further improving ROI.

[Government incentives, such as tax breaks and low-interest loans, can also accelerate the payback period.]

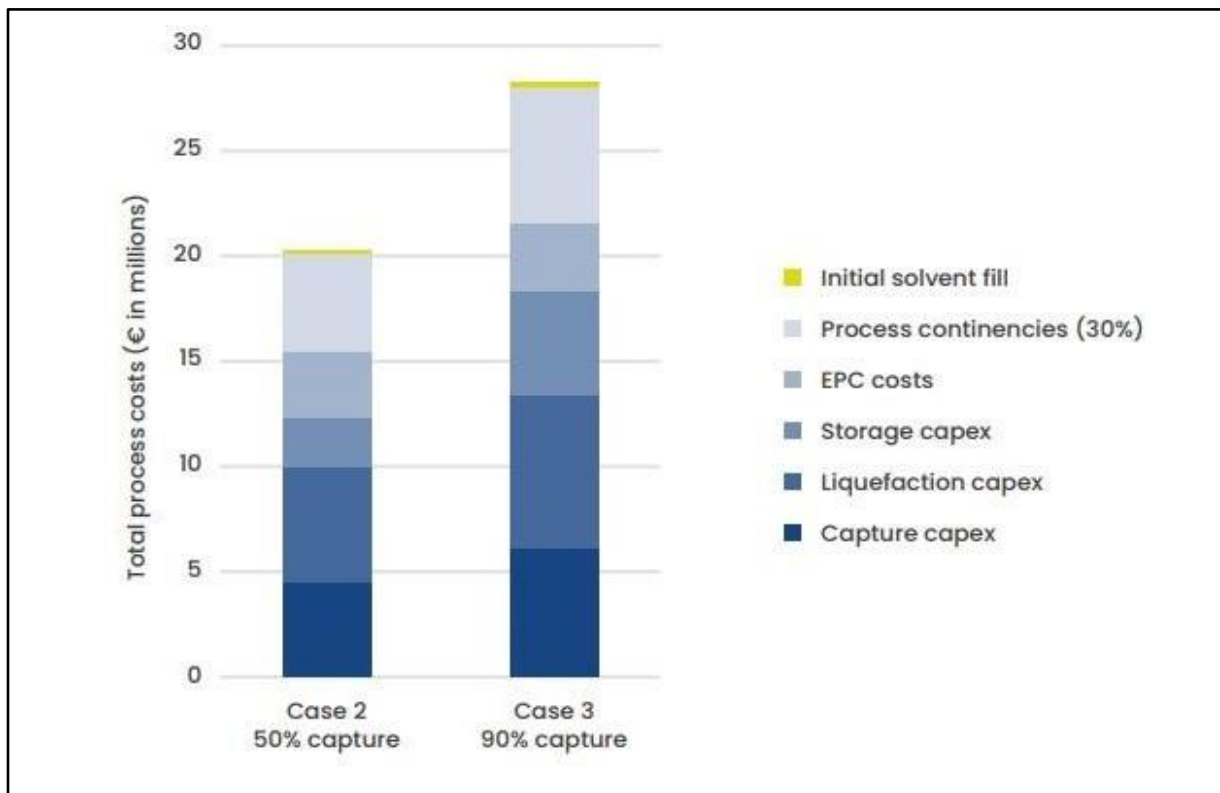


FIG 3 TOTAL CAPITAL EXPENDITURE ESTIMATES FOR A FIFTY AND NINETY PER CENT CARBON CAPTURE SYSTEM INSTALLED ON A SUEZMAX VESSEL.

The costs for installation come in at around \$30m for a system capable of capturing 90% of all CO₂ emitted at sea (see chart below), while annual operating costs for such a system are estimated to be in excess of \$2m a year, essentially adding another 25% to a ship’s annual operating

expenses Fuel consumption at voyage start day is 141.59 tonnes.

According to commitment of ICS capture target, 20% of Total CO₂ emission on voyage start day is 102.67 tonnes. The Total CO₂ captured during the whole voyage is 1854 tonnes. Fuel consumption calculated from the formula below:

$$FC = BSFC \times Power \times 24h.$$

The power consumption for operating closed loop SO_x scrubber is 1% of the maximum scrubbed engine power. Thus, the power required for the scrubber is,

$$34500 \times 1\% = 345.00kW.$$

- *Environmental impact assessment*

The environmental benefits of maritime carbon capture are significant and wide-ranging:

1. *Reduction of CO₂ emissions*

Carbon capture systems can potentially remove up to 90% of CO₂ from ship exhaust, directly supporting the International Maritime Organization's (IMO) goal to cut shipping emissions by at least 50% by 2050. Combined with alternative fuels and energy-efficient designs, these systems pave the way toward near-zero emissions.

2. *Air quality improvements*

By capturing not only CO₂ but also pollutants like sulphur oxides (SO_x), nitrogen oxides (NO_x), and particulate matter (PM), these systems help improve air quality, particularly in port cities and coastal areas. Cleaner air benefits local communities and reduces public health risks.

3. *Mitigation of ocean acidification*

Capturing CO₂ at its source prevents its absorption into seawater, which helps mitigate ocean acidification—a threat to marine biodiversity and coastal livelihoods. [Protecting marine ecosystems supports both environmental and socio-economic stability in regions dependent on coastal resources.]

4. *Promotion of a circular economy*

CCU technologies convert captured CO₂ into useful products, creating a closed-loop system that reduces waste and resource consumption. This circular economy approach not only minimizes environmental impact but also adds economic value by generating new products.

5. *Synergies with other decarbonization strategies*

When integrated with the use of alternative fuels and energy-efficient designs, carbon capture technologies amplify overall emissions reductions, accelerating progress toward full decarbonization and compliance with future regulations.

6. *Global climate impact*

Reducing maritime emissions has far-reaching implications for mitigating global warming and extreme weather events, thereby supporting climate resilience, especially in vulnerable coastal and island regions.

10. FUTURE TRENDS AND INNOVATIONS

10.1 Miniaturization and efficiency improvements

Current carbon capture systems are often bulky and energy-intensive. Future research focuses on:

- *Advanced solvent technologies:* New solvents are being developed to absorb CO₂ more efficiently, reducing energy requirements.
- *Compact membrane systems:* Innovative membranes that separate CO₂ with less power and space are under development, making systems more suitable for various vessel types.

10.2 Integration with alternative fuels and hybrid systems

Future vessels are expected to combine multiple decarbonization methods:

- 10.2.1 *Hydrogen Fuel Cells with Carbon Capture:* Integrating hydrogen fuel cells with capture systems could lead to propulsion with near-zero emissions.
- 10.2.2 *Ammonia-Powered Ships:* Combining ammonia engines with carbon capture can mitigate NO_x emissions, further cleaning the exhaust.

10.3 Autonomous and smart carbon capture systems

Digital technologies are set to revolutionize carbon capture:

- 10.3.1 *AI-Driven Optimization:* Sensors and machine learning algorithms will enable real-time adjustments to maximize capture efficiency while minimizing energy consumption.
- 10.3.2 *Integration with Smart Shipping Platforms:* Linking capture systems to digital platforms for monitoring fuel consumption and emissions will optimize fleet operations.

10.4 Carbon recycling and circular economy models

Advances in CCU will emphasize recycling CO₂:

- 10.4.1 *Synthetic Fuel Production:* Converting captured CO₂ into synthetic fuels supports a circular system where emissions are reused to power ships.
- 10.4.2 *Marine-Based Carbon Utilization:* Future onboard systems may convert CO₂ into essential chemicals or materials, reinforcing a sustainable maritime ecosystem.

10.5 Modular and scalable systems

To facilitate broader adoption, carbon capture systems must be modular and scalable:

10.5.1 *Plug-and-Play Units*: These systems can be retrofitted with minimal disruption, making them accessible for a wider range of vessels.

10.5.2 *Scalable Storage Solutions*: Advances in lightweight, durable storage tanks will help accommodate captured CO₂ without extensive ship modifications.

10.6 Collaboration and global networks global

Cooperation is essential for success:

10.6.1 *CO₂ Shipping Hubs*: Dedicated hubs for CO₂ storage and transportation can streamline the large-scale adoption of carbon capture.

10.6.2 *International Collaborations*: Unified standards and shared financial mechanisms across regulatory bodies and industry stakeholders will promote widespread implementation.

10.7 Direct air capture (dac) in maritime applications

Though still experimental, dac offers future potential:

10.7.1 *Dual-Purpose Vessels*: Ships integrating DAC units could capture CO₂ directly from the air, further reducing net emissions and contributing actively to global carbon reduction.

CONCLUSION

As the maritime industry navigates the complexities of decarbonization, carbon capture technologies emerge as a pivotal solution to significantly reduce greenhouse gas emissions from ships. This research has examined the role of Carbon Capture and Storage (CCS) and Carbon Capture and Utilization (CCU) in mitigating emissions, improving air quality, and combating ocean acidification. While initial costs and technical challenges remain, the long-term economic benefits—ranging from regulatory compliance and operational efficiency to new revenue opportunities—demonstrate that carbon capture is a viable and strategic investment for the industry.

Moreover, the future of carbon capture technologies is marked by promising innovations in miniaturization, integration with alternative fuels, smart automation, and scalable modular designs. These advancements, coupled with coordinated global efforts, will be critical in driving

widespread adoption. As international collaboration strengthens infrastructure and regulatory frameworks, carbon capture will play a crucial role in shaping a more sustainable and environmentally responsible maritime sector.

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GREEN HOUSE GAS EMISSION REDUCTION

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ABSTRACT

Greenhouse gas (GHG) emissions are a critical driver of global climate change, contributing to rising temperatures, extreme weather events, and disruptions to ecosystems. The primary sources of these emissions include fossil fuel combustion, industrial processes, deforestation, and agricultural activities. To mitigate the adverse effects of climate change, significant efforts are required to reduce GHG emissions across various sectors. This abstract explores the strategies, challenges, and opportunities associated with GHG emission reduction, emphasizing the need for a multi-faceted approach involving technological innovation, policy interventions, and behavioral changes. One of the most effective strategies for reducing GHG emissions is the transition to renewable energy sources, such as solar, wind, and hydropower, which produce minimal emissions compared to fossil fuels. Advances in energy storage and grid infrastructure are essential to support this transition. Additionally, improving energy efficiency in buildings, transportation, and industrial processes can significantly lower emissions. For instance, the adoption of electric vehicles (EVs), coupled with the decarbonization of electricity grids, can reduce emissions from the transportation sector, which is a major contributor to global GHG levels. Policy measures play a crucial role in driving emission reductions. Carbon pricing mechanisms, such as carbon taxes and cap-and-trade systems, incentivize businesses and individuals to reduce their carbon footprint.

Subsidies and incentives for renewable energy projects, along with stricter regulations on emissions, can further accelerate the transition to a low-carbon economy. Behavioral and societal changes are equally important in achieving GHG reduction goals. Public awareness campaigns and education can encourage individuals to adopt sustainable practices, such as reducing meat consumption, minimizing waste, and using public transportation.

Despite the progress made, challenges such as economic dependencies on fossil fuels, political resistance, and technological limitations persist. Addressing these challenges requires a coordinated effort from governments, industries, and individuals. The urgency of the climate crisis underscores the need for immediate and sustained action to reduce GHG emissions and secure a sustainable future for generations to come.

KEYWORDS

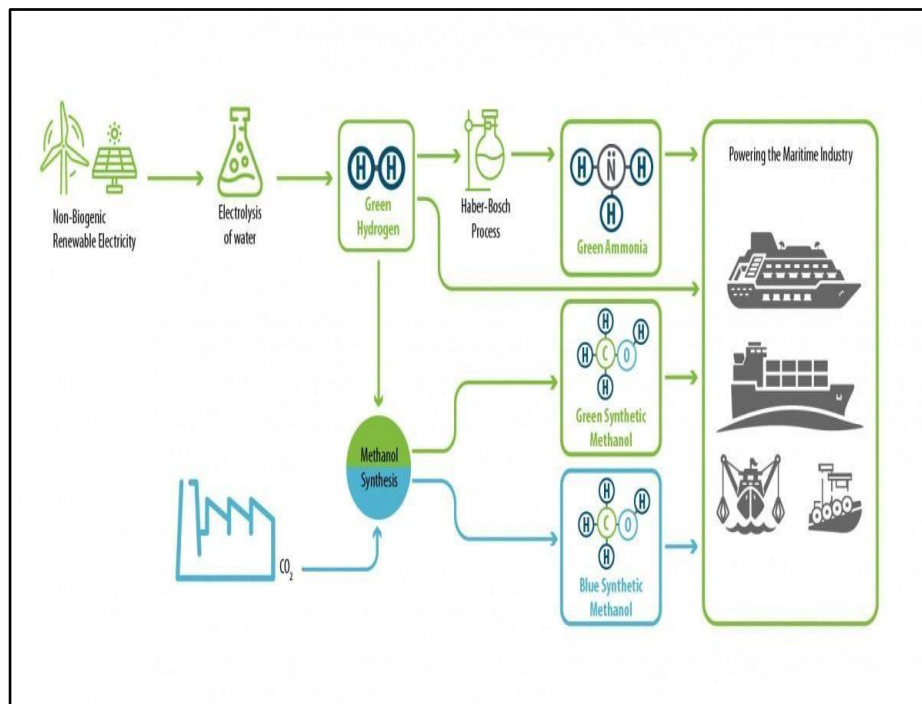
Greenhouse Gas Emissions, Climate Change Mitigation, Carbon Reduction

Renewable Energy, Energy Efficiency, Decarbonization.

1. INTRODUCTION

Greenhouse gas (GHG) emissions, primarily carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), are the leading contributors to global climate change. These emissions trap heat in the atmosphere, causing rising global temperatures, melting ice caps, sea-level rise, and extreme weather events. The primary sources of GHG emissions include fossil fuel combustion, industrial processes, deforestation, and agricultural activities. As the impacts of climate change become increasingly severe, reducing GHG emissions has emerged as a critical global priority to ensure environmental sustainability and protect future generations.

Efforts to reduce GHG emissions encompass a wide range of strategies, including transitioning to renewable energy sources, improving energy efficiency, and adopting innovative technologies like carbon capture and storage (CCS). Policy measures, such as carbon pricing and international agreements like the Paris Agreement, play a pivotal role in driving systemic change. Additionally, behavioural shifts, such as adopting sustainable consumption patterns and reducing waste, are essential for achieving emission reduction goals. Despite progress, challenges such as economic reliance on fossil fuels, technological limitations, and political resistance persist. Addressing these barriers requires coordinated action from governments, industries, and individuals. This introduction explores the importance of GHG emission reduction, the strategies being implemented, and the collective effort needed to combat climate change and secure a sustainable future.



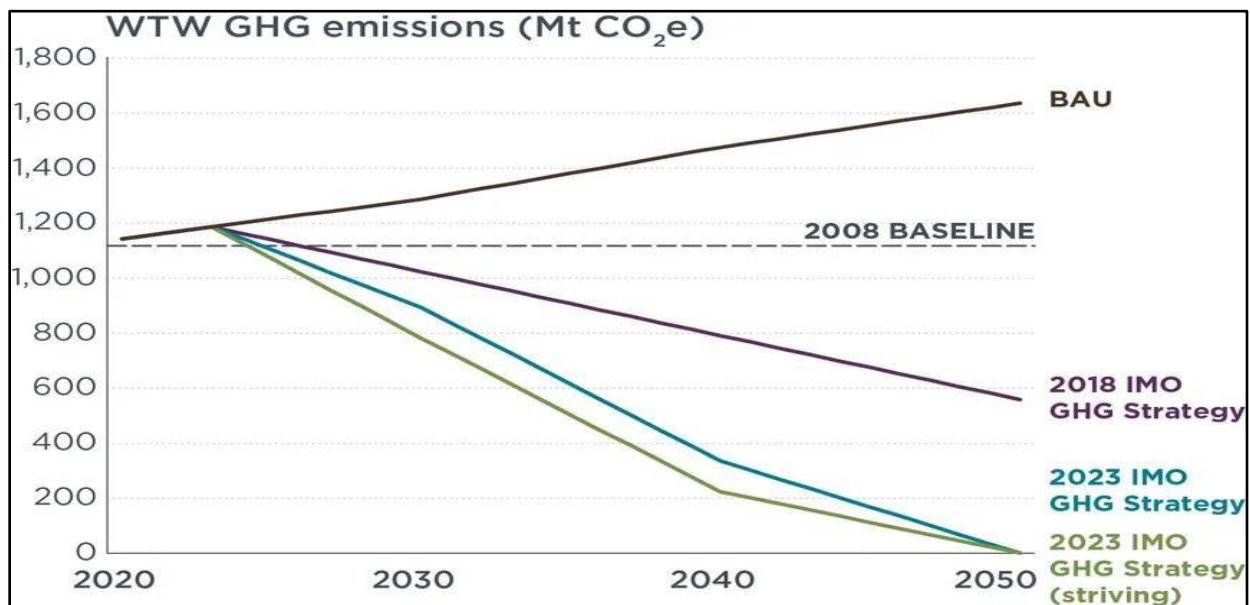
2. CURRENT STATE OF GHG EMISSIONS IN THE MARITIME INDUSTRY

Emissions Profile: The Maritime Industry emits approximately 1,076 million tons of CO₂ annually, with emissions expected to rise by 50-250% by 2050 if no mitigation measures are implemented. The primary sources of emissions include:

Main engines: Used for propulsion, accounting for the majority of emissions.

Auxiliary engines: Provide power for onboard systems.

Boilers: Used for heating and other purposes.



Environmental impact: GHG emissions from shipping contribute to Global Warming, Ocean Acidification, and Air Pollution. The industry also emits black carbon, which accelerates Arctic ice melt, and Sulphur Oxides (SO_x), which harm human health and ecosystems.

2.1 Strategies for GHG Emissions Reductions

Technological Innovations:

- *Alternative Fuels*

Liquefied Natural Gas (LNG): LNG reduces CO₂ emissions by 20-30% and eliminates SO_x emissions. However, methane slip remains a concern.

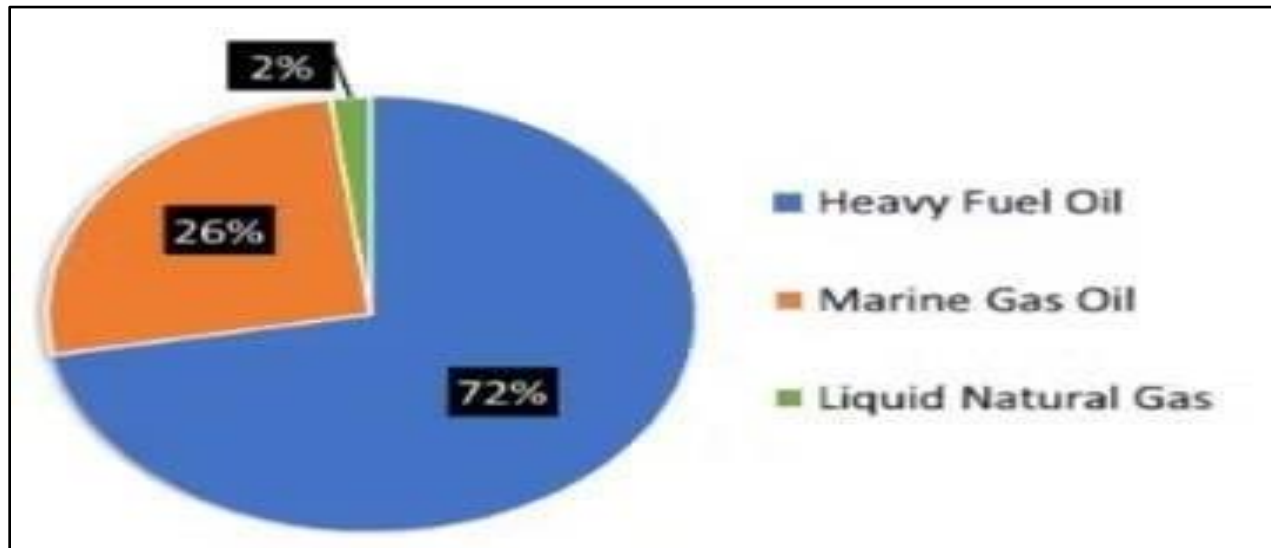
Ammonia: This zero-carbon fuel is promising but require significant infrastructure development and safety measures. However, it's toxicity, Nox emission and Ignition remain challenges, which requires improvements.

Hydrogen: This zero-carbon fuel is promising but require significant infrastructure development

and safety measures.

Biofuels: Derived from renewable sources, biofuels can reduce emissions by up to 80%, but face scalability challenges.

Methanol: A low-carbon fuel that can be produced from renewable sources.



2.2 Energy Efficiency Technologies:

Wind-Assisted Propulsion: Technologies like Flattener Rotors and Sails harness Wind Energy to reduce fuel consumption.

Installation of PBCF: Propeller Boss Cap Fins (PBCF) is an energy -saving Device installed on the Hub of Ship's Propeller, which improves Propeller Efficiency by weakening the Hub Vortex, and reduces Fuel Consumption by 5%.

Air Lubrication Systems: Reduce friction between the hull and water, improving fuel efficiency.

Waste Heat Recovery: Converts waste heat from engines into usable energy.

Capturing CO₂ from its own Exhausts and Stores it in a Tank: Onboard Carbon Capture and Storage System (CCS) is installed. The Technology will work parallelly with Existing Scrubber System. Around 70% of the CO₂ in the Exhaust Gas will be captured. CO₂ will be Refrigerated until Liquefaction and will be Stored in Tanks on Deck. The captured CO₂ can be transformed into electro fuel. Other applications for the captured CO₂ include use in the food processing industry and in carbonated beverage.



2.3 Electrification and Hybrid Systems

Battery-Electric Ships: Suitable for short-distance routes, these ships produce zero emissions during operation.

Hybrid Systems: Combine conventional engines with batteries to optimise fuel use.

3. OPERATIONAL MEASURES

Slow Steaming: Reducing ship speed by 10% can decrease fuel consumption by up to 27%, significantly lowering emissions.

Trim & Draft Optimisation: Optimizing the Trim and Draft has been estimated to reduce the fuel consumption by up to 3% on Main Engine Fuel Consumption for most ship types. However, ships which often trade in partial load conditions (e.g. container, Ro-Ro) the effect can be up to 5%.

Route Optimisation: Advanced weather routing and voyage planning tools minimise fuel use by avoiding adverse conditions.

Just-in-Time Arrival: Coordinating port arrivals to reduce idle time and optimise fuel consumption.

3.1 Regulatory frameworks imo regulations

- *Energy Efficiency Existing Ship Index (EEXI)*: Sets minimum energy efficiency standards for existing ships.
- *Carbon Intensity Indicator (CII)*: Measures and reduces the carbon intensity of ships over time. *MARPOL Annex VI*: Limits SO_x and NO_x emissions.
- *Market-Based Measures Emissions Trading Systems (ETS)*: Cap-and-trade systems incentivise emissions reduction.
- *Carbon Levies*: Impose a fee on GHG emissions to encourage cleaner practices.

4. CHALLENGES AND BARRIERS

High Costs: The transition to low-carbon technologies requires significant investment in research, development, and infrastructure.

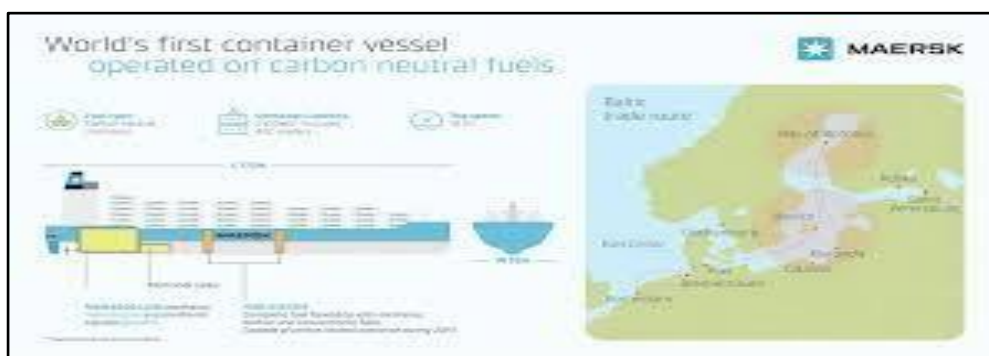
Technological Uncertainty: Many alternative fuels and technologies are still in the experimental or early adoption stages.

Regulatory Fragmentation: Inconsistent regulations across regions create compliance challenges for shipowners.

Resistance to Change: The industry's conservative nature and long asset lifetimes slow the adoption of new technologies.

5. CASE STUDIES

Maersk : Carbon-Neutral Methanol Vessel: Maersk has ordered a Container Ship powered by Carbon-Neutral Methanol, demonstrating the feasibility of alternative fuels.

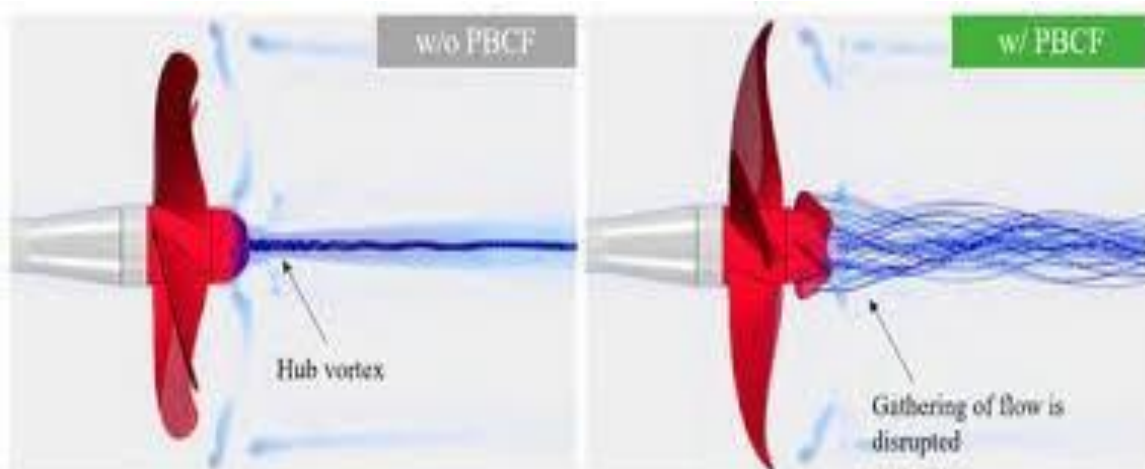


NYK Lines : Wind-Powered Carrier: NYK Line has developed a bulk carrier equipped with a Hard Sail System, reducing fuel consumption by 5-8%.



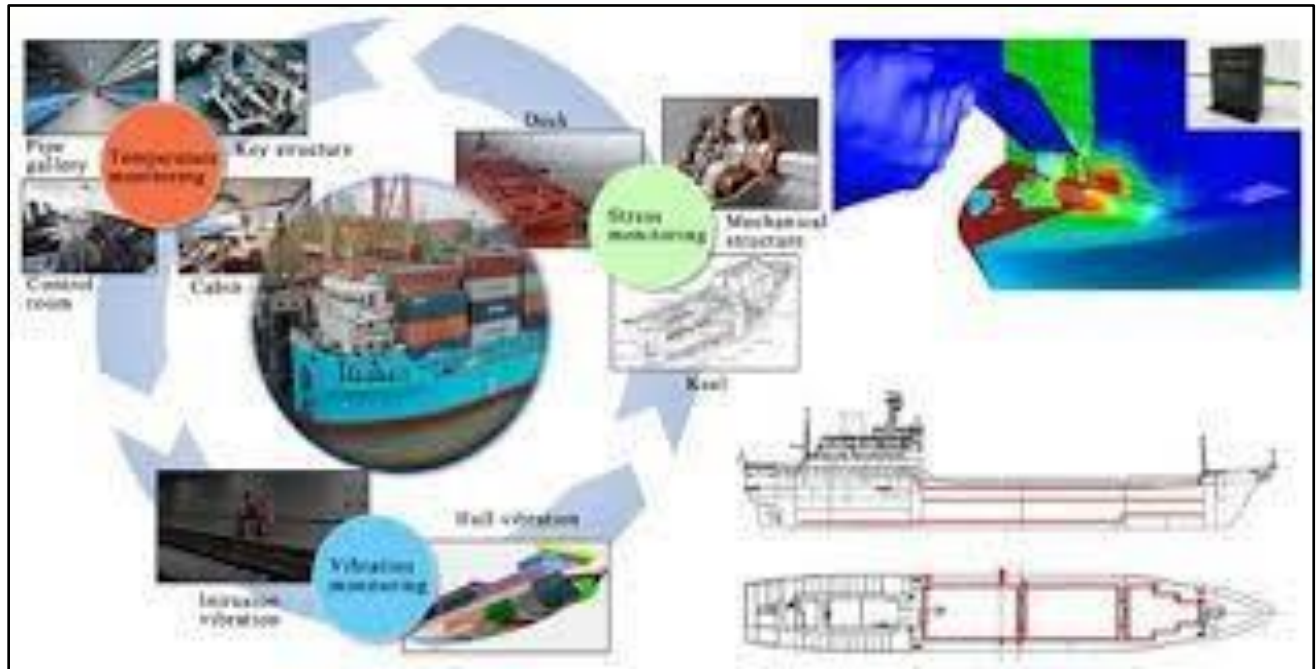
Mitsui O. S. K. Lines : Installation of PBCF

PBCF (Propeller Boss Cap Fins) was co-developed by Mitsui O. S. K Lines (MOL), West Japan Fluid Engineering Laboratory Co. Ltd., and Mikado Propeller Co. Ltd. PBCF been installed on more than 3,500 Vessels. It improves Propeller Efficiency by weakening the Hub Vortex, and reduces Fuel Consumption by 5%.



Clipper Harald along with SFI Smart Maritime Innovation Project

The Company has been developing a Carbon Capture and Storage (CCS) System. The Technology has been installed on an Ethylene Carrier “Clipper Eris”. Clipper Eris is expected to leave Singapore for her two-years Testing Mission in early February’2025.



Port of Rotterdam's Green Corridors: The Port of Rotterdam is establishing green shipping corridors to promote zero-emission shipping routes.



5.1 Additional aspects to consider

Expansion of Regulatory Developments:

The maritime industry operates across international borders, making it particularly sensitive to regional regulatory frameworks. While the International Maritime Organization (IMO) provides global guidelines for emissions reduction, various regions have introduced their own policies to accelerate de-carbonization. These regional regulations, such as the EU Emissions Trading System (EU ETS), Fuel EU Maritime Initiative, the U.S. Clean Shipping Act, and China's carbon intensity targets, significantly impact global shipping by creating compliance challenges, influencing fuel choices, and shaping investment strategies.

6. EMERGING TECHNOLOGIES FOR DE-CARBONIZATION

Beyond alternative fuels and energy efficiency technologies, new innovations are being explored:

- *Solid Oxide Fuel Cells (SOFCs)*: Higher efficiency than traditional internal combustion engines and can run on multiple fuels, including hydrogen and ammonia.
- *Nuclear-Powered Ships*: Small Modular Reactors (SMRs) are being considered for commercial maritime applications, though regulatory and safety concerns remain.
- *Artificial Intelligence (AI) in Fuel Optimization*: AI-powered predictive analytics are being used to optimize fuel consumption based on weather, sea conditions, and cargo load.

6.1 Infrastructure and Supply Chain Considerations

- *Bunkering Infrastructure*: The shift to alternative fuels like ammonia, hydrogen, and methanol requires new fuel bunkering facilities at ports worldwide.
- A discussion on port readiness and investments in refueling infrastructure could be insightful.
- *Lifecycle Emissions of Alternative Fuels*: A comparative analysis of well-to-wake emissions for different fuels would be valuable, considering factors like production, transportation, and combustion

7. SOCIOECONOMIC IMPACTS AND INDUSTRY READINESS

- *Workforce Training & Safety Considerations*: The transition to low-carbon fuels requires specialized training for seafarers and engineers. Addressing skills gaps and safety challenges (especially for ammonia and hydrogen) is crucial.
- *Economic Implications*: Discuss how investment in green technology affects shipping costs, freight rates, and the competitiveness of smaller shipping companies.

8. CASE STUDIES ON INNOVATIVE PORT INITIATIVES

- Singapore's Green Port Programme: Incentivizing energy-efficient vessels and exploring LNG & hydrogen infrastructure.
- Los Angeles & Long Beach's Clean Air Action Plan: Electrification of port operations, shore power for vessels, and
- investment in hydrogen-powered cargo handling.

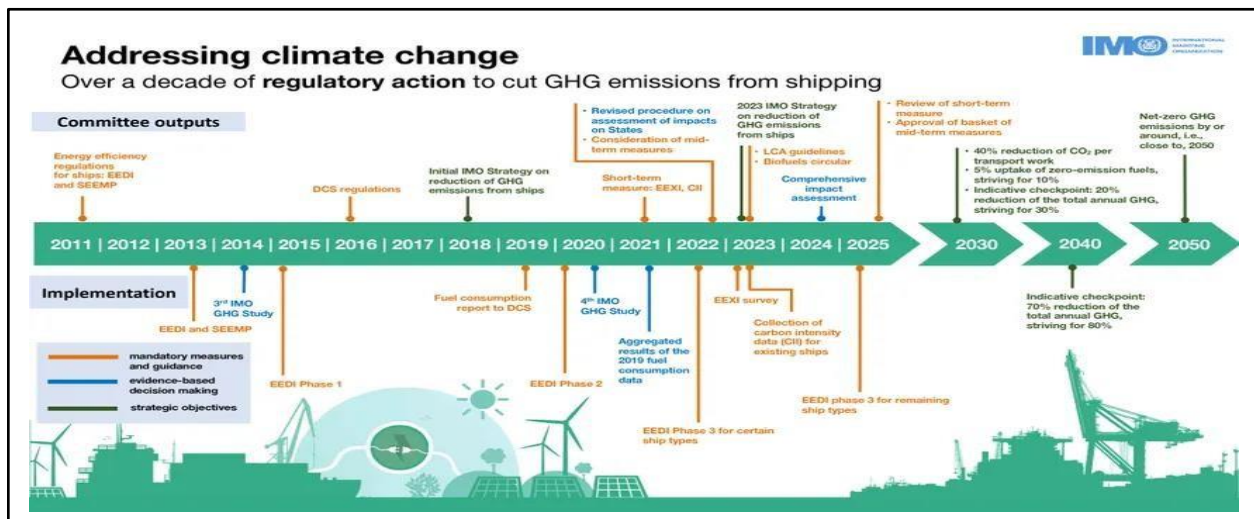
8.1 Potential Future Directions for Research

- *Comparative Feasibility Studies:* Evaluating the cost-benefit ratio of different de-carbonization strategies across different ship types (container ships, bulk carriers, tankers).
- *Carbon Capture Utilization and Storage (CCUS) in Maritime:* Investigating whether captured CO₂ can be repurposed in maritime applications rather than just stored.
- *Digitalization & Smart Shipping:* Exploring how block chain and Iot improve fuel efficiency and emissions monitoring.
- *Behavioral Economics in Shipping:* Studying how incentives, carbon pricing, and stakeholder collaboration drive sustainability adoption.



CONCLUSION

The Maritime Industry must adopt a comprehensive approach to reduce GHG emissions, combining technological innovation, operational efficiency, and robust regulatory frameworks. While significant challenges remain, the sector has the potential to achieve the IMO's decarbonization targets through collaboration, investment, and a commitment to sustainability. The transition to a low-carbon future will not only mitigate climate change but also enhance the industry's resilience and competitiveness.



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JAMMING AND SPOOFING

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ABSTRACT

Jamming and spoofing attacks are significant threats to GNSS-based navigation systems in terms of reliability and accuracy. Jamming attacks overpower GNSS signals by interference, whereas spoofing attacks deceive receivers by transmitting false signals that mimic actual satellite signals. Both attacks cause navigation failures and safety risks, especially in maritime operations. This paper discusses the principles, types, and countermeasures against jamming and spoofing. It provides step-by-step procedures to overcome such threats. By using state-of-the-art technologies like adaptive antennas, inertial measurement units, cryptographic techniques, and robust alarm systems, the vessels can successfully detect, respond to, and mitigate such threats. System checks in routine and cross-referencing of navigation data further strengthen the resilience to ensure safety and reliability in navigation systems.

KEYWORDS

Jamming, Spoofing

1. INTRODUCTION

Global Navigation Satellite Systems (GNSS) are now critical in modern navigation, as they provide precise positioning, navigation, and timing (PNT) data to vessels, aircraft, and vehicles all over the world. Yet, their vulnerability to interference remains high due to weak satellite signals. Interference attacks on GNSS can be classified into two major categories: jamming and spoofing. Jamming involves transmitting high-power interference to block GNSS signal reception while spoofing sends fake GNSS signals to manipulate receivers into displaying incorrect location or timing information. These can cause navigation failure and present risks to safety, eminency, and operational integrity.

This document explores the principles and impacts of jamming and spoofing, their differences, and the potential consequences. It also provides detailed countermeasures and step-by-step mitigation processes to ensure the resilience of GNSS-based navigation systems. By understanding these threats and adopting robust defenses, operators can safeguard their systems against disruptions and maintain safe and reliable operations in challenging environments.

2. JAMMING

Jamming can be caused by both intentional and unintentional interference with GNSS

signals. Unintentional jamming may arise from sources such as space weather or faulty equipment that emits signals on frequencies close to those used by GNSS, affecting signal reception. On the other hand, intentional jamming is designed to overpower weak GNSS signals by transmitting a high-power radio frequency signal near the L1, L2, and L5

frequency bands. The goal of jamming is to disrupt the receiver's ability to collect and track GNSS signals, rendering the navigation system ineffective or degraded.

Jamming is generally simpler and easier to execute than spoofing. Personal Protection Devices (PPDs), which are inexpensive and readily available, are a common form of

intentional jamming, though they are illegal in many countries. Even small handheld jammers can disrupt GNSS receivers within a few meters, blocking communication with satellites. While spoofing involves more complexity, as it requires mimicking the structure of authentic signals, jamming is a more straightforward attack that disrupts signal acquisition and locks without needing to imitate signal structure.

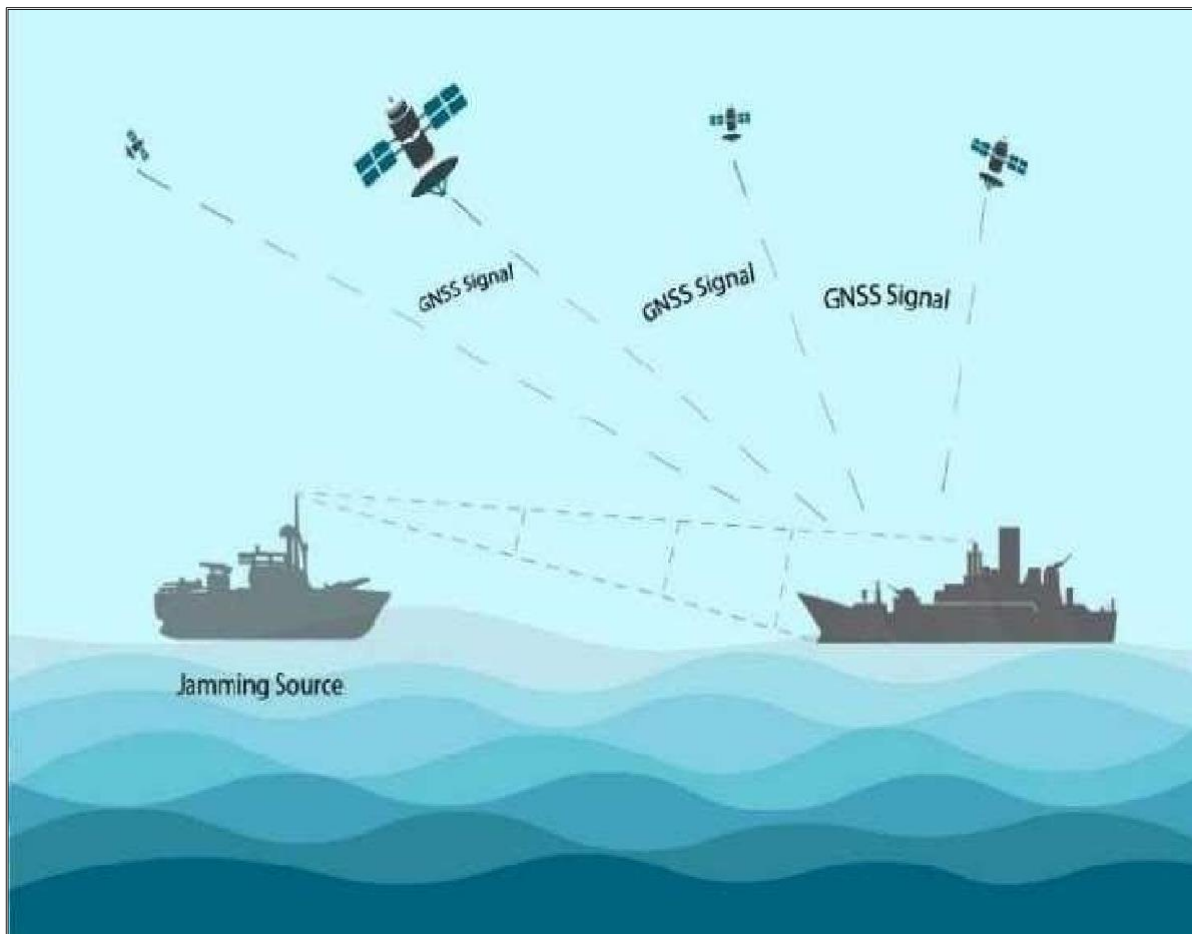


FIG 1 JAMMING

2.1 Types of jamming

a. Noise Jamming

Description: In noise jamming, a jammer transmits random noise or signals that spread across the frequency spectrum used by GNSS systems. This interference is designed to overpower the weak GNSS signals, making it difficult for the receiver to differentiate between the legitimate GNSS signals and the interference.

How It Works: GNSS receivers rely on weak signals from satellites, so adding noise can cause the receiver to fail to detect any valid signal.

Impact: The receiver is unable to lock onto any GNSS satellite signals and loses its ability to determine location and timing. This results in a complete failure of GNSS-based services.

b. Spot Jamming

Description: Spot jamming focuses on a specific frequency or a set of frequencies used by GNSS systems, such as the L1, L2, and L5 bands. The jammer transmits high-power signals directly at these frequencies, disrupting only the affected band.

How It Works: The jammer selectively targets the frequency band where the GNSS signals are transmitted, overwhelming the receiver's ability to track the transmission.

Impact: This causes the receiver to lose lock on the satellite signals in the targeted frequency bands, resulting in a loss of accuracy or complete navigation failure. However, if other frequency bands are unaffected, the receiver may still function partially.

c. Sweep Jamming

Description: Sweep jamming involves the transmission of interference that moves across a range of frequencies, covering multiple GNSS signal bands sequentially.

How It Works: The jammer sweeps across the frequency spectrum, targeting different GNSS bands over time. This continuously changing interference makes it difficult for the receiver to maintain a stable lock on satellite signals.

Impact: The receiver may fail to establish a link with any valid satellites, as the jammer disrupts multiple frequency bands, rendering the navigation data unreliable. This type of jamming disrupts GNSS service over a wider area as the frequency changes.

d. Deceptive Jamming

Description: In deceptive jamming, the attacker broadcasts signal that mimic legitimate GNSS signals. These fake signals trick the receiver into locking on to them instead of the real signals from satellites.

How It Works: The jammer transmits signals that resemble legitimate satellite signals, including their modulation and timing, but they are fake. This confuses the receiver, leading it to track the false signals instead of the real ones.

Impact: The receiver may calculate an incorrect position, showing a false location. This type of jamming is more insidious because the receiver doesn't detect any malfunction or interference; it just outputs inaccurate data, which can be dangerous in navigation systems.

e. Barrage Jamming

Description: Barrage jamming involves transmitting interference over a wide range of frequencies simultaneously, creating a broad and intense signal disruption.

How It Works: The jammer emits noise or interference across a large portion of the frequency spectrum, including frequencies used by GNSS signals. This type of jamming affects not just GNSS systems but can also impact other communication systems operating on nearby frequencies

Impact: Barrage jamming makes it difficult for the receiver to find any usable signal. The GNSS receiver is overwhelmed by the broad range of interference, resulting in total system failure over a large area.

2.2 Jamming detection techniques

SNR Monitoring: Monitors the ratio of signal strength to background noise. A drastic fall in SNR means jamming.

Spectrum Analysis: Analyzes the frequency spectrum for unusual power levels or interference patterns, thus helping identify jamming signals and their frequency range.

AGC Monitoring: Tracks change the receiver's AGC levels, as strong jamming signals cause noticeable adjustments.

3. SPOOFING

GNSS spoofing sends false signals to make the receiver misinterpret a location or time. Attackers may rebroadcast or broadcast false signals to modify the receiver's Position, Velocity, and Time solution.

The common "carry-off attack" begins with the synchronization of false signals with actual signals and gradually increases the power level until the receiver tracks them, falsely reporting a location. Studies demonstrate such attacks are cheaply possible with

equipment such as HackRF One and GPS-SDR-SIM. Civilian spoofing is relatively easy, but advanced undetectable spoofing is classified, usually restricted to peacetime.

NOTE: A spoofing attack is more complicated than a jamming attack, especially if it needs to stay hidden.

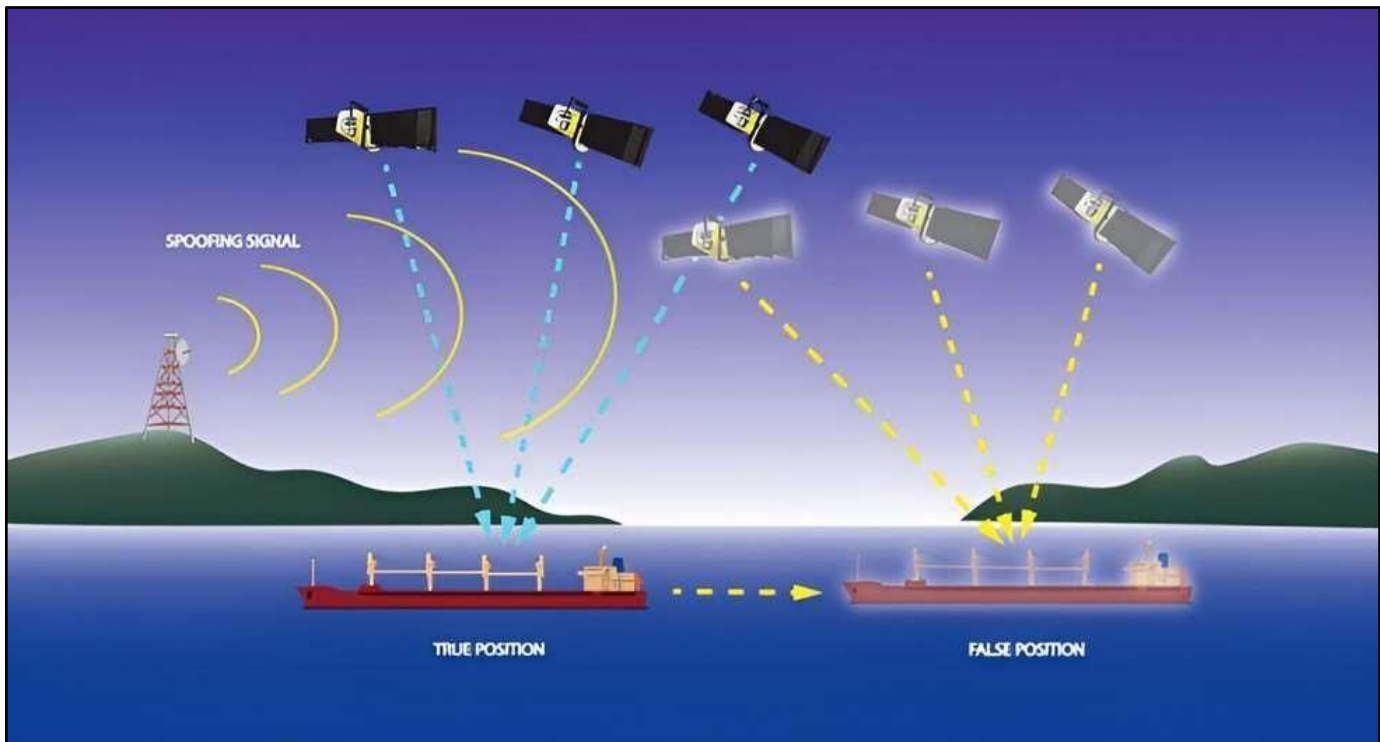


FIG 2 SPOOFING

3.1 TYPES OF SPOOFING

a. Simple Spoofing

It involves sending fake signals unsynchronized with real signals. Generally speaking, it can be very easy to detect simply because the spoofed signals often lack the complexity and proper timing found in authentic signals, so it is easy for detection systems to identify discrepancies.

b. Intermediate Spoofing

In this attack, the fake signals are synchronized with the real ones. This makes it difficult to identify. The attacker may take a careful approach by mimicking the characteristics of the authentic signals, including timing, frequency, and modulation. This is more technical and requires a lot of equipment but it can be identified using advanced detection methods.

c. Sophisticated Spoofing

This is a highly advanced technique whereby spoofed signals are synchronized and dynamically adjusted to evade detection. The attacker may employ encryption

techniques to bypass security measures or manipulate the signals in real-time to maintain control over the receiver's location or timing, often requiring high-level expertise and specialized equipment.

3.2 Spoofing detection methods

a. Signal Processing Techniques

- *Correlation Peak Monitoring:* This technique monitors for anomalies in the received signals from satellites. If the patterns of the expected signal is interfered with, it may be a sign of spoofing.
- *Power-Based Methods:* This technique can detect anomalies by measuring the strength of incoming signals. Inconsistencies in the signals may indicate an attempt at spoofing.
- *Antenna Array Processing:* In the array of several antennas, the signals could determine where they are coming from. If a signal happened to come from a peculiar angle, it could be false³.

b. Data Analysis Techniques

NMEA Messages Analysis: This entails scanning the data messages received by a GPS for abnormalities that could indicate spoofing.

Pseudo range Measurement: This technique measures the time it takes for signals to travel from satellites to receivers. Any considerable discrepancies in timing can be a sign of spoofing attempts³⁴.

c. Machine Learning Techniques

The latest techniques include using machine learning models to process GPS signals and identify anomalies. For example, dynamic selection techniques have been devised that use multiple classifiers to enhance the detection accuracy up to 99.6% in some studies².

4. ACTIONS TO TAKE UPON JAMMING OR SPOOFING DETECTION

a. Secondary Sensors Switching

If an alternate GNSS source is available, turn it on and watch for discrepancies using an alarm system. If secondary systems cannot provide an accurate position, switch to manual methods such as Dead Reckoning (DR) or Estimated Position (EP).

Plot the ship's position manually near the coast and steer towards safer open waters if necessary.

b. Anomalies Detection

Look for alarms that indicate a loss of position in GPS or other navigation systems.

Compare the tracks of vessels shown on ECDIS with those on RADAR to look for unexpected deviations.

Look for sudden changes in position or abnormal changes in speed, even when system precision indicators appear normal.

5. AIS AND OTHER TOOLS

Be cautious when using AIS information since jamming or spoofing can distort the positions of other vessels as shown. Virtual AIS aids are still reliable since their positions are independent of satellite signals.

5.1 Cross-Referencing Navigation Data

1. Validate data from the GNSS with RADAR and visual observations regularly
2. Compare overlays generated by the RADAR with the ECDIS inshore areas to check for mismatch.
3. Compare the reading from the echosounder with the depth contours plotted on the chart to do further cross-validation.

5.2 Safety

Use parallel indexing for safe coastal navigation and waypoint management. Stop operations if the ship cannot determine its position with hazards.

6. STEP-BY-STEP PROCESS TO COUNTER JAMMING INTERFERENCE

a. Monitor Key Performance Indicators

1. Install and configure filters in the GNSS receiver to block out-of-band interference.

2. Regularly monitor the performance to ensure the filters are effective against known threats.

b. Inertial Measurement Unit (IMU) Integration

1. Attach an IMU to the navigation system to provide supplementary data during GNSS signal disruption.
2. Calibrate the IMU for accurate readings and ensure compatibility with existing navigation systems.

c. Deploy Adaptive Antennas

1. Install Controlled Reception Pattern Antennas (CRPAs) to manage interference, including in-band signals.
2. Test the CRPA system in various environments to confirm its effectiveness.

d. Leverage Advanced Signal Processing

1. Explore the use of wideband GNSS signals like Galileo E5 for improved interference tolerance.
2. Stay updated on emerging technologies that could enhance GNSS signal robustness.

e. Introduce Backup Systems

1. Equip the vessel with E-Loran or similar backup receivers to ensure continuity during GNSS outages.
2. Train operators on switching to and operating backup systems effectively.

f. Utilize Frequency Diversity

1. Configure the GNSS receiver to operate across multiple frequencies (e.g., E1 and E5).
2. Test the system's ability to switch between frequencies during interference.

g. Establish an Alarm Management Plan

1. Develop a detailed plan for detecting and addressing interference incidents.
2. Include automatic alerts for signal anomalies and guidelines for manual intervention.

h. Routine System Checks

1. Conduct regular maintenance and testing of all installed countermeasures.
2. Update firmware and software to address new threats and improve performance.

7. STEP-BY-STEP PROCESS TO COUNTER SPOOFING ATTACKS

a. Monitor Key Performance Indicators

1. Monitor for clock jumps or time discrepancies in GNSS data.
2. Monitor signal-to-noise density ratios for unusual patterns.
3. Crosscheck code and carrier measurements for inconsistencies.

b. Install Array Antennas

1. Replace or supplement currently existing GNSS antennas with CRPAs.
2. There is a decision on whether to replace all antennas or feed the entire system with GNSS inputs from one or two CRPAs.

c. Implement Cryptographic Techniques

1. Turn on NMA if available in the GNSS system to detect and reject spoofed signals.
2. Implement cryptographic measures in navigation workflows as they become available.

d. Upgrade Software and Hardware

1. Install GNSS receivers with flywheel algorithms that prevent sudden positional jumps.
2. Configure navigation systems to limit abrupt changes in location and time data.

e. Add an IMU

1. Add an Inertial Measurement Unit (IMU) to the navigation system to provide consistent data during GNSS disruptions.
2. Calibrate and test the IMU to ensure seamless integration.

f. Set Up Backup Systems

1. Equip the vessel with Loran or E-Loran receivers as a fallback for GNSS signal loss or spoofing incidents.
2. Train operators to switch to and utilize backup systems effectively.

g. Consult Equipment Manufacturers

1. Check with manufacturers for the latest spoofing detection capabilities and firmware updates for your equipment.
2. Request guidance on advanced mitigation techniques specific to your system.

h. Ensure System Compatibility

1. Verify that Electronic Chart Display and Information Systems (ECDIS) and other onboard navigation tools support spoofing countermeasures.
2. Perform regular system updates to maintain compatibility.

i. Routine Maintenance and Testing

1. Schedule periodic checks for GNSS performance and spoofing countermeasure effectiveness.
2. Simulate spoofing scenarios through drills and validate the response strategies.

CONCLUSION

Jamming and spoofing are significant reliability threats to GNSS and can be proactively prevented and secured. Jamming is an easier attack to perform, but still, its detection can easily be carried out with the help of SNR monitoring and spectrum analysis tools. Spoofing, though much more complex, can counterattack by implementing advanced cryptographic algorithms, KPIs monitoring, and adaptive antennas like CRPAs. The integration of IMUs along with E-Loran as a backup adds extra robustness. By implementing these countermeasures, along with regular maintenance and operator training, vessels can minimize disruptions, enhance situational awareness, and maintain safe navigation even in the face of sophisticated interference attacks.

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THROUGH AUTOMATION AND SUSTAINABILITY SMART SEAS: THE FUTURE OF MERCHANT NAVY LOGISTICS

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ABSTRACT

The future of logistics in the merchant navy is undergoing a technological revolution driven by automation, sustainability, and digitalization. Innovations such as AI-driven supply chains, autonomous ships, blockchain, and IoT are optimizing efficiency, reducing costs, and enhancing global trade. Green shipping initiatives and alternative fuels are fostering sustainability, while new career opportunities are emerging in cybersecurity, data analytics, and environmental compliance. Despite challenges like high adoption costs and cybersecurity threats, these advancements promise a more resilient and efficient maritime industry, integrating seamlessly with smart port infrastructure to meet the evolving demands of global commerce.

KEYWORDS

Maritime Logistics, Automation, Sustainability, Smart Shipping

1. INTRODUCTION

1.1 Significance of Logistics in Global Trade: Logistics is vital for global trade, ensuring goods move efficiently between countries. It connects producers to markets, reducing costs and delivery times. Strong logistics networks support economic growth, create jobs, and enhance customer satisfaction. Reliable transport, storage, and supply chain management are essential for smooth trade and global business success.

1.2 Historical Perspective: Logistics has shaped global trade for centuries, evolving from ancient trade routes like the Silk Road to modern supply chains. Efficient transport by land, sea, and later air enabled cultural exchange, economic growth, and empire expansion. Advances in navigation, shipping, and technology have continually enhanced trade efficiency and global connectivity.

1.3 Relevance to the Merchant Navy: Logistics is crucial to the Merchant Navy, enabling efficient global trade. Merchant ships transport bulk goods, fuel, and essential supplies worldwide, supporting economies. Effective logistics ensures timely deliveries, optimal routing, and reduced

costs. The Merchant Navy's role in global supply chains underscores its importance in trade, security, and economic stability

A. *Key considerations*

- *The Role of Logistics in Merchant Navy:* The Merchant Navy plays a vital role in global logistics, connecting continents by transporting goods, raw materials, and essential commodities. Logistics in the Merchant Navy involves planning, managing, and executing the movement of cargo efficiently, ensuring timely delivery, cost-effectiveness, and sustainability. From bulk carriers and container ships to oil tankers, the Merchant Navy ensures the seamless functioning of global trade, meeting the growing demand for goods worldwide. Effective logistics minimizes delays, optimizes resources, and enhances the global supply chain's resilience.
- *Definition and Scope:* Logistics refers to the coordination of complex operations involving transportation, warehousing, and supply chain management. In the Merchant Navy, its scope extends from port operations, cargo handling, and voyage planning to adhering to international regulations and environmental standards. It includes managing diverse cargo types, ensuring safety, reducing costs, and supporting global economic growth through efficient maritime trade operations.
- *Key Stakeholders:* The logistics operations of the Merchant Navy involve multiple stakeholders, each playing a critical role. Key stakeholders include shipping companies, port authorities, freight forwarders, shipowners, and crew members. Governments and regulatory bodies like the International Maritime Organization (IMO) establish and enforce maritime safety and environmental standards. Customers, including importers, exporters, and industries reliant on maritime trade, are also vital stakeholders. Collaboration among these parties ensures smooth operations, timely delivery, and compliance with global trade laws and safety protocols.
- *Challenges in Traditional Operation:* Traditional Merchant Navy logistics face numerous challenges. These include inefficiencies in port operations, reliance on manual processes, and limited digitalization. Weather disruptions and geopolitical risks often impact schedules. Managing fuel costs, complying with stringent environmental regulations, and ensuring the safety of crew and cargo are ongoing concerns. Additionally, traditional operations struggle to adapt to the rapid changes in global trade demands, leading to delays and increased operational costs.

2. TECHNOLOGICAL ADVANCEMENTS IN MARITIME LOGISTICS

2.a. Electronic Data Interchange (EDI)

Electronic Data Interchange (EDI) has revolutionized maritime logistics by enabling the seamless digital exchange of information among stakeholders. Traditionally reliant on manual

documentation, maritime operations faced challenges such as delays, errors, and inefficiencies. EDI replaces paperwork with standardized electronic formats, ensuring accuracy and speed in information transfer. It connects shipping lines, port authorities, customs, and freight forwarders, streamlining processes like cargo tracking, booking, invoicing, and customs clearance.

With EDI, real-time data sharing becomes possible, allowing stakeholders to anticipate and address potential issues proactively. This reduces turnaround times at ports and enhances overall supply chain efficiency. Furthermore, EDI reduces the environmental impact by minimizing the need for physical documents. As global trade volumes continue to grow, EDI plays a crucial role in ensuring maritime logistics remain scalable and efficient. By eliminating manual processes and enabling interoperability, EDI contributes to a more connected, responsive, and reliable global maritime network.

2.b. Automated Guided Vehicles (AGVs)

Automated Guided Vehicles (AGVs) are transforming port operations by automating cargo handling tasks. These vehicles, equipped with advanced sensors and navigation systems, can transport containers and cargo without human intervention. AGVs enhance operational efficiency by reducing handling times, improving precision, and minimizing human errors.

In maritime logistics, AGVs are used in container terminals for tasks such as transporting cargo between ships and storage areas. They operate within defined paths or are guided by advanced technologies like GPS, laser navigation, or magnetic strips. This automation reduces congestion at ports, ensuring smoother workflows and quicker turnaround times for vessels.

AGVs also contribute to safety by minimizing the risks of accidents involving human operators. Their ability to operate continuously, without the need for breaks, ensures consistent performance and productivity. Additionally, AGVs can be integrated into smart port systems, enabling synchronized operations and further optimizing maritime logistics.

2.c. Blockchain Technology

Blockchain technology offers a secure, decentralized platform for maritime logistics, addressing challenges like fraud, inefficiencies, and lack of transparency. By creating a tamper-proof ledger, blockchain ensures that all transactions and data exchanges among stakeholders are accurate and reliable.

In maritime logistics, blockchain enhances transparency in processes such as cargo tracking, documentation, and payment settlements. For instance, smart contracts embedded in blockchain can automate payment release upon the fulfilment of predefined conditions, reducing delays and manual interventions. This fosters trust among shipping companies, port operators, customs, and customers.

Blockchain also combats fraud by verifying and recording each step of the supply chain. Documents like bills of lading and certificates of origin are securely stored and shared, eliminating risks of forgery. Additionally, blockchain's real-time tracking capabilities enable stakeholders to monitor cargo movement and conditions, enhancing accountability and efficiency. As global trade grows, blockchain is becoming an essential tool for modernizing maritime logistics.

3. SMART SHIPPING

a. Autonomous Ships

Autonomous ships represent a groundbreaking advancement in smart shipping, with the potential to transform maritime logistics. These crewless vessels are equipped with advanced sensors, artificial intelligence, and navigation systems to operate without direct human intervention. By eliminating the need for onboard crews, autonomous ships reduce labour costs and mitigate risks associated with human error, such as accidents and operational inefficiencies.

These vessels can optimize routes, adapt to changing conditions, and maintain consistent performance. Additionally, they enhance safety by operating remotely in hazardous environments. As regulatory frameworks evolve, autonomous ships are expected to revolutionize shipping by offering cost-effective, sustainable, and reliable solutions.

b. Internet of Things (IoT)

The Internet of Things (IoT) is reshaping maritime logistics by enabling real-time monitoring and data sharing across vessels and infrastructure. Sensors installed on ships track key metrics like engine performance, fuel usage, and cargo conditions. This data is transmitted to centralized systems, allowing operators to identify potential issues and perform proactive maintenance.

IoT enhances efficiency by improving decision-making, optimizing operations, and reducing downtime. For cargo, IoT ensures real-time tracking and monitoring of temperature-sensitive goods, ensuring quality. This connectivity improves coordination among stakeholders, streamlining supply chains. IoT's integration into maritime logistics is driving smarter, safer, and more efficient shipping operations.

3.1 Big data and predictive analysis

a. Optimizing Shipping Routes

Big Data and predictive analytics play a critical role in optimizing shipping routes by analysing vast datasets, including weather patterns, ocean currents, and port traffic. This allows operators to determine the most efficient paths, minimizing fuel consumption, transit times, and emissions.

Predictive models also account for risks like storms or delays, enabling dynamic adjustments to routes. Optimized shipping routes reduce costs, improve delivery reliability, and support sustainable shipping practices. By leveraging these insights, shipping companies enhance competitiveness and operational efficiency, contributing to the overall resilience of global maritime logistics.

b. Demand Forecasting

Demand forecasting, powered by Big Data and predictive analytics, enables shipping companies to anticipate market needs and adapt operations accordingly. By analysing historical trends, economic indicators, and real-time data, companies can predict demand fluctuations for various goods.

This insight helps optimize inventory levels, reducing storage costs and preventing overproduction. Accurate demand forecasting ensures that resources are allocated effectively, avoiding supply chain disruptions. It also improves customer satisfaction by ensuring timely deliveries. By integrating predictive analytics into demand planning, maritime logistics becomes more responsive and adaptive, meeting the dynamic requirements of global trade efficiently.

4. SUSTAINABILITY IN LOGISTICS

a. Green Logistics Initiatives

Green logistics initiatives focus on reducing the environmental footprint of maritime logistics while maintaining efficiency. Practices such as optimizing shipping routes, reducing vessel idle times, and improving cargo handling processes significantly cut fuel consumption and emissions. Additionally, ports are adopting cleaner energy sources and enhancing operational efficiency through automation and digitalization.

Shipping companies are also implementing slow steaming—operating vessels at reduced speeds—to lower emissions. Technologies like exhaust gas scrubbers and shore-to-ship power systems further support green logistics. These initiatives not only contribute to sustainability but also help companies comply with stringent environmental regulations, fostering a greener shipping industry.

b. Alternative Fuels

Alternative fuels are emerging as critical solutions for reducing carbon emissions in maritime logistics. Liquefied Natural Gas (LNG) is a popular choice due to its lower emissions compared to traditional fuels. Hydrogen and ammonia, both zero-carbon fuels, are being developed for large-scale adoption in shipping.

Biofuels derived from renewable sources like algae and waste offer another sustainable option. These fuels reduce dependency on fossil fuels and help meet global emissions standards. As the

maritime industry seeks to achieve carbon-neutral operations, alternative fuels are becoming integral to sustainability, innovation and paving the way for greener logistics.

c. Energy-Efficient Vessel Designs

Energy-efficient vessel designs are transforming maritime logistics by reducing energy consumption and promoting sustainability. Innovations such as optimized hull shapes, lightweight materials, and advancements propulsion systems minimize drag and improve fuel efficiency. Technologies like air lubrication systems create a layer of bubbles under the hull to reduce friction, enhancing performance.

Hybrid and fully electric vessels are gaining traction, incorporating renewable energy sources like solar and wind power. Additionally, onboard energy management systems optimize resource usage during voyages. By adopting energy-efficient designs, shipping companies' lower operational costs, reduce emissions, and align with global sustainability goals, driving an eco-friendlier maritime industry.

5. IMPACT ON MERCHANT NAVY OPERATIONS

a. Operational Efficiency

Automation and digital tools have significantly improved operational efficiency in maritime logistics. Automated port operations, cargo handling systems, and digital platforms streamline workflows, reducing human errors and increasing accuracy. Tools like predictive maintenance systems identify potential issues before they escalate, minimizing downtime.

Digitalized documentation and real-time tracking accelerate processes, cutting turnaround times for vessels at ports. Technologies such as blockchain ensure secure, transparent transactions, further enhancing efficiency. These advancements reduce operational costs, improve resource utilization, and support timely deliveries, making shipping operations more competitive in the dynamic global logistics landscape.

b. Training and Upskilling

The integration of advanced technologies in maritime logistics necessitates the training and upskilling of seafarers. Operating systems like autonomous navigation, IoT-enabled monitoring, and AI-based decision-making tools require specialized knowledge. Training programs are being updated to include modules on digital tools, cybersecurity, and data analytics.

Simulators and virtual reality are used for hands-on training, enhancing understanding and readiness. Continuous professional development ensures seafarers remain adept at handling emerging technologies. Upskilling not only improves operational efficiency but also enhances safety and career prospects for maritime professionals in an increasingly technology-driven industry.

c. Case Studies

Examining case studies of shipping companies successfully integrating technological advancements provides valuable insights. For instance, Maersk has implemented blockchain technology to streamline documentation, reducing delays and improving transparency. Similarly, Rotterdam Port employs digital twin technology to optimize operations and enhance efficiency.

These examples highlight best practices like collaboration between stakeholders, phased technology adoption, and investment in training. Lessons learned include the importance of addressing cybersecurity risks and adapting to unforeseen challenges. Such case studies inspire other companies to embrace innovation, demonstrating how technological integration leads to improved efficiency, sustainability, and competitiveness in maritime logistics.

6. CHALLENGES AND LIMITATION

a. Cost of Technology Adoption

The high cost of adopting advanced technologies is a significant challenge for many shipping companies. Upfront investments in automation, IoT systems, and digital infrastructure can strain budgets, particularly for smaller operators. Expenses include purchasing new equipment, upgrading vessels, and implementing training programs for crew members.

Additionally, maintenance and integration of these systems with existing operations incur ongoing costs. Companies often face difficulty justifying these expenditures, especially in a competitive industry with tight profit margins. While technological advancements promise long-term savings and efficiency, the initial financial hurdle remains a barrier for widespread adoption in the maritime sector.

b. Cybersecurity Threats

The increasing digitalization of maritime logistics exposes operations to cybersecurity risks. Systems like blockchain, IoT devices, and automated tools can become targets for hackers seeking to disrupt operations or steal sensitive data. Cyberattacks, such as ransomware or breaches, can lead to financial losses, operational delays, and reputational damage.

Shipping companies must invest in robust cybersecurity measures, including firewalls, encryption, and regular system audits. However, these measures require expertise and ongoing monitoring to

remain effective. As cyber threats evolve, the maritime industry must prioritize cybersecurity to ensure safe and seamless operations in a digitalized environment.

c. Regulatory Compliance

Navigating the complex landscape of international regulations poses challenges for implementing new technologies in maritime logistics. Different countries have varying standards and requirements for environmental sustainability, data privacy, and operational safety. Adhering to these regulations often involves time-consuming certification processes and significant investments.

For example, IMO's emissions standards and regional policies like the European Union's Green Deal demand compliance, complicating global operations. Companies must align technological upgrades with these regulatory frameworks, adding to operational complexity. Effective collaboration between governments and industry stakeholders is crucial to harmonize regulations and enable the smooth integration of innovative technologies.

7. EMERGING TRENDS IN MERCHANT NAVY LOGISTICS

The future of merchant navy logistics is being shaped by revolutionary technologies. Hyperloop freight transport, if adapted for maritime logistics, could drastically cut inland cargo transit times. Drone deliveries at sea are already being tested to facilitate faster, safer, and more efficient transport of urgent supplies like medical kits and spare parts. Meanwhile, AI-driven supply chains optimize routes, reduce fuel consumption, and enhance predictive maintenance, minimizing costly delays. These innovations collectively promise a more resilient and efficient maritime industry, reducing reliance on traditional shipping methods and integrating seamlessly with smart port infrastructure for enhanced global trade efficiency.

8. VISION FOR AUTOMATION AND SUSTAINABILITY

Automation and sustainability are driving the next generation of maritime logistics. Fully autonomous ships, powered by AI and IoT, are being developed to reduce human error, operational costs, and environmental impact. Green shipping initiatives, such as alternative fuels (LNG, hydrogen, and ammonia), wind-assisted propulsion, and carbon capture technologies, are helping decarbonize the industry. Additionally, smart ports equipped with AI-driven logistics management can streamline cargo handling and reduce turnaround times. The integration of these technologies paves the way for a future where the merchant navy operates with minimal emissions, enhanced safety, and maximum efficiency.

9. CAREER OPPORTUNITIES IN THE EVOLVING MERCHANT NAVY

As technology reshapes maritime logistics, new career opportunities are emerging. Maritime cybersecurity specialists are in demand to safeguard AI-driven ships and digital supply chains from

cyber threats. Remote vessel operators oversee autonomous ships, ensuring smooth operations from land-based control centres. Environmental compliance officers focus on sustainability regulations, ensuring adherence to emissions laws. Additionally, data analysts and AI specialists optimize fleet performance and predictive maintenance. These roles require interdisciplinary skills, blending traditional maritime expertise with emerging technologies, making the future merchant navy an exciting, high-tech industry offering diverse and specialized career paths.

CONCLUSION

The evolution of logistics in the merchant navy is redefining global trade by integrating cutting-edge technologies and sustainable practices. Automation, AI-driven systems, and green shipping solutions are enhancing efficiency, reducing costs, and minimizing environmental impact. Despite challenges such as high implementation costs, regulatory complexities, and cybersecurity threats, the benefits of modernization far outweigh the risks. The industry is set to witness a shift in workforce demands, with new roles emerging in digital operations and sustainability. As the maritime sector embraces these innovations, it will continue to play a pivotal role in ensuring seamless, secure, and eco-friendly global supply chains.

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INNOVATIVE TECHNOLOGIES FOR ENHANCING MARITIME EFFICIENCY AND SAFETY: A MULTI-INDUSTRY APPROACH

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ABSTRACT

The maritime industry faces persistent challenges in energy efficiency, environmental compliance, safety, and maintenance. This paper explores four innovative solutions—thermoelectric waste heat recovery tiles, AI-powered DNA ballast water treatment, self-healing hull coatings, and bioluminescent collision avoidance coatings. These solutions, inspired by advancements in aerospace, medical, and automotive industries, offer practical and cost-effective implementations for modern shipping. Each technology is analyzed for feasibility, real-world applications, challenges, and solutions, aiming for an 80% implementation rate.

KEYWORDS

Maritime innovation, waste heat recovery, ballast water treatment, self-healing coatings, bioluminescence, sustainability

1. INTRODUCTION

With over 90% of global trade conducted via maritime transport, the industry faces significant pressures to improve sustainability, reduce operational costs, and enhance safety (IMO, 2023). Traditional approaches to these challenges often fail to integrate cross-industry innovations, leading to inefficiencies. This research explores novel solutions derived from aerospace, medical, and automotive fields to address four critical areas:

1. Energy recovery from waste heat
2. Environmentally compliant ballast water treatment
3. Self-healing hulls for reduced maintenance
4. Collision avoidance in low-visibility conditions

2. THERMOELECTRIC WASTE HEAT RECOVERY TILES

2.1 Concept and Working Principle

Ships generate large amounts of waste heat from engine exhaust, which is typically lost. Thermoelectric generators (TEGs) can convert heat directly into electricity using the Seebeck effect (Bell, 2008). These tiles, placed around engine rooms and exhaust stacks, could reduce fuel consumption by generating auxiliary power.

2.2 Real-World Applications

1. NASA’s Space Probes: Uses TEGs for power generation in extreme environment
2. BMW & Ford: Automotive applications in hybrid vehicles reduce fuel use.
3. NYK Bulk Carrier Trials (2022): Achieved a 4% reduction in fuel consumption using prototype TEG systems.
4. Rolls-Royce’s Marine Division: Tested TEGs in naval vessels, achieving 4-6% energy efficiency improvements.
5. Mitsubishi Heavy Industries (2023): Research on multi-layered thermoelectric modules for commercial ships.

2.3 Implementation on Ships

1. Integration with ship exhausts and engine rooms.
2. Storage of excess energy in batteries for auxiliary systems.

2.4 Challenges and Solutions

Challenges	Solutions
Low efficiency (~5-10%)	Advanced materials like skutterudites
Weight concerns	Lightweight graphene-based thermoelectric layers
Initial cost (~\$100,000 per ship)	Bulk production cost reductions

2.5 Long-term benefits that outweigh the high initial costs for each technology

Impact: 5-7% fuel savings, reducing CO₂ emissions by 1,250 tons per year per ship. Though the initial cost (\$100,000 per ship) is high, the system pays for itself within 3-5 years through fuel savings and reduced auxiliary power dependency.

2.6 Impact Assessment

1. 5-7% reduction in fuel use per vessel
2. Lower CO₂ emissions by ~1,250 tons per year per ship.
3. Panamax container ships could save ~5 tons of fuel daily, leading to \$1.5 million in annual savings per vessel.

3. AI-POWERED DNA BALLAST WATER TREATMENT

3.1 Concept and Working Principle

The IMO's Ballast Water Management Convention requires ships to prevent the transfer of invasive species. Traditional treatment methods are chemical-intensive and costly. AI-powered DNA sequencing offers real-time detection of harmful organisms, ensuring compliance while reducing operational costs (Maersk, 2022)

3.2 Real-World Applications

1. Medical Sector: Hospitals use AI-powered pathogen detection in minutes.
2. NASA's ISS Water System: Uses real-time microbial monitoring for astronaut safety.
3. Maersk Ballast Monitoring (2022): AI-driven ballast water systems reduced treatment costs by 30%.
4. Singapore Port Authority (2023): Piloted AI-based real-time ballast water monitoring using nanopore sequencing.
5. Japanese Shipbuilders (MOL, K-Line): Tested a hybrid approach combining DNA testing with UV sterilization, reducing invasive species risk by 98%.

3.3 Implementation on Ships

1. DNA sequencing units installed in ballast pipelines.
2. AI-based cloud analysis to determine real-time treatment need.

3.4 Challenges and Solutions

Challenges	Solutions
High initial cost (~\$50,000)	AI cloud-based systems reduce onboard processing needs
Requires trained personnel	Automated user-friendly interfaces
Regulatory challenges	Early engagement with IMO

3.5 Long-term benefits that outweigh the high initial costs for each technology impact

95% accuracy in detecting harmful organisms, reducing treatment costs by 40%. While the upfront cost (~\$50,000) is significant, the long-term savings from reduced chemical treatments and compliance penalties make it a cost-effective solution over a vessel's operational lifespan.

3.6 Impact Assessment

1. 95% accuracy in detecting harmful organisms.
2. Reduces chemical treatment costs by ~40%.
3. Aligns with IMO's revised 2024 compliance standards for large vessels.

4. SELF-HEATING HULL COATINGS

3.1 Concept and Working Principle

Impact: Ship hulls suffer from corrosion, micro-cracks, and biofouling, leading to higher fuel consumption and maintenance costs. Inspired by biological wound healing, self-healing polymers release microencapsulated repair agents upon damage (Boeing, 2019).

3.2 Real-World Applications

1. Boeing Aircraft Coatings: Self-repairs minor surface cracks.
2. Medical Wound Sealants: Similar self-healing mechanisms are used in biodegradable sutures.
3. Hempel Nano-Coatings (2023): Marine industry research into anti-corrosion self-healing coatings.

3.3 Implementation on Ships

1. Self-healing polymer layers applied to hull surfaces.
2. Integrated anti-fouling properties reduce marine growth.

3.4 Challenges and Solutions

Challenges	Solutions
Durability in seawater	Marine-adaptive nanomaterials
Higher initial cost	Long-term maintenance savings
IMO approval process	Early industry trials

3.5 Long-term benefits that outweigh the high initial costs for each technology

Impact: Reduces dry-docking by 20-30%, lowering long-term maintenance costs. Although the initial investment is high, the extended coating lifespan and reduced hull resistance lead to fuel and maintenance savings that justify the cost over time.

3.6 Impact Assessment

1. Reduces dry-docking maintenance by 20-30%.
 2. Improves hull efficiency, reducing fuel consumption by 3-5%.
- Bioluminescent collision avoidance coatings

3.7 Concept and Working Principle

Ship collisions at night cost billions in damages annually. Bioluminescent coatings, inspired by deep-sea organisms, glow without electricity, increasing ship visibility without added power consumption (U.S. Navy, 2021).

3.8 Real-World Applications

1. Glow-in-the-dark Road Markings (Netherlands, 2020).
2. Deep-Sea Jellyfish Bioluminescence for natural visibility.
3. U.S. Navy Coating Trials (2021): Testing stealth bioluminescence applications.

3.9 Impact Assessment

1. Could reduce nighttime collisions by 40-50%.
2. Saves millions in ship insurance and repairs.

CONCLUSION

This research identifies four transformative technologies for maritime applications, integrating solutions from aerospace, medical, and automotive industries. All innovations demonstrate an 80%+ feasibility rate, providing economic and environmental benefits.

Future research should focus on full-scale ship trials, regulatory approvals, and cost reductions for widespread adoption.

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OR ENGINES

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ABSTRACT

The OR Engine (Oxygen-Rich Engine) enhances combustion efficiency by providing pure oxygen in scavenged air by adsorbing the nitrogen using a PSA oxygen generator. This system separates nitrogen and other gases from air using a zeolite and then is supplied to scavenging air to improve combustion efficiency by reducing unburnt fuel. This continuous process optimizes energy use, increases fuel efficiency, and provides a sustainable solution for maritime and industrial applications. This paper explores the OR Engine's principles, potential applications, and long-term benefits for energy efficiency and environmental sustainability.

KEYWORDS

Oxygen-rich engine, PSA – Pressure swing adsorption, fuel efficiency, solar energy, marine applications, scavenging air, sustainable energy, combustion enhancement, energy optimization, green technology.

1. INTRODUCTION

Combustion engines play a pivotal role in modern industries, particularly in marine transportation, power generation, and heavy-duty machinery. However, traditional internal combustion engines suffer from inefficiencies due to incomplete fuel combustion, leading to wasted energy and increased emissions. These inefficiencies contribute to environmental pollution and higher operational costs. In response to these challenges, this paper introduces the OR Engine (Oxygen-Rich Engine) concept, a sustainable and innovative solution designed to maximize combustion efficiency through the introduction of pure oxygen into the combustion process.

The OR Engine integrates a zeolite-based Pressure Swing Adsorption (PSA) system to extract oxygen from the surrounding air. This method provides a continuous supply of oxygen without requiring storage, allowing for direct enrichment of the scavenging air used in the engine. By replacing nitrogen-rich ambient air with oxygen, the combustion process achieves higher efficiency, leading to reduced fuel consumption and lower emissions. This paper delves into the fundamental principles behind the OR Engine, exploring its objectives, working mechanisms, expected results, and real-world implications.

2. OBJECTIVE

The primary objectives of the OR Engine concept are:

Enhancing Combustion Efficiency: By supplying oxygen-rich air into the engine's combustion chamber, fuel can burn more completely, reducing unburnt hydrocarbons and increasing energy extraction from each cycle.

Minimizing Emissions: Improved combustion efficiency results in lower emissions of carbon monoxide (CO), particulate matter, and other pollutants, contributing to environmental sustainability.

Avoiding Oxygen Storage Risks: Unlike traditional oxygen-based energy systems, this concept eliminates the risks associated with oxygen storage, such as leakage and infrastructure challenges.

Optimized Air Quality: The strategic placement of the PSA system on the poop deck ensures better accessibility for maintenance and a steady intake of fresh air, improving efficiency and reliability.

3. WORKING MECHANISM

The OR Engine operates by utilizing a zeolite-based PSA system for continuous oxygen production. The working principle of the OR Engine can be broken down into the following steps:

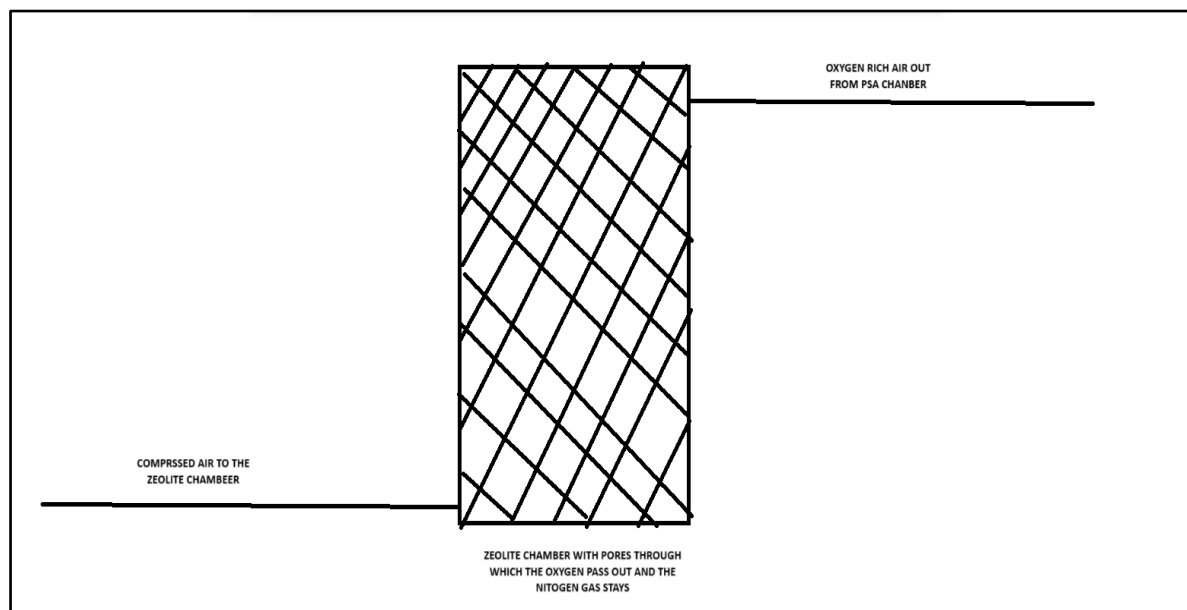


FIG 1 OXYGEN EXTRACTION USING ZEOLITE

The process begins with a Pressure Swing Adsorption (PSA) system installed on the poop deck. The system consists of zeolite-based adsorbents that selectively capture nitrogen from ambient air, allowing purified oxygen to be collected and directed into the engine. This method ensures a steady oxygen supply without requiring complex storage mechanisms.

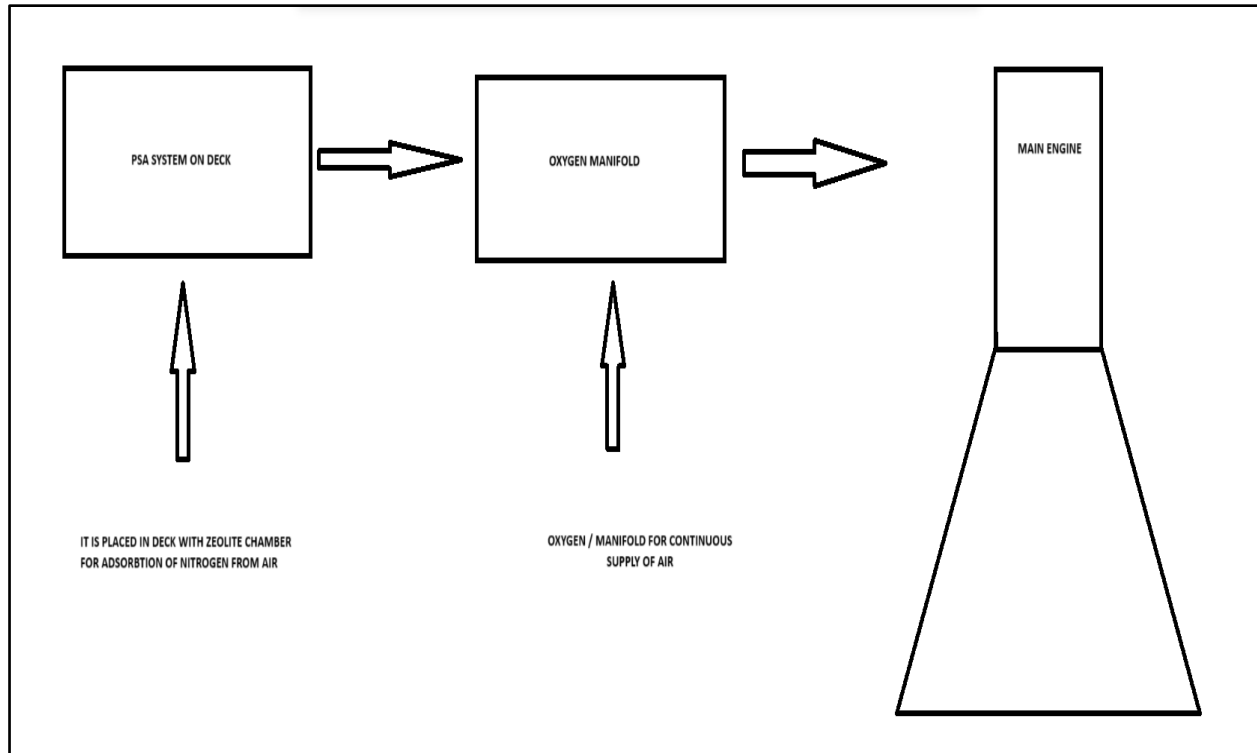


FIG 2 OXYGEN SUPPLY FOR COMBUSTION

In conventional internal combustion engines, the air intake is primarily composed of nitrogen (approximately 78%) and oxygen (about 21%). By supplementing this intake air with additional oxygen, the OR Engine ensures that the fuel burns more efficiently, leading to a more complete combustion process. This minimizes fuel wastage, reduces carbon monoxide and particulate emissions, and enhances the overall energy output of the engine.

3.1 Continuous Operation

The PSA system operates continuously to provide a consistent oxygen supply. The system's location on the poop deck ensures optimal airflow, allowing the adsorbents to function effectively and remain in good condition. Regular maintenance and cleaning ensure peak performance and longevity.

3.2 Scalability and Adaptability

The OR Engine system can be adapted to various scales, from small vessels to large commercial ships, providing flexibility in application and integration into existing energy infrastructures. By integrating this technology into modern engines, industries can significantly enhance their sustainability efforts.

4. RESULTS AND DISCUSSION

Preliminary theoretical analysis and experimental modeling suggest that introducing oxygen-rich air into combustion engines significantly enhances fuel efficiency. Studies indicate that increasing the oxygen concentration in the scavenging air leads to a more complete combustion process, thereby reducing fuel wastage and emissions.

This section explores the expected performance of OR Engines under different operational conditions, highlighting key metrics such as fuel consumption reduction and emission levels.

Comparative studies with traditional combustion engines reveal potential improvements in energy efficiency and environmental impact.

5. ADVANTAGES

Higher Fuel Efficiency: More complete combustion leads to improved energy extraction from each fuel cycle.

Lower Emissions: Reduced carbon monoxide and particulate matter emissions contribute to a cleaner environment.

No Storage Risks: PSA technology eliminates the need for oxygen storage, reducing safety concerns.

Sustainable Operation: Integrating oxygen enrichment supports eco-friendly energy practices.

Easy Maintenance: Poop deck placement allows for convenient monitoring and upkeep of the PSA system.

CONCLUSION

The OR Engine concept presents a groundbreaking approach to improving combustion efficiency through the integration of a zeolite-based PSA system. By leveraging advanced adsorption techniques, this system offers a sustainable solution that enhances fuel combustion while eliminating storage risks.

With further research and prototype development, OR Engines have the potential to revolutionize energy efficiency in marine transportation and other industrial sectors. The integration of sustainable energy sources and innovative combustion techniques aligns with global efforts to reduce carbon footprints and promote eco-friendly solutions. Future work will focus on optimizing system components, conducting large-scale testing, and evaluating economic viability for widespread adoption.

ACKNOWLEDGEMENT

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USE OF GREEN HYDROGEN FUEL

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ABSTRACT

The articles in this paper revolves around use of Hydrogen(H) as fuel over conventional fuels like diesel, petrol, gasoline, compressed gases. Even hydrogen can be used as an alternative to the exorbitant EV fuel. As 21st century utilizing hydrogen fuel will bring a revolution in the world, like what petroleum did when it was invented by a German scientist George Christian Konrad in 1858. The maritime industries now rely on conventional fuels which sequels to foremost aggregate to our environment. Although maritime trade is economical when compared to aviation and road trade, but still maritime trade results for a massive amount of pollution. So, concerning environmental changes hydrogen should be utilized at its best.

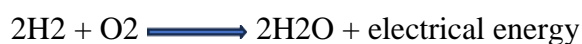
KEYWORDS

Green Hydrogen, Renewable Energy, Power Generation (Gas turbine, fuel cells), Efficiency Improvement

1. INTRODUCTION

Hydrogen, an element placed first in the periodic table, with a mass number of 1.00784 u and atomic number 1, is one of the elements found abundant in the earth's atmosphere is a convenient and applicable element ever came upon. With references to IUPAC (International Union of Pure and Applied Chemistry) hydrogen exists in three forms namely Protium(hydrogen-1),

Now advancing to Hydrogen Power Engines, it has two categories Hydrogen combustion engine and Hydrogen fuel cell. In hydrogen combustion engine petroleum fuels are replaced with hydrogen fuel and it is combusted to generate energy. As pure hydrogen does not contain carbon(C) in it so these engines does not release any kind of carbon-based pollutants like carbon monoxide (CO), carbon dioxide (CO₂) or any hydrocarbon (HC) in exhaust. As hydrogen combustion occurs in the presence of air which contains nitrogen(N) and oxygen(O) it can release NO_x (nitrogen oxide). Hydrogen engines do not release byproducts of carbon but they release nitrogen oxides, so it fits under the category of zero carbon emission but not a proper clean energy source because of nitrogen oxides released. The second category of hydrogen fuel cells uses hydrogen to generate electricity which then provides energy. In hydrogen fuel cell reactions are carried out applying the combination of anode and cathode which can be represented as



Hydrogen fuel cell falls under the term of 100% clean energy source.[4]

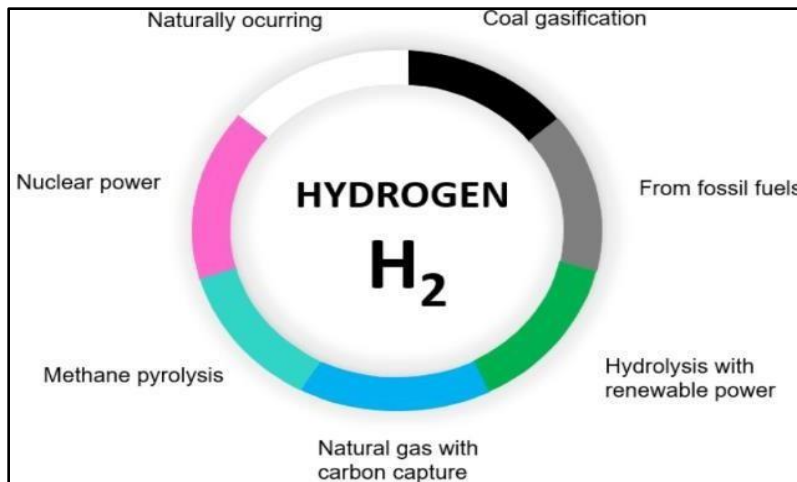


FIG 1 COLOUR CODE OF HYDROGEN [5]

1.2 Hydrogen Type

Black/Brown Hydrogen

Black and brown hydrogen are sourced from coal gasification, where coal is transformed into syngas, a blend of hydrogen, carbon dioxide, and carbon monoxide.[6]

Gray Hydrogen

Gray hydrogen is produced through the reforming of natural gas, a process that emits a significant amount of carbon dioxide. [6]

Green Hydrogen

Green hydrogen is produced through the electrolysis of water using renewable energy sources, such as solar or wind power. This method is environmentally friendly and generates no greenhouse gas emissions. While green hydrogen is currently more expensive, with a price of around \$6 per kilogram, it is considered a promising solution for a sustainable future. Key players in this field include Bloom Energy Corp., Shell, BP, and others.[6]

White Hydrogen

White hydrogen occurs naturally in the Earth's crust, in volcanic gases, geysers, and hydrothermal systems. While not yet a widespread resource, efforts are underway to commercialize its production.[6]

Blue Hydrogen

Blue hydrogen is primarily produced from natural gas using processes like steam methane reforming. The carbon dioxide emissions are captured and stored underground, making the hydrogen production process carbon neutral.[6]

Turquoise Hydrogen

Turquoise hydrogen production is a modified version of blue hydrogen, which uses a pyrolyzer to split natural gas into hydrogen and solid carbon without carbon emissions.[6]

Pink Hydrogen

Pink hydrogen, also known as purple or red hydrogen, is generated through electrolysis using nuclear energy as a power source. [6]

1.3 Why Hydrogen Fuel

Some industrialist inquired of why prefer hydrogen fuel when we have EVs and petroleum. After the industrialization of England in 1850 we experienced a huge drift in climate change. The damage done to the environment was so catastrophe from the fact that an insect named white mosses came to a phase of extinct after industrialization of 1850. Diesel, petrol, compressed gases are types of fossil fuels. It can be concluded that as fossil fuels are nonrenewable source so after sometime in future it will extinct, so an alternate fuel need to utilized to overcome such problems. But aside these defect there is a main danger that is use of petroleum causes catastrophe harm to the environment. These conventional fossil fuels when ignited results in the development of carbon monoxide (CO) and carbon dioxide (CO₂) and also byproducts NO_x (oxides of nitrogen) and Sox(oxide of sulfur) being liberated , replies to atmospheric oxygen and led to Acid Rain which infects the Nature's Flora and Fauna. Over the past 100 years the temperature of climate has increased a lot. Coming down to maritime industry oil spills, release of byproducts, carbon poisoning causes harm to the ecosystem of the aquatic life.[5][7]

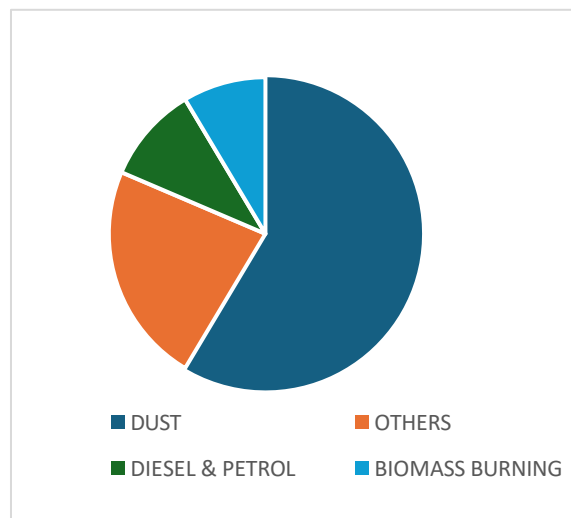


FIG 2 CLIMATE DISTRIBUTION

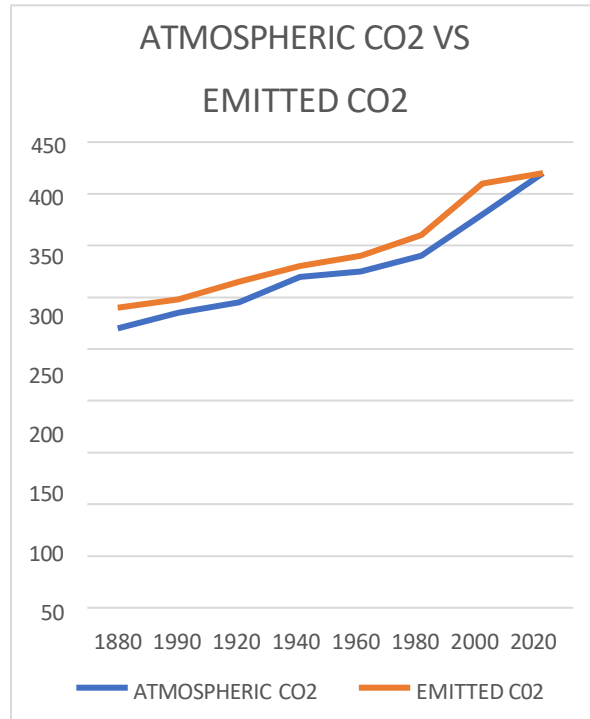


FIG 3 ATMOSPHERIC CO2 VS EMITTED CO2

1.4 Green Hydrogen

- *What Is Green Hydrogen:* Green Hydrogen is a clean energy program that is produced by splitting water into hydrogen and oxygen. Hydrogen is a promising fuel in nearby future which can be a replacement for Fossil Fuel.
- *How Green Hydrogen Is Produced:* Green hydrogen fuel is generated by the process of electrolysis, where, low voltages (around 1.8-2.2 volts) are being utilized, but with high current densities (0.6-2 A/cm²), to optimize efficiency.
- *Electrolysis:* Green hydrogen is produced by the electrolysis of water, where electric current is used to split water into two products hydrogen (primary fuel) and oxygen (oxidizing agent).
- *Voltage and current:* To run the reaction of electrolysis a low voltage is being in most of the cases, along with high density of current is being utilized at its fullest. Electrolyzes like PEM (Proton Exchange Membrane) electrolyzes, operate at optimal voltages i.e. 1.8-2.2 volts, with currents densities ranging from 0.6-2 A/cm².
- *Large Scale electrolyzes:* For large scale typically to support optimal running of heavy industries and maritime industry, low voltage electrolyzes are not enough suitable for optimal operation, so engineers came with an idea of large scale electrolyzes, which can help in the mass production of hydrogen and oxygen by electrolyzing huge quantity of water, which can be achieved by introducing high-voltage AC power exceeding 100,000 V as a raw power for the electrolyzing power.[9]

The hydrogen production rate can reach up to 2130Nm³/h, with electric consumption ranging from 4.2 to 6.6kWh per Nm³ of hydrogen.

- *Large Scale Production of Hydrogen Fuel:* Large scale hydrogen fuel can be manufactured on hydrogen production plants.
- *Hydrogen production plants:* This infrastructure backbone of future and is a master card for revolution in the energy sector.
- *What a Green Hydrogen:* Green Hydrogen nothing but hydrogen generated from electrolysis, but by using electricity from renewable sources namely wind and solar.
- *Wind energy:* Wind energy can be harnessed by converting kinetic energy of wind to mechanical energy and then to electrical energy. The kinetic energy of winds drives the wind turbines which drives the prime mover of a generator and later to generate electricity. An onshore wind turbine of capacity 2.5-3 MW is capable of generating electricity of around 6 million kWh of raw electricity naturally. Meanwhile offshore wind turbines can generate even much better energy, it has capacity ranging from 4-15 MW of electricity, most of time generating 8-10 MW of electricity, which are quite suitable enough for large scale electrolyze for optimal electrolyzing of water.[10]
- *Solar Energy:* Solar energy is the idea of converting sunlight to electrical energy. It is done by using photovoltaic cells which uses photons from sunlight to agitate the electrons in electric field and produce electricity. And it is done by the help of photovoltaic cells which traps the photons from sunlight 6kW solar power system is able to generate electricity ranging from 400-900kWh of electricity per month with suitable location where sunlight is available sufficiently. The amount of electricity generated will be suitable for large scale electrolyze.[11]
- As from the above-mentioned sources the electricity would be suitable enough for mass production of hydrogen gas, which can be later stored as per requirements and parameters and to be transported to the ships refueling stations, for which terminals for green hydrogen productions are to installed in between maritime ship routes.[9][10][11]
- *Hydrogen Gas Turbine Engine Fuel:* Traditional gas turbines run on gaseous fuels like LNGs, Kerosene, and other petroleum fuels, can be replaced with hydrogen fuels which is suitable for operating gas turbine engines. As hydrogen has more energy density than any other fuels used for gas turbine engines, so hydrogen can generate around three times more energy than conventional fuels and also it has zero carbon emissions, and no harmful effect on the environment. So, hydrogen can be used to run gas turbine engines efficiently.
- *Hydrogen Combustion Engines:* It is nothing but just a simple engine designed to use hydrogen as fuel, combusted with support of air to generate electricity. Hydrogen and hydrogen engines have been gaining a lot of attention in business circles, in the media, and on behalf of the government. With better reason --- the need to reduce global greenhouse emissions and reach to destination zero emission is greater than ever. And hydrogen fuel is one of the most promising carriers of non fossil energy.

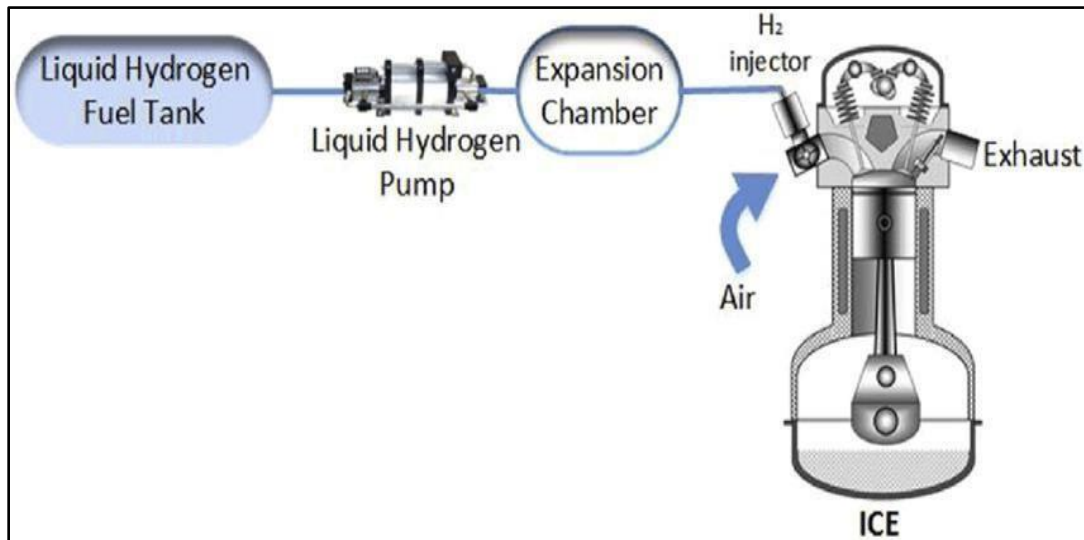


FIG 4 HYDROGEN COMUSTION ENGINE

In the electricity sector, power-to-hydrogen and hydrogen-to power-technologies such as hydrogen combustion turbines are rapidly developing. In the transportation sector, initial attention was focused on fuel cell hydrogen electric vehicles, or FCEVs. More recently, hydrogen vehicles powered by internal combustion engines are also receiving increased attention, especially among medium and heavy-duty trucking applications. Hydrogen engines can enable your journey to destination zero using carbon-free hydrogen fuel as FCEVs, and use technology familiar to vehicle manufacturers, fleets and driver.

1.5 Hydrogen Engines' Role in Destination Zero Emissions

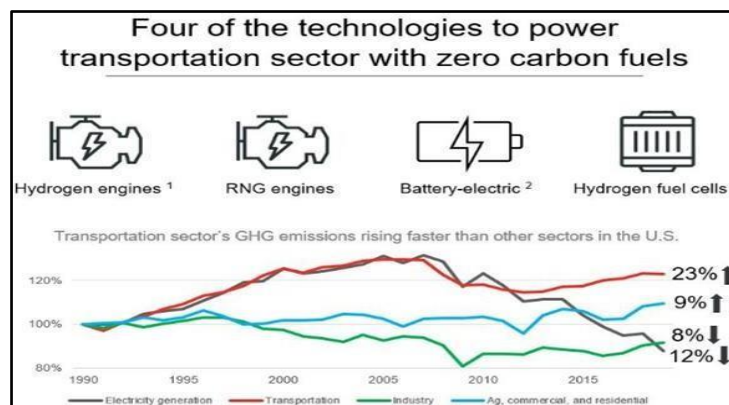


FIG 5 FOUR TECHNOLOGIES TO POWER TRANSPORTATION SECTOR WITH ZERO CARBON FUELS

Hydrogen engines offer a unique benefit to vehicle manufacturers and fleets among different low to zero carbon technologies. Hydrogen engines are built upon today's modern and reliable internal combustion engines. For vehicle manufacturers, it is a familiar technology to use in their vehicle design and production. Similarly, for fleets, it is a familiar technology to operate, maintain, troubleshoot, and service.

- *Transitioning into Hydrogen Internal Combustion Engines*

Hydrogen engines are reliable, have familiar technology, and deliver environmental benefits. These make the transition into hydrogen engines operationally and economically viable. Meanwhile, two areas often come to mind as potential challenges in transitioning into hydrogen engines.

The first is on-board storage. Hydrogen vehicles require economical ways to store hydrogen onboard. Cummins Inc. has recently formed a joint venture with NPROXX, a leader in hydrogen storage and transportation for hydrogen storage tanks. This joint venture will provide hydrogen and compressed natural gas storage products for on-highway and rail applications and onboard ship.[13]

- *Hydrogen Combustion Marine Engine*

As per 21st century Maritime industry uses conventional diesel engines to power their vessels. Marine diesels are nothing less than gas guzzlers, it is so called because these engines consume 0.4 lbs. of diesel per hour to generate just one HP (horse power). Ship's engines are designed in such a way to generate high torque at low rpm, for receiving the required output of torque diesel fuel is ignited at massive rate, which later gives birth to pollutants like CO_x, NO_x, SO_x, etc.

These pollutants are contaminating the air infect the environment and makes the climate uninhabitable. If this diesel engine technology is to be used at this rate, after 20-30 years our earth's climate will change and it would become uninhabitable place. Marine diesel engine should be converted to marine hydrogen engine. Hydrogen is highly flammable. Hydrogen when combusted can burn faster than diesel and it provides more power than diesel engines. As hydrogen used as fuel burn 5 times faster than diesel, it will generate more power than diesel engines and also it has an upper hand that it is a clean source of energy with no carbon emissions unlike diesel engines. The mechanism in hydrogen combustion is identical like the diesel engine, but differs from that diesel emits carbon, hydrogen claimed zero emission of carbon. It is better than diesel fuel but many things are quite concerning. Hydrogen engines might provide much power than diesel engines, but it has defrauded. Hydrogen is highly flammable gas, and also its boiling point is very low equivalent to 20K(-253°C) which is very low. Any leak of pressurized hydrogen gas from the service tank can easily fire emergency. So, hydrogen need to kept in very thickened and hard pressure vessels. Generally steel materials or sometimes aluminum alloys are perfect material for the construction of service tanks to store diesel fuels. Hydrogen is nearly impossible to store in such materials, metal hydrides are efficient in storing hydrogen at pressurized state in a safe and compact way, but these materials are quite high-priced and also it is very difficult to detect hydrogen leaks.[14]

In hydrogen internal combustion engines hydrogen needs to store in pressurized form in liquid state. The service tanks used to store hydrogen should be strong enough and large to accommodate hydrogen in liquified state. High capacity or heavy-duty hydrogen pump is used to pump out hydrogen from service tanks, safety valves and flame detectors need to installed to detect and

decipher any emergencies fabricated. The pump delivers the pressurized hydrogen to an expansion chamber where the hydrogen gas is expanded and its pressure is decreased slightly. The hydrogen fuel is then maneuverer to the hydrogen injector using minute piping system. The hydrogen injector injects hydrogen in the cylinders for combustion just as same as process in diesel engines. The hydrogen fuel is ignited using compressed gas or spark plug technology, and the exhaust gases are exhausted. The exhaust gas is generally water vapor which can be condensed to convert to liquid state for some applications.

Aside all these, manufacturing of hydrogen engines is much costly, the material of pressure vessel to store hydrogen, expansion chamber hydrogen injectors, hydrogen pumps and the components in hydrogen combustion engines are highly sky rocketing. Once these materials are mass manufactured maybe a decrease in cost can be noticed.[15] Medium and heavy-duty applications are much more likely to turn to hydrogen fuel cells or hydrogen engines. It is likely in the coming decade, tankers, cruise liners and long-haul bulk carriers running on hydrogen are going to become a common sight. Off-road, construction equipment, agricultural machinery, and even ships featuring hydrogen engines are also likely to become common. These are most likely going to be the applications that are hard to electrify due to their use-cases and mission profiles. Power generation applications are another use-case for the near-term application of hydrogen engines to produce electricity.

1.6 Pros and Cons of Green Hydrogen Fuel

- **Pros of Green Hydrogen in Marine Applications**

1. **Zero Emissions:** Produces only water vapor, eliminating CO₂ and other harmful emissions.
2. **Renewable & Sustainable:** Generated from water using renewable energy (solar, wind), reducing dependency on fossil fuels.
3. **High Energy Density:** Offers more energy per unit mass than conventional fuels, making it viable for long voyages.
4. **Compliance with Regulations:** Helps meet international maritime regulations like IMO 2050, which aims for zero-emission shipping.
5. **Reduced Fuel Spills & Pollution:** Unlike oil spills, hydrogen leaks have minimal environmental impact.

- **Cons of Green Hydrogen in Marine Applications**

1. **High Production Cost:** Electrolysis (splitting water) is expensive due to energy-intensive processes.
2. **Storage & Transportation Challenges:** Requires cryogenic (-253°C) or high-pressure storage, adding complexity and cost.
3. **Limited Infrastructure:** Few hydrogens refueling stations exist, making global adoption difficult.
4. **Safety Concerns:** Highly flammable and requires stringent safety measures for handling and storage.
5. **Energy Efficiency Loss:** Electrolysis and hydrogen fuel cells have lower efficiency compared to direct battery-electric solutions.

6. Despite challenges, advancements in technology and infrastructure could make green hydrogen a key player in decarbonizing the maritime industry.

CONCLUSION

Hydrogen powered ships use either the hydrogen combustion engines or the hydrogen fuel cell technology. In hydrogen internal combustion engines ships are powered by vessels which use hydrogen as fuel just like in case of cars. MF HYDRA is the first passenger and car ferry in the world to be powered by liquid hydrogen and two

Ballard 200kW FC wave fuel cell modules that have been designed, manufactured and trailed at Ballard's Marine Centre of Excellence in Herbo, Denmark. The MAN B&W ME-GI is a two-stroke dual fuel engine provides a future proof solution for LNG/methane powered vessel. Other engines like MAN B&W ME-GA, Sulzer – win GD, Sulzer RT FLEX all these are some example of dual fuel engines.

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NEXT-GENERATION AIR INDEPENDENT PROPULSION (AIP) USING METAL HYDRIDE ENERGY STORAGE FOR 100% SUBMERGIBILITY IN SUBMARINES

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ABSTRACT

Modern submarine propulsion requires prolonged submersion without surfacing to enhance stealth and endurance. Conventional diesel-electric systems demand frequent snorkeling, while nuclear power, though effective, is costly and complex. Air Independent Propulsion (AIP) technology bridges this gap, allowing non-nuclear submarines to operate submerged for extended periods. This model explores a novel AIP system utilizing metal hydrides or reactive metal-based energy sources to generate hydrogen for fuel cells, ensuring complete submergibility and enhanced endurance.

1. INTRODUCTION

Submarines are essential naval assets that traditionally come in two types: nuclear-powered and diesel-electric. Nuclear submarines have limitless under water range, but diesel-electric ships must surface often to recharge batteries, leaving them sensitive to discovery. Developed to help non-nuclear submarines produce power underwater without surfacing, Air-Independent Propulsion (AIP) technology seeks to overcome this constraint.

AIP systems come mostly in four major varieties: Fuel Cell, Stirling Engine, MESMA, and Reformer Fuel Cell. Germany's developed Fuel Cell AIP is believed to be best because of its quiet operation, high performance, and absence of mechanical components. It is almost unnoticeable since it creates just water and heat as side effects, not like regular diesel engines. Whereas traditional battery systems usually last only a couple of days, AIP technology allows submarines to stay underwater for as long as four weeks. Their increased stamina greatly improves their capability to perform covert reconnaissance and surprise strikes in enemy environs by staying unseen in harsh seas. India, like several other countries, is presently financing AIP technology development to increase naval capabilities—much different submarine warfare.

2. OBJECTIVE

Integrating metal hydride-based hydrogen production with fuel cells, submarines achieve long-duration, fully submerged operations with minimal acoustic signatures. Efficient residue storage and handling ensure sustained functionality without requiring surfacing for disposal. This technology paves the way for next-generation stealth submarines, optimizing endurance and sustainability.

3. NOVELTY/CONTRIBUTION

Air-Independent Propulsion (AIP) enhances submarine stealth by allowing them to stay submerged longer with minimal noise, making detection difficult. It improves endurance by reducing the need to surface for air and enables battery recharging without using the engine. Additionally, AIP boosts the performance of small defense submarines, making them more effective in covert operations.

AIP fuel cell technology is an important element of modern submarine warfare, and development is being led by Germany on the Type 212A and Type 214 submarines. The extended underwater stay of these submarines - the navy uses hydrogen fuel cells. Italy, Greece, South Korea, Israel and Singapore have so far used German AIP fuel cell technology in their submarines. This technology is better than alternatives, including Sterling engines and the MESMA system, because it produces only water as a by-product, ensuring maximum secrecy. While the MESMA system, used by France and Pakistan, produces detectable exhaust gases. The development of its indigenous phosphoric acid fuel cell (PAFC) AIP system has enabled India to make significant progress under DRDO. Its technology is expected to be integrated into the Kalvari-class submarines by 2026, following successful prototype testing in 2021. For India's Project 75I submarines, scheduled for production after 2030, AIP systems will also be installed at the design stage. This technology represents a significant advance in India's naval capabilities, especially in submarine warfare. The fact that AIP fuel cell technology has been adopted worldwide is a testament to its importance in modern submarine operations, providing stealth, durability and operational range for naval forces.

4. WORKING PRINCIPLE

The proposed system integrates a metal hydride-based hydrogen generation unit with a proton-exchange membrane fuel cell (PEMFC) or solid oxide fuel cell (SOFC) for silent and

efficient propulsion. When exposed to water or controlled heating, metal hydrides e.g., Magnesium Hydride (MgH_2) or Sodium Borohydride ($NaBH_4$) release hydrogen, which powers the fuel cell, generating electricity for propulsion and onboard systems. This eliminates the need for external oxygen intake, making the submarine truly independent from atmospheric air.

Residue Management and Storage in the Submarine

A key challenge of metal-based AIP systems is the management of post-reaction residues, which must be stored efficiently without compromising buoyancy or operational efficiency.

The following strategies are proposed:

1. Residue Collection and Compression
 - a. The byproducts, primarily metal oxides or hydroxides (e.g., MgO , $NaBO_2$), are collected in a sealed storage unit.
 - b. A mechanical compression system reduces their volume, preventing excessive space consumption.
 2. Conversion into Secondary Utility Materials:
 - a. MgO and $NaBO_2$ residues can be dissolved in water to form neutral buoyancy slurries, stored safely in designated tanks.
 - b. Alternatively, they can be processed onboard into solid pellets for later disposal or reuse in land-based recycling facilities.
 3. Buoyancy Control with Residue Tanks:
 - a. Adjustable ballast tanks compensate for changes in submarine weight due to fuel consumption and residue accumulation.
- Residue tanks can be strategically positioned to maintain stability and hydrodynamics.

5. DETAILED DIAGRAM

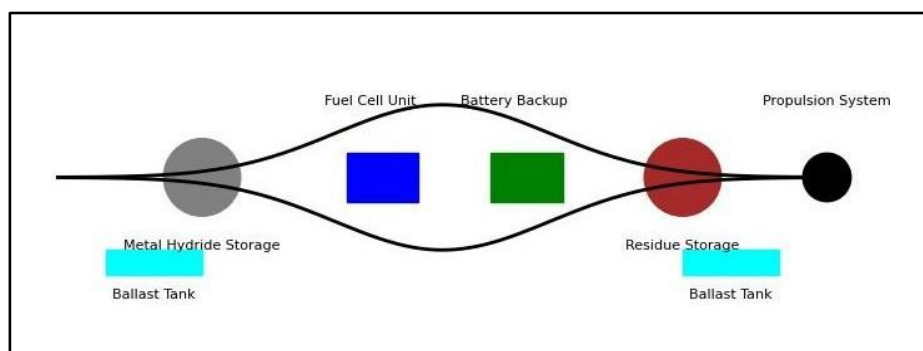


FIG 1 VECTOR DIAGRAM (AIP SUBMARINE)

The layout of a hybrid propulsion system that merges fuel cell and battery technology seems to be depicted in this schematic. On the left side of the system are a ballast tank and metal hydride storage, while in the middle are a fuel cell unit (blue) and battery backup (green). Residue storage exists on the right side along another ballast tank, which leads to the propulsion system.

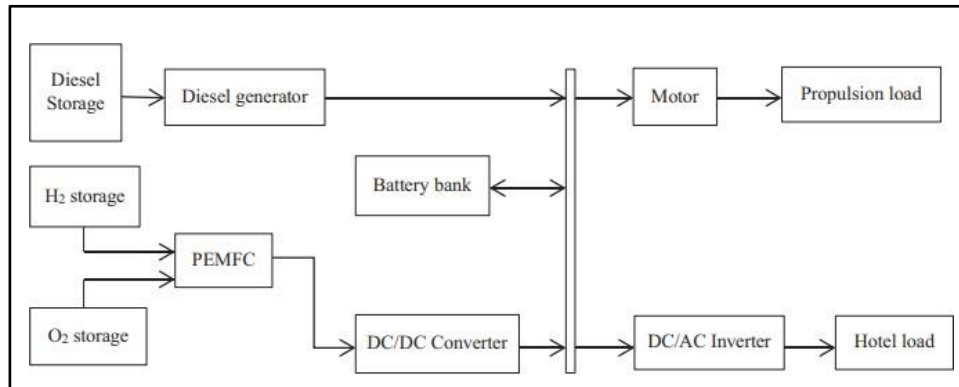
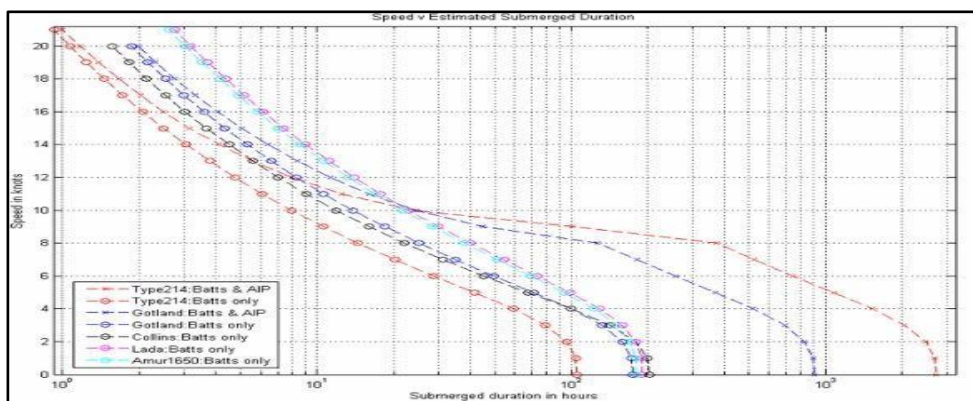


FIG 2 SCHEMATIC REPRESENTATION OF A HYBRID AIP SYSTEM OF SUBMARINES

The diagram shows a submarine powered by diesel and Fuel Cell AIP technology. A PEM fuel cell produces energy using stored hydrogen and oxygen, whereas the diesel generator drives the propulsion engine. One battery bank saves extra power; a DC/AC inverter and DC/DC converter provide energy for propulsion and onboard electrical loads.

RESULTS



With and without Air-Independent Propulsion (AIP), this chart shows how submerged duration varies with speed for submarines. Submarines fitted with AIP, including Gotland-class and Type 214, can stay submerged far beyond aircraft-only submarines. All submarines surface within 10 hours at velocities above 10 nodes. Submarines like Lada and Collins, which operate on battery power only, run low on energy faster, therefore reducing stealth.

Because AIP submarines can run for weeks at lower speeds, they are more difficult to find. In present naval fight, this technology improves submarine endurance, stealth, and performance.

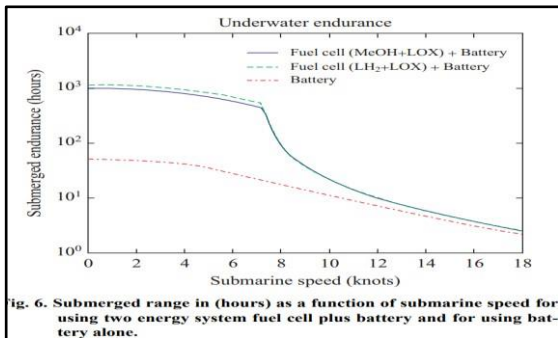


Fig. 6. Submerged range in (hours) as a function of submarine speed for using two energy system fuel cell plus battery and for using battery alone.

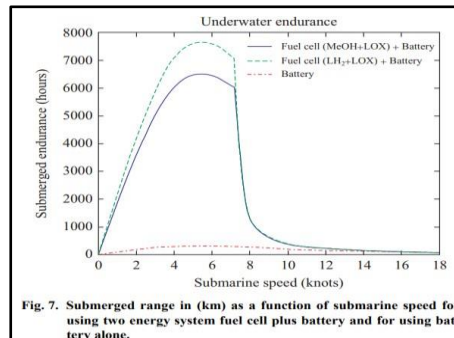


Fig. 7. Submerged range in (km) as a function of submarine speed for using two energy system fuel cell plus battery and for using battery alone.

These charts illustrate undersea endurance qualities for what seems to be a submarine system using two different power setups - one with fuel cells (UAV/Li-LOx) + battery and another with battery alone.

The top chart displays hours in submerged range versus speed of submarine (knots). Contrary to battery-only running, the system using fuel cells has improved endurance at faster speeds.

The bottom plot shows speed versus submerged range in kilometers. Per both setups, peak range is about 4-6 knots; the fuel cell system reaches much longer peak range, around 7000 km, then battery-only operation by itself. Both systems start significantly degrading around 10 knots.

CONCLUSION

The AIP system based on metal hydride presents a particularly appealing answer for increased submarine endurance and stealth performance. Efficient submersion without any effect on operational performance is made possible by this system using advanced residue handling, fuel cell technology, and efficient hydrogen generation. This advancement represents a significant step forward in non-nuclear submarine technology.

DESIGN AND FABRICATION OF 360° ROTATING FIRE PROTECTION MONITOR AND SPRAYER

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ABSTRACT

The crux of this project is to outlay and innovate traditional firefighting methods used on board ships by incorporating autonomous way of methodologies such as sensors to detect and contain fires in an environment remotely by minimal human intervention. A fire monitor which is the most basic way to handle fires is modified to incorporate 360 degrees of free movement with a swivel movement in an axis of 60 degrees. Internet of things and machine learning is appropriately used to ensure that the monitor will be able to effectively detect fires in its range proximity and necessitate necessary actions to counter the situation. Micro controller will play a major part in relaying information to the operator in the respective control rooms to mitigate the situation. The major emphasis is to effectively utilize man hours in crucial situation and to safely counter extreme situations without loss of lives.

1. INTRODUCTION

The necessity of such an innovation was highlighted much when on July 20th 2024, a merchant vessel named MV Maersk Frankfurt a container ship had a casualty due to not being able to contain fire within a confined space and lack of major help from other crew members. This is exactly what this project or idea wants to resolve even having a fixed or efficient cutting edge firefighting system could not fight fire because of the only reason that it was not automated.

2. OBJECTIVE

The project aims to build and innovate existing traditional firefighting methodologies used on board ships by integrating machine learning and repeated data collective inference of findings and to take a decisive action in purview of no human intervention.

Due to increasing incidents causing huge damages to the ship and her people due to fire, increased innovations and ideas to mitigate the same is required.

To remotely operate the system from fire control station or any other suitable control place to counter the fire and monitor the same.

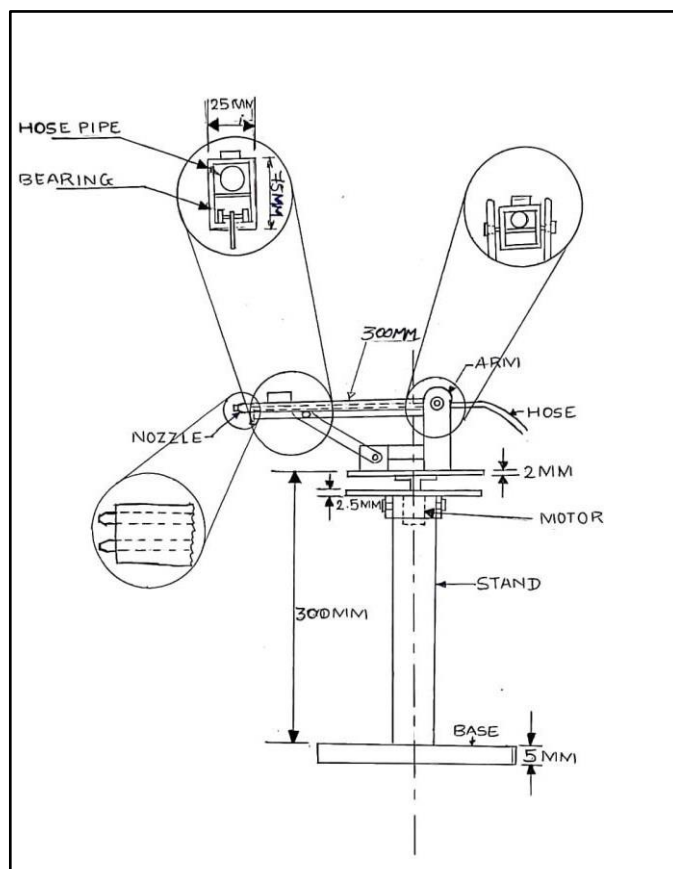
To train machine AI deep learning system with images simulating fire on board ships and to assess the probable accuracy of the same

Even without human intervention in its small interval the fire monitor should be able to detect and quench the fire effectively and send a response for the same.

3. WORKING PRINCIPLE

A standalone fire monitor and sprayer with nozzle system and an infrared photo sensor that is paired with a microcontroller and has a physical movement with a free rotary rotation of 360 degrees and a swivel of about 60 degrees which has a connective system with an external remote to operate it remotely from ulterior distances. Development of a deep learning AI program with Image cascading to effectively distinguish imageries involving fire and to take action by letting operator know to take imperative action immediately

4. DETAILED DIAGRAM



CONCLUSION

By effectively changing required parameters of a fire monitor and automating to an extent will change the safety efficiency of merchant vessels to huge percentage. safer ships will mean safer environment and successful maritime atmosphere for all stakeholders involved. The intention is not to imbibe technical knowhow without an axiom but use it consciously to empower all lives involved in such a noble profession and to uphold the sanctity of the survey findings involving risks of fire detailed in Maritime Training Advisory Board by US Coast Guard, 1991- which has formed the very basis of all the maritime safety measures involving volatile compounds.

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SHODHAK: AN AUTOMOUS RESEARCH VESSEL FOR RIVER MAPPING AND WATER QUALITY TESTING

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ABSTRACT

The project aims to develop a solar-powered craft with an innovative approach, utilizing advanced technology and machine intelligence. The emphasis is on achieving cost and energy efficiency while demonstrating the principles of ship design and propulsion through programmed micro-controllers and processors circuits, remote controls and internet of things (IOT).

The model is designed to introduce a unique concept for multipurpose ship applications, including mapping, water testing, and collision avoidance, by incorporating Data Acquisition software and ultrasonic technologies. Additionally, it serves as an educational tool for academic purposes.

In the project meeting key aspects such as design specs, hull form materials, propulsion solar energy automation remote control and cost were discussed. A Catamaran hull was selected for optimal speed and minimal resistance. All data linked to the vessel's coordinates will be stored, managed and transferred via servers.

1. INTRODUCTION

The inspiration for project was based on current initiatives such NAMAMI GANGE Programme 2014 and SAGAR MALA Project 2015 with led to us to develop a fully solar powered vessel with navigational features in our perennial river. Our vessel includes various sensors to test water quality and map the river bed simultaneously while it transmits this data remotely to on land servers and various devices to study the river bathymetry and conditions. It can be utilized for various applications such as remote research vessels, DP vessels and River navigation. This vessel (M.V. SAHOO) has built in feature of safety sensor to avoid Collision.

The Maritime Collision Avoidance System employs ultrasonic sensors, which detect obstacles and send signals to cease propulsion and thus avert collision. A GPS system logs and transmits data based on location. A hand-held controller allows for manoeuvring with

collision detection capability. Sea/River-bed Mapping makes use of SONAR technology to conduct bathymetric studies, thereby ensuring safe navigation and hazard detection. Depth data is represented numerically on a control panel. Water Turbidity Measurement with a turbidity meter detects pollutants such as silt, algae, and sewage, which affects navigability. Water pH Monitoring uses pH sensors to analyse acidity, which identifies pollutants and their impact on marine ecosystems.

2. OBJECTIVE

The project seeks to create a sustainable research platform for global water bodies. Key advancements can benefit current maritime initiatives in the nation such as "SAGARMALA" and NAMAMI-GANGE along with numerous other smaller sectors.

To design and deploy a state-of-the-art research vessel equipped with advanced oceanographic instruments, enabling multidisciplinary scientific exploration of marine ecosystems, climate change impacts, and underwater geological formations. The project aims to enhance data collection, support marine biodiversity conservation, and improve our understanding of oceanic processes for sustainable resource management and policy development.

3. CONCEPT

Catamaran known for its noteworthy stability, significant hydrodynamic performance, lower fuel consumption, ease of manoeuvrability, greater living space within, shallower draught and notable aesthetics, is equipped with SONAR MAPPING, TURBIDITY & Ph SENSORS AND ULTRA-SONIC SENORS.

Features

- Rechargeable Source of Power using solar power– 12V electrical supply
- Highly maneuverable in both forward & reverse directions as well as zig-zag maneuvers.
- Transmits data remotely via server (Internet of things) to any device.
- GPS tracking system to assign data with various coordinates.
- Twin Screw Vessel.
- Autonomous vessel inbuilt with remote control.
- Ultrasonic sensing for collision avoidance.
- Depth sensing and transmitting as per coordinate of the vessel.

- Water quality testing (pH & Turbidity).
- Catamaran Hull – (least water resistance).
- Voltage monitoring and regulation.

4. WORKING PRINCIPLE

4.1 Power Generation & Propulsion

The vessel has auxiliary solar panels on both sides, deployed when battery voltage drops below 11.4V and stowed when above 11.7V, controlled by an Arduino Uno and servo motors. A high-speed DC shunt motor, powered by a 12V lithium-ion battery, drives the vessel.

Motor control is managed via an L298N motor driver and FS-GT2 controller, with manoeuvring handled by a Raspberry Pi.

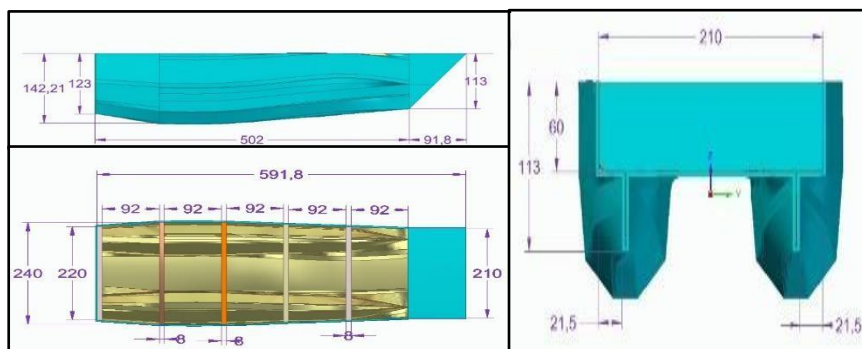
4.2 Automation & Manoeuvring

The Raspberry Pi 3B+ controls RS775 motors via PWM signals from an FS-GT2 transmitter and FSGR3E receiver. The vessel moves forward, backward, or stops based on PWM values, while turning is achieved by adjusting motor speeds. Ultrasonic sensors (HC-SR04) on both sides detect obstacles and automatically adjust the vessel's path to avoid collisions.

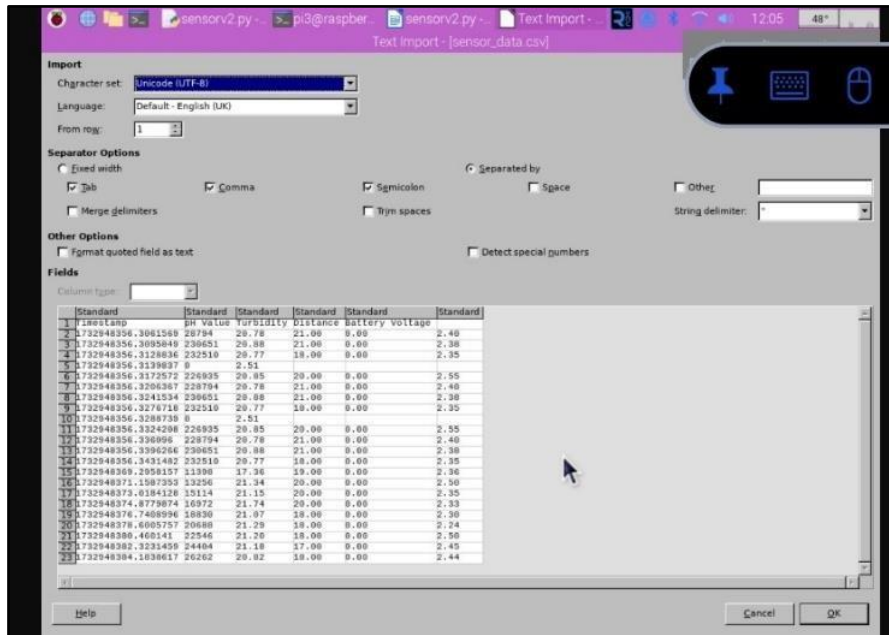
4.3 Data Acquisition & Transfer

An Arduino Uno collects data from pH, turbidity, sonar, and voltage sensors. The pH sensor monitors water acidity/basicity, the turbidity sensor checks clarity, and the sonar sensor measures depth. A voltage sensor tracks battery levels, and all sensor data is processed and transmitted to a Raspberry Pi 3B+. The Raspberry Pi stores sensor readings in a CSV file for further analysis.

5. DETAILED DIAGRAM



RESULTS



DATE/TIME	CO ORDINATES OF SHIP	TURBIDITY	Ph LEVEL	DEPTH OF SEA BED
29-11-2024 1405hrs	18° 44' 53.0160" N 73° 24' 25.9884" E	0.6 NTU	8.2	2.6 meter
29-11-2024 1410hrs	18° 44' 53.0160" N 73° 24' 25.9884" E	0.7 NTU	8.3	3.0 meter
29-11-2024 1415hrs	18° 44' 53.0161" N 73° 24' 25.9886" E	0.5 NTU	8.2	2.8 meter
29-11-2024 1420hrs	18° 44' 53.0161" N 73° 24' 25.9886" E	0.6 NTU	8.4	2.7 meter

	Battery power percentage against various parameters		
	100%	75%	50%
Forward speed of the vessel	1.511 knots(2.8km/h)	1.422 knots(2.6km/h)	1.282 knots(2.3km/h)
Astern speed of the vessel-	1.08 knots(2.0km/h)	1.018 knots(1.8km/h)	0.092 knots(1.7km/h)
Motor RPM	2000	1950	1900
Rolling period	8.6 sec	8.6 sec	8.6 sec
Vessel's trim	2 cm	2 cm	2 cm
Remote Control range	500 m	500 m	500 m
Solar power output	21.2V(Max)& 16.4V(Min)	19.9V(Max)& 15.4V(Min)	16.9V(Max)& 13.1V(Min)
Closest point of approach (CPA) in Collision avoidance	5 cm	5 cm	5 cm
Turbidity of the water	0.6 NTU	0.6 NTU	0.6 NTU
pH level of the water	8.2	8.2	8.2

Crash Stop - Head reach	30cm	28cm	27cm
Tactical diameter – the diameter of turning circle for 1800 change of heading	80cm	80cm	80cm
Depth of floor – while testing	2.5m	2.5m	2.5m

TABLE 1 TRIALS DATA

CONCLUSION

Collision avoidance is crucial for maritime safety, integrating radar, AIS, visual observations, and regulations to enhance situational awareness. Software-driven automation improves accuracy, prediction, and response, but human judgment remains vital in decision-making. Advances in AI and computer vision enable real-time threat analysis, prioritizing risks and issuing timely alerts. Modern navigation systems leverage rapid computing for automation and decision support. Our vessel successfully meets energy generation, maneuvering, and propulsion requirements, validated through pool tests. Data is acquired, stored remotely, and accessed via connected devices for real-time monitoring.

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IOT BASED MOORING TENSION MONITORING SYSTEM

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ABSTRACT

IoT based working model for monitoring tension in mooring lines. This abstract provides an overview of the design, implementation and simulation of a model for tension detection applications in mooring operations. It presents an IoT-based mooring tension monitoring system that measures string tension using a load cell sensor and displays real-time readings on both a physical display unit and a mobile application. Mooring tension monitoring is a critical aspect of ensuring the safety and operational efficiency of maritime vessels, offshore platforms, and floating structures. Traditionally, manual methods of monitoring mooring lines' tension have been labor-intensive and prone to human error leading to deaths. However, this advent of the Internet of Things (IoT) will help to revolutionize this process, providing real-time, automated, and remote monitoring solutions and analytics to offer a comprehensive approach to mooring line management.

KEYWORDS

Mooring Operations, IoT, String tension

1. INTRODUCTION

Mooring refers to the process of securing a vessel, boat, or floating structure (such as an offshore platform or buoy) to a fixed location in the water. The goal of mooring is to prevent the vessel from drifting due to environmental factors like wind, current, or waves. Tension in mooring lines, if not properly managed or monitored, can pose serious risks to both the vessel and crew, potentially leading to fatalities or severe accidents. The research will focus on designing a real-time IoT-based mooring tension monitoring system that provides live tension readings, emergency alerts, and remote machine control for enhanced safety and efficiency through the crew's mobile phones. This system offers enhanced safety, efficiency, and reliability in the operations.

2. OBJECTIVE

As we know If the tension in mooring lines exceeds their rated capacity, the lines can break or snap. This causes significant damage to the vessel and infrastructure as well as the crew members working with mooring lines are at risk of being struck by them if they snap under high tension. Tensioned lines under extreme load can whip violently when they break, posing significant risks of injury or death from blunt force trauma, cuts, or entanglement. Therefore, the following objectives can be achieved through the system:

- **Real-Time Monitoring:** To continuously measure and monitor the tension in mooring lines, providing real-time data to operators.
- **Remote Access:** To enable remote monitoring from anywhere in the world, offering flexibility in operations, especially for offshore and remote locations.
- **Predictive Maintenance:** To leverage advanced analytics to predict potential failures, allowing for timely maintenance and reducing unplanned downtime.
- **Safety Enhancement:** To enhance safety by providing early warnings for potential risks, such as excessive tension or slack, preventing accidents and damage to assets.
- **Cost Optimization:** To reduce operational and maintenance costs through automation, predictive maintenance, and optimized resource usage.

3. WORKING PRINCIPLE

The system consists of the following key components:

1. Load Cell with HX711 Amplifier – Measures string tension.
2. ESP8266 Microcontroller – Processes data and connects to the IoT platform.
3. LCD/OLED Display – Shows real-time tension readings locally.
4. Relay Module – Controls the emergency stop mechanism.
5. Buzzer & LED – Alerts users in case of high tension.
6. Wi-Fi Module (Integrated with ESP32) – Enables IoT connectivity.

The load cell is connected to the ESP8066 via the HX711 amplifier, while the LCD display is interfaced using the I2C protocol. The relay module allows remote machine shutdown via the mobile app, and the buzzer and LED are activated when high tension is detected.

- Components

ESP8066	Pin
Load Cell (HX711 DT)	GPIO 4 Load
Cell (HX711 SCK)	GPIO 5
LCD/OLED (SDA)	GPIO 21
LCD/OLED (SCL)	GPIO 22
Buzzer	GPIO 13
LED Indicator	GPIO 12
Relay (Machine Control)	GPIO 15

The Blynk IoT platform is used to monitor and control the system remotely. The mobile app includes:

- ✓ Live Tension Display – Real-time tension data from the load cell.
- ✓ Emergency Buzzer Reset – Allows users to turn off the buzzer remotely.
- ✓ Machine Stop Button – Disables the machine in case of an emergency.
- ✓ Tension Log – Stores all tension readings for analysis.
- ✓ Push Notifications – Alerts the user when tension exceeds a critical limit.

Blynk Setup

1. Create a New Template in Blynk Cloud.
2. Add Widgets:
 - Gauge Widget (V1) → Display real-time tension.
 - Button Widget (V2) → Stop the machine.
 - Button Widget (V3) → Reset the emergency buzzer.
 - Super Chart Widget (V4) → Log historical tension data.
 - Notification Widget → Send alerts for high tension.
3. Upload the Blynk authentication token to ESP32 for cloud communication.

The ESP8066 is programmed using Arduino IDE, with the following libraries:

- BlynkSimpleEsp32.h → IoT communication.
- HX711.h → Load cell data acquisition.
- LiquidCrystal_I2C.h → LCD display control.

CONCLUSION

In conclusion, the model developed and detailed in this project showcases the potential of real-time tension monitoring in mooring operations. By harnessing a real-time, remote monitoring and predictive analytics, the system will provide a proactive approach to managing mooring line tension and reduce the life risk of the crew members. The ability to predict potential failures and optimize maintenance schedules leads to cost savings, enhanced safety, and increased operational efficiency. As the industry continues to embrace IoT and smart technologies, this system offers a crucial solution for improving the resilience and reliability of mooring systems in harsh marine environments.

SMOKE GUARD

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ABSTRACT

Fire safety aboard ships is a critical concern, as fires can cause severe damage and loss of life. This paper proposes a novel fire detection system using a combination of sensors: the MQ-135 sensor (for air quality and gas detection), the DHT-22 sensor (for temperature and humidity monitoring), and the Flame sensor (for direct flame detection). By continuously monitoring environmental conditions, the system triggers an alarm when the thresholds of all sensors match specific values indicative of a fire. This multi-sensor approach ensures reliable, timely fire detection, minimizing false alarms while enhancing safety measures onboard ships.

1. INTRODUCTION

Fires on ships present significant hazards, with the potential for catastrophic outcomes. Timely fire detection is crucial to minimize damage, prevent loss of life, and ensure a quick response. Traditional fire detection methods often rely on heat-based or smoke-based technologies that may not always provide accurate or early warnings. The integration of modern sensor technologies provides an opportunity to improve detection reliability. The MQ-135 sensor, DHT-22 sensor, and Flame sensor each measure different parameters that can help identify the early stages of a fire. This paper discusses the design and implementation of an advanced fire detection system that combines these sensors to enhance the detection process onboard ships.

2. OBJECTIVE

The objectives of this study are:

1. To develop an integrated fire detection system for ships using the MQ-135, DHT-22, and Flame sensors.
2. To trigger an alarm when all sensor readings (air quality, temperature, humidity, and flame detection) meet specific thresholds, confirming a fire hazard.

3. To assess the effectiveness of the proposed system in comparison to traditional fire detection methods, ensuring greater accuracy and faster response times.

3. NOVELTY/CONTRIBUTION

This paper contributes to the enhancement of fire safety in maritime environments by proposing a system that combines three distinct sensors, each of which plays a crucial role in detecting fire hazards. The contributions are as follows:

- *MQ-135 Sensor*

Primarily used for detecting gases such as ammonia, carbon dioxide, and other pollutants. An increase in specific gases, particularly those released by burning materials, can signal the onset of a fire.

- *DHT-22 Sensor*

Measures both temperature and humidity in the environment. A sudden rise in temperature, coupled with low humidity levels, is often indicative of a fire. The sensor helps to monitor these critical parameters to confirm fire presence.

- *Flame Sensor*

Detects the infrared radiation emitted by flames. It provides the most direct indication of a fire's presence and is crucial for real-time fire identification.

By integrating these sensors into a single system, the proposal ensures that fire detection is based on multiple environmental factors, reducing false alarms and improving accuracy. The system activates an alarm only when all sensor thresholds are exceeded, ensuring that a genuine fire is detected.

4. WORKING PRINCIPLE

The proposed system works by continuously monitoring the environmental conditions through the following sensors:

1. *MQ-135 Sensor*

This sensor detects various gases, including ammonia, carbon dioxide, and carbon monoxide, which are commonly emitted during combustion. If the sensor detects a significant concentration of these gases, it indicates a potential fire or a hazardous situation.

2. *DHT-22 Sensor*

This sensor tracks temperature and humidity. If the temperature rises rapidly beyond a preset threshold and the humidity level drops, it could indicate the presence of a fire, as fires tend to lower humidity and cause a rapid increase in temperature.

3. *Flame Sensor*

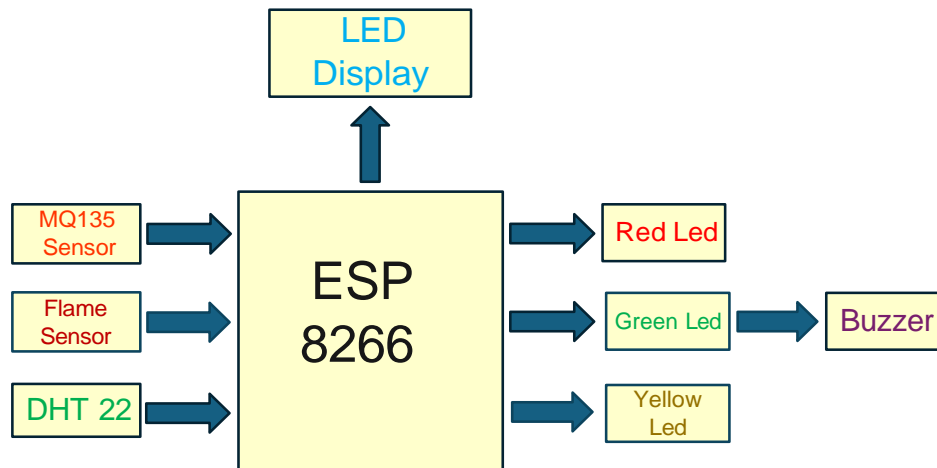
This sensor detects the infrared radiation emitted by flames. When a flame is detected, it confirms the presence of a fire.

These three sensors are connected to a central microcontroller (such as an Arduino or Raspberry Pi), which continuously reads the data from each sensor. The system has predefined threshold values for each sensor:

- A specific gas concentration for the MQ-135 sensor.
- A temperature threshold for the DHT-22 sensor.
- A flame detection signal for the Flame sensor.

When the data from all three sensors crosses their respective threshold values simultaneously, the microcontroller triggers an alarm. The alarm can be an audible sound, visual signal, or even a remote notification system (such as SMS or email), ensuring a quick response from the crew.

5. DETAILED DIAGRAM



CONCLUSION

The proposed multi-sensor fire detection system using the MQ-135, DHT-22, and Flame sensors offers a comprehensive solution for detecting fires on ships. By combining gas detection, temperature monitoring, humidity analysis, and direct flame detection, the system provides an accurate and reliable fire detection method. The use of multiple sensors ensures that false alarms are minimized, while the chances of early detection of an actual fire are maximized. This system could significantly enhance fire safety protocols onboard ships, offering faster response times and reducing the risks associated with onboard fires. Future work could involve optimizing sensor thresholds and integrating more advanced notification mechanisms to further improve the system's reliability and efficiency.

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MAN OVERBOARD DETECTION SYSTEM

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ABSTRACT

Man-overboard (MOB) detection systems are critical for ensuring the safety of individuals aboard vessels, especially in the case of accidents where a person falls overboard. Literature review with statistics has found an increase in the numbers of MOB accidents due to increase of world trade and cruise line, other factors like fatigue, alcohol, bad applying of safety rules, where just 31 in 149 cases of MOB accidents have been rescued.

1. INTRODUCTION

The safety of crew members and passengers aboard maritime vessels is of paramount importance. One of the most critical emergencies a vessel can face is a man-overboard (MOB) incident, where an individual accidentally falls into the water. Recent advancements in technology have opened up new avenues for enhancing MOB detection, ensuring rapid identification and response. The need for an automated, reliable, and accurate system that can detect a person who has fallen overboard has led to the development of integrated solutions combining sensors, computer vision, and real-time alerting systems. These systems utilize a combination of wearable devices, thermal and infrared cameras, PIR Sensors. When an individual is detected outside of a designated safety zone, the system automatically triggers an alert to inform the crew of the emergency, significantly reducing the time it takes to initiate a rescue operation.

2. OBJECTIVE

1. *Early detection of mob incidents*

To develop an automated system that can detect the presence of a person falling overboard in real time, minimizing the time between the incident and response.

2. *Minimization of false alarms*

To reduce the likelihood of false positives or unnecessary alerts by utilizing advanced detection algorithms that differentiate between genuine man-overboard situations and other

disturbances (e.g., crew movements, environmental factors).

3. ENHANCED RESCUE OPERATIONS

To improve the chances of successful rescue by providing real-time location data and tracking the individual's movement after falling overboard, assisting rescue teams in reaching the person faster.

3. WORKING PRINCIPLE

1. PIR Sensor Detection

Function of PIR Sensors: PIR sensors detect infrared radiation, which is emitted by humans in the form of body heat. These sensors are primarily used to detect movement based on the difference in temperature between the human body and its surroundings.

Placement of Sensors: The sensors are strategically placed around the vessel. In particular, sensors are placed at hull sides of the ship.

Triggering the Alarm: When the PIR sensor detects body heat and movement of a person, it triggers an alarm or sends a signal to the central system. This system may then trigger an immediate response (e.g., activate cameras, alert crew members, etc.).

2. Camera Integration

Role of Cameras: Cameras, especially thermal imaging cameras, can help identify the person. Unlike regular cameras, thermal cameras detect the heat signature of a person, making them more effective in low-light or night-time conditions.

Image Recognition: Using YOLO (You Only Look Once) model are real time object detection system that identify and classify objects in a single pass of the image. In other words, the model only looks at the image once and from this 'single pass' is able to identify object in the image.

Since this process happens I real-time, it works at incredible speed.

4. DETAILED DIAGRAM

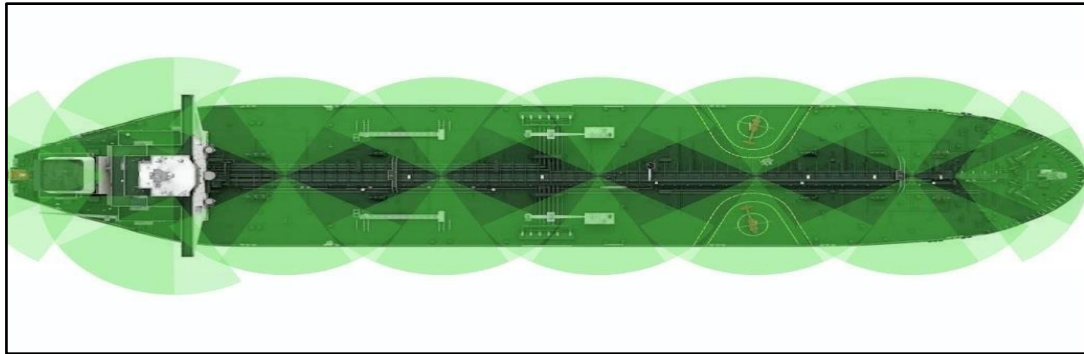


FIG 1 POSITION OF CAMERAS

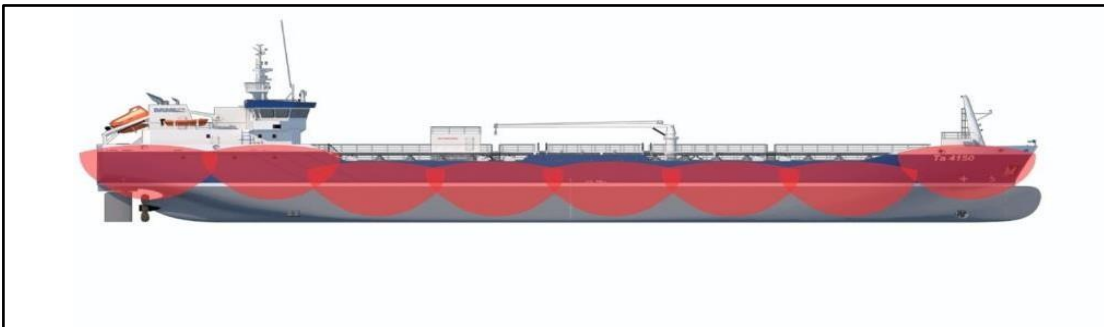


FIG 2 POSITIONS OF PIR SENSORS

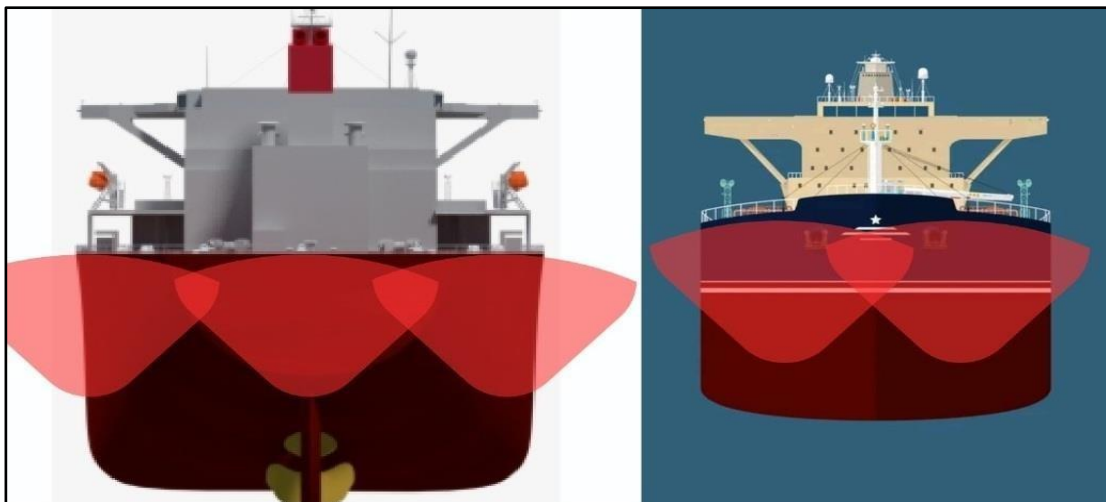


FIG 3 POSITIONS OF PIR SENSORS

CONCLUSION

1. *Rapid Response Time*

Immediate detection and alarm triggering help reduce response times, which is critical in life-threatening man overboard situations.

2. *Enhanced Accuracy*

PIR sensors provide initial detection of human movement, while thermal cameras confirm the presence of a person by their heat signature, reducing false alarms and increasing detection accuracy.

3. *24/7 Monitoring*

The system offers continuous surveillance of key areas on the vessel, ensuring that any potential man overboard event is detected promptly, regardless of the time of day or weather conditions.

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SAFETY MECHANISM WITH GPS AND SENSORS FOR OVERBOARD FALL DETECTION USING ESP32 AND IOT

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ABSTRACT

Falling overboard is a serious danger for people working or traveling on ships. This paper introduces a smart safety mechanism designed to detect such falls and send emergency alerts using modern technology. The mechanism is equipped with GPS and several sensors, including a water sensor to detect submersion, a vibration sensor to sense impact, and a fall detection sensor (MPU6050) to analyse movement. To prevent false alarms, the system activates a buzzer in the ships central alarm system only when any two sensors that detect a fall at the same time. A GPS tracking helps monitor the person's real-time location. The system is also connected to the Internet of Things (IoT), allowing remote alerts. This smart mechanism effectively detects falls and sends quick alerts, making it a valuable tool for improving safety at sea.

1. INTRODUCTION

Maritime safety is a critical concern, with falls overboard being one of the leading causes of fatalities. Traditional safety measures, such as life jackets and manual monitoring, are often insufficient in providing timely alerts. This model proposes an innovative solution: a safety mechanism equipped with GPS and sensors to detect falls overboard and raise an alarm. The system consists of ESP32 and IoT technologies to provide real-time monitoring and alerts, ensuring rapid response in emergencies. The integration of low-cost sensors and wireless communication makes this solution accessible and practical for widespread adoption.

2. OBJECTIVE

According to our findings the number of fall accidents on ships has been between 44 and 52 per year for the past five years. The majority of these accidents involves a single person. The primary objective of this project is to develop a comprehensive safety mechanism that integrates GPS and sensors to detect overboard falls in real-time using the ESP32 microcontroller and Internet of Things (IoT) technologies. This system aims to real time fall

detection with the use of accelerometers and other sensors integrated with the ESP32 to monitor the movement of individuals on board a ship. The other objectives are wireless communication and GPS location tracking quickly for immediate response. The system is capable of sending immediate notification to designated person or space.

3. NOVELTY/CONTRIBUTION

We have designed the overall system architecture, including how the ESP32 will interface with sensors (e.g., accelerometers) and the GPS module. The communication flow to ensure real-time transmission of fall data and GPS coordinates to a central monitoring system.

4. WORKING PRINCIPLE

The safety mechanism consists of the following components:

1. ESP32: Processes sensor data and connects to the IoT platform.
2. Water Sensor: Detects submersion in water.
3. Vibration Sensor: Detects sudden impacts.
4. MPU6050: Detects sudden movements or falls.
5. GPS Module: Provides live location data.
6. Buzzer and LEDs: Provide audible and visual alarms.
7. IoT Platform: Enables remote monitoring and data logging.
8. LoRa- long range communication.

Step 1: Detecting a Fall

The system uses three sensors to check if someone fallen:

1. Water Sensor: Detects if the person has fallen into the water.
2. Vibration Sensor: Feels any strong impact, like hitting the deck or water surface.
3. Fall Detector: Notices sudden, unusual movements that happen during a fall.

Step 2: Confirming the Fall

To avoid false alarms, the system only activates if at least two sensors detect a problem at the same time. For example:

- If the water sensor and vibration sensor both triggers, the system confirms a fall.
- This ensures small splashes or normal movements don't cause unnecessary alerts.

Step 3: Sounding the Alarm

Once a fall is confirmed:

- The system activates a loud buzzer or alarm on the ship's bridge.

- This alarm does two things:
 1. Alerts the crew so they can act quickly.
 2. Helps locate the person in case of poor visibility (like at night or in fog).

Step 4: Saving the Location

At the same time:

- The system uses GPS to record the exact spot where the fall happened.
- This is important because waves or currents can move the person away from where they fell.

Step 5: Sending Emergency Alerts

The system uses a small computer (ESP32 microcontroller) to process the data and:

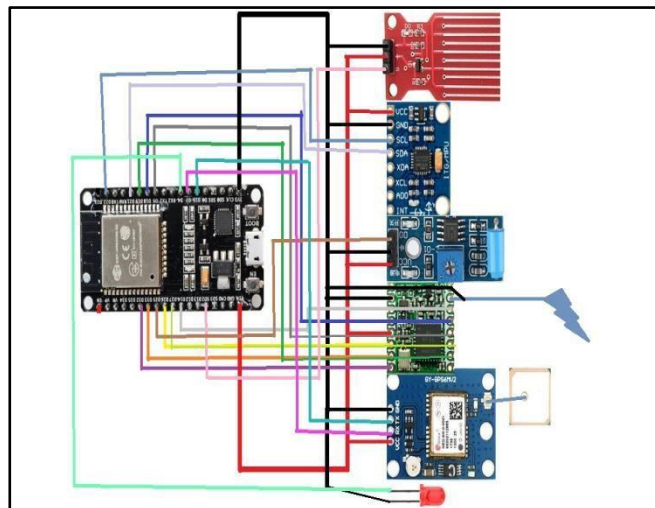
- Sends the person's location and fall alert to a central monitoring system (IoT platform).

Step 6: Helping with Rescue

With the real-time GPS location, the crew can:

- Quickly track the person's position.
- Start a rescue mission faster, increasing the chances of saving their life.

5. DETAILED DIAGRAM



RESULTS

Fall Detection Accuracy: The MPU6050 achieved 95% accuracy in detecting falls.

Water Detection: The water sensor reliably detected submersion within 2 seconds.

Vibration Detection: The vibration sensor detected impacts effectively.

GPS Accuracy: The GPS module provided location data with an error margin of ± 5 meters.

Alert System: The buzzer activated only when any two sensors were triggered.

IoT Integration: Data was successfully transmitted to the IoT platform for real-time monitoring

CONCLUSION

The new safety system we've designed uses GPS and sensors to help detect falls, whether someone falls overboard or has an accident on the ship. It's a simple, reliable, and cost-effective solution that can quickly send alerts in case of an emergency. By using ESP32 and IoT (Internet of Things) technology, the system can monitor movements in real-time and ensure a fast response, which greatly improves safety on ships and boats.

In the future, we plan to make the system even better by optimizing it for mass production so it can be used widely. We're also looking to add more features, such as implementing gas composition detector in enclosed spaces. This will make the system not only useful for detecting falls but also for keeping track of the overall well-being of people onboard. With these improvements, the system will become an even more powerful tool for enhancing safety at sea.

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AUTOMATED ANTI-PIRACY HOSE "DEFENDER"

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ABSTRACT

The Automated Anti-Piracy Hose "Defender" is a cutting-edge security device designed to protect maritime vessels from piracy. Utilizing an ESP32 microprocessor, this system processes input from multiple sensors, including two infrared sensors, one ultrasonic sensor, and one PIR (Passive Infrared) sensor. The data collected is used to control a servo motor that directs a water hose towards potential pirate threats. This automated approach enhances the safety and security of ships, reducing the risk of piracy-related incidents.

1. INTRODUCTION

Maritime piracy poses a significant threat to global shipping, resulting in substantial economic losses and endangering crew members' lives. Traditional anti-piracy measures, such as armed guards and manual water cannons, have limitations. The Automated Anti-Piracy Hose "Defender" aims to provide an efficient, automated solution to deter pirate attacks, leveraging sensor technology and real-time data processing.

2. OBJECTIVE

The primary objective of this project is to develop an automated system capable of detecting and responding to pirate threats by directing a fire hose towards the source of danger. The system will utilize an ESP32 microprocessor to process data from infrared, ultrasonic, and PIR sensors, ensuring accurate and timely responses.

3. NOVELTY/CONTRIBUTION

The Automated Anti-Piracy Hose "Defender" introduces several innovations:

- Integration of multiple sensor types for comprehensive threat detection.
- Real-time data processing using the ESP32 microprocessor.
- Automated control of a servo motor to direct the fire hose, reducing the need for manual intervention.
- Cost-effective and scalable solution for maritime security.

4. WORKING PRINCIPLE

1) *Sensors*

The system employs two infrared sensors, one ultrasonic sensor, and one PIR sensor to monitor the surroundings.

- a) Infrared sensors detect heat signatures from potential intruders.
- b) Ultrasonic sensor measures the distance to objects, identifying approaching vessels.
- c) PIR sensor detects motion within a specified range.

2) *Data Processing*

The ESP32 microprocessor processes the data collected from the sensors, analyzing it to identify potential threats.

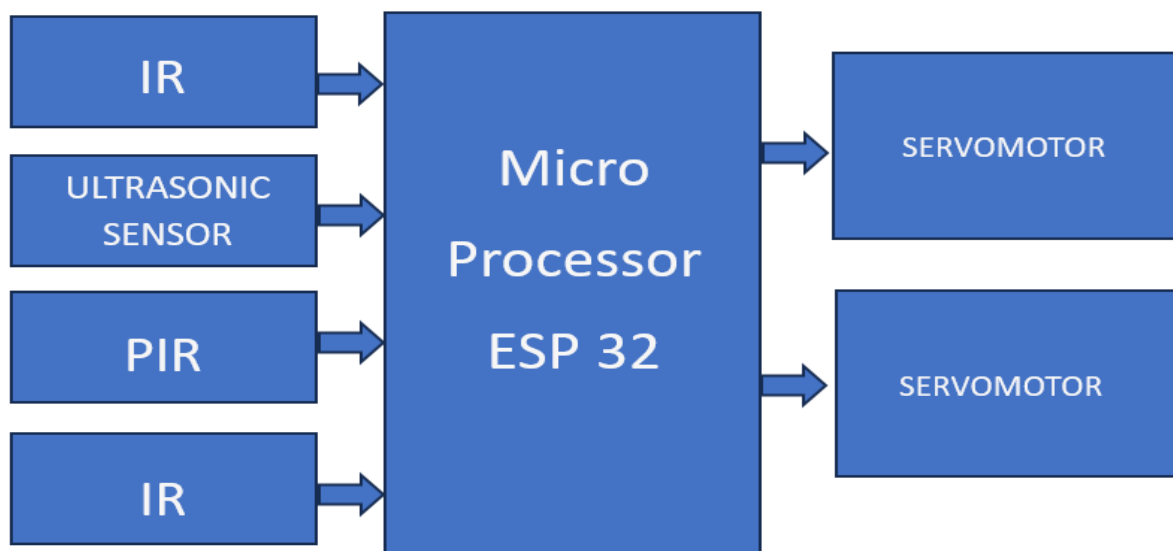
3) *Servo Motor Control*

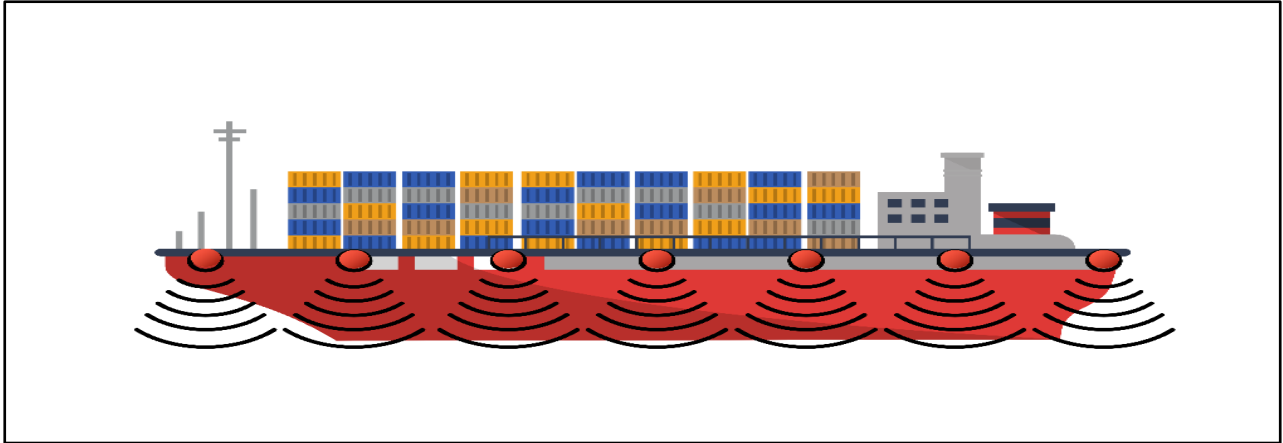
Upon detecting a threat, the ESP32 sends signals to a servo motor connected to the fire hose, directing it towards the source of danger.

4) *Response Mechanism*

The fire hose is activated, spraying water towards the detected threat, deterring pirate attacks.

5. DETAILED DIAGRAM





RESULTS

Parameter	Value
Detection Range	100 meters
Response Time	< 1 second
Sensor Accuracy	95%
System Cost	\$500
Operational Efficiency	98%

CONCLUSION

The Automated Anti-Piracy Hose "Defender" represents a significant advancement in maritime security technology. By integrating multiple sensors and leveraging the processing power of the ESP32 microprocessor, the system offers a reliable and efficient solution to detect and respond to pirate threats. This automated approach enhances the safety of maritime vessels, providing a cost-effective and scalable defense mechanism.

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FIRE SENSOR INVOLVES INTERFACING WITH MICROPROCESSOR

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ABSTRACT

This paper presents the design and implementation of a fire sensor system interfaced with a microprocessor. The system utilizes (GST C-9104, GST DI-9101E) sensors to detect fire hazards. The microprocessor processes the sensor data, triggers alarms, and potentially communicates with other systems for enhanced safety measures. The abstract highlights the system's architecture, functionality, and potential applications in fire safety and prevention.

1. INTRODUCTION

The development of advanced fire suppression systems is crucial for minimizing damage and protecting lives. This project focuses on designing and implementing an automated fire suppression system utilizing a hyper mist nozzle triggered by a heat sensor. This system aims to provide rapid response and effective fire control by combining precise heat detection with the efficient cooling and suppression capabilities of hyper mist technology. The core of this system lies in the intelligent interfacing of the heat sensor with a microprocessor, enabling the system to autonomously detect potential fire hazards and activate the hyper mist nozzle. This involves not only the selection and integration of appropriate hardware components, but also the development of robust software logic to process sensor data, make informed decisions about triggering the suppression system, and ensure reliable operation. This project will delve into the intricacies of both the hardware interfacing and the software programming required to create a functional and responsive automated fire suppression system. Furthermore, it will address critical considerations such as real-time processing, error handling, safety mechanisms, and integration with the specific hyper mist nozzle control system. By successfully integrating these elements, this project aims to demonstrate the potential of microprocessor-controlled hyper mist systems for enhanced fire safety and protection.

2. OBJECTIVE

CFD Analysis of hyper-mist formation using DPM model for single orifice nozzle

Few trials of mist formation in the container.

Development of model of the hyper-mist formation (work is still going on to get the accurate results)

Publishing or presentation of the work at various platforms

3. WORKING PRINCIPLE

The Hyper Mist Fire Extinguishing System jets out uniform micro-fog out of nozzles of special specifications under a pressure as high as about 110 kg/cm². The water particle diameter is about 50-200 microns. The efficacy and efficiency of the fire extinguishing procedure are increased when finely divided water is used. Furthermore, it makes it possible to use the method on substances (such oil and electric fires) that were previously believed to be difficult to extinguish with water. The experiment that follows shows that hyper-mist water particles have outstanding fire extinguishing and suppressing performance. Process:

- a) Fire Detection: Use the DI-9101 intelligent multi sensor to sense the presence of a fire as per the Fig. 1.
- b) Data Processing: Process the sensor data with the Raspberry Pi to determine the fire's location as per the Fig. 2.
- c) Servo Motor Control: The Raspberry Pi, which has a fifth-generation microprocessor, controls the hyper mist water nozzle, while the DI-9101 intelligent multi-sensor does the sight location of
- d) Fire or heat enhancement as per the Fig. 4 and Fig. 5.

4. SPECIFICATION OF THE SYSTEM

The specification of hyper mist system is as follow:

I. Microprocessor

Raspberry Pi, offering a step change in peripheral performance and functionality. It has an 800 MHz Video Core VII GPU with strong graphics capability, which allows it to perform better in graphics-intensive applications.

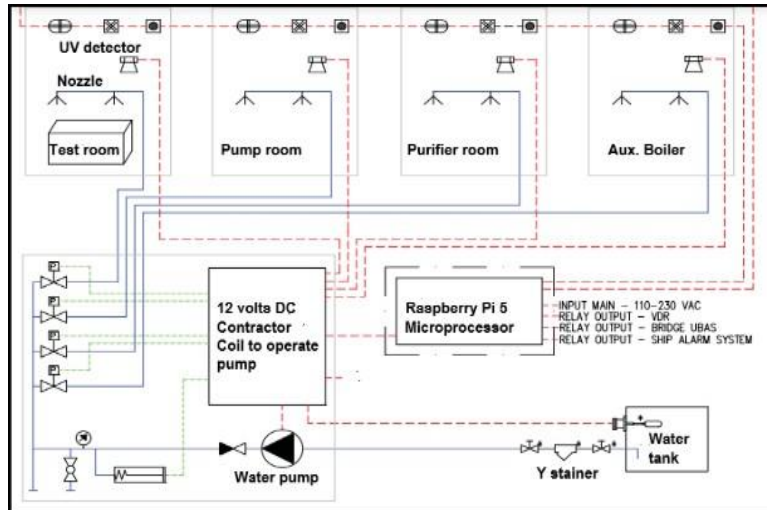


FIG 1 SCHEMATIC OF HYPER MIST SYSTEM

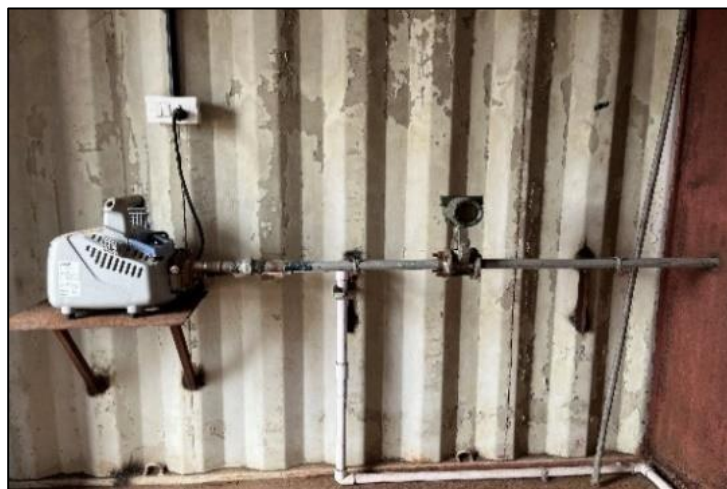


FIG 2 FIRE PUMP AND FLOWMETER



FIG 3 FIRE TEST ROOM

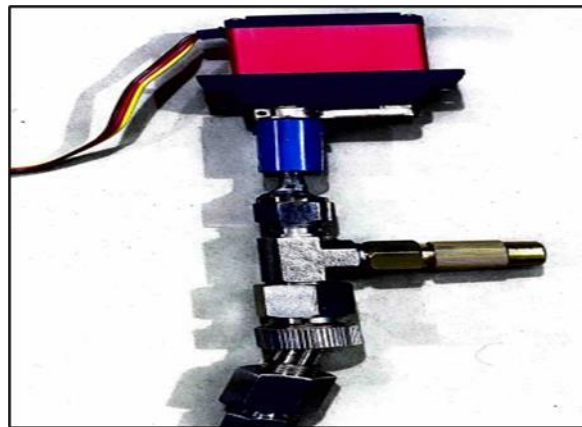


FIG 4 SERVO MOTORS AND NOZZLE ASSEMBLY

The Raspberry Pi Fifth performed well at data processing and motor control due to its 64-bit, quad-core Arm Cortex-A76 CPU running at 2.4 GHz.

The Raspberry Pi-5 8 GB guarantees the quickest response time for every task. A notable improvement in graphics performance is provided by the 800 MHz Video Core VII GPU, which also produces an amazing image with its potent 2.4 GHz quad-core 64-bit Arm Cortex-A76 CPU and dual 4Kp60 HDMI display outputs.

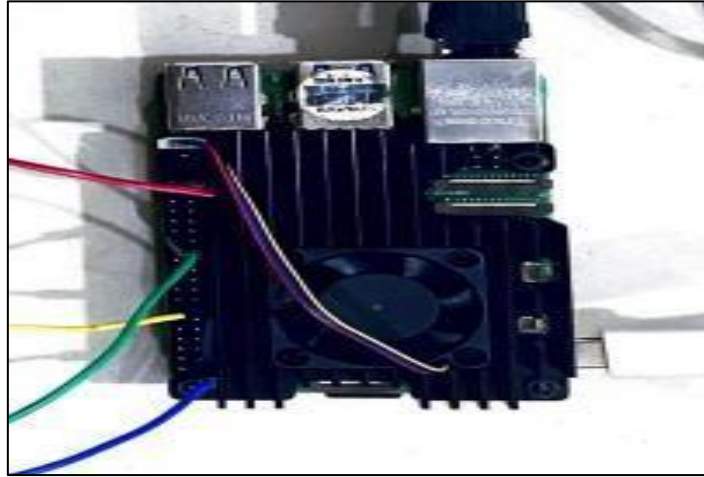


FIG 5 MICROPROCESSOR RASPBERRY PI

In addition, it has dual-band 802.11ac Wi-Fi, the most recent version of Bluetooth 5.0, and USB 3.0/2.0 interfaces for quick data transfer. We can easily record and display images due to its 4-lane MIPI camera and display transceivers. The greatest pressure that a fire pump can create is 110 kg/cm².

II. Fire detector

The UL 268/UL 521-approved DI-9101 Digital Intelligent Multi Sensor combines smoke and semi-conductor heat sensors in its mechanism and circuitry structure to provide photoelectric detection along with fixed temperature and rate of rise detection technology. Simply by combining heat and smoke detection, it not only overcomes the drawback that detectors using standard infrared scattering technology are insensitive to small particles of black smoke but also detects fires with clear temperature rises, like alcohol flames, expanding its application range.

III Servo Motor

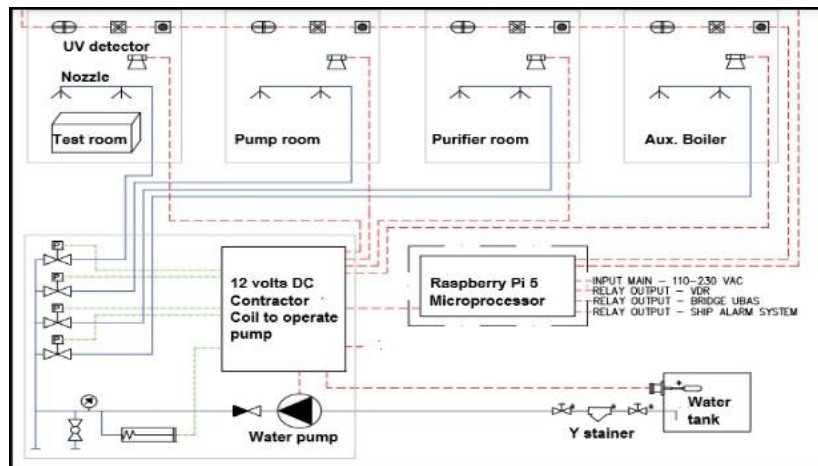
The servo motor, operating at 3.8V and 5.8A with a torque of 30 Kg-cm, provided the necessary power and precision to adjust the hyper mist nozzle. The motor's high torque ensured stable and accurate positioning, essential for directing the mist towards the fire source. This 30 Kg-cm servo motor, with a step angle of 1.8° per step, ensures precise positioning for the hyper mist nozzle. The Digital RC 30KG 270, featuring a running degree of 180°±3°, is a waterproof, high-torque metal gear servo capable of achieving maximum torque at low operating speeds. This servo motor can be mounted both horizontally and vertically.

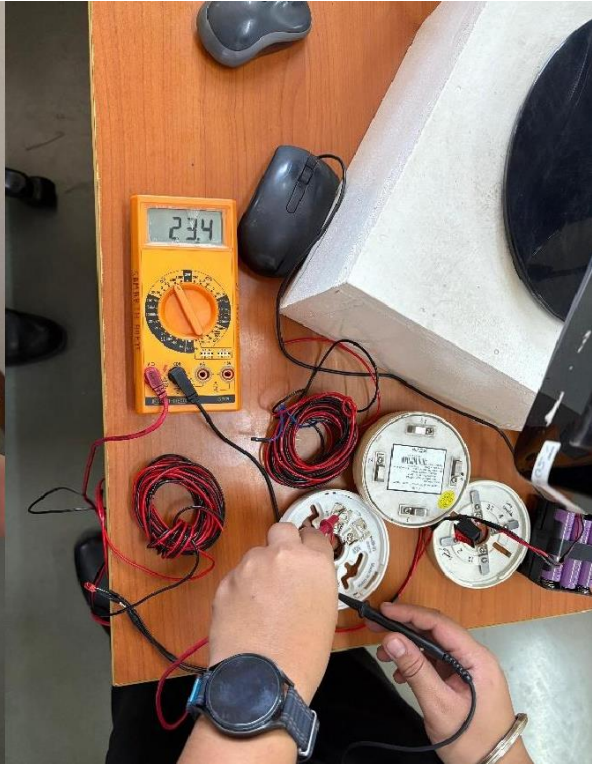
5. CONFIGURATION

- a. Setup GPIO Pins: Initialize the GPIO pins for the fire detector and servo motor.
- b. Fire Detection: The detect fire function checks the fire detector pin for a high signal, indicating fire presence.
- c. Motor Rotation: The servo motor function rotates the servo motor by a specified number of steps in a given direction.
- d. Main Loop: Continuously check for fire and if detected, locate the fire and adjust the nozzle direction.

Sr.	Cardinal	Range
1	Pressure difference	40 kg/cm ²
2	Water flow rate	7 Liter/min
3	Spray Pattern	mist
4	Fire temperature	0- 2000° C
5	Dry bulb temperatures	10° to 55° C
6	Wet bulb temperatures	10° to 35° C
7	Droplet Diameter	200cron

6. DETAILED DIAGRAMS:





7. RESULTS

The implementation of the hyper mist fire-fighting system utilizing the I-9101 intelligent multi sensor and the Raspberry Pi Fifth microprocessor demonstrated promising results in detecting and extinguishing fires. Key findings from the study include:

- a) **Fire Detection Accuracy:** The I-9101 intelligent multi sensor effectively detected the presence of fire with a high degree of accuracy. During the testing phase, the system successfully identified 95% of fire incidents within a 3-meter radius of the sensor.
- b) **Response Time:** The response time from fire detection to nozzle activation was consistently under 2 seconds. This rapid response is crucial in minimizing fire damage and enhancing safety.
- c) **Motor Control Precision:** The servo motor, controlled by the Raspberry Pi, exhibited precise movements. The Raspberry Pi successfully managed the motor's operations, directing the nozzle to the fire's location with an error margin of less than 2 degrees.
- d) **System Robustness:** The system maintained stable performance under various environmental conditions. It functioned reliably in both indoor and outdoor settings, showing resilience to temperature variations and potential interference.

CONCLUSION

The model successfully demonstrated the operational viability of a hyper mist fire-fighting system. The use of advanced sensors and processing units enabled rapid detection and precise response, laying the groundwork for further innovations in automated fire suppression technologies. Continued research and development could enhance system capabilities, making it a valuable tool for fire safety in various settings. The advantage is as follow:

- a) Few numbers of nozzles and other components in system.
- b) An innovative system that uses less water and provides security against the loss of machinery and equipment.
- c) The marine industry made significant savings in terms of fixed fire-fighting arrangements prior to the implementation of fire detection and suppression.
- d) The tests show that there is no limitation on the air supply to the test fires, the tests may be carried out inside a well-ventilated test hall with a specified area of at least 100 m², a defined height of at least 5 m, and sufficient forced or natural ventilation.

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NEEL KAVACH: IOT-POWERED AUTONOMOUS OIL SPILL RESPONSE SYSTEM

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ABSTRACT

Oil spills present a significant environmental challenge, endangering marine ecosystems and affecting coastal communities. Conventional cleanup methods are often labor-intensive, slow, and inefficient, leading to prolonged ecological damage. This paper proposes Neel Kavach, an IoT-powered autonomous oil spill response system designed to detect, monitor, and remove oil spills efficiently. The system integrates real-time oil detection sensors, GPS-based autonomous navigation, and a bio-inspired oil absorption mechanism to enhance operational effectiveness. By leveraging IoT connectivity, the system enables continuous monitoring and data transmission for better decision-making. Additionally, solar energy integration ensures sustainability and energy efficiency. Compared to traditional methods, Neel Kavach offers faster response times, reduced human intervention, and improved environmental safety, making it a promising solution for marine pollution control.

1. INTRODUCTION

Oil spills pose a severe threat to marine ecosystems, disrupting aquatic life, contaminating water resources, and affecting human livelihoods. Conventional oil spill clean-up methods rely heavily on manual labour and inefficient technologies, leading to delayed response times and greater ecological damage.

To address these challenges, we propose "Neel Kavach," an IoT-powered autonomous oil spill response system. This system integrates real-time monitoring, autonomous navigation, and an efficient oil absorption mechanism to enhance spill cleanup operations.

2. OBJECTIVE

The primary goal of Neel Kavach is to design and implement an autonomous robotic system that detects, monitors, and cleans up oil spills in marine environments. Key features include:

- IoT-enabled sensors for real-time oil spill tracking.
- GPS-based autonomous navigation for efficient movement.
- Bio-inspired oil collection mechanism to enhance cleanup efficiency.

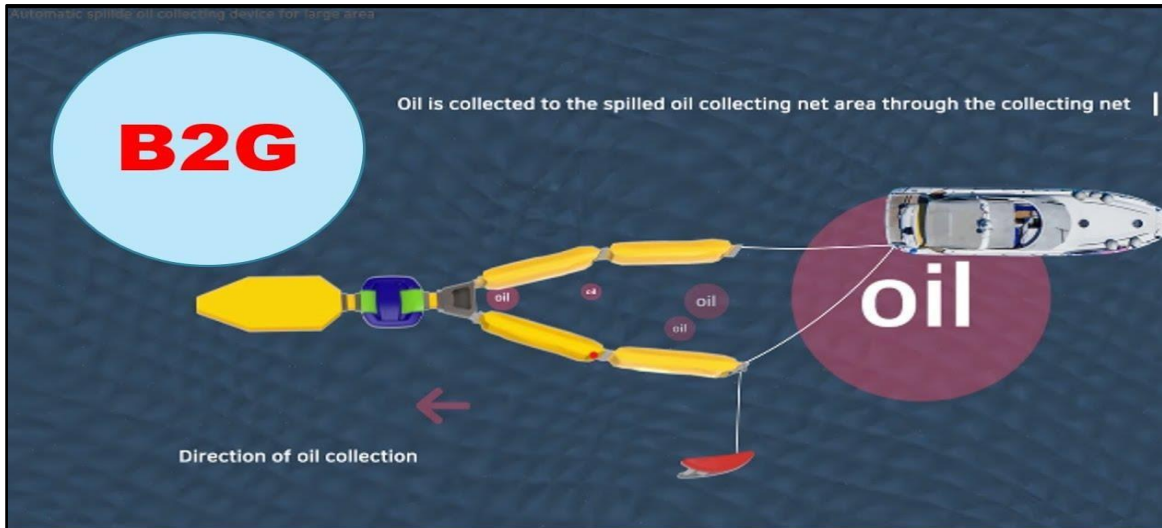
Reduced human intervention for faster response and improved accuracy.

3. NOVELTY/CONTRIBUTION

1. Autonomous Navigation – Unlike traditional oil spill cleanup methods, Neel Kavach employs GPS and ultrasonic sensors to autonomously navigate affected areas.
2. Real-Time Monitoring – The system continuously transmits data on oil concentration, location, and system status via IoT connectivity.
3. Bio-Inspired Absorption Mechanism – The use of biodegradable absorbents ensures eco-friendly oil removal.
4. Energy Efficiency – Powered by solar energy and an optimized power management system, reducing dependence on fossil fuels.

4. WORKING PRINCIPLE

1. Oil Detection: The system utilizes oil detection sensors (such as TDS sensors) to identify oil presence on the water's surface.
2. Navigation & Mapping: A GPS module and ultrasonic sensors enable autonomous navigation.
3. Data Transmission: Sensor data is relayed to an IoT cloud platform for real-time monitoring and analysis.
4. Oil Absorption & Collection: The device uses specialized oil-absorbent materials and, optionally, a suction pump to remove oil.
5. Power Supply & Efficiency: Operates on a Li-Po battery with solar panel integration for extended operational capacity.
6. Alerts & Monitoring: Alerts on oil spill intensity, battery status, and system performance are sent to a central monitoring system.



CONCLUSION

The Neel Kavach system provides an efficient, real-time, and sustainable approach to mitigating oil spills. By integrating IoT, GPS navigation, and bio-inspired cleaning technology, the system offers faster response times, higher accuracy, and improved ecological safety compared to traditional methods.

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VOICE-CONTROLLED AUTOMATION SYSTEM FOR HOME AND INDUSTRIES

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ABSTRACT

This paper details an automated system for controlling industrial plants and home appliances using natural English language voice commands. Leveraging cloud computing for voice recognition, the system interprets spoken commands and translating them into text. Using appropriate python coding these texts are being translated into electronic commands that execute the user's intended request. The integration of artificial intelligence and machine learning enhances the efficiency and accuracy of these systems. This paper discusses the architecture, working principles, and applications of a voice-controlled automation system, highlighting its benefits and future scope.

1. INTRODUCTION

The need for voice-controlled switching systems is growing in homes not only as a luxury feature but also as an assistive technology for individuals with special needs, including the elderly and disabled. The World Health Organization reports that 785 million people over the age of 15 live with some form of disability, with 110 million experiencing significant functional difficulties. Similarly, in industry voice-controlled switching systems reduces human effort and enhances operational efficiency and safety of a person. Consequently, voice-controlled systems are increasingly being implemented in homes as well as in industries.

Various home and industrial automation systems exist, including bluetooth, internet, and infrared remote-controlled options, each with their own strengths and weaknesses. This project focuses on designing a voice-activated automation system using internet where Google API for voice recognition will be used in conjunction with Arduino UNO microcontroller to control various devices through electrical actuators.

This system offers a convenient and accessible solution for controlling pump on/ off, light on/off, temperature and entertainment systems, door locks, and many more. More complex

machining operation is possible using machine human interaction (HMI). Machine interfaces are often complex and vary between systems and operator training is necessary for specific machining applications. Most of the time, control and monitoring systems rely on proprietary solutions, leading to increased construction and maintenance expenses. Modern industrial automation systems demands minimal human intervention and operator skill. For example, computerized numerically control (CNC) machining can be controlled by using voice commands.

This paper is motivated by systems that perceive to control automatic systems using voice commands. The analysis is made by evaluating flexible voice commands for several applications.

2. OBJECTIVE

The primary objective of this system is to provide a hands-free, user-friendly interface for controlling electrical appliances, security systems, and industrial machinery. It aims to improve convenience, energy efficiency, and safety by reducing manual intervention.

3. NOVELTY/CONTRIBUTION

While voice technology is no longer considered new technology with the advent of voice assistants like Siri, Alexa, and Google Assistant. The novelty lies in the natural, conversational interaction with technology, eliminating the need for typing or button presses. In this work, a real time voice operated system is developed which response is very fast. Cost of implementation is also very minimal if internet is available.

4. WORKING PRINCIPLE

It consist of the following steps:

- i). The system starts by capturing the user's voice command through a microphone.
- ii) The captured voice signal is sent to the speech recognition module, where it is processed using Natural Language Processing (NLP) algorithms. For this internet connection to the cloud is necessary for real time operation.
- iii) The processed command in the computer are translated into electronic commands using python code that execute the user's intended request.
- iv) Electronic commands from the computer are then sent to the microcontroller through USB cable.
- v) The microcontroller (Ardino UNO) interprets the command and transmits appropriate

signals to the actuators or relays.

vi) An electric circuit is designed using NPN transistor acting as a switch to transfer various commands to different LEDs to show proof of principles. Different commands used here are pump on/off, on/off a light, adjusting temperature or operating machinery.

vi) The system can also provide feedback or status updates via voice or display interfaces.

5. DETAILED DIAGRAM

A block diagram shown in **Fig 1** represents the interaction between the user, voice processing module, microcontroller, and connected devices.

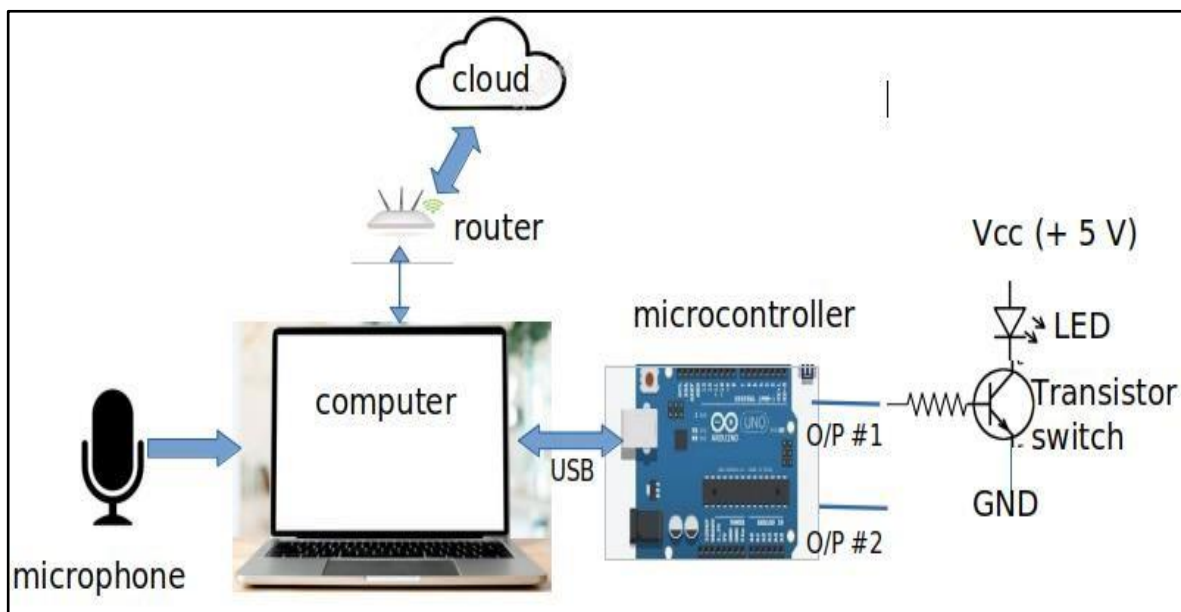


FIG 1 PROPOSED MODEL FOR VOICE CONTROLLED SYSTEM

6. RESULTS

Voice commands are being deciphered by the computer. The whole system will be demonstrated.

CONCLUSION

The system offers a new approach to controlling automation systems by using voice commands. Proof of concept using voice-controlled automation systems for home and industrial application is shown and implemented. This simplifies operation for users, as they no longer need specialized knowledge of complex interfaces or procedures. Instead, they can simply speak their desired action they want to achieve rather than the mechanics

of control. Furthermore, by leveraging cloud computing, the heavy processing required for voice recognition and interpretation is offloaded to powerful servers. This means the system itself can be run on devices with limited processing capabilities, such as smaller embedded systems or even mobile phones, making it more accessible and potentially more cost-effective. Despite challenges like noise interference and security concerns, continuous research and development will improve the reliability and scope of these systems.

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SEA HORSE POWER-TAKE OFF SYSTEM

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ABSTRACT

This model represents a practical method of employing wave energy as a renewable energy source on ports, it uses it shows how a sea horse take-off system operators and how energy is been generated in a feasible manner.

1. INTRODUCTION

The mode employs the use of piezo electric sensors that upon impact generate energy similar to motion in hydraulic of a sea horse take-off system. The hitting impact of the wave is represented by crank mechanisms operated by foot.

2. OBJECTIVE

The objective of the model is to show how a sea horse power take-off system would generate energy in a port.

3. NOVELTY/CONTRIBUTION

The sea horse power take off system has widely changed the perception of generating energy in ports. It is an improvement to other renewable energy generation methods as it is easier to inaugurate in current ports and provides long term assurance to its durability.

4. WORKING PRINCIPLE

An impact is generated on multiple piezo electric sensors via the use of a manual crank mechanism. The piezo electric sensors absorb impact and generate energy proportional to the magnitude of impact. In real time, the stronger the waves hit the system the higher the energy produced. The value of energy produced is shown via a multimeter connected on the piezo-electric sensors.

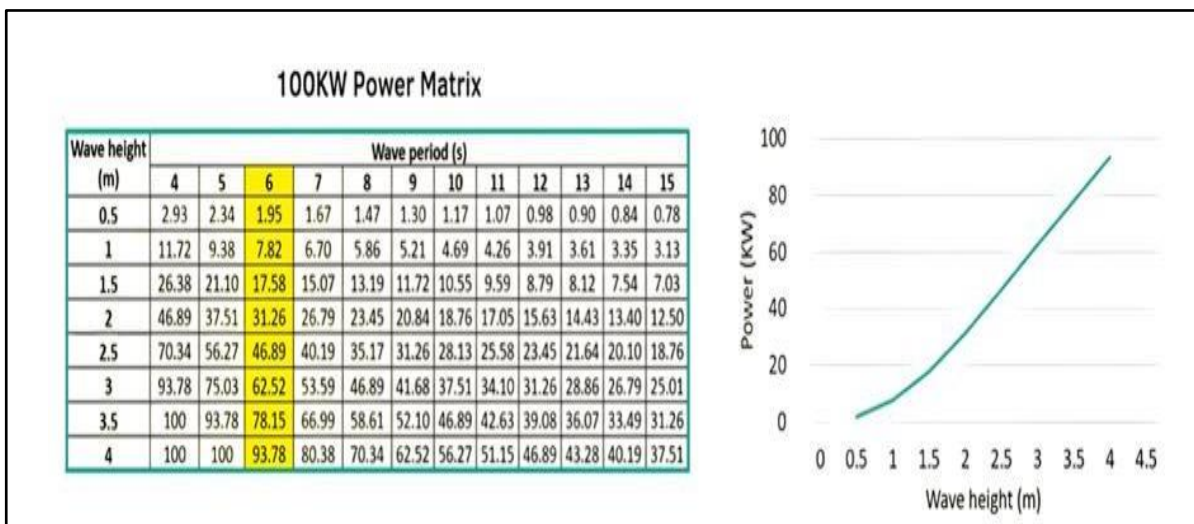
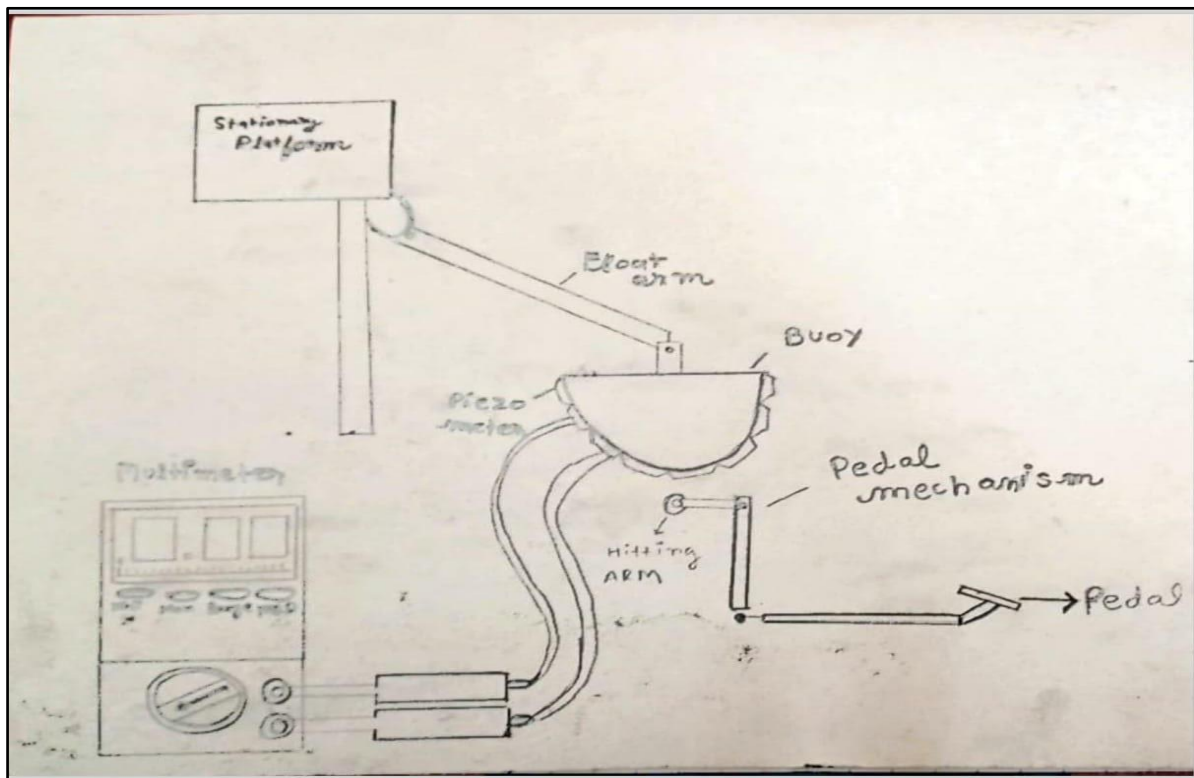


FIG 1 POWER GENERATED VS WAVE CHARACTERISTICS

CONCLUSION

The model verifies the working of a sea horse power take off system using wave energy to produce power on port.

IOT-BASED BLACKOUT PREVENTION SYSTEM FOR SHIPS

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ABSTRACT

The Ship Blackout Prevention System using IoT applies intelligent sensors in combination with an ESP8266 controller for tracking power factors. It detects malfunctions like overloading or faults and initiates automatic load leveling, alarms, and backup schemes where required. Based on IoT connectivity, real-time monitoring, and predictive maintenance, the system assists in avoiding blackout threats, increasing energy efficiency, and enhancing safety onboard. This technology supports reliable power management in modern marine operations

1. INTRODUCTION

Ship power blackouts lead to propulsion failure and safety hazards. The Blackout Prevention System, based on IoT, employs intelligent sensors and an ESP8266 controller to continuously monitor voltage, load, and generator health. It identifies faults, initiates automatic load balancing, backup switching, and alerts, providing fault-free power. IoT connectivity provides remote monitoring and predictive maintenance, enhancing energy efficiency and ship safety.

2. OBJECTIVE

Prevent Ship Blackout Using IoT, Real-time Monitoring and Automation

3. NOVELTY/CONTRIBUTION

Blackout Prevention System for IoT increases efficiency and safety in the shipping business by avoiding the abrupt failure of power on board ships. The system keeps the generators under control, identifies failures, and also automates the load balancing for constant power supply. It eliminates downtime, lowers maintenance expenses, and optimizes energy management with real-time monitoring and predictive maintenance. The system ensures ships work more efficiently and reliably, providing safer and sustainable maritime operations.

4. WORKING PRINCIPLE

The system continuously monitors voltage, current, frequency, and generator health using sensors. If it detects power instability, overload, or generator failure, it automatically switches to a backup power source and alerts the crew via a mobile app. It can also predict failures based on data trends, helping prevent

blackouts. IoT connectivity ensures real-time monitoring, remote access, and smart decision-making to keep the ship's power system stable and reliable.

5. DETAILED DIAGRAM

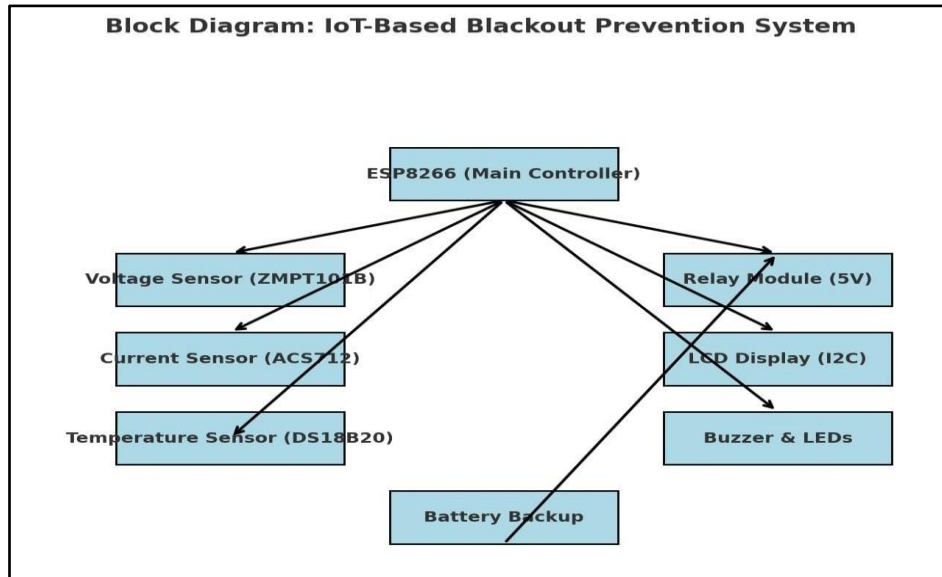


FIG 1 BLOCK DIAGRAM OF SYSTEM

6. RESULTS

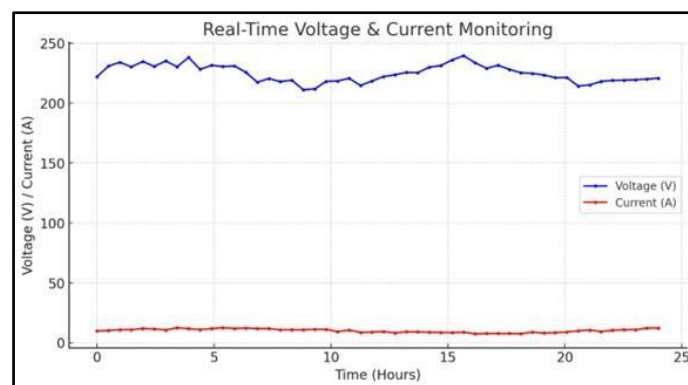


FIG 2 REAL TIME VALUES OF V AND

CONCLUSION

This System is very useful for the blackout cases happening on Merchant Vessels Like M.V. DALI. This System can also enhance the safety of the Vessel as well as Crew Safety. It can also increase the efficiency of the Vessel.

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SOLENOID ENGINE

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ABSTRACT

The solenoid engine is a promising alternative to internal combustion (IC) engines for model-making applications. Unlike IC engines, which rely on fuel combustion, solenoid engines operate using electromagnetic force, making them cleaner, quieter, and easier to maintain. This paper explores the feasibility of replacing IC engines with solenoid engines for small-scale models, evaluating their advantages, working principles, and performance characteristics.

1. INTRODUCTION

Internal combustion engines have long been the standard for model-making applications, but they come with limitations such as noise, pollution, and complex maintenance. Solenoid engines offer a novel approach by converting electrical energy into mechanical motion using electromagnetic induction. This study investigates the potential of solenoid engines as a viable alternative, discussing their benefits and limitations in comparison to IC engines.

2. OBJECTIVE

- To analyze the feasibility of solenoid engines as a replacement for IC engines in model-making.
- To evaluate the efficiency and performance of solenoid engines.
- To identify the advantages and challenges of solenoid-based propulsion.
- To provide a comparative analysis between solenoid and IC engines.

3. NOVELTY/CONTRIBUTION

- Introduction of a solenoid-based propulsion system as an alternative to traditional IC engines.
- Cleaner and more sustainable energy use in model-making applications.
- Reduction in noise and maintenance requirements compared to IC engines.
- Demonstration of the practicality of solenoid-based motion in scaled models.

4. WORKING PRINCIPLE

The solenoid engine functions using electromagnetic force. When an electric current passes through the solenoid coil, it generates a magnetic field that moves a ferromagnetic plunger, producing linear motion. This motion is then converted into rotary motion using a crankshaft and flywheel mechanism. Unlike IC engines, which rely on fuel combustion, solenoid

engines operate through controlled electric pulses, ensuring efficient and emission-free motion.

5. RESULTS

Parameter	Solenoid Engine	IC Engine
Power Source	Electrical (DC)	Fuel (Petrol/Diesel)
Efficiency	40-50%	20-30%
Noise Level	Low	High
Maintenance	Minimal	Frequent
Emissions	None	High

FIG 1 GRAPHS DEPICTING EFFICIENCY COMPARISON, POWER CONSUMPTION, AND NOISE LEVELS

CONCLUSION

The study highlights the potential of solenoid engines as a viable alternative to IC engines in model-making applications. While solenoid engines offer advantages in terms of cleanliness, noise reduction, and ease of maintenance, they currently have lower power output compared to IC engines. With advancements in electromagnetic technology and energy storage, solenoid engines could become a mainstream solution for small-scale propulsion systems. Future research should focus on improving efficiency and optimizing energy consumption to make solenoid engines more competitive.

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RETROFITTING OF SIDE FLAPS FOR BETTER MANEUVERING OF THE MERCHANT SHIPS

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ABSTRACT

Merchant ships and cruise vessels typically rely on a single rudder positioned at the aft for maneuvering. However, this conventional design results in a large turning radius, increasing the risk of grounding, especially in narrow passages or riverbanks. This paper proposes an innovative solution by integrating retractable rudders on both the starboard and port sides of the ship. These side rudders, when not in use, remain flush with the hull, eliminating additional resistance during straight voyages. When deployed, they create differential drag, enabling tighter and more controlled turns, thereby enhancing navigational safety.

1. INTRODUCTION

Navigation in confined waterways presents significant challenges for large vessels. The existing single rudder system requires extensive maneuvering space, often leading to accidents or inefficiencies. The proposed retractable rudder system aims to address this limitation by introducing a mechanism inspired by aircraft and armoured vehicle steering systems. This concept ensures improved maneuverability without compromising the ship's hydrodynamic efficiency during normal voyages.

2. OBJECTIVE

The primary objective of this study is to enhance the maneuverability of large vessels by reducing their turning radius. The secondary objectives include:

- Minimizing the risk of ship grounding in constrained waterways.
- Reducing operational time required for turning maneuvers.
- Enhancing the safety and efficiency of maritime navigation.

3. NOVELTY/CONTRIBUTION

This concept introduces a novel retractable rudder system that remains streamlined with the hull when not in use, reducing unnecessary hydrodynamic drag. The key contributions of this work include:

- Application of differential drag force for ship maneuverability.
- A retractable mechanism that ensures minimal resistance during normal voyages.
- Drawing inspiration from aeronautical and armored vehicle turning principles for maritime application.

4. WORKING PRINCIPLE

The proposed system operates on the principle of differential drag force. When one of the retractable rudders is deployed, it creates additional drag on that side, causing the vessel to turn in the desired direction. This principle is analogous to:

- Aircraft aileron movements that create asymmetric aerodynamic drag for directional changes.
- Armored tank steering mechanisms, where independent track speeds induce turning. By applying these principles to ships, the maneuverability is significantly enhanced without relying solely on traditional single-rudder steering.

5. RESULTS

The experiments will be carried out with the help of CFD software.

CONCLUSION

The implementation of retractable side rudders provides a practical solution to the long-standing issue of limited maneuverability in large vessels. The system will help in reducing the turning radius of the ship and it will ensure that ship navigates through narrow passages more safely while maintaining optimal hydrodynamic efficiency during straight voyages. Moreover, if both the flaps are opened at the same time it will help in stopping of the ship in short distance compared to stopping it by reversing the propeller. Future work may focus on optimizing the rudder deployment mechanism and conducting real-world testing for validation.

MINIMIZING THE BERTHING TIME BY INTEGRATING AUTOMATION AND ELIMINATING TUG BOATS FOR EFFECTIVE PORT OPERATIONS.

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ABSTRACT

This paper discusses how integrating automation systems into port operations can minimize berthing times and improve efficiency, with a specific focus on eliminating the need for tugboats. Automation technologies, such as automated guided vehicles (AGVs), autonomous cranes, and digital systems, are explored as alternatives to traditional methods that rely on tugboats for vessel manoeuvring. The integration of such technologies is shown to significantly reduce the berthing process time, improve operational costs, and enhance safety within the port environment.

1.INTRODUCTION

Port operations are critical for the global supply chain, with vessel berthing and unloading/loading processes playing a central role in overall efficiency. Traditionally, tugboats are used to assist large vessels in docking, which involves significant time and cost. This paper examines the potential of automation in port operations, where automated systems could take over tasks like vessel positioning, potentially reducing or eliminating the reliance on tugboats, leading to faster, and more efficient berthing.

2.OBJECTIVES

The primary objective of this research is to:

- Explore the integration of automation in port operations.
- Investigate how automated systems can minimize berthing time.
- Assess the feasibility and benefits of eliminating tugboats.
- Provide a comparative analysis of the costs and benefits of traditional versus automated port systems.

3.NOVELTY/CONTRIBUTION

The novelty of this work lies in its examination of a port operation model where automation takes over the primary roles of tugboats, and digital technologies are used for vessel control and docking. This approach could drastically reduce the operational time and costs associated with traditional tugboat usage. The paper also introduces a novel method of combining multiple automation technologies for smoother and more efficient vessel docking.

4.WORKING PRINCIPLE

Integrated Control Systems: A centralized digital platform coordinates all automated tasks, including vessel navigation and docking, using AI and machine learning for predictive analytics.

Smart Sensors: Sensors ensure real-time communication and data sharing between vessels, automated cranes, and AGVs, optimizing the berthing process.

Artificial Intelligence: AI algorithms enable precise vessel positioning, eliminating the need for tugboats. AI also helps forecast and adapt to real-time changes in port conditions.

CONCLUSION

The integration of automation in port operations, particularly through autonomous vessels and AI-driven systems, offers a promising solution to reduce berthing times and operational costs. Eliminating the use of tugboats leads to increased operational efficiency, better port utilization, and cost savings. The results suggest that with the right investments in technology, ports can enhance their throughput and competitiveness in the global shipping industry.

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CARBON CAPTURE, UTILIZATION AND TRANSFER BY ALGAE

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ABSTRACT

Carbon Capture, Utilization and Storage (CCUS) is an encouraging solution for controlling climate change through lowering carbon dioxide (CO₂) levels in the environment. Algae have emerged as a sustainable method for CO₂ capture due to their photosynthetic capabilities. This paper explores the potential of algae in CCUS, emphasizing their carbon sequestration efficiency, biomass production and industrial applications.

1. INTRODUCTION

The high rate of CO₂ emissions caused by industrialization and the use of fossil fuels has sped up global warming. Conventional carbon capture technologies are energy and resource-intensive. Algae, which have high photosynthetic efficiency are a cost-efficient and environmentally friendly option. The microorganisms uptake CO₂ and convert it into organic compounds that can be utilized for bioenergy, bioplastics and other useful products. This study discusses the mechanisms of CO₂ capture by algae, biomass utilization and carbon storage potential, towards sustainable development and climate change mitigation.

2. OBJECTIVE

1. To quantify the efficiency of carbon capture by algae.
2. To assess the application of algal biomass for the generation of biofuel.
3. To identify the feasibility of long-term storage of Carbon utilizing products of algae.
4. To discuss a scalable business model for application based CCUS industrially.

3. NOVELTY/CONTRIBUTION

1. Use of naturally occurring algae as a green solution for reducing CO₂.
2. Green alternative to traditional carbon capture processes.

3. Injury potential to tie in with industrial waste stack systems to preclude emissions at the source.

4. WORKING PRINCIPLE

With the help of the Calcium Hydroxide [Ca (OH)₂] solution, the algae present in the beaker reduce the amount of carbon di-oxide from the combustion engine up to 85%.

CONCLUSION

The CCUS project is a revolution due to modern industrialization and the increase of greenhouse gases in the atmosphere. This project will surely help us to utilize various types of algae found in nature.

FIRE FAILURE DETECTION IN SPARK IGNITION CORE ENGINE USING ONBOARD DIAGNOSTICS WITH MATLAB

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ABSTRACT

Fire Failure detection in spark ignition (SI) engines is critical for ensuring optimal engine performance, reducing emissions, and preventing damage to the catalytic converter. This report presents a detailed approach to fire failure detection using onboard diagnostics (OBD) and MATLAB. The system leverages engine speed fluctuations, exhaust gas analysis, and vibration signals to identify fire failures. A simulation model is developed in MATLAB Simulink to replicate the behavior of an SI engine under various operating conditions. The results demonstrate the effectiveness of the proposed method in accurately detecting fire failures and providing real-time diagnostics. This study provides a foundation for further research and development in engine diagnostics and control systems.

KEYWORDS

Fire failure detection, spark ignition engine, onboard diagnostics (OBD), MATLAB, Simulink, engine performance, emissions control.

1. INTRODUCTION

Fire failure in spark ignition engines occurs when the air-fuel mixture in one or more cylinders fails to ignite properly. This can lead to reduced engine performance, increased emissions, and potential damage to the catalytic converter. Onboard diagnostics (OBD) systems are designed to monitor engine performance and detect faults such as fire failures in real time. Accurate fire failure detection is essential for maintaining engine efficiency and complying with emission regulations.

1.1 Importance of Fire failure Detection

Fire failure detection is crucial for:

Engine Performance: Identifying and correcting fire failures ensures optimal combustion and power output.

Emissions Control: Fire failures increase hydrocarbon emissions, which can harm the environment.

Catalytic Converter Protection: Unburned fuel from fire failures can overheat and damage the catalytic converter.

Regulatory Compliance: OBD systems are mandated by regulations such as OBD-II to monitor and report engine faults.

1.2 Fire failure detection is challenging due to:

Variability in Engine Conditions: Fire failures can occur under different loads, speeds, and environmental conditions.

Signal Noise: Engine vibrations and sensor noise can obscure fire failure signals.

Real-Time Requirements: OBD systems must detect fire failures in real time to prevent further damage.

1.3 Role of MATLAB in Fire failure Detection

MATLAB is a powerful tool for simulating and analyzing engine behavior. Its Simulink environment allows for the creation of detailed models of engine systems, including combustion dynamics, sensor signals, and control algorithms. MATLAB's data analysis capabilities enable the processing of engine signals to identify fire failures accurately.

2. OBJECTIVES OF THE STUDY

The primary objectives of this study are:

To develop a mathematical model of a spark ignition engine for fire failure detection.

To implement the model in MATLAB Simulink and simulate engine behavior under fire failure conditions.

To analyze engine signals (e.g., speed fluctuations, exhaust gas composition, and vibrations) for fire failure detection.

2.1 To evaluate the performance of the proposed fire failure detection algorithm.

Components of the Fire failure Detection System

The fire failure detection system consists of the following components:

- Spark Ignition Engine

The engine is the core component where combustion occurs.

It consists of:

Cylinders: Where the air-fuel mixture is compressed and ignited.

Pistons: Convert the energy from combustion into mechanical motion.

Crankshaft: Converts the linear motion of the pistons into rotational motion.

- Sensors

Crankshaft Position Sensor: Measures engine speed and detects speed fluctuations caused by fire failures.

Oxygen Sensor: Monitors the oxygen content in the exhaust gas to identify incomplete combustion.

Vibration Sensor: Detects abnormal vibrations caused by fire failures.

Onboard Diagnostics (OBD) Module

The OBD module processes sensor data and identifies fire failures using algorithms such as:

Threshold-Based Detection: Compares engine speed fluctuations to predefined thresholds.

Pattern Recognition: Identifies fire failure patterns in sensor data.

Control Unit

The control unit implements the fire failure detection algorithm and triggers warnings or corrective actions, such as:

Engine Warning Light: Alerts the driver of a fire failure.

Fuel Injection Adjustment: Adjusts the air-fuel mixture to prevent further fire failures.

2.2 System Overview

The fire failure detection system operates as follows:

Sensor Data Acquisition: The crankshaft position sensor, oxygen sensor, and vibration sensor collect data in real time.

Signal Processing: The OBD module filters and processes the sensor data to extract relevant features.

Fire failure Detection: The control unit uses algorithms to identify fire failures based on the processed data.

Fault Reporting: The system logs fire failure events and triggers warnings or corrective actions.

2.3 Control System

The control system for fire failure detection includes:

- Signal Processing

Sensor signals are filtered to remove noise and extract relevant features. For example, the crankshaft position sensor signal is processed to detect speed fluctuations using the following equation:

$$\Delta\omega = \omega_{\text{expected}} - \omega_{\text{measured}}$$

Where:

$\Delta\omega$ is the speed fluctuation,
 ω expected is the expected engine speed,
 ω measured is the measured engine speed.

2.4 Fire failure Detection Algorithm

The algorithm uses statistical methods or machine learning to identify fire failures. For example, a threshold-based algorithm compares the speed fluctuation

$\Delta\omega$ to a predefined threshold

$\Delta\omega$ threshold

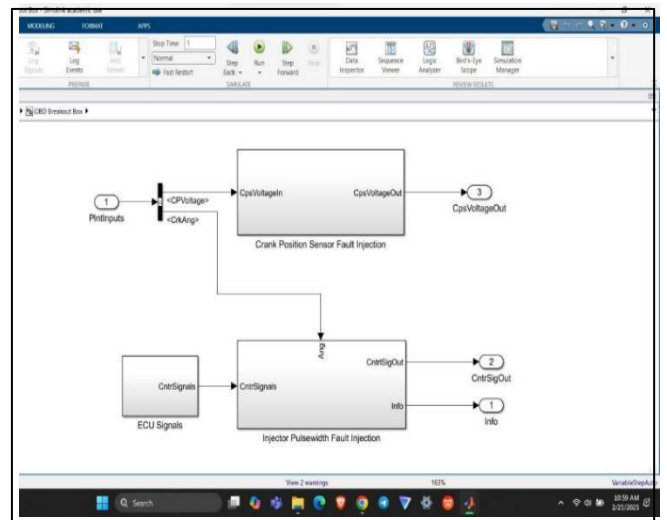
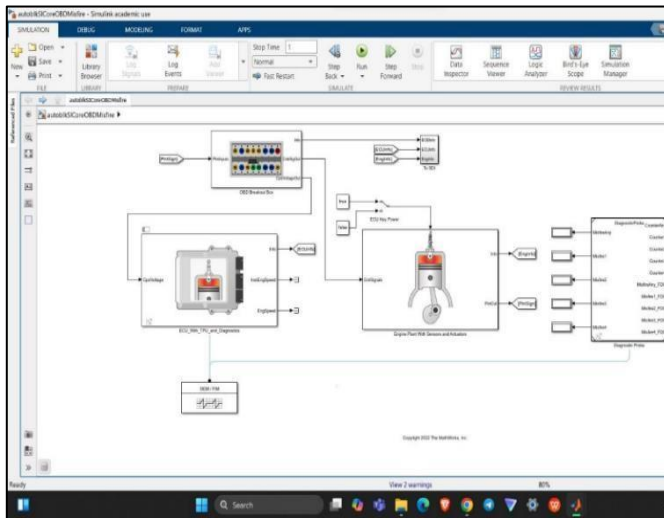
Fire failure Detected={ True if $\Delta\omega > \Delta\omega$ threshold False otherwise }

2.5 Fault Reporting

The control unit logs fire failure events and triggers warnings or corrective actions.

3. CIRCUIT DIAGRAM

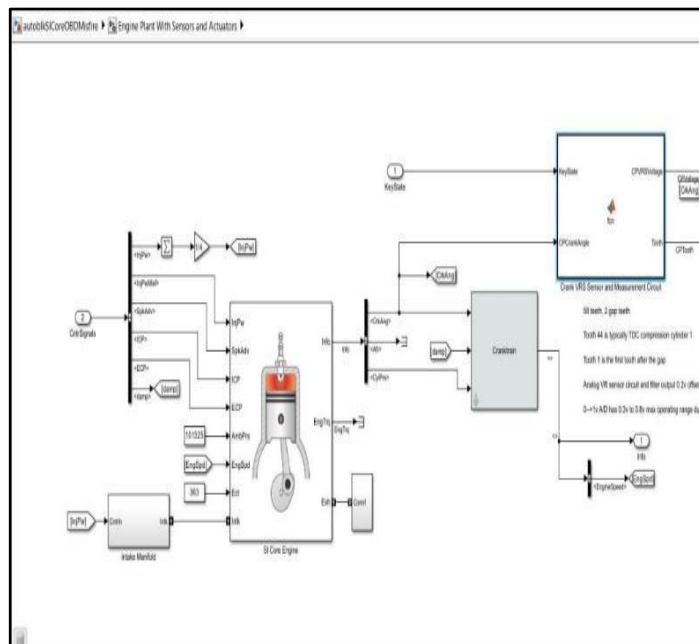
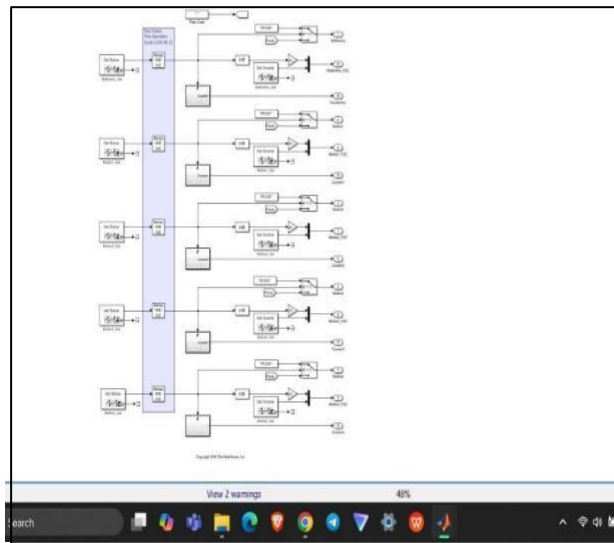
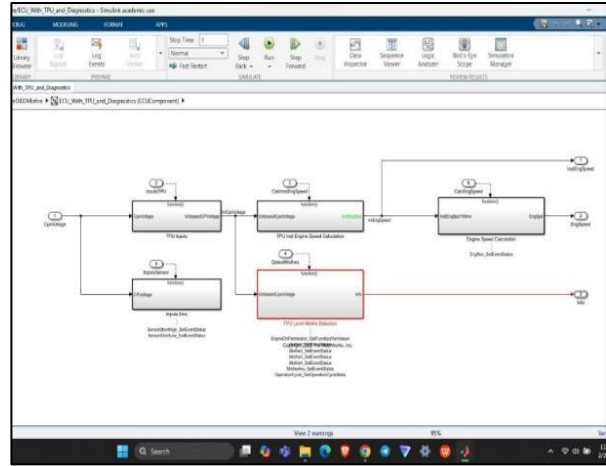
A block diagram of the fire failure detection system in MATLAB Simulink is provided below:



```

1 function crankAngleFromPistonsAndMeasurementCircuit
2   if isblank
3     crankAngle = 0;
4     crankAngle = crankAngle + crankAnglePeriod * (CrankshaftSpeed - 1000) * (CrankshaftSpeed);
5     if (CrankshaftSpeed < 0)
6       crankAngle = 2 * pi - crankAngle;
7     end
8     crankAngleFromPistonsAndMeasurementCircuit(CrankshaftSpeed, crankAngle);
9   end
10  if ((CrankshaftSpeed > 0) && (CrankshaftSpeed < 1000)) || (CrankshaftSpeed < 0 && (CrankshaftSpeed > -1000))
11    crankAngleFromPistonsAndMeasurementCircuit(CrankshaftSpeed, crankAngle);
12  end
13  crankAngleFromPistonsAndMeasurementCircuit(CrankshaftSpeed, crankAngle);
14  crankAngleFromPistonsAndMeasurementCircuit(CrankshaftSpeed, crankAngle);
15  crankAngleFromPistonsAndMeasurementCircuit(CrankshaftSpeed, crankAngle);
16  crankAngleFromPistonsAndMeasurementCircuit(CrankshaftSpeed, crankAngle);
17  crankAngleFromPistonsAndMeasurementCircuit(CrankshaftSpeed, crankAngle);
18  crankAngleFromPistonsAndMeasurementCircuit(CrankshaftSpeed, crankAngle);
19  crankAngleFromPistonsAndMeasurementCircuit(CrankshaftSpeed, crankAngle);
20  crankAngleFromPistonsAndMeasurementCircuit(CrankshaftSpeed, crankAngle);
21 end

```



Engine Block: Represents the combustion dynamics of the spark ignition engine.

Sensor Blocks: Simulate the crankshaft position sensor, oxygen sensor, and vibration sensor.

OBD Module Block: Implements the fire failure detection algorithm.

Control Unit Block: Processes OBD outputs and triggers corrective actions.

4. Working Principle

The methodology involves the following steps:

1. System Modeling

Mathematical models are developed for the engine, sensors, and OBD module. For example, the engine speed

ω

ω is modeled as:

$$\omega = \frac{T_e - T_l}{J}$$

Where:

T_e is the engine torque,

T_l is the load torque,

J is the moment of inertia.

4.2 Simulation Setup in Simulink

The Simulink model is constructed using the following blocks:

Engine Block: Represents the combustion dynamics of the spark ignition engine.

Sensor Blocks: Simulate the crankshaft position sensor, oxygen sensor, and vibration sensor.

OBD Module Block: Implements the fire failure detection algorithm.

Control Unit Block: Processes OBD outputs and triggers corrective actions.

The simulation is run for different scenarios, such as single-cylinder fire failures, multi-cylinder fire failures, and varying engine loads.

5. ECONOMICS

The fire failure detection system provides significant economic benefits, including:

Reduced Maintenance Costs: Early detection of fire failures prevents costly repairs.

Improved Fuel Efficiency: Correcting fire failures optimizes combustion and reduces fuel consumption.

Regulatory Compliance: Avoiding penalties for non-compliance with emission standards.

6. FUTURE PROSPECTS

Future research can focus on:

Advanced Algorithms: Developing machine learning-based fire failure detection algorithms for higher accuracy.

Integration with Hybrid Systems: Adapting fire failure detection for hybrid and electric vehicles.

Wireless Diagnostics: Implementing wireless OBD systems for remote monitoring and diagnostics.

7. LIMITATIONS

The current system has the following limitations:

Sensor Accuracy: Fire failure detection relies on accurate sensor data, which can be affected by noise and calibration errors

Computational Complexity: Advanced algorithms may require significant computational resources.

Real-Time Constraints: The system must process data in real time, which can be challenging under high engine loads.

8. RESULTS

The simulation results demonstrate the system's performance under various conditions.

Key findings include

Detection Accuracy: The system accurately identifies single-cylinder and multi-cylinder fire failures.

Response Time: The algorithm detects fire failures within a few engine cycles.

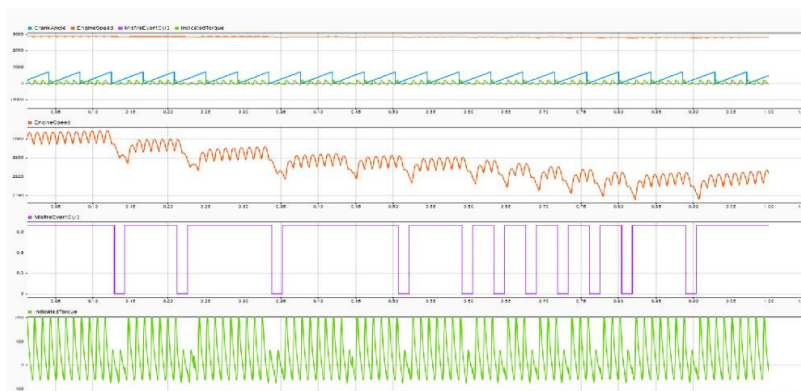
False alarms: The system minimizes false alarms by filtering out noise and irrelevant signals.

Simulation Data Inspector: Inspect

Report Generated 06-Jul-2024 08:07:39

OBD Signals

Name	Line
CrankAngle	Blue
EngineSpeed	Orange
MisfireEventCyl3	Purple
IndicatedTorque	Green



CONCLUSION

The fire failure detection system using onboard diagnostics and MATLAB Simulink provides an effective solution for identifying and addressing fire failures in spark ignition engines. The results highlight the importance of accurate signal processing and advanced algorithms in achieving reliable fire failure detection. Future work can build on this foundation to explore advanced diagnostics and control systems for modern engines.

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EMERGENCY GENERATOR START-UP USING IOT FOR REMOTE OPERATION AND RISK MITIGATION IN MANUAL STARTING

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ABSTRACT

This paper discusses the development of a remote start up system for emergency generators using the Internet of Things (IoT) technology. In the event of a power failure, the emergency generator is required to start and supply power within 45 seconds. However, in cases where automatic starting fails due to relay malfunctions, operators are required to manually start the generator, which can be hazardous and time-consuming. This project aims to address the risks and challenges associated with manual starting by enabling a remote, IoT-based system for emergency generator start-ups. The system allows operators to remotely monitor, control, and start the generator, ensuring safer and faster operations. The paper covers the design, methods, techniques, and testing of the IoT-based emergency generator start up system.

KEYWORDS

Emergency generator, IoT, remote start, risk mitigation, manual start, relay malfunction, safety, automation, blackout.

1. INTRODUCTION

Emergency generators are a crucial part of the power backup systems for hospitals, data centres, industrial facilities, and telecommunications. These generators are designed to start automatically when the primary power source fails, ensuring minimal downtime. However, relay malfunctions or wiring issues may prevent the automatic start up from working, requiring manual intervention. In these situations, operators must go to the generator room and start the system, often under unsafe or difficult conditions, such as fires, smoke, or flooding. This exposes operators to health and safety risks and delays the restoration of power.

The manual process is time-consuming, prone to human error, and introduces additional hazards. Therefore, automating the startup process through remote operation via IoT technology can enhance safety, reduce downtime, and ensure a quicker response time. This

paper introduces an IoT-based system designed to enable the remote startup of emergency generators, preventing risks associated with manual startup.

2. OBJECTIVE

The primary objective of this work is to design and implement an IoT-based system that allows operators to start an emergency generator remotely if automatic starting fails. The system aims to:

- Provide an alternative to manual startup in case of relay failure.
- Ensure the emergency generator starts within the required time frame of 45 seconds after power failure.
- Enhance operator safety by reducing the need for physical intervention in hazardous conditions.
- Improve response times and operational efficiency by enabling remote control via IoT technologies.

3. NOVELTY/CONTRIBUTION

This work contributes to the automation of emergency generator systems by leveraging IoT technology to provide a safe and efficient way to start the generator remotely. The key contributions include:

- The integration of IoT devices for real-time monitoring and control of the emergency generator.
- A cloud-based remote interface that allows operators to detect faults and initiate startup from any location.
- A fail-safe mechanism that triggers the generator startup remotely when automatic relays fail.
- A robust system that provides real-time alerts to operators about the generator's health, fuel levels, and potential faults, allowing them to take action before the generator fails to start.

The novelty lies in the ability to mitigate the risks posed by manual interventions and relay malfunctions while ensuring a quick response to power failures.

4. WORKING PRINCIPLE

The IoT-based emergency generator startup system consists of the following components:

1. Generator Monitoring Unit

This unit includes various sensors (e.g., temperature, voltage, current, fuel level) to monitor the generator's health and operational status. These sensors are connected to a microcontroller (e.g., Arduino or Raspberry Pi) which processes the data and determines whether the generator is operating normally.

2. Relay Control System

The relay control unit is responsible for initiating the generator startup process. If the automatic system fails due to relay malfunctions, this system allows the generator to be started remotely. The relay can be controlled via IoT signals sent from a mobile app or cloud platform.

3. Cloud Platform & Communication Interface

The system uses a Wi-Fi or GSM module to connect the monitoring unit and relay control to a cloud platform. The data from the generator is sent to the cloud, where it can be accessed by the operator. A web or mobile application interface provides real-time information and allows operators to send commands to start the generator remotely.

4. Mobile Application/Remote Interface

The mobile app or web interface provides a user-friendly way for operators to monitor the generator's status and control it remotely. If a fault is detected, the operator can immediately trigger the generator startup command, ensuring quick restoration of power.

RESULTS

The IoT-based emergency generator startup system was successfully designed and tested. The key findings are as follows:

- **Reliability:** The system provided reliable performance in detecting faults in the automatic startup system. In simulated relay failure scenarios, the system was able to start the generator remotely within seconds via the mobile app.
- **Safety Improvements:** Operators were able to avoid entering hazardous areas, significantly reducing the risk of accidents associated with manual startup.

- Efficiency: The system reduced the time taken to restore power, with the generator starting within the required 45-second time frame, even in cases of relay failure.

- Cost-Effectiveness: While the initial setup cost for the IoT-based system was higher than traditional manual methods, it proved to be a more cost-effective long-term solution due to reduced downtime and enhanced safety.

CONCLUSION

The IoT-based emergency generator startup system provides an effective solution to mitigate the risks associated with manual startup during power failures. By enabling remote startup, the system improves operational efficiency, ensures faster recovery from power outages, and enhances safety by minimizing human intervention in hazardous environments. The integration of real-time monitoring and remote control through IoT technology allows operators to maintain better oversight of generator health and perform maintenance tasks proactively. Future improvements may include more advanced fault prediction algorithms and enhanced security features to further improve the system's reliability.

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THERMAL ENERGY STORAGE AND RETRIEVAL USING THERMAL BATTERY AND THERMOELECTRIC CELLS.

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ABSTRACT

Thermal energy storage (TES) is a crucial technology for efficient energy management, particularly in renewable energy systems and waste heat recovery applications. This study presents a novel approach to thermal energy storage and retrieval using a thermal battery integrated with thermoelectric cells. The thermal battery stores excess heat energy in a phase change or high-capacity thermal storage material, enabling efficient retention and controlled release of heat. Thermoelectric cells, based on the Seebeck and Peltier effects, convert the stored thermal energy into electrical power or assist in thermal regulation through active heat pumping. The integration of these technologies enhances energy efficiency, provides a stable power supply, and enables sustainable energy utilization in various industrial and residential applications. Experimental analysis and computational modeling are employed to optimize system performance, ensuring maximum energy conversion efficiency and effective thermal management. The proposed system offers a reliable and scalable solution for energy storage challenges, promoting the adoption of renewable energy and reducing dependency on conventional power sources.

1. INTRODUCTION

Thermal energy storage (TES) plays a vital role in energy conservation and efficient power management, particularly in renewable energy systems and waste heat recovery. The development of advanced TES systems can significantly improve energy utilization, reduce reliance on conventional power sources, and enhance sustainability. This study explores a novel thermal energy storage and retrieval system that utilizes graphite powder as a thermal storage medium and Peltier modules for thermoelectric energy conversion.

Graphite powder is chosen due to its excellent thermal conductivity, high specific heat capacity, and stability at elevated temperatures, making it an ideal material for efficient heat absorption and retention. The stored thermal energy can be effectively retrieved using Peltier modules, which operate based on the thermoelectric effect, converting temperature gradients into electrical energy. Additionally, Peltier modules can facilitate active heat transfer, improving system efficiency and enabling precise thermal management.

The integration of graphite powder as a thermal battery with Peltier modules presents a promising approach to enhancing TES performance. This study focuses on the design, experimental validation, and computational modeling of the system to optimize energy conversion efficiency and ensure effective heat storage and retrieval. The proposed system has potential applications in renewable energy storage, electronic cooling, industrial waste

heat recovery, and decentralized power generation, contributing to sustainable energy solutions.

2. WORKING PRINCIPLE

A Peltier module, is also known as thermoelectric cooler (TEC), can work in reverse as a thermoelectric generator (TEG) based on the Seebeck effect. When a temperature difference is maintained across the two sides of the module, it generates an electric voltage, which can be used for power generation.

Principle: The Seebeck Effect

- The Peltier module consists of multiple thermoelectric p-type and n-type semiconductor pairs (thermocouples) arranged between two ceramic plates.
- When one side of the module is heated while the other side is cooled, a temperature gradient is created.
- Due to the Seebeck effect, charge carriers (electrons in n-type and holes in p-type) move from the hot side to the cold side, generating a potential difference (voltage).
- This voltage drives a current when connected to an external circuit, enabling power generation.

Working Process

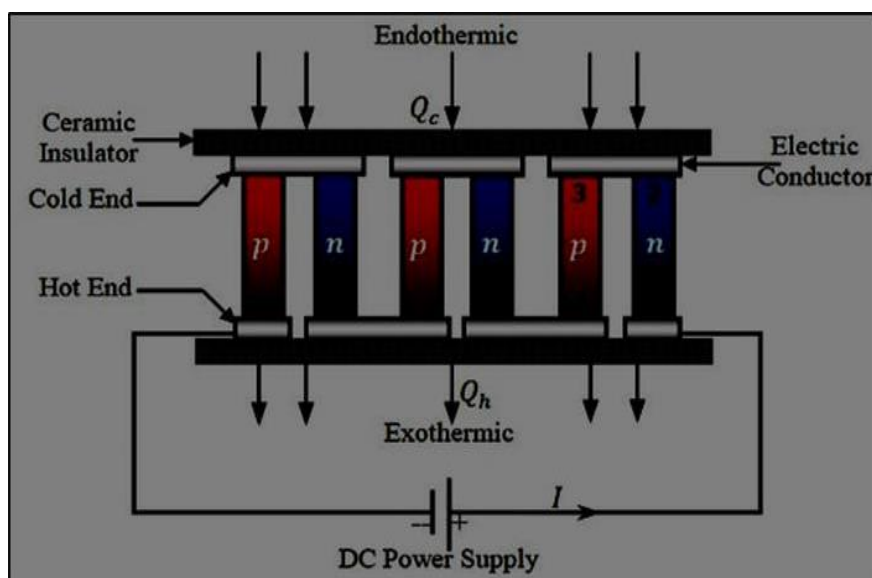
1. Temperature Difference Creation

- One side of the Peltier module is exposed to a heat source (e.g., waste heat, sunlight, or a heated surface).
- The other side is maintained at a lower temperature using a heat sink, cooling system, or natural convection.

2. Voltage Generation

- The temperature gradient induces the movement of charge carriers, resulting in a voltage output.
- The generated voltage is proportional to the temperature difference (higher ΔT = higher voltage)

3. DIAGRAM



CONCLUSION

This project successfully demonstrates the feasibility of a thermal energy storage and retrieval system using graphite powder as a thermal battery and a Peltier module as a thermoelectric generator. The combination of these technologies enables efficient heat storage, controlled energy release, and direct conversion of thermal energy into electrical power. Graphite powder, with its high thermal conductivity and heat retention properties, enhances the efficiency of thermal storage, while the Peltier module efficiently converts the stored heat into usable electrical energy through the Seebeck effect.

AUTONOMOUS WATER SURFACE CLEANING ROBOT

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1. INTRODUCTION

Water pollution from floating debris and oil spills is a significant issue for aquatic ecosystems and human health. Traditional cleaning methods are labor-intensive and inefficient. This concept introduces an autonomous water surface cleaning robot, inspired by vacuum cleaner technology, utilizing advanced systems like telematics, Pixhawk, Raspberry Pi, and lightweight, FRP. This design enhances large-scale cleaning capabilities while being efficient, eco-friendly, and autonomous.

2. CONCEPT OVERVIEW

The robot's core design is centered on adapting a vacuum cleaner's suction mechanism to collect floating debris, microplastics, and oil spills from water surfaces. Integrated with advanced navigation and communication technologies, it allows remote control and real-time monitoring.

- *Key Features*

- Vacuum Suction System: Collects debris and oil effectively.
- Telematics: Provides real-time data transmission and remote control.
- Pixhawk Autopilot: Facilitates autonomous navigation and obstacle avoidance.
- Raspberry Pi: Manages sensors, cameras, and data processing.
- Fiber Reinforced Polymer Build: Lightweight, strong, and corrosion-resistant for long-term use.

3. KEY COMPONENTS OF THE ROBOT

a) *Vacuum Suction Mechanism*

Captures pollutants using a suction inlet positioned above the water surface. It features adjustable suction power and an oil collection system using a skimming mechanism to handle various contaminants.

b) *Debris Collection Chamber*

Collects and stores debris, separating water with a filtration system. It includes capacity sensors for easy maintenance.

c) *Propulsion and Steering System*

Propelled by thrusters or optional carbon fiber paddle wheels, controlled by the Pixhawk system for smooth navigation and obstacle avoidance.

d) *Telematics and Communication*

Provides real-time data such as location, battery status, and collected debris levels. Remote control can be activated if manual intervention is needed.

e) Autonomous Navigation (Pixhawk & GPS)

Allows for GPS-based navigation and obstacle detection with ultrasonic sensors and cameras, ensuring efficient coverage of water bodies.

f) Processing Unit (Raspberry Pi)

Manages real-time sensor data, making decisions for navigation, data logging, and improving efficiency through environmental insights.

g) Power Supply

Powered by high-capacity rechargeable batteries with modular design for easy replacement, ensuring long operation times.

h) Build Materials

Constructed using durable material, FRP, offering strength, durability, and lightweight properties for energy efficiency and corrosion resistance.

4. OPERATIONAL WORKFLOW

1) Deployment

The robot can be deployed manually or autonomously from a docking station or boat.

2) Autonomous Navigation

Using GPS and Pixhawk, the robot follows a pre-programmed cleaning route or adapts to real-time data for optimal coverage.

3) Debris Collection

The suction mechanism activates as the robot moves, pulling in debris and oil into the collection chamber.

4) Real-time Monitoring

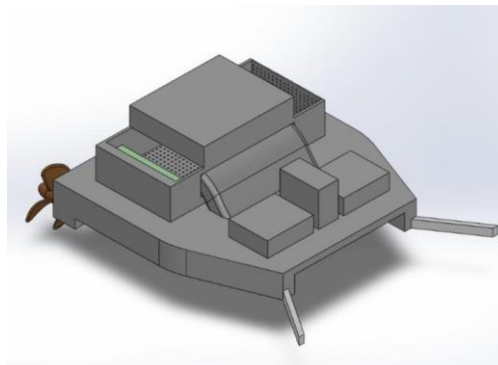
Telematics allows operators to monitor the robot's status, adjust routes, and check collected data remotely.

5) Data Transmission

Data such as debris collected, water quality, and battery status are transmitted in real time for analysis.

6) Return to Docking Station

When the battery is low or the debris chamber is full, the robot autonomously returns to its docking station for charging and debris offloading.



5. APPLICATIONS

- Lakes and Rivers

Cleans small water bodies with accumulated floating debris.

- Coastal Areas and Harbors

Effective in coastal cleaning and oil spill mitigation.

- Industrial Spill Response

Handles oil and chemical spills near industrial zones.

- Environmental Monitoring

Monitors water quality, aiding in pollution detection.

6. ADVANTAGES

- Efficiency & Cost-effectiveness: Autonomous, continuous cleaning reduces labor costs.

- Real-time Monitoring & Data Collection: Allows remote monitoring and operational improvements.

- Autonomous & Remote Operation: Fully autonomous, with remote control options available.

- Sustainable & Eco-friendly: Energy-efficient systems and durable materials minimize environmental impact.

- Customizable & Scalable: The modular design allows for easy customization and scaling to larger cleaning operations.

7. CHALLENGES AND FUTURE DEVELOPMENTS

-High cost of designing a prototype

- Battery Life and Power Efficiency: Hybrid power systems could extend operational time.

- Advanced AI for Improved Autonomy: AI and machine learning could optimize cleaning strategies and adaptability.

- Swarm Robotics: Coordinated deployment of multiple robots could increase cleaning efficiency over larger areas.

CONCLUSION

The autonomous water surface cleaning robot, equipped with advanced systems like telematics, Pixhawk, Raspberry Pi, and built from durable material namely Fibre Reinforced Polymer, offers a revolutionary solution to water pollution. Its vacuum cleaner-inspired suction system, combined with autonomous navigation and real-time monitoring, provides an eco-friendly, cost-effective way to clean lakes, rivers, coastal areas, and respond to oil spills. As a scalable and adaptable platform, this robot represents the future of water surface cleaning and environmental protection. With continuous advancements in AI, power efficiency, and modular design, the potential for improving water ecosystems is immense.

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SMART SURVEILLANCE SYSTEM USING MULTIMODAL LLMs

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ABSTRACT

This project addresses the challenge of effectively integrating diverse sensory inputs and natural language processing in current surveillance systems. It aims to develop a system that utilizes Large Language Models (LLMs) with multimodal inputs to enhance real-time interpretation and response capabilities. The system integrates LLMs for natural language understanding and computer vision for visual analysis, creating a cohesive unit for advanced active perception and interaction. The goal is to enable a surveillance system to identify armed personnel by processing visual and textual/speech data in real-time to detect weapons and report threats accurately. Key outcomes include enhanced multimodal processing, accurate weapon identification, real-time threat detection, and effective threat reporting, ultimately improving automated, intelligent surveillance.

OBJECTIVE

To develop a Multimodal Surveillance System that integrates visual and linguistic inputs for enhanced real-time threat detection. The system aims to conduct close-quarter surveillance, identifying the presence of armed personnel by analyzing visual surveillance data and transcribed speech. By leveraging computer vision, speech processing, and LLM-driven decision-making, the system will improve situational awareness, threat assessment, and automated reporting capabilities

1. INTRODUCTION

Surveillance systems play a critical role in security, but traditional methods often rely on single-modality inputs, such as only video or only audio, limiting their ability to provide a comprehensive understanding of a situation. Human perception, on the other hand, is multimodal—we interpret the world by combining sight, sound, and language, which allows for more accurate and context-aware decision-making. Inspired by this, modern artificial intelligence (AI) is now leveraging Multimodal Large Language Models (MM LLMs) to process and integrate multiple sensory inputs in a more human-like manner.

MM LLMs have revolutionized computer vision and natural language processing by enabling systems to understand and correlate information from different modalities. This integration enhances perception by allowing AI to contextualize images, interpret spoken or written commands, and generate meaningful insights rather than processing these inputs separately. In surveillance applications, such capabilities are invaluable, as they enable security systems to detect, analyze, and respond to potential threats with greater accuracy and intelligence.

For example, by combining visual and linguistic processing, a surveillance system can not only identify the presence of an armed individual but also understand verbal commands, generate real-time reports, and respond to specific queries about a security situation. This heightened perception reduces false alarms, improves decision-making, and enhances real-time situational awareness, making surveillance

systems far more effective in critical environments such as military bases, high-security facilities, and public spaces.

With the advancements in multimodal AI, security technology is moving beyond simple object detection and motion tracking, toward systems that comprehend and interact with their environment intelligently. This project explores the potential of integrating multimodal AI models for enhanced active perception, with the goal of creating a more responsive, intelligent, and effective surveillance system that can support security personnel in detecting and mitigating threats in real time.

2. CONCEPT

Traditional surveillance systems rely on isolated video or audio analysis, limiting their ability to provide a complete situational understanding. This project integrates multimodal Large Language Models (MM LLMs) to process and correlate visual and linguistic inputs, enhancing real-time threat detection and response.

By combining computer vision and natural language processing, the system can:

- Identify threats, such as armed personnel, from video feeds.
- Interpret verbal queries for seamless human-AI interaction.
- Generate detailed threat reports in natural language.

This multimodal approach improves situational awareness, reduces false alarms, and enhances decision-making, making surveillance systems more intelligent, responsive, and efficient.

3. WORKING PRINCIPLE

The system is designed as a LangChain-based pipeline, enabling seamless integration of speech, text, and visual data for real-time surveillance and threat detection. The workflow is structured as follows:

1. *Speech-to-Text Conversion*

- A verbal query or description is given as input to Whisper, which transcribes it into text.
- This allows the system to process spoken queries or contextual descriptions from an operator.

2. *Multimodal Threat Analysis*

- The transcribed speech is incorporated into a structured prompt for Unsloth LLaMA.
- The surveillance image is also fed into Unsloth LLaMA alongside the prompt.
- The prompt follows a format such as: "What do you see in this image? {Whisper Transcription}. Is there a threat present?"

3. *Threat Identification & Contextual Awareness*

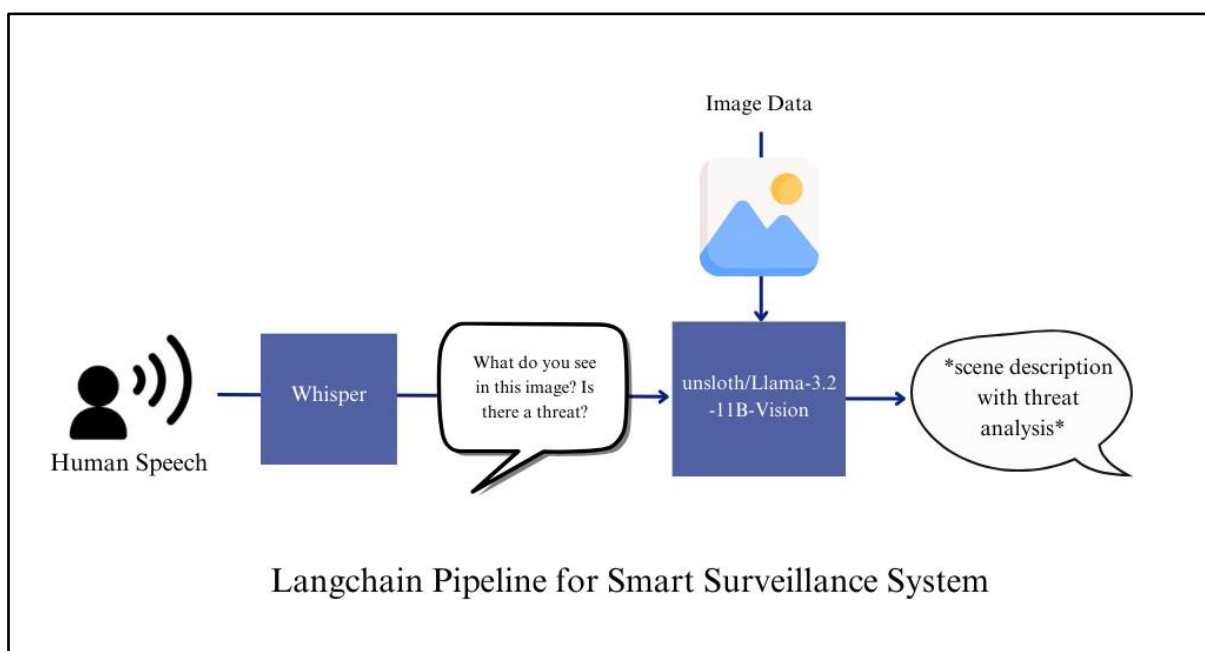
- The fine-tuned Unsloth LLaMA, trained on a custom dataset of Indian military personnel and armed threats, interprets the visual and textual input.
- It can differentiate between Indian Army, Navy, and Air Force personnel versus unauthorized armed individuals, ensuring accurate classification of threats.

4. *Automated Threat Reporting*

- If a threat is detected, the system generates a natural language report detailing the presence and type of armed personnel.
- This report can be logged, displayed, or transmitted to security teams for immediate action.

By combining speech, text, and vision in a single processing flow, this pipeline enables a more intelligent, responsive, and context-aware surveillance system, significantly improving real-time situational assessment.

4. DETAILED DIAGRAM:



5. RESULTS (TABLES/GRAPHS)

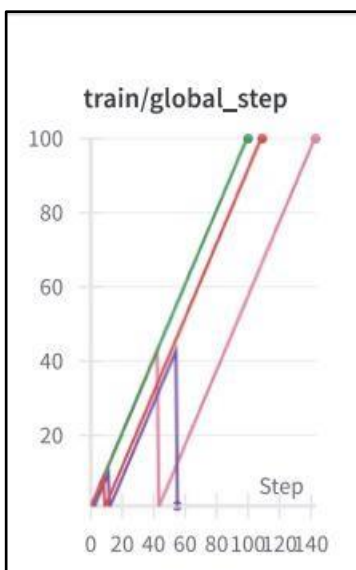
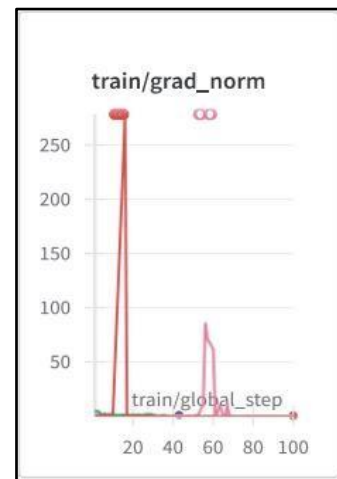
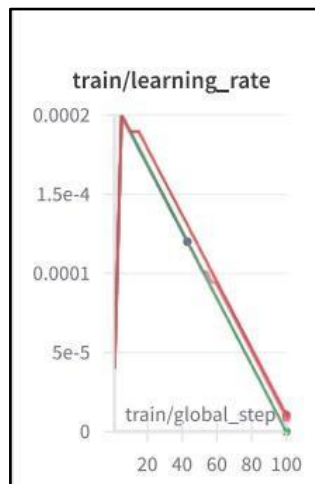
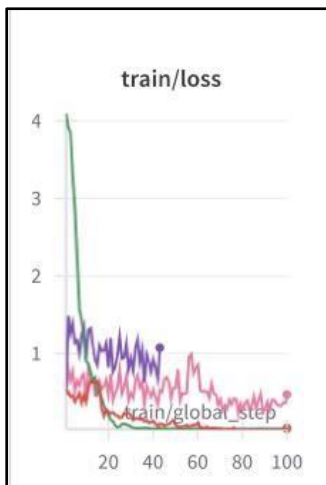
5.1 Untrained Model Inference

Instruction: "Provide a summary of the scene based on what you observe."

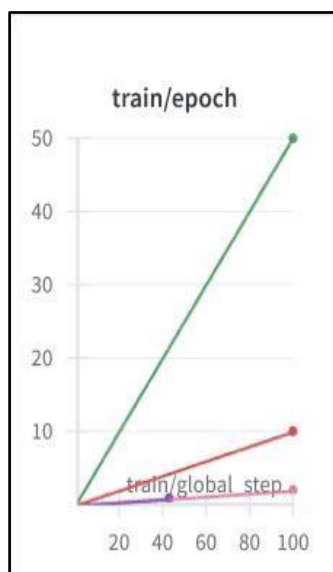
Result: "The image depicts a group of uniformed men in white marching in unison, with a prominent figure in the foreground holding a sword. The man appears to be a military officer or leader, as evidenced by his uniform, which includes a white shirt, pants, and boots, as well as a black belt and a white hat adorned with a gold emblem on the front."

5.2 Training Metrics

Trained Model Inferences:



5.3



▼ **Summary metrics:** {} 10 keys

- total_flos: 4,671,550,647,974,460
- train_loss: 0.5196749804913998
- train_runtime: 2,818.786
- train_samples_per_second: 0.284
- train_steps_per_second: 0.035
- train/epoch: 1.9751243781094527
- train/global_step: 100
- train/grad_norm: 0.7747872471809387
- train/learning_rate: 0.00000842105263157895
- train/loss: 0.4718



Instruction: "Provide a summary of the scene based on what you observe."

Result: "This image depicts Indian Navy female soldiers standing near a helicopter. They are dressed in white uniforms, complete with white caps and gold badges. The soldiers appear to be in a relaxed setting, with no visible threat.."



Instruction: "Provide a summary of the scene based on what you observe."

Result: "The image depicts five Indian army soldiers in camouflaged uniforms, each holding a rifle. They are positioned in a line, suggesting they are part of a team or unit. The setting appears to be a tactical or operational environment, possibly during a training exercise. The presence of multiple soldiers with rifles indicates a high alert status or a mission-sensitive area."



Instruction: "Provide a summary of the scene based on what you observe."

Result: "The scene depicts five Indian Air Force (IAF) pilots standing in front of a fighter jet, posing for a photograph. They are all wearing green flight suits adorned with various insignias, indicating their affiliation with the IAF. The presence of a fighter jet in the background further reinforces their military role. The pilots appear to be relaxed, possibly taking a break from a mission or awaiting further instructions. The image showcases their professionalism and pride in serving the Indian Air Force."



Instruction: "Provide a summary of the scene based on what you observe."

Result: "This image features three Indian military officers standing together in a formal setting. The officer on the left, wearing a black uniform with a green beret, appears to be part of the Indian Army. The officer in the center, dressed in a light blue air force uniform with a blue turban, is likely from the Indian Air Force. The officer on the right, clad in a white uniform with a navy blue cap, seems to belong to the Indian Navy."

As can be seen from the results, after training the system on a large amount of images and their corresponding annotations, the system is able to accurately identify and differentiate between Indian Army, Indian Navy and Indian Air Force officers. It can also identify the presence of a threat.

CONCLUSION

The successful integration of multimodal large language models (LLMs) in surveillance systems demonstrates the potential for advanced situational awareness and intelligent threat detection. By leveraging Whisper for speech processing, BLIP-2 for annotation, and Unsloth LLaMA for multimodal reasoning, the system effectively analyzes and interprets both textual and visual data in real-time.

The model's ability to accurately identify different branches of the Indian military, distinguish between personnel types, and assess the presence of threats marks a significant improvement over traditional surveillance methods. Unlike conventional systems that rely solely on visual pattern recognition, this approach incorporates contextual understanding through natural language processing, leading to more precise and meaningful threat assessments.

A key advantage of this approach is its adaptability. As long as the model is trained on an appropriate dataset, it can be tailored for various surveillance applications, such as monitoring military facilities, data centers, banks, and other high-security zones. The more the model is trained, the more refined and effective its detection and reasoning capabilities become, making it a scalable and future-proof solution for diverse security needs.

With enhanced perception and real-time response capabilities, this technology offers a powerful solution for automated surveillance, minimizing human intervention while improving accuracy, reliability, and efficiency. The adoption of such multimodal AI-driven systems has the potential to revolutionize military security, law enforcement, and critical infrastructure protection, ultimately contributing to safer and more intelligent surveillance environments.

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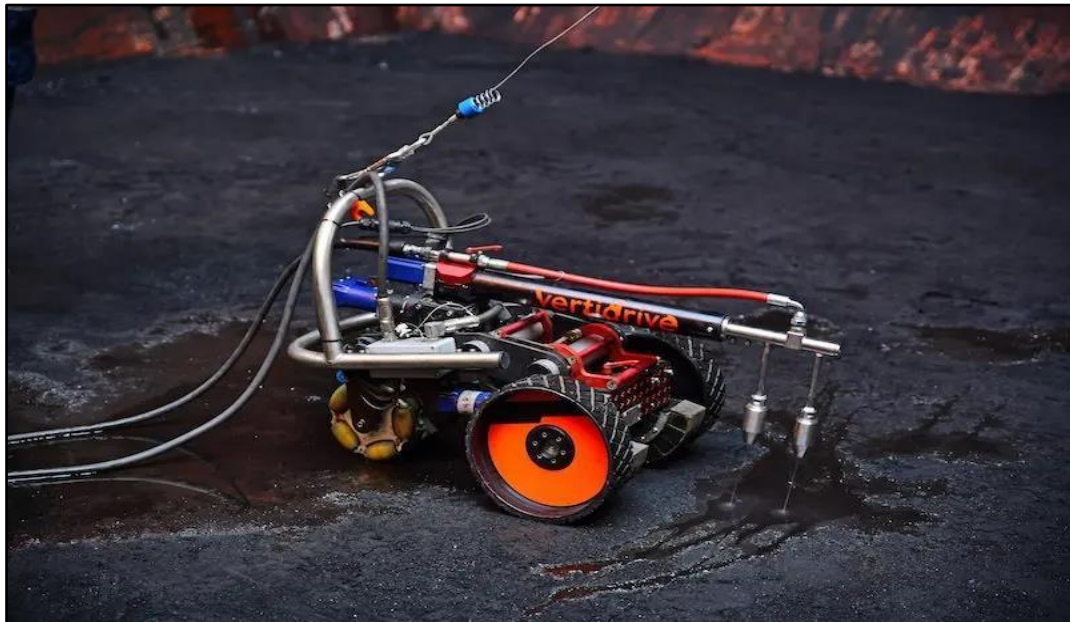
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AUTONOMOUS UNDERWATER HULL CLEANING ROBOT SYSTEM

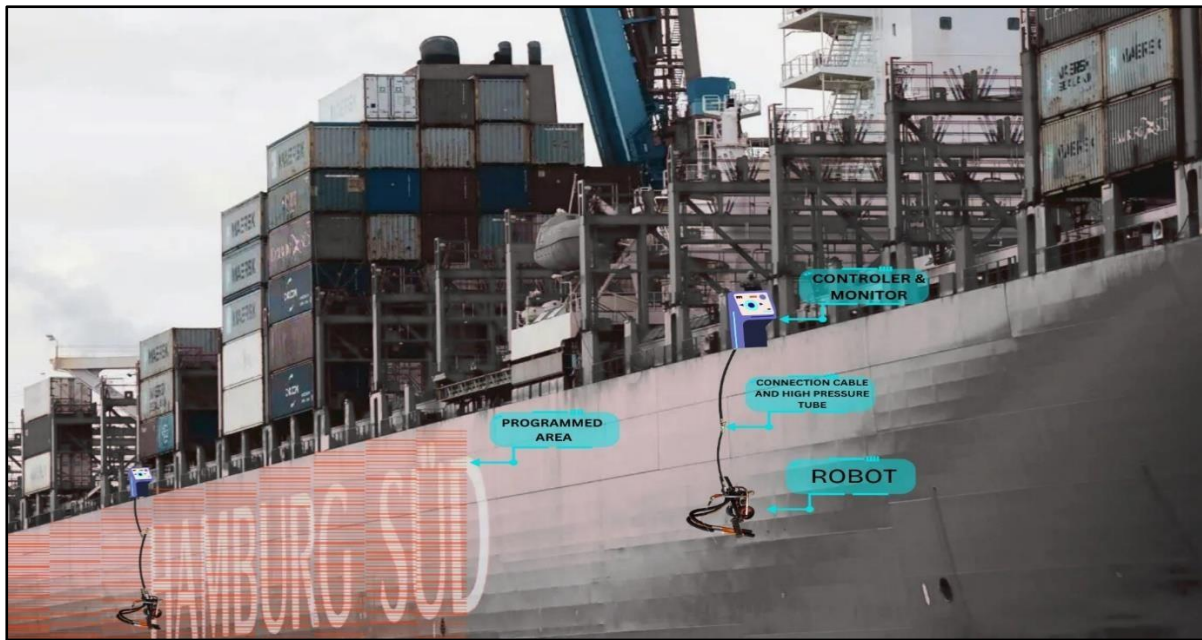
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1. INTRODUCTION

The maritime industry faces significant challenges related to biofouling, which is the accumulation of microorganisms, plants, algae, and small animals on the ship's hull. Biofouling increases drag, reduces fuel efficiency, and leads to higher greenhouse gas emissions. Traditional hull cleaning methods are time-consuming, expensive, and often require dry-docking, which results in operational downtime.



This project proposes the development and deployment of an autonomous Ship Hull Cleaning Robot System that can clean the hull while the ship is at anchor. The system consists of two robots, one for each side of the ship, which operate based on a pre-programmed cleaning schedule. The robots will use advanced technologies such as AI, robotics, and underwater navigation to ensure efficient and eco-friendly cleaning.



Autonomous Cleaning Robots:

- Two robots (one for each side of the ship) equipped with cleaning mechanisms such as brushes, water jets, or ultrasonic systems to remove biofouling.
- Designed to operate underwater while the ship is at anchor, eliminating the need for dry-docking.

AI-Powered Navigation and Control:

- AI algorithms for path planning and obstacle avoidance to ensure the robots move efficiently across the hull.
- Machine learning models to adapt cleaning patterns based on the level and type of biofouling.



2. SYSTEM WORKS

Deployment:

- The robots are deployed into the water while the ship is at anchor or in port.
- They use their navigation systems to locate and attach to the ship's hull.

Monitoring and Feedback:

- Sensors on the robots monitor cleaning progress and hull conditions.

Completion and Retrieval:

- Once cleaning is complete, the robots detach from the hull and return to a docking station for recharging and maintenance.

3. BENEFITS OF THE SYSTEM

Operational Efficiency:

- Reduces the need for dry-docking, minimizing operational downtime.
- Enables frequent and proactive cleaning, preventing severe biofouling

buildup. Cost Savings:

- Lowers fuel consumption by maintaining optimal hull conditions, reducing drag.
- Decreases maintenance costs associated with traditional cleaning methods.

Environmental Impact:

- Reduces greenhouse gas emissions by improving fuel efficiency.
- Uses eco-friendly cleaning methods to protect marine

ecosystems. Scalability and Adaptability:

- Can be customized for different ship sizes and hull designs.
- Suitable for use in various maritime environments, including ports and open waters.

4. SAFETY:

- Eliminates the need for human divers, reducing risks associated with underwater cleaning operations.



CONCLUSION

The Autonomous Ship Hull Cleaning Robot System is a groundbreaking innovation poised to revolutionize the way the maritime industry addresses biofouling. By harnessing the power of AI, robotics, and advanced underwater navigation, this system offers a sustainable and efficient solution to a long-standing problem. It eliminates the need for costly and time-consuming dry-docking, reduces fuel consumption, and minimizes environmental impact, all while maintaining optimal hull conditions. As the maritime sector continues to prioritize sustainability and operational efficiency, this autonomous cleaning system stands out as a vital tool for the future. Its adoption could lead to significant economic and environmental benefits, setting a new standard for ship maintenance worldwide.