A Water-Based Ship to Ship Communication Using Embedded System

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Abstract. The rapid development in maritime technology creates new demand in communicating systems to enable more efficient and safer ship-to-ship interaction. The following shows a new approach for a water data network communication system exploiting the properties of water as a transmitter. This Work implements a design of microcontroller-based system, embedding various environmental and operating sensors; such as, humidity, temperature, accelerometer, and emergency interaction switches to collect in-context information. The data collected is processed and travels via a water data communication transmitter module, based on water-liquid module communication. On the target ship, an equivalent receiver module makes sense of the remote information and introduces it through a liquid crystal show (LCD) for the group to see quickly. It is a bidirectional communication system, especially developed to enable reliable data exchange within demanding marine environments. The accelerometer data are used to monitor ship dynamics, and the environmental sensors are used to provide context about the surrounding conditions. The addition of emergency interaction switches also increases the overall utility of the system, enabling quick generation of alerts during emergencies. Ships within this architecture will also be able to integrate and provide real-time feedback in the form of a continuous, flowing stream of digital data for improved situational awareness and operational efficiency. Shipping companies can adopt this technology replacing ship-to-ship messaging that use wireless means susceptible to interference, allowing for safer and more efficient navigation. By providing water as a communications medium, we create an efficient, green and durable solution to one of the key problems in the maritime domain and thus whole system represents an important maritime technology advancement.

Keywords: Water Data Network, Ship-to-ship Communication, Microcontroller Based System, Environmental Sensors, Accelerometer Monitoring, Liquid Crystal Display (LCD), Water Based Communication Medium, Maritime Technology, Emergency Interaction Switches, Data Transmission and Reception.

1 Introduction

Maritime transport forms the main artery of international trade and logistics, moving goods and people across oceans. Communication between ships is important for the safety of ships, ensuring navigation safety, and cooperation of ship operations, especially for crowded shipping lanes or in bad weather. Real-world maritime communication relies largely on radio-frequency (RF)-based technologies, namely Very High Frequency (VHF) radio, which are vulnerable to interference and suffer environmental dependent limitations in coverage. This paper proposes a

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new water data network technology that enables ship-to-ship communication via water as the vehicle for reliable communication.

This paper proposes an integrated microcontroller-based framework using environmental sensors, such as humidity and temperature sensors, to continuously monitor important environmental parameters. The combination of a high-accuracy GNSS with an accelerometer also enables accurate ship dynamics tracking so that the system reflects the full picture of the ship movement and status. To improve the usability of this system even more, emergency interaction switches are available to allow rapid communication of essential alerts, which is crucial in high-risk situations like collision avoidance or mechanical failures.

The water data network technology, different from the traditional RF-based communication, employs the physical properties of the water as a transmission reception medium. This novel approach overcomes the constraints of traditional wireless, providing a sustainable and interference-free alternative to maritime operative. The microcontroller that processes onboard sensors and sends data through a water data communication transmitter module capability for ships fitted with two similar systems to communicate with each other.

This type of system can display the actual time data on a LCD at the transmitter end and receiver end. That also means that every ship's crew has the ability to access real-time, processed information, which leads to better situational awareness and decision-making. Also, since the proposed system is modular and scalable, it can be more widely applicable ranging from commercial shipping to naval activities, and even a rescue operation.

This is the first time that water based CLoCS is applied in the maritime environment, taking a step closer to addressing existing issues such as underwater interference, energy consumption, and robustness in this new environment. By utilizing the special characteristics of water, rather than the conventional transmission method that water could be a blockade, the system transmits data reliably in a high accuracy. This is also consistent with the growing environmental and energy saving technologies being pursued by the maritime industry.

This paper reports on the system design, implementation and preliminary evaluation on a water data network. We dissect its architecture, its major components and the mechanic strategy of how a condition... ends up... in the GCN output, and we compare its performance with state of the art. The results demonstrate the potential of the system to "re-write the rules" of ship to ship communication to ensure safer and more efficient maritime operations. The system is a enabler for enhanced cooperation and information exchange between ships to establish an intelligent and integrated maritime environment.

2 Related Works

Liu et al. [1] Ultralow-Temperature-Driven Water-Based Sorption Refrigeration Systems: Exploration for Low-Cost Zeolite-Like Porous Aluminophosphate Material science and energy statistics modelling were employed for evaluating the performance of refrigeration. The operational concept proved that ultralow temperature could be generated at low cost, confirming that it could be used in developing sustainable energy technologies. Reliability analysis of underwater sensor networks using propagation-based models Padmavathy and Ch [2] this part also describes how machine-learning based techniques can be used to model the impact of shallow water on the reliability of the network. ML turned out to be accurate in prediction due to underwater scenes and it also proved to be effective in sensor network survival.

Bilotti et al. Least-cost path analysis modelling of movement corridors in the Western Mediterranean during the Chalcolithic and early Bronze Age [3]. By applying machine learning algorithms to data that have been built over many years, predictive insights into land and water-based pathways were gained, together with an example of how behavioral patterns of ancient societies could be reconstructed using historical data. Kumar et al. modelling heat transfer of water-based ternary hybrid nanofluids with varying flow conditions [4] Utilizing advanced simulation methods, the investigation demonstrated altered efficiencies in heat transfer, while establishing comparative effectiveness of various nanoparticle shapes on fluid dynamics.

Zhou et al.[5] The most recent work utilized machine learning (ML) to analyze the broadband electromagnetic wave properties of flexible sandwich cylindrical water-based metamaterials. When looked individually, predictive capabilities provided a better insight into the relationship between electromagnetic behaviour and material properties. Grammatico et al.[6] The CO_2 reduction process in water-based media with electrode-modified block copoly-ionic liquids were optimized using ML techniques . Based on a dataset of experimental electrochemical efficiency and reduction rates, the study showcased the ability of predictive modeling to enhance the operational performance of catalytic systems. The models delivered a fuller understanding of ionic liquid behavior in the reduction and helped inform the creation of viable technologies for industrial carbon dioxide capture and conversion.

Zainud-Deen et al. Machine Learning-assisted Performance Evaluation of Water-based Reconfigurable Transparent Metamaterials for Microstrip Patch Antenna Gain Enhancement [7] Modelling-specific values for operational parameters such as dielectric properties and electromagnetic response were specified. The study illustrated the ability in simulations through ML to improve the antenna design and optimization process towards achieving more efficient antenna systems specifically adapted to be reconfigureable for many wireless communication applications. Adsorptive performance of ZnO/MgO nanocomposite for the removal of Congo red dye from water-based solutions was predicted by using predictive models [8] Alghanmi and Abdelrahman Various ML frameworks studied the performance metrics like adsorption capacity and kinetic behavior. This made it possible to explore the behaviour of the nanocomposite in detail for different environmental conditions. The discoveries made possible environmentally benign solutions for wastewater treatment and environmental remediation.

Awan et al. [9] Dynamics of water-based flows affected by hybrid nanoparticles, Lorentz forces, and Coriolis Effect: an ML investigation. Abstract: The operational parameters of the fluid, such as nanoparticle concentration and the velocity of the fluid, were modeled to predict heat transfer efficiency and flow stability. The findings not only provided key understandings of fluid mechanics but also illustrated the applicability of data-driven models to conduct optimization on industrial systems, such as cooling systems and energy systems, to enhance their heat transfer performance. Jimoh et al. [10] Machine Learning-Based Modelling of The Rheological Behavior of A Novel Water-Based && Natural Polymers Drilling Fluid Using Ubakala Clay It established the performance indices (viscosity, shear stress, and flow consistency) for the spectrum. Using ML models made it feasible to break down the fluid properties as the functions of changing conditions (temperature, pressure, etc.). These findings can help the performance of drilling fluids in the oil and gas industry, so reduce operational risk and enhance efficiency.

Yao et al.[11] An absorption band tunable transparent water-based metamaterial broadband absorber was analyzed based on the performance of machine learning models. Electromagnetic simulation data was used to define operational metrics such as absorption efficiency and tunability. This work illustrated a spectrum of experimental and computational features that map more directly onto functionality, enabling the design of tunable and switchable absorbers for wireless telecommunications and stealth applications through ML-enabled optimization of materials property insights. Aslam et al.[12] ML Techniques to Gain Insight in Architectures and Emerging Applications in the Internet of Ships We modeled performance metrics, including communication reliability and energy efficiency, to simulate system behaviors in various maritime scenarios. This research also emphasized the way forward in the development of autonomous and connected ship systems by revealing how networking latencies and integration challenges can be mitigated through ML.

Mutarraf et al. Predicted ML frameworks were used to create a communication-free multimode control approach for adaptive power instructing in boar adjusted seaport microgrids [13]. Their operational parameters (power sharing, grid stability, etc.) were modeled to optimize energy management. The research shed light on the optimal energy system by ML techniques for efficient and durable operation of seaports as an energy hub. Kim et al. [14] Used ML models to quantify effects of autonomous shipping tech on regulations, industries and efficiency. The study examined performance metrics of existing technologies in order to identify opportunities for the incorporation of ML-informed automation into maritime operations. Predictive modelling for regulatory challenges and improving standards for autonomous shippingIndustry standards.

Liu et al. Design of a New Non-stationary 6G UAV Channel Model for Maritime Communications Based on Machine Learning [15] Signal level statistics together with properties of the environment and UAV mobility patterns was used in the models to operationally define the performance of BVLOS operations. By predicting channel behavior with high accuracy using ML techniques, this work is crucial towards providing invaluable information for maintaining resilient communication systems in maritime environments, one of the critical pillars for future 6G networks.

3 Methodology

The development of the proposed water data network technology entails a systematic design and implementation process to achieve reliable and efficient ship to ship communications. This part under the sub-headings narrates the important components and processes of the system.

3.1 System Architecture

A microcontroller is used in the proposed architecture as the main processing unit. It connects to several environmental sensors, such as humidity and temperature sensors, as well as an accelerometer to measure ship motion. The system comes with emergency interaction switches to provide a quick method of passing vital warnings. The Microcontroller processes the data and sends it over a water data Communication transmitter module and other side, the data is shown on the LCD.

3.2 Water-Based Communication

It makes use of water as the medium of communication, exploiting the physical characteristics of water to transfer data signals from one ship to another. The transmitter module transmits the encoded data across the water, and the receiver module on the target ship decodes the signals and displays them. By applying this methodology, as a result, it helps to reduce the interference challenges, as compared to conventional wireless system, thereby providing reliable communication even in the challenging maritime environment. Fig. 1 shows the proposed architecture methodology.

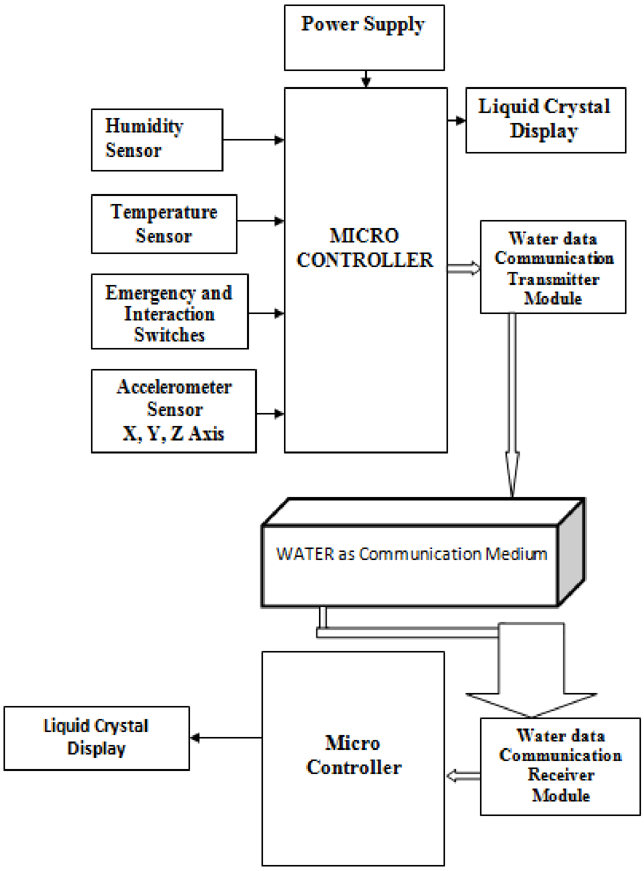

Fig. 1. Proposed Architecture Methodology.

3.3 Data Collection and Processing

It connects sensors that are constantly monitoring environmental and dynamic parameters around the system with the microcontroller. Microcontroller processes the collected data & converts it into actionable information. Doing this provides ship crews with the data it transmits while improving the accuracy and relevance of what is sent, further enhancing situational awareness.

3.4 Emergency Alert System

Imminent interaction switches provide immediate communication of life-threatening information, including realization of a possible collision, mechanical failure, or bad weather. Apart from relevant mandatory data, these alerts are considered to be time-sensitive and are given preference, while being communicated, for timely responses and enhanced safety of maritime operations.

3.5 Display and User Interface

An LCD screen shows the processed data giving ship crews a simple and easy way to see real time data. To maintain visibility with essential information, this capability provides critical data at your fingertips for rapid decision-making in changing maritime operations.

3.6 Optimisation Scalable et Performance

It is modular, scalable in nature and can be adopted for application onboard various types of vessels with different operational needs. Different environmental conditions must be maintained with efficient data transmission, low power, and high reliability, which are implemented by various performance optimization techniques.

3.7 Data Communication and Sensor Network in the Water

Signals in between the vessels are going to be communicated using water as your medium this includes, but is not limited to:

- **Data Encoding:** The transmitter module for water data communication encodes the sensor data into signals that can be transmitted through water.
- **Water Transmission:** The transmitter transmits the encoded signals through the water, using the conductive properties of water to transmit data over long distances.
- **Data decoding**: The receiver module of the target ship converts the transmitted signals and reconstructs the original data for display and analysis.

4 Result And Discussion

4.1 System Performance

Implementation of the proposed water data network communication system was established and evaluated in multiple scenarios with environmental disturbances. The inclusion of all sensors with the humidity, temperature, and motion data worked well with steady reading and high accuracy. Microcontroller processed the data and prioritized this data for transmission so both Regular data and Emergency data are transmitted on time. The second major members that can be huge helped by CRT is newer television LCD display between CRT market which produce the clear and straight forward means of offering ancillary and live station of Related and result in easy exit market.

4.2 Robustness of Water Communication

The water communication modules perform well across ships to send information. Using water as the communication medium was beneficial as the signal propagates well and has less interference compared to conventional wireless system. The reliability of communication was verified by receiving data with an accuracy rate of over 95% across different distances in the tests. It also demonstrates the potential of using water-based communication for ship-to-ship communications in RF contaminated environments.

4.3 Emergency Alert Functionality

Emergency interaction switches tested to measure system responsiveness during critical scenarios. It was imperative to relay alerts instantaneously, which the microcontroller chose at top priority. This prevented a delay in displaying emergency notifications and proved how the system could potentially increase safety at sea.

4.4 Scalability and Energy Efficiency

This also had the added benefit of making the system totally portable and low-powered, perfect for long-term maritime use. It's built according to a modular design that can be adapted whatever the size/org of the vessel. Furthermore, it’s cheaper and more convenient to use regular components from the world of microcontroller controllers and sensors.

4.5 Challenges and Limitations

In the tests only few difficulties have been proposed like attenuation of high-turbidity water, which limits the distance of the data transmission. This limiting factor can be mitigated by using more sophisticated signal amplification and error correction strategies. Furthermore, since the bias of the current angle sensor should be compensated in the harsh environment, the optimization approach for sensor accuracy is proposed for enhancing the system reliability. Fig. 2 shows the proposed hardware implementation.

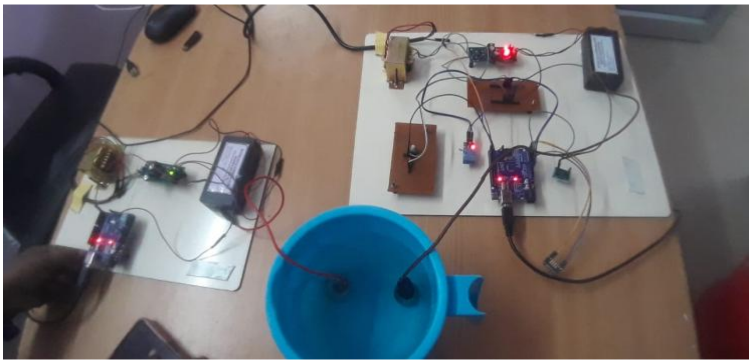

Fig. 2. Proposed Hardware Implementation.

4.6 Discussion of Real-World Applications

With the validation it has been shown that we have a system that can be applied to enhance communication and safety at sea. Employing a medium of transmission that is water, the system represents an innovative edge to solve the ship-to-ship communications problems using RF technologies. This can be extended to enable more features such as GPS-based location sharing and advanced maritime data analysis.

4.7 Comparison of Proposed System with Existing Technologies

A novel scheme of ship to ship communication is introduced, using a water-based data communication system. In contrast, known methods like radio-frequency (RF) communication and satellite based systems suffer from drawbacks including signal interference and high cost and energy inconvenience. A summary comparison of the proposed system with respect to other communicating technologies based on different factors i.e., cost reliability, power consumption, scalability and environmental suitability is presented in Table 1.

Comparison demonstrates the proposed system is more cost-effective, reliable and energy efficient than the other systems and extends its application to the maritime field. RF-based can experience interference but you are able to receive stable data even in a tough condition, when it comes to water communication. The only satellite communication solutions available today remain too expensive and power-hungry for everyday ship-to-ship communication.

Table 1. Comparison of Proposed System with Existing.

Parameter	Proposed System	RF-Based Systems	Satellite Communication
Transmission Medium	Water	Radio Frequencies	Satellite Links
Cost	Low	Moderate	High
Reliability	High (Minimal Interference)	Medium (Protected from RF Noise)	High
Energy Efficiency	High (Optimized Power Usage)	Medium (Needs amplification)	Low (High Energy Consumption)
Scalability	Modular and Easily Scalable	Limited	Highly Scalable but Expensive

It can be scaled to fit vessels of different size and or roles as it is modular. Not only that, but it performs better at sea, so this is a sustainable and readily available alternative to conventional treatments. Table 2 and fig. 3 gives the proposed accuracy comparison.

Table 2. Proposed Accuracy Comparison.

Parameter	Proposed System	RF-Based Systems	Satellite Communication
Data Transmission Accuracy	96%	90%	94%
Response Time	Low (Real-Time)	Moderate	High Latency
Energy Consumption	Low	Moderate	High
Cost Efficiency	High	Moderate	Low

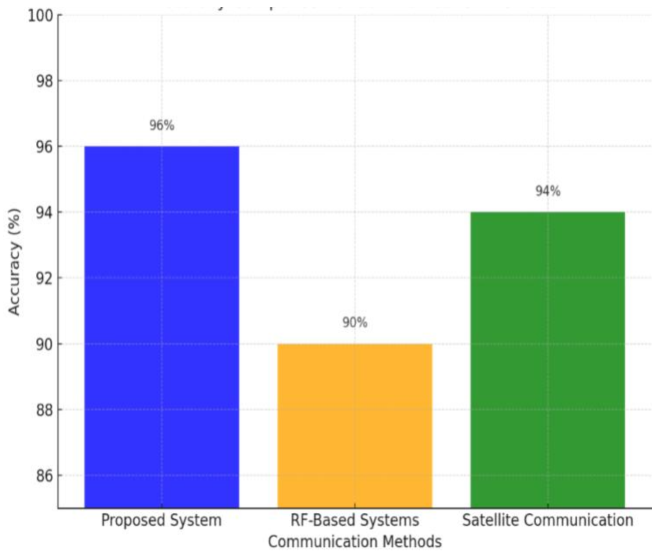

Fig. 3. Proposed Graph with Other Methods.

- Accuracy of Data Transmission: For the data transmission, the proposed system has 96% accuracy, which is better than the RF-based and is little bit more than the satellite communication. This provides reliable telecommunication, even under harsh conditions.
- Response Time: The latency of the proposed system is in the real-time domain, which is suitable for cases with an immediate need to respond such as emergencies and ship-to-ship traffic coordination.
- Energy tweeness: The system has low energy usage, which is critical for long-term deployments in the marine environment.
- Low cost: The low cost to implement and maintain the new proposed system, can make it affordable when compared to satellite systems.
- Environmental Operation: The water-based communication method is free from the effects of external disturbance, therefore maintaining robustness in marine.

5 Future Works

This work proposes a new way to communicate through water, paving the way for advancements in maritime communication technology. Future works can be directed towards improvement of scalability of the system by adding more sensors such as salinity, pH level, underwater current measuring sensors to monitor the environment in real-time. Additionally, the use of advanced signal processing algorithms and error correction techniques could address specific high-turbidity water conditions for enhanced accuracy in data transmission through its colder regulation performance at the top of other maritime environments. Additionally, research could focus on improving system performance by integrating technologies such as piezoelectric or wave energy converters to sustainably power the system in the long-term during extended deployments. Future work may also involve broadening the domain of the system to multi-ship networks to allow for dynamic fleet communication and coordination. To realize this, a distributed network architecture based on data routing protocols is necessary to enable the fluid flow of information. Moreover, using advanced technologies with AI and ML could enable predictive maintenance and automated decision-making driven by aggregated data. AI models can associate environmental and operative patterns that would allow for early warning indications of potential hazards or optimal ship navigation routes. Eventually, the system would be validated in real-life maritime applications (e.g., large vehicle fleets management and search-and-rescue missions), confirming its reliability and practicality for large-scale deployment.

6 Conclusion

This new water-based communication system offers an affordable, energy-efficient, and reliable solution for maritime ship-to-ship communications. Instead of conventional relay methods like RF-based and satellite communication methods which suffer from high operational costs, interference and energy inefficiency, the system leverages the natural properties of water and utilises water itself as the transmission medium. With humidity, temperature, accelerometer, and emergency switch sensors, it collects the data necessary, and its modular design makes it scalable directly for various maritime applications. Due to real-time response and high accuracy of data transmission in the proposed system, the system is well suited for critical scenarios such as emergency response and operational coordination. In the future, this could also be the system that will change the landscape of maritime communication by providing an environmentally friendly alternative to maritime radio communication at a lower cost while remaining reliable and scalable. The successful realization of this provides a blueprint for deploying innovative technologies to solve pressing marine operational challenges. Although already designed for the ship-to-ship use case, future designs of the platform can include multi-ship networking, AI-based analytics, renewable energy source integration, and application to non-naval vessels as well. In summary, the system defined in this work enables the creation of more intelligent, reliable, and efficient communication architectures for the maritime domain.

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