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ARTICLE

Overview of Key Technologies for Remote Wireless Operation Platform on Water Surface

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ABSTRACT

The underwater environment is complicated and full of hazards, making it tough to complete with just one piece of underwater operation equipment. Building a high-speed, low-latency wireless connection between a remote wireless operation platform on water surface and other operation platforms in order to achieve long-distance transmission of high-definition image data and control commands, as well as collaborative operations among multiple platforms, has become a development trend and focus of exploring complex and dangerous waters. This paper summarizes and elaborates on underwater communication technology, long-distance data transmission technology, multi-submersible robot collaborative operation, and information interaction technology, as well as the development status of key technologies of remote wireless operation platform on water surface. And the research direction and focus of the remote wireless operation platform on water surface are prospected.

1. Introduction

Exploration, exploitation, and utilization of marine resources have attracted unprecedented interest and enthusiasm in recent years. Underwater environments are complicated and volatile, necessitating the use of

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machines to perform perilous jobs. In earthquake and tsunami warning, ecosystem monitoring, oil drilling, and military surveillance, various underwater detection and extraction devices, submarines, and unmanned vehicles are commonly utilized [1]. These operational duties rely heavily on communication between equipment and between equipment and platforms. Some underwater operation activities are difficult to execute with a single underwater operation gear because they are complicated and risky. To achieve long-distance transmission of high-definition image data and control commands, it is critical to create a high-speed and low-latency wireless link between the surface remote operation platform and other operating platforms. To give control commands to underwater robots and receive underwater detection information, information contact with underwater multipurpose robots is also required. Underwater robots should communicate with one another to build a cooperative underwater operation system.

Remote wireless operating system for water surface is divided into three parts: water surface remote monitoring system, long-distance data transmission system, and on-site equipment monitoring and control system. Each part divides the work to complete the monitoring and control tasks with the help of wireless technology [2]. The remote monitoring terminal system is primarily an interactive system that allows users to input control commands and process data about remote equipment status. Over extended distances, the long-distance data transmission system transfers various forms of control data from the user and site equipment status information. The on-site equipment monitoring and control system operates the equipment based on control data from the monitoring terminal, simultaneously checks the status of the equipment, performs necessary analysis, and sends these states back to the monitoring system via the transmission channel. Figure 1 illustrates this.

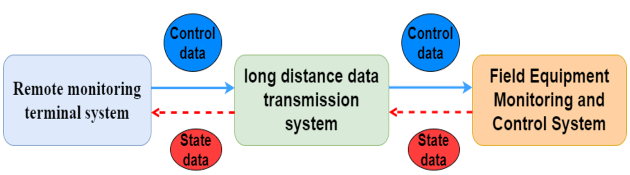

Figure 1. Remote wireless operating system for water surface

The hold-type remote monitoring technique, the completion-type remote monitoring method, the complete remote monitoring method, and the human-computer interaction remote monitoring method are the four types of remote wireless operation control methods [3]. The hold-type remote monitoring technique delivers control commands to the equipment control system, which the equipment completes independently, and the monitoring equipment just monitors the equipment and intervenes when necessary. The complete remote monitoring approach involves the remote monitoring system merely issuing control commands to the equipment control system, not monitoring the equipment's implementation process, and reporting to the remote monitoring system after the work is completed. The equipment control system and the equipment are separated in the complete remote monitoring technique, and the local control system of the equipment merely controls the actuator of the equipment, with the remote monitoring system handling all operation control. The remote monitoring technique for human-machine interaction is controlled by the remote monitoring system, and the local operator operates and maintains the equipment, which is controlled by the local operation and the remote monitoring system in tandem.

Without the use of underwater communication technology, information exchange between surface platforms, underwater robots, and platforms and underwater robots, as well as joint operations, are impossible. Communication between two parties underwater or between underwater and above water is referred to as underwater communication. Underwater communication systems are currently divided into two categories: underwater wired communication and underwater wireless communication. The core technologies of the distant wireless operation platform are summarized in this paper: underwater communication technology, long-distance data transmission technology, numerous underwater robots cooperative operation and information interaction technology, and so on.

2. Research Status of Key Technologies of Remote Wireless Operation Platform

2.1 Study of Information Interaction between Surface Platforms

The remote data transmission and control system between platforms is typically made up of a central control system and several platforms, with active self-reporting and interactive query being the most common data transmission and control modalities. The surface remote operation platform establishes a high-speed, low-latency wireless link with other operation platforms in order to achieve long-distance transfer of high-definition image data and control commands, allowing several platforms to work together. Wireless communication allows one platform to grasp the goal, action, current condition, and other information of the other, complete data transmission, and execute the appropriate commands for collaborative activities. It can be separated into explicit and implicit communication depending on the style of communication. Implicit communication refers to the platform obtaining information from the outside world and their internal sensors in order to collaborate with one another; the security platform does not directly contact with information. Explicit communication is a multi-security platform solution that uses a specific medium to complete the information transfer and exchange between platforms. Implicit communication lacks data exchange, making it difficult to complete complex tasks; explicit communication, while capable of completing advanced collaboration strategies not possible with implicit communication and completing the transfer and exchange of information between platforms, suffers from communication quality issues such as network delay and local communication conflicts [4].

There are commonly two forms of long-distance HD image transmission: cable transmission and wireless transmission. The standard wired transmission method is used to transmit data to the control system and operating equipment. The communication effect is relatively optimal, and wired data transmission is rapid, effective, and dependable. It is commonly employed in basic fixed communication systems. However, because of the wire's limitations, increasing or moving the operation platform and other connected equipment over large distances becomes cumbersome and difficult. The advantages of wireless communication, such as high scalability, not being limited by geographic environment, low cost, good adaptability, not having to worry about wiring problems, and ease of maintenance, have attracted extensive attention and are widely employed in a variety of industries. The application cost of wireless communication has decreased dramatically as RF technology has advanced, the transmission rate has increased, and the efficacy and dependability in industrial applications have increased. 5G technology, broadband wireless access technology, WiFi, and other wireless communication distance communication technology have become ubiquitous in people's daily lives in recent years [5]. 5G technology achieves high-speed low-latency wireless connections through optimal networking deployment, allowing for fast networking and access to the cloud platform, real-time upload and download of large amounts of data, and the formation of data interaction between platforms at any time and from any location. View data and high-definition photos between platforms via a remote wireless operating system to control the most up-to-date real-time operational status and offer the foundation for system decision-making [6].

A high-speed and low-latency wireless link between the remote wireless operation platform on water surface and other operation platforms is required for the transfer of long-distance high-definition image data and control directives. Collaborative task planning is a key technology for achieving multi-platform collaborative control, which entails taking into account the performance of platforms as well as the importance of tasks, assigning different tasks to appropriate platforms, and ensuring that the multi-platform collaborative system completes all tasks with the best solution. The remote wireless operating platform unites two media, above and below the water, and provides improved data collecting and analysis processing. As a result, wireless communication technology is not only a technical requirement for multi-platform cooperative system integration, but it is also essential for system collaboration.

2.2 Research on Communication Technology between Underwater Robots and Platforms

The communication between underwater parties is the communication between two or more devices underwater, and the communication between underwater and water is primarily the data transmission between the underwater operational robot and the water platform. According to whether or not an umbilical cable connects them to the platform, underwater robots are classified as Remotely Operated Vehicles (ROV) or Autonomous Underwater Vehicles (AUV) [7]. Underwater and above-water communication systems are currently divided into two categories: underwater wired communication and underwater wireless communication. Two separate underwater robots correlate to these two underwater communication technologies.

The umbilical cable connection is used to transmit both power and control signals from the unmanned surface boat to the underwater robot in the forward direction and image data from the underwater robot to the unmanned surface boat in the reverse direction in real time between the ROV and the unmanned surface platform [8]. There is no umbilical cord connecting the AUV to the mother ship, and wireless communication is used to engage with the platform for information and underwater data transmission, and the boat has its own power source and intelligent autonomous navigation. The majority of existing underwater robots are controlled via remote telemetry information (and electricity) transmitted via fiber optic cable, cable, or umbilical cable. The umbilical cable transfers power and control signals from the unmanned surface boat to the underwater robot in the forward direction, as well as picture data in real time from the underwater robot to the unmanned surface boat in the reverse direction. Underwater wired communication technology, which involves laying submarine fiber optic cable and transmitting data via optical fiber, has the following benefits: high transmission rate, high capacity, and good anti-interference. Furthermore, the high cost and vulnerability to corrosion by seawater and submerged animals make underwater communication unsuitable for widespread use [9].

Control commands from the surface remote operating platform, as well as underwater image data and other status data, are sent to the surface platform via cable. Only a tiny diameter coaxial cable or optical fiber is necessary if only information is being conveyed and no power is being transmitted. A significantly thicker diameter umbilical cable is necessary if power is also delivered to the robot. Robots that use umbilical cords have an almost limitless underwater range, and robots that carry cables for navigation usually have two options. The robot uses the cable-laid navigation approach for single-use, smaller diameter coaxial or fiber optic cables. When the robot is sailing, the spool is carried by the robot, and the cable or fiber optic cable is automatically released from the tail. The robot does not have to bear the large cable tension, and the cable is automatically released when the robot completes the task and needs to return; for the slightly thicker diameter of the repeated use of the cable, the robot uses the towing cable navigation method, the platform is equipped with an automatic tension control cable winch, when the robot enters the water navigation, towing cable navigation, when the cable tension exceeds the first class set value Strong currents and deep sea navigation, in particular, need the use of the. The cable applied by the wire-controlled robot is under more pressure in strong currents and deep sea navigation, and there are more reefs in the strait, which can easily cause cable breakage and other problems.

2.3 Research on Information Interaction Technology for Multi-Underwater Robots

The process of sending and receiving information, sometimes known as underwater communication, is known as underwater information interaction. Because the underwater environment is complicated and unknown, underwater communication faces numerous technical challenges, and underwater communication has lagged behind ground, air, and space communication [10]. Underwater wireless electromagnetic wave communication, underwater acoustic communication, and underwater optical communication are the three main types of underwater wireless communication technologies [11].

Underwater electromagnetic communication dates back to the First World War, when France was the first to conduct submarine communication experiments using electromagnetic waves. During World War II, the United States Scientific Research and Development Administration conducted research on short-range radio-magnetic communication among divers, but electromagnetic communication in seawater is severely attenuated, and the higher the frequency, the greater the attenuation, so it cannot meet the requirements of long-range underwater networking and can only be used for close-range communication [12]. Aside from the influence of saltwater features on underwater electromagnetic wave communication, the flow of seawater has a significant impact on underwater electromagnetic wave communication, which is currently exclusively employed for long-distance communication in shallow water environments [13].

The United States Navy Hydroacoustic Laboratory developed the world's first hydroacoustic communication system in 1945, which was primarily used for submarine communication. Hydroacoustic communication is the most advanced technology in the field of underwater communication; the acoustic wave attenuation is small in the process of underwater acoustic communication, and hundreds of meters of communication transmission can be achieved. Underwater, acoustic systems have had a lot of success and are widely utilized in communication, sensing, detection, navigation, location, and other domains. However, underwater detecting equipment cannot transmit high-definition real-time video over acoustic communication due to high latency, considerable signal attenuation, serious multipath effect, restricted communication bandwidth, and other characteristics [14]. Random interference also affects hydroacoustic transmission, and data is easily stolen [15].

The United States military began to pay attention to underwater laser technology development in the early 1990s. However, laser communication is now only employed for satellite-to-submarine communication, and underwater transceiver development is behind. Traditional underwater electromagnetic wave communication and hydroacoustic communication are contrasted to underwater optical communication, which has the advantages of ultra-high bandwidth, high data transfer rate, security, and inexpensive installation and operation costs [16]. Water as a communication medium is the fundamental disadvantage of underwater optical communication, but water is also a highly absorbing medium for light signals, in addition to optical scattering generated by particles in the ocean [17].

2.4 Research on Cooperative Operation of Multiple Underwater Robots

As operating activities become more complicated, a single underwater robot may be unable to handle all of the requirements. Because of their spatial distribution, efficiency, resilience, and flexibility, many underwater robotic systems have benefits that no single underwater robot can match [18]. Multiple platforms of underwater robots working together to work in difficult seas help them to avoid risky circumstances, ensure crew safety, and decrease property damage. As a result, multi-robot underwater cooperative operation is progressively becoming one of the research hotspots, with the control module as the fundamental technology [19]. The CoCoRo underwater micro-UAV cluster produced by the EU [20], the Micro Underwater Explorers (M-AUEs) cluster built by the University of California [21], and the SwarmDiver underwater micro-UAV cluster developed by Aquabotix, USA are all examples. To increase the efficiency of cooperative activities, the literature [22] suggested a generalized multi-robot cooperative control model employing a deep neural network training model. The literature [23] thoroughly summarizes the classification and current research state of AUV, formation control, and hydroacoustic communication capabilities, as well as forecasting formation control's future growth path. Harbin Engineering University, Northwestern Polytechnic University, and the Chinese Academy of Sciences' Shenyang Institute of Automation all do related research on multi-submersible robotic systems in China [24]. The multi-submersible robot formation navigation control and cooperative positioning of multi-submersible robots are studied at Northwestern Polytechnical University [25]. Harbin Engineering University is investigating multi-submersible robot system distributed control structure and task coordination mechanism, as well as multi-submersible robot coordination approaches [26,27].

The control system is at the heart of the multi-robot underwater collaboration process, in which each robot communicates with the others and provides mutual detection information in real time to keep a safe distance across many platforms. From the perspective of operation control, there are three types of multi-robot collaborative operation architecture: centralized, distributed, and hybrid [28]. A comparison of the characteristics of these three collaborative operation architectures is shown in Table 1.

Low transmission data rate, delayed transmission, inadequate security, and interference in underwater robotic cooperative operation communication limit coordination and precision. Technical difficulties such as underwater remote high-speed dynamic communication and linkage between underwater and air networks must be solved in order to achieve data exchange across different robots on multiple platforms [29].

Table 1. Comparison of multi-robot cooperative operation architectures

	Advantages	Disadvantages
Centralized	Only one control unit for task division and management, easy to control	Less flexibility
Distributed	Each member is equal to each other and makes all their own decisions about their actions	Poor resource sharing and coordination
Hybrid	Unified management of some members of the underwater robot, followed by task division and division of labor, sharing of resources and coordination of conflicts	Complex structure for system complexity and distributed autonomous decision making among multiple robots

3. Conclusions

The remote wireless operation platform is connected to other platforms via a high-speed, low-latency wireless connection, and hydroacoustic communication is used remotely. Communication between other platforms and ROVs in the near range uses twisted-pair cables in the umbilical cable to transmit both the operation commands of underwater HD cameras, sonar, and manipulators, as well as the signals used by the surface manipulation console to control them [30]. In the complicated and varied underwater environment, optical communication is used to accomplish information interaction and data sharing between multipurpose underwater robots. The remote wireless operating platform combines hydroacoustic and wireless communication, with hydroacoustic communication being used when wireless communication is out of range and wireless communication being used when it is. It offers high data rate, high security, and short delay time communication transmission between platforms, platforms and underwater multipurpose robots, and underwater robots, and improves cooperative operation coordination and precision.

Without the use of underwater communication technology, information exchange between surface platforms, underwater robots, and platforms and underwater robots, as well as joint operations, are impossible. One of the most essential technologies in the development of remote operating platforms is underwater communication technology. Security, transmission speed, or real-time, and transmission efficiency are the primary issues in underwater communication technology today. The core challenge of remote control, underwater communication network, and underwater communication security issues are the focus of future development. The US has implemented large application projects in the fields of underwater acoustic communication, radio communication, and optical communication, among others. In the future, it is anticipated to break the underwater communication and cross-domain communication bottlenecks. China has conducted seawater quantum communication experiments, demonstrating for the first time the viability of underwater quantum communication with communication distances of hundreds of meters.

At the same time, an essential long-term development plan direction for remote operation platforms is underwater robot formation cooperative control technology with higher system reliability and higher data update rate. High system compatibility, signal power augmentation, encryption and decryption, and modulation technologies are predicted to be represented in future advancement in robot formation cooperative control technology. A future development trend is to combine explicit and implicit communication amongst individual case platforms. Furthermore, as remote operation platforms face increasingly difficult mission missions, future research on multi-platform collaborative systems will focus on how to achieve dynamic collaborative task assignment and redistribution, maximize the characteristics of each platform, target, and avoid conflicts and interference within collaborative formations.

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Conflict of Interest

There is no conflict of interest.

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