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Editorial

Sensors and Measurement Systems for Marine Engineering Applications

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1. Introduction

In recent years, vast developments and applications of sensor technologies have been recorded in various industries, including shipbuilding. Therefore, the employment of novel sensors in marine environments has significantly progressed, as illustrated by some key examples. For example, wireless sensor networks (WSNs) have emerged as an efficient and cost-effective alternative for the real-time monitoring of the marine environment, used for oil spill detection and localization [1], offering significant advantages such as ease of deployment [2]. Optical-fiber-based sensors have attracted considerable attention for environmental applications such as the in situ measurement of seawater salinity [3] and structural health monitoring in marine applications [4,5] due to their durability under extreme temperature and pressure conditions, high sensitivity, and flexibility. In addition, piezoelectric energy harvesters have been proposed to eliminate batteries from future sensing devices [6,7], while piezoelectric sensors have already been employed to determine ocean wave height and period, as well as underwater objects [8]. Furthermore, nanofibrous grids utilizing piezoelectric fibers demonstrate high-resolution, self-powered tactile sensing capabilities, suggesting their use in real-time motion tracking and spatial sensing in marine environments [9], whereas monolithic printed sensors pave the way for on-demand, on-site fabrication [10]. These examples underscore the vast technological developments that have been pivotal in addressing the challenges related to marine research and environmental protection.

Moreover, over the past three decades, the miniaturization of sensors has led to the newly developed field of "microsensors"—an emerging field that has grown rapidly, building on the significant advancements of the semiconductor industry. Consequently, the sensors deployed on ships have followed the same trend, taking their role one step further by incorporating semiconductor-based technology into standard marine equipment and measuring systems. Typical types of sensors employed aboard are gas detection sensors, gas/air flow sensors, humidity sensors, temperature/pressure sensors, speed/acceleration sensors, strain sensors, IMUs, etc., which are all essential with regard to vessel safety since the proper operation of all modern vessels relies heavily on the information provided by the onboard measuring devices that quantify critical performance parameters. As a common example, a typical Ro-Ro vessel has four medium-power 4-stroke engines installed onboard, which are required for the operation of the corresponding generator sets [11]. Failure to detect a possible malfunction by the appropriate sensing system in any of the installed engines, even one, can lead to immediate safety compromises, as outlined by the corresponding safety regulations [12], with severe consequences. In addition, modern sensing devices play a vital role in advancing marine technology by enabling the integration of new technologies, such as the Internet of Things (IoT), big data, and cloud computing [13]. These technologies rely heavily on sensing devices for functionality and also contribute to their rapid development.

This Special Issue encompasses the diversity of nine relevant studies, spanning from the design of novel sensors and energy-harvesting solutions for the maritime industry

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to advanced engine-monitoring systems. Specifically, it comprises eight articles and one review, which are briefly outlined in the next section. It is important to note that the purpose of this editorial is not to elaborate on each of the papers presented but rather to encourage readers to explore them further.

2. An Overview of the Published Articles

In the first article, Bardakas et al. (contribution 1) present a novel rotational–linear triboelectric nanogenerator (RL-TENG) that converts rotational motion to linear motion to harvest rotational energy. The device employs ZnO nanoparticles as a triboelectric material, demonstrating a modular design for various applications. The RL-TENG design offers several advantages, including reduced wear and increased temperature during operation, compared to traditional rotational tribogenerators. This technology has significant implications for maritime applications, particularly in wind energy harvesting for powering remote monitoring systems or other low-power devices.

In the second article, Pagonis et al. (contribution 2) introduce a mass air flow sensor designed for low- and medium-power internal combustion engines in the marine industry. The sensor fabrication process is based on additive manufacturing and PCB technology. The complex design of the sensing element housing geometry, which is manufactured through 3D printing, is based on standard airfoil geometry, while it is derived through suitable CFD simulations. The key features of the proposed device are its low cost, fast on-site manufacturing, robustness, and simplicity, suggesting numerous potential applications in marine engineering.

In the third article, Yu et al. (contribution 3) present a case study of super-long steel pipelines floating offshore, focusing on controlling deformation and avoiding resonance for safety. Their study employs wireless communication equipment and aerial photography technology to monitor strain and vibration during construction. This monitoring method prevents excessive deformation, resonance, and the destruction of anticorrosive coatings during floating transportation. The obtained results provide a detailed strain and modal analysis as well as effective monitoring technology for offshore steel pipeline transportation safety.

In the fourth article (contribution 4), Jiao et al. elaborate on a novel MEMS piezoresistive pressure sensor designed to operate under harsh environmental conditions. The specific sensor demonstrates adequate linearity and sensitivity over a wide operating range, while a digital temperature compensation system impedes linearity drift due to temperature variation. The specific technology has significant implications for maritime applications, particularly in harsh environments, where robust and accurate pressure sensing is required.

In the fifth article, Yang et al. (contribution 5) propose a novel Principal Component Analysis integrating a Long Short-Term Memory Network (PCA-LSTM) model for predicting the productivity of cutter suction dredgers. The developed model involves operational parameters that are based on mechanism analysis, while it is considered a deep learning-based approach capable of dealing with operation series data with a special memory mechanism. The specific methodology has the potential to improve the efficiency and productivity of dredging operations, leading to cost savings and reduced environmental impacts.

In the sixth article, Li et al. (contribution 6) present a novel method for measuring ocean surface currents in the Kuroshio region using Gaofen-3 SAR data. The developed method, which combines sub-aperture processing and least-squares (LS) technology to measure current vectors, demonstrates the capability of the Gaofen-3 SAR to accurately retrieve the ocean surface current field in the Kuroshio region. The specific methodology has significant implications for climate studies and maritime navigation in dynamic oceanic environments.

In the seventh article, Tsitsilonis et al. (contribution 7) present a method for identifying engine malfunctioning through instantaneous crankshaft torque (ICT) measurement analysis. Briefly, this study demonstrates the usefulness of engine ICT as a nonintrusive diagnostic measurement, allowing for quick and less resource-intensive identification of engine malfunctions. The developed methodology has significant implications for maritime applications, particularly for maintaining the reliability and safety of marine engines.

In the eighth article, Daud et al. (contribution 8) propose a novel Gaussian-process-based inversion methodology for Seabed Logging (SBL) for detecting potential hydrocarbon-saturated reservoirs underneath the seabed by employing electromagnetic waves (EM). The specific method allows for greater flexibility in modeling a variety of EM responses, while the obtained results indicate that it can efficiently predict the hydrocarbon depth in seabed logging, having significant implications for offshore oil and gas exploration and production.

The last article in this Special Issue, a review by Prabowo et al. (contribution 9), provides a comprehensive survey of the developed sensor technology for maritime applications, covering various aspects, such as logistics, shipping activities, the hydrodynamic characterization of new design hulls, advanced machinery performance, arctic-based field observations, vibration-based damage detection, corrosion control and monitoring, and the measurement of explosions on critical maritime infrastructures. The specific review highlights the importance of sensors in maritime-based industries and research, as well as the potential for further advancements in the field.

3. Conclusions

This Special Issue aims to contribute to the exploration of significant advancements in sensor and measurement system technologies. Through a brief overview of the selected research papers, this editorial highlights the innovative approaches and potential impacts of sensor-driven solutions in addressing the challenges faced by the maritime sector. The articles presented in this Special Issue provide valuable insights into the implications for future research in the maritime industry, which can be summarized as follows.

The transformative impact of sensor technologies on maritime engineering is underscored by the convergence of innovation, interdisciplinary collaboration, and the continuous pursuit of safety, efficiency, robustness, and low costs. For instance, additive manufacturing has emerged as a potential enabler that offers flexibility, speed, cost-effectiveness, and adaptability to diverse operational environments for sensor fabrication; the work by Pagonis et al. illustrates this paradigm shift, showcasing the seamless integration of additive manufacturing and standard airfoil geometry in the design of mass airflow sensors for marine engineering applications. In addition, the development of micro-pressure sensors tailored to harsh environments by Jiao et al. showed the need for robust sensor technologies in marine applications; most probably, future research will explore the integration of advanced materials to improve sensor performance and longevity in challenging marine conditions. Furthermore, the selected research papers highlighted the multifaceted roles of sensor/measurement system technologies in enhancing safety, efficiency, and predictive capabilities across various maritime domains. From the development of rotational–linear triboelectric nanogenerators by Bardakas et al., offering renewable energy solutions for maritime applications, to the advanced monitoring of offshore steel pipelines by Yu et al., leveraging wireless communication and aerial photography to mitigate transportation risks, each study underscores the transformative potential of sensor-driven solutions.

Additionally, the deployment of novel analytic techniques, as demonstrated by Yang et al., Tsitsilonis, and Theotokatos, empowers maritime stakeholders with predictive insights, real-time diagnostic capabilities, and better productivity prediction, thereby optimizing resource utilization and mitigating operational risks. Future research could explore the application of advanced radar technologies for precise ocean current measurements, aiding climate studies and maritime navigation in dynamic ocean environments, the potential of non-intrusive diagnostic measurements for quick and less resource-intensive identification of engine malfunctions (e.g., employing engine Instantaneous Crankshaft Torque), and de-risking hydrocarbon exploration in deep marine environments by accurately predicting hydrocarbon depths, leading to more cost-effective exploration campaigns.

The future trajectory of sensor technologies in the maritime industry is promising, focusing on novel sensors and measuring systems that can enhance safety, efficiency, sustainability, and technological advancements to meet the continuously evolving needs of marine applications. Thus, the current studies presented in this Special Issue should be seen not only as the research results of investigations carried out by the respective researchers but also as key starting points, inviting readers to continue with new studies on the themes explored.

In light of the aforementioned considerations, it is the editor's belief that future marine sensing devices will increasingly incorporate advances from other scientific disciplines, revolutionizing their manufacturing and operation, similar to the miniaturization that occurred due to the vast advances in the semiconductor industry in the past. Consequently, many of the current drawbacks associated with employing almost solely semiconductor technology as the foundation for modern sensing devices, such as complicated manufacturing processes, expensive sensor packaging, indirect electrical communication between the sensing integrated circuit and the necessary readout circuitry, and high prototype fabrication cost, will generally be overcome.

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