Journal of
Marine Science and Engineering

MDPI

Editorial

Frontiers in Deep-Sea Equipment and Technology II

Weicheng Cui [1,2,*], Lian Lian [3,4] and Dahai Zhang [5]

[1] Research Center for Industries of the Future, Westlake University, Hangzhou 310030, China
[2] Key Laboratory of Coastal Environment and Resources of Zhejiang Province (KLaCER), School of Engineering, Westlake University, Hangzhou 310024, China
[3] School of Oceanography, Shanghai Jiao Tong University, Shanghai 200240, China; llian@sjtu.edu.cn
[4] China State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
[5] Ocean College, Zhejiang University, Zhoushan 316021, China; zhangdahai@zju.edu.cn
* Correspondence: cuiweicheng@westlake.edu.cn

1. Introduction

The vast oceans could play a pivotal role in resolving the conflicts between population, resources, and the environment in the twenty-first century. This positions the ocean as a strategic space and a treasure trove of resources for human society to achieve sustainable development. To study the ocean environment and exploit its resources, a fundamental understanding of complex and intertwined oceanic processes across a wide range of spatial and temporal observational scales is necessary [1]. This understanding heavily relies on various research fleets and equipment to support increasingly complex, multidisciplinary, multi-investigator research projects. These projects include those in support of autonomous technologies, ocean observing systems, process studies, remote sensing, and modeling [2].

In response to this need, the *Journal of Marine Science and Technology* (*JMSE*) launched a Special Issue on the topic of "Frontiers in Deep-Sea Equipment and Technology II". The feedback from the authors was very positive, resulting in numerous submissions for this Special Issue. Ultimately, 30 papers were published, falling into the following six categories: ROV and its variants, AUVs for multi-agent cooperation, gliders and other specific equipment, pressure-resistant hulls, component technology, and robotic fish [3].

Given that many authors were unable to submit their papers within the deadline and considering the rapid technological advancements in this field, we decided to launch another Special Issue to continue this topic, albeit with a slightly different focus as announced. While the previous Special Issue had many papers focused on the design and development of various submersibles, in this issue, we emphasized that "we particularly welcome papers on the design, analysis, and testing of various new methods, new theories, new sensors, and new equipment used in deep seas".

Following the launch, we received numerous submissions and, based on the same standards established by the *JMSE Journal*, ultimately selected 12 papers for publication within the time frame of this Special Issue. We are deeply grateful to all the authors who contributed to the success of this Special Issue, and we are pleased to know that *JMSE* intends to compile all these papers into a book for further promotion.

The purpose of this Editorial is to provide a brief introduction to all the papers included in this issue. Based on a preliminary analysis, these papers are grouped into four categories: AUV's wireless power transfer system, water entry and descent process, subsea production system, and marine cleaning equipment. In the following sections, each topic is discussed in the context of the papers that have been published in this Special Issue.

2. AUV's Wireless Power Transfer System

Autonomous underwater vehicles (AUVs) are increasingly critical in marine resource utilization, scientific exploration, and military applications. However, power supply remains a key issue, limiting their long-term operation. Recently, wireless power transfer

Citation: Cui, W.; Lian, L.; Zhang, D. Frontiers in Deep-Sea Equipment and Technology II. *J. Mar. Sci. Eng.* **2024**, *12*, 635. https://doi.org/10.3390/jmse12040635

Received: 29 October 2023
Accepted: 8 April 2024
Published: 9 April 2024

(WPT) technology has seen extensive research and application in various fields. In this paper, Wen et al. (contribution 1) proposed a compact WPT system for AUVs, featuring a planar magnetic coupler. They integrated a passive induction (PI) coil into the circular transmitter (Tx) coil to create a uniform magnetic field (UMF), enhancing the stability of the WPT system under radial and axial misalignments. They also provided a method for constructing a UMF with a PI coil, aiming to stabilize the magnetic field intensity. Their analysis showed the integrated coil improves radial misalignment tolerance compared to a conventional coil. Adjusting the series capacitor connected with the Tx coil can achieve a zero-phase angle input condition. Experiments indicated the proposed magnetic coupler with an integrated coil enhances output power stability and power transfer efficiency under possible misalignments compared to a conventional coupler.

In underwater charging, AUV docking devices are used for homing, energy supply, and data exchange, enhancing AUV endurance and enabling continuous, large-scale operation. Du et al. (contribution 2) designed a funnel-shaped, multi-degree freedom underwater docking device based on a deep-sea platform to improve the AUV docking success rate. The device adjusts its heading, pitch, and roll angles according to the current flow direction and AUV position. An underwater hydraulic system was developed to drive these adjustments, powering hydraulic cylinders, motors, and other components. They established a model for the heading angle adjustment circuit and derived its open-loop transfer function. After simulating the hydraulic circuit's dynamic response performance, they used an optimized PID algorithm for improvement. The model's accuracy and the control algorithm's effectiveness were validated through pool experiments with the docking device.

Liu et al. (contribution 3) explored the issue of fault-tolerant control (FTC) for autonomous underwater vehicles (AUVs) equipped with multiple thrusters. They specifically focused on scenarios involving current disturbances, thruster faults, and modeling uncertainty. The main objectives of their research were to minimize energy consumption, which can be exacerbated by control signal chattering, and to enhance the tracking accuracy of AUVs operating in deep-sea environments. To address these challenges, they proposed a fault-tolerant control method for AUVs with multiple thrusters, grounded in a finite-time extended state observer (FTESO). In more detail, they designed a FTESO based on an integral sliding mode surface to estimate the generalized uncertainty, which is a composite of current disturbances, thruster faults, and modeling uncertainty. They thoroughly analyzed the fast, finite-time, uniform, and ultimately bounded stability of the proposed FTESO. Subsequently, using the estimated value derived from FTESO, they developed an FTC method for AUVs that is based on non-singular fast terminal sliding mode surfaces.

3. Water Entry and Descent Process

Dong et al. (contribution 4) conducted a comprehensive study on the hydrodynamic and motion characteristics of an unmanned aerial-underwater vehicle (UAUV), a novel vehicle capable of both flight and underwater cruising, expected to perform continuous, uninterrupted observations and sampling by crossing the free water surface multiple times. They employed the Reynolds-averaged Navier–Stokes method to investigate the multi-degree-of-freedom UAUV's complete water-entry process at various velocities and pitch angles. To balance computational accuracy and cost, they employed adaptive mesh refinement and an adaptive time-stepping strategy, capturing the slamming pressure accurately with reasonable computational effort. Their research involved simulations of the vehicle at different initial velocities and pitch angles, followed by an analysis of the variable physical properties. They found that both initial velocity and pitch angle significantly influence the hydrodynamic behavior, including time-varying force, while the thickness ratio greatly impacts added mass and pressure. Their results indicated that a higher entry velocity yields a larger peak vertical force, and the transverse hydrodynamic characteristics vary significantly for oblique water entries at different pitch angles.

Benthic landers, compared to remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs), offer cost-effective operations and increased endurance. Establishing an appropriate descent velocity is crucial for their design, as it can prevent retrieval failures and enhance sea trial efficiencies. In their research, Zhang et al. (contribution 5) proposed an effective strategy for the configuration and optimization of a self-developed benthic lander. Sea trial data was used to validate their scheme, confirming its accuracy and efficiency. Overall, their findings offer valuable insights for the logical configuration and practical deployment of benthic landers.

Guo et al. (contribution 6) developed an improved constitutive model for shape memory alloys (SMAs), crucial for deep-sea intelligent actuators in marine engineering. They extended the one-dimensional thermodynamic equation for SMAs using an improved logistic nonlinear function to construct macroscopic variable-speed phase transition relations. The model was tested against traditional models and experimental data under constant load and temperature. The results indicated that the improved model accurately describes slow phase transitions with fewer variable parameters and adjustable phase transition rates, providing valuable theoretical support for designing SMA deep-sea actuators.

4. Subsea Production System

Hao et al. (contribution 7) conducted an in-depth analysis of the mechanical behavior and sealing performance of core-sealing components in subsea production systems (SPS), which are interconnected by subsea connectors. They examined the loading conditions of the subsea clamp connector to understand the load transfer relationship between components under different modes. Mathematical models were developed for load transfer in both preloading and operation modes, introducing the concept of mechanical transfer efficiency. A three-dimensional finite element model of the subsea clamp connector was established to analyze the impact of complex loads. The simulation results showed that internal pressure loading enhances the sealing of the subsea connector, and the stress distribution in core-sealing components under bending moment loading is significantly asymmetric. Axial tensile loads reduce the effect of the bending moment on the strength of the core seal member but further weaken the seal. These simulations were validated through an experimental system.

To address the sensitivity of radial seals to axial overload failure, which can lead to leaks, Li et al. (contribution 8) proposed two semi-analytical methods. They developed an analytical model based on membrane theory for the joint strength of the connection and seal under axial tension and compression and a finite element model for the radial metal seal's joint strength. The overload sealing performance method was derived using a finite element model and the Reynolds equation for laminar flow. They analyzed the effects of critical parameters on joint strength and overload sealing performance and conducted experiments to evaluate these aspects. Results showed that an internally turned sealing surface and pipe deflection can improve joint strength and that the compression-type connector can remain sealed under maximum axial overload. The proposed methods offer insights into the radial metal seal's behavior under axial overload.

A similar method is extended to predict the sealing performance of the subsea pipeline compression connector (contribution 9). This method integrates a macroscopic analytical model for the interference process, a mesoscopic finite element analysis of the internally turned sealing surface, and a calculation of the leakage ratio using the Abbott–Firestone curve. They analyzed the impact of geometry parameters and conducted experiments to validate their method. Results indicated that compression connectors designed using this method could reliably seal a rough internally turned surface within five times the pipeline's thin-wall thickness threshold. This approach saves 57% of design time and reduces machining time and costs.

Subsea clamp connectors are prone to sealing and locking failures due to harsh marine environments and complex loading conditions. This poses risks to subsea oil and gas field safety. Therefore, accurately predicting their reliability under realistic operating conditions is crucial. An et al. (contribution 10) used finite element numerical simulation and multiple response surface methodology (MRSM) to analyze the reliability of subsea clamp connectors, considering key structural parameters and based on seal failure and yield failure criteria. The approach was validated in the Bohai Sea, showing that the system's failure probability was primarily influenced by seal radius, flange contact angle, and internal pressure. The connector's reliability was calculated to be 98.73%, as confirmed by a sealing performance test. This study offers a practical method for analyzing the reliability of subsea clamp connectors, considering multiple factors, and contributes to ensuring the safety of subsea oil and gas fields.

Underwater wet-mateable connectors are essential for cost- and time-efficient installation, maintenance, and reconfiguration in industries like oil and gas, offshore renewable energy, and undersea observatories. Song et al. (contribution 11) proposed a methodology for designing and testing such connectors. They introduced an innovative wet-mateable electrical connector with dual-bladder pressure-balanced oil-filled technology, derived generalized equations of differential pressure, and proposed a thermal-electric-structure coupling simulation procedure. They conducted finite element analysis involving coupled multi-field problems. A prototype connector was developed, and its electrical performance was tested successfully under 3000 m of ocean depth pressure, achieving a leading level in China. This comprehensive study on wet-mateable connectors' design, theory, simulation, and testing provides valuable insights for ocean scientists, especially in developing countries.

5. Marine Cleaning Equipment

Addressing the challenge of marine fouling on marine steel piles, Li et al. (contribution 12) proposed an innovative configuration for marine steel pile cleaning equipment. This novel design employs a scraping method and a telescopic mechanism, applying a multi-cylinder synchronous control strategy to the cleaning equipment. They successfully produced a test prototype of the cleaning equipment, designed to overcome issues of eccentricity and tilt often encountered in ocean engineering.

To evaluate the multi-cylinder synchronous control performance under various working conditions, they established a simulation model of the operation process of the equipment's telescopic mechanism using the MATLAB Simulink module. They conducted tests to preliminarily verify the synchronous working performance of the telescopic mechanism of the cleaning equipment under no-load conditions.

The test results were promising. Under no-load conditions, the relative errors between the three cylinders and the target displacement were as low as 0.8%, 0.4%, and 0.2%, respectively. The cleaning equipment could reach the specified working position at the given working speed, and the displacement synchronization error between each cylinder was controlled within 1 mm.

These results demonstrate that the telescopic mechanism exhibits excellent synchronization, ensuring the stability of the cleaning equipment during operation and effectively preventing eccentricity and tilt. As such, this study provides a valuable reference for the manufacturing of similar cleaning equipment, potentially enhancing the efficiency and effectiveness of marine fouling clean-up efforts.

6. Conclusions

Following the success of our previous edition [3], this Special Issue continues to highlight the most recent advancements in deep-sea equipment and technology. Over the course of this issue, we have published twelve high-quality papers, each contributing important insights and findings to the field.

The topics discussed encompass four critical areas: the wireless power transfer systems of autonomous underwater vehicles (AUVs), the water entry dynamics of freely falling unmanned aerial–underwater vehicles and the descent dynamics of Benthic Landers, the connectors utilized in subsea production systems, and the cleaning equipment designed to combat fouling on marine steel piles. Each of these subjects represents a key technological challenge to be addressed in the ongoing development of deep-sea equipment.

While the number of papers in this issue is slightly fewer than anticipated, it is nonetheless a substantial contribution for a Special Issue. Alongside the papers published in the previous Special Issue, these two editions provide a comprehensive and up-to-date overview of the state of deep-sea equipment and technology.

We, the editors, are deeply grateful for the invaluable contributions of our authors and reviewers, as well as the unwavering support of our Editorial Office. It is our hope that these two Special Issues will serve as a catalyst for further advancements in this field, inspiring new research and technological innovation in deep-sea equipment.

Funding: This work was supported by the National Key Research and Development Program (2022YFC2805200), start-up funding from Westlake University under grant number 041030150118, and the Scientific Research Funding Project of Westlake University under Grant No. 2021WUFP017.

Acknowledgments: All the authors are greatly acknowledged for their support, and the arrangement of publishing this Special Issue as a book by MDPI is appreciated.

Conflicts of Interest: The authors declare no conflicts of interest.

List of Contributions:

1. Wen, H.; Li, J.; Zhang, K.; Ye, J.; Yan, Z.; Song, B.; Tong, X. Enhancing Power Transmission Stability of AUV's Wireless Power Transfer System with Compact Planar Magnetic Coupler. *J. Mar. Sci. Eng.* **2023**, *11*, 566. https://doi.org/10.3390/jmse11030566.
2. Du, X.; Zong, C.; Zhang, B.; Shi, M. Design, Simulation, and Experimental Study on the Hydraulic Drive System of an AUV Docking Device with Multi-Degree Freedom. *J. Mar. Sci. Eng.* **2022**, *10*, 1790. https://doi.org/10.3390/jmse10111790.
3. Liu, X.; Zhang, M.; Liu, X.; Zhao, W. Finite-Time Extended State Observe Based Fault Tolerant Control for Autonomous Underwater Vehicle with Unknown Thruster Fault. *J. Mar. Sci. Eng.* **2022**, *10*, 1624. https://doi.org/10.3390/jmse10111624.
4. Dong, L.; Wei, Z.; Zhou, H.; Yao, B.; Lian, L. Numerical Study on the Water Entry of a Freely Falling Unmanned Aerial-Underwater Vehicle. *J. Mar. Sci. Eng.* **2023**, *11*, 552. https://doi.org/10.3390/jmse11030552.
5. Zhang, Q.; Dong, C.; Shao, Z.; Zhou, D. Analysis of the Descent Process and Multi-Objective Optimization Design of a Benthic Lander. *J. Mar. Sci. Eng.* **2023**, *11*, 224. https://doi.org/10.3390/jmse11010224.
6. Guo, J.; Pan, B.; Cui, W.; Hu, S. A Nonlinear Phase Transition Dynamic Model for Shape Memory Alloys Based Deep Sea Actuators. *J. Mar. Sci. Eng.* **2022**, *10*, 1951. https://doi.org/10.3390/jmse10121951.
7. Hao, X.; Yun, F.; Jiao, K.; Chen, X.; Jia, P.; Wang, X.; Wang, L. Mechanical Behavior and Sealing Performance Study of Subsea Connector Core-Sealing Components under the Combined Action of Internal Pressure, Bending Moment, and Axial Load. *J. Mar. Sci. Eng.* **2023**, *11*, 1691. https://doi.org/10.3390/jmse11091691.
8. Li, Z.; Wang, G.; Wang, X.; Yao, S.; Yun, F.; Jia, P.; Wang, L. Semi-Analytical Methods for the Joint Strength and Sealing Performance in the Failure Process of the Subsea Pipeline Compression Connector. *J. Mar. Sci. Eng.* **2023**, *11*, 1417. https://doi.org/10.3390/jmse11071417.
9. Li, Z.; Wang, G.; Yao, S.; Yun, F.; Jia, P.; Li, C.; Wang, L. A Semi-Analytical Method for the Sealing Performance Prediction of Subsea Pipeline Compression Connector. *J. Mar. Sci. Eng.* **2023**, *11*, 854. https://doi.org/10.3390/jmse11040854.
10. An, W.; Wang, Y.; Chen, B.; Duan, M.; Zhang, X. Analysis of the Reliability of Subsea Clamp Connector Based on Multiple Response Surface Methodology. *J. Mar. Sci. Eng.* **2023**, *11*, 1378. https://doi.org/10.3390/jmse11071378.
11. Song, W.; Yang, C.; Cui, W.; Song, C.; Yang, P.; Hong, J.; Lei, Y.; Liu, Q.; Wang, Z. An Underwater Wet-Mateable Electrical Connector with Dual-Bladder Pressure-Balanced Oil-Filled (PBOF) Technology. *J. Mar. Sci. Eng.* **2023**, *11*, 156. https://doi.org/10.3390/jmse11010156.
12. Li, C.; Pang, N.; Xu, K.; Geng, Q.; Wang, X.; Yun, F.; Gao, L. Application of Multi-Cylinder Synchronous Control for Telescopic Mechanism of Marine Steel Pile Cleaning Equipment. *J. Mar. Sci. Eng.* **2023**, *11*, 1010. https://doi.org/10.3390/jmse11051010.

References

1. Committee on Evolution of the National Oceanographic Research Fleet (CENORF); National Research Council. *Science at Sea: Meeting Future Oceanographic Goals with a Robust Academic Research Fleet*; The National Academies Press: Washington, DC, USA, 2009.
2. Lin, M.; Yang, C. Ocean Observation Technologies: A Review. *Chin. J. Mech. Eng.* **2020**, *33*, 32. [CrossRef]
3. Cui, W.C.; Lian, L.; Pan, G. Frontiers in Deep-Sea Equipment and Technology. *J. Mar. Sci. Eng.* **2023**, *11*, 715. [CrossRef]