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Overview of Key Technologies for Water-based Automatic Security Marking Platform

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ARTICLE INFO	ABSTRACT
	Water-based automatic security marking platform composed of multifunctional underwater robots and unmanned surface vessel has become the development trend and focus for exploring complex and dangerous waters, and its related technologies have flourished and gradually developed from single control to multi-platform collaborative direction in complex and dangerous waters to reduce casualties. This paper composes and analyzes the key technologies of the water-based automatic security marking platform based on the cable underwater robot and the unmanned surface vessel, describes the research and application status of the key technologies of the water-based automatic security marking platform from the aspects of the unmanned surface vessel, underwater robot and underwater multi-sensor information fusion, and outlooks the research direction and focus of the water automatic security inspection and marking platform.

1. Introduction

The underwater environment is complex, human diving depth is limited and dangerous, and water safety is an important task for public security organs. For underwater detection, search, detonation, and other work, frogmen are primarily used for manual processing, which not only makes the case inefficient but also poses a risk to personnel safety. Underwater robots can replace divers for underwater work in complex and risky conditions. Robots are also fast-growing and becoming widely employed in numerous industries, thanks to the Internet of Things,

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big data, cloud computing, artificial intelligence, and other high-tech. The underwater environment is complex, human diving depth is limited and dangerous, and water safety is an important task for public security organs. For underwater detection, search, detonation, and other work, frogmen are primarily used for manual processing, which not only makes the case inefficient but also poses a risk to personnel safety. Underwater robots can replace divers for underwater work in complex and risky conditions. Robots are also fast-growing and becoming widely employed in numerous industries, thanks to the Internet of Things, big data, cloud computing, artificial intelligence, and other high-tech. Police robots can not only assist the police in completing some daily tasks for the public's convenience but also in a variety of security activities to replace police patrol work and reduce police casualties [1]. They can also replace the police in toxic and hazardous work in reconnaissance, detonation, rescue, and other tasks to reduce police casualties. The deployment of robots in dangerous areas is critical for reducing fatalities.

The underwater fully automated security check marker platform is a heterogeneous platform system based on Unmanned Surface Vessel (USV) and Remotely Operated Vehicle (ROV), as shown in Figure 1. Underwater robots require positioning services from a mother ship when performing underwater operation tasks, which limits the range of activities of underwater robots [2]. Replacing the mother ship of the underwater robot with a USV can be used as a relay station to provide energy resupply and information interaction for the underwater robot, forming a heterogeneous robotic synergy platform between the USV and the underwater robot to improve the operational efficiency of the underwater robot and reduce costs [3]. In addition, there are many research institutions that collaborate USVs with underwater robots or other devices [4]. The literature [5] proposed the synergistic operation of USVs with unmanned aerial vehicles (UAVs) to enhance the advantages of USVs and UAVs and form a new collaborative platform of coupled USV-UAV systems. The literature [6] investigates the design, construction and control strategies of USV-ROV systems with the aim of developing inspection and surveillance technologies that are compatible with maritime and submarine applications. The literature [7] presents the development of the USV-ROV maritime unmanned platform architecture, control system, sensor system and control algorithms, as well as the results of sea trials.

The water-based automatic security marking platform consists of USV, ROV, water control system, launch and recovery system, umbilical cable, cable manage-ment system and other devices, as shown in Figure 2 [9]. The water-based fully automated security marking platform incorporates a number of advanced technologies such as sensor technology, wireless communication technology, data processing technology, and intelligent control technology [10]. The USV, for example, is designed like a double-hulled surface boat and has superb speed, wave resistance, maneuverability, and stability [11]. The use of air channels to generate surface power, along with an air culvert power system on the water, can prevent interference and encroachment on the hydrographic situation and the equipment carried on the hull caused by the undersea rudder and propeller propulsion system. The use of air channels to generate surface power, along with an air culvert power system on the water, can prevent subsea rudder and propeller propulsion system interference and encroachment on the hydrographic situation and the equipment carried on the hull. The underwater robot is launched and recovered by the launch and recovery system, and the length of the loaded umbilical cable is proportional to the robot's diving depth. The cable management system is a two-strand cable-connected housing intermediary device that can be used to store and stow the neutral cable, minimize or lessen the effect of the surface mothership's motion on the ROV, and increase the underwater robot's operational radius. The umbilical cable transmits 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, mainly involving information transmission technology [12]. The water-based automatic security marking platform is equipped with a high-precision sonar detector, by wireless operation platform for underwater structure modeling, hull connection control multifunctional underwater robot, the robot equipped with underwater high-definition camera set, high-power searchlight, metal detector, node detector, capable of information fusion processing, integrated sonar and electromagnetic detection function, sonar detection accuracy of different water quality research, the use of electromagnetic detection to determine the type of target object, able to study and judge the high-risk area and issue an alarm, the hull to mark the dangerous area, mainly involving sonar detection, multi-sensor information fusion and other technologies.

This study focuses on the essential technologies used in completely automated security marking platforms on water, such as unmanned surface vehicles, multifunctional underwater robots, multi-sensor fusion detection, and so on, and forecasts the trend of fully automated security
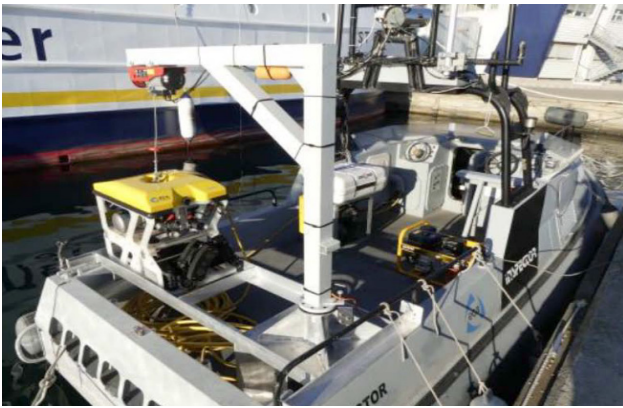
screening platforms on water.
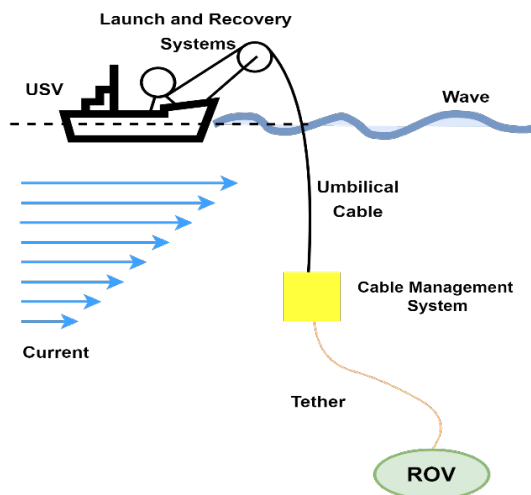

Figure 1. USV-ROV [8]

Figure 2. Structural components of the water automatic security check marker platform [9]

2. Water-based Automatic Security Marking Platform Key Technology Research Status

2.1 Research on USV

USVs are classified as propeller or water jet propulsion based on their propulsion method [13]. USVs are fitted with advanced control systems, sensor systems, and communication systems to undertake a variety of complicated missions such as scientific research, environmental missions, maritime resource exploitation, military use, detection, and hazardous missions such as demining. Figure 3 depicts a description of the challenge, research issues, and current state of the art for USVs.

USVs were first developed during World War II and were primarily employed for military purposes [14]. USVs were widely deployed in the US Army's anti-mine ship system in the 1970s and played a key part in military mis-

sions [15]. The USV is an open architecture design with a range of mission-oriented modular components developed by Textron [16]. The Watcher II, built by Yunzhou Technology Co., Ltd. in China, is the world's second unmanned missile boat and one of only two unmanned missile boats to successfully execute missile test firings [17]. The USV features a number of different piloting modes. The USV has numerous piloting modes and is outfitted with electro-optical and radar equipment as well as missile launchers, allowing it to conduct intelligent patrol, reconnaissance, and search and rescue operations.

USV has also been applied in post-disaster search operations and structural damage assessment, such as the World Trade Center in 2001, Fukushima Daiichi nuclear power plant in 2011, Hurricane Wilma in 2005 and Hurricane Ike in 2008 [18]. The literature [19] summarized and prospected the application and role of USV in disaster relief to provide some theoretical guidance for the research in this field. Scientific research is another need for USVs, with experts from C & C Technologies and Texas A & M University employing them for hydrographic surveys and scientific applications [20]. The China Meteorological Administration (CMA) built the "Tianxiang *I*" in 2008, which was the first international usage of autonomous marine exploration vessels for meteorological exploration. The "*Jinghai*" series of surface unmanned boats, developed by Shanghai University, can detect underwater topography and hydrology, as shown in Figure 4. It has also conducted polar marine mapping in Antarctica, making it China's first unmanned surface vessel to do independent mapping in the polar areas [21]. Literature [22] proposed that an autonomous boat that uses waves as propulsion and solar panels to power electronic equipment attain extraordinarily long endurance and play a key role in encouraging the implementation of worldwide ocean observation expeditions.

Underwater robots must be deployed and recovered regularly due to their range and the stability of underwater data transmission. This raises the expense and risk, as well as the inability to operate 24 hours a day, seven days a week, and with low efficiency. As a result, using unmanned surface boats to boost underwater robot performance has a lot of practical applications. The underwater automatic security check marker platform employs cable remote control of the underwater robot, as well as cable remote control of the underwater robot and unmanned surface boat via umbilical cable connection, with umbilical cable forward transmission of power and control signals from the unmanned surface boat to the underwater robot, as well as reverse real-time image data transmission from the underwater robot to the unmanned surface boat. Some ROVs with sufficiently strong armored or umbilical

USV		
Key Questions for Research	**Challenge**	**Status of Technology**
Reliable Communication Systems	Autonomous GNC of single USV	Scientific Research
Suitable Hull Design	Autonomous GNC of USVs and other vehicles	Environmental Missions
Powerful GNC Strategies	Multiple USVs in formation	Military Uses
Cooperation Subsystems	Reliability	Other Applications
	Quality of Mission Outcomes	

Figure 3. The summary of the current status of USV research

cables can rely on the armored or umbilical cables to pull the ROV body out of the water if the body loses power in the event of failure. ROVs have substantially improved in terms of safety [23].

In conclusion, USVs are becoming more common in scientific studies and some maritime operations. The deployment of USVs can significantly enhance work efficiency, minimize people activities above and below the sea, and lower hazards and expenses. The potential of USVs for marine scientific research and military applications is clear, including the junction of numerous disciplines, particularly in the realm of artificial intelligence, and the future development trend is for USVs to be extremely intelligent. A current research focus is how to increase the autonomous capabilities of unmanned surface boats in order to complete various tasks in challenging operational settings. To make the intelligent system more forward-looking, unmanned surfaces improve the capacity to forecast the future and boost the system's autonomous learning capabilities.

Figure 4. *"JingHai-I"* USV [24]

2.2 Research on Underwater Robots

Underwater robots are a form of extreme operating robot that works underwater. They come in a variety of shapes and sizes and have been in development for over 60 years [25]. Depending on whether there is an umbilical cable between the mother ship and the hull, unmanned underwater robots are classified as Remotely Operated Vehicles (ROV) or Autonomous Underwater Vehicle (AUV). In real-time, the umbilical cable transfers power and control signals from the mother ship to the vessel in one direction and picture data from the vessel to the mother ship in the other. The AUV, on the other hand, has no umbilical cord connecting it to the mother ship; instead, it navigates autonomously using the power source integrated into the hull and its intelligence. The umbilical cable provides power, information exchange, and safety for ROVs, but it also limits the range of activities that ROVs can perform. As a result, AUVs, which do not require umbilical cables, are self-energizing, and operate on autonomous forces, have naturally become a hot spot for research. However, there are significant technological challenges in building AUVs, and the technology is not yet mature. Figure 5 depicts a description of the challenge, research issues, and current state of the art in the field of underwater robots.

2.2.1 AUV

In comparison to ROVs, AUVs do not require umbilical cords to link to the mother ship and hence have a larger operating radius, more maneuvering freedom, smaller size, and no requirement for expensive life support and surface support systems [26]. Because of their distinct advantages,

Underwater Robotics			
	Key Questions for Research	**Challenge**	**Status of Technology**
ROV	Seafloor Topography Top-flow anti-interference capability Detection and Identification of Underwater Targets	Operating Accuracy Range of Activities Hydraulic Power	Mature Technology Reach Almost Any Ocean Depth Wide range of applications
AUV	Dynamics of AUV Multi-AUV Communication Technology Navigation Positioning Control Technology	Adequate Power Supply AUV Docking Technologies Information Transmission Submergence depth	Research Hotspots Excellent Potential Applications Technology is Still Immature

Figure 5. The summary of the current status of Underwater Robots research

AUVs are used in a variety of industries, including military, civilian, and scientific research. AUVs are mostly utilized for underwater construction, patrol and reconnaissance, and intelligence gathering in the military, which is why governments all over the world are working to develop better AUV systems [27]. Advanced AUV systems have been developed around the world. The US military uses the REMUS line of underwater robots created by Woods Hole Ocean Systems Laboratory for military operations such as mine countermeasures [28]. The United States deployed the REMUS series of underwater robots developed by Woods Hole Ocean Systems Laboratory in military duties such as anti-mine operations [29]. REMUS-6000 and other autonomous underwater robots were later developed for underwater searches and mapping [30]. AUVs are extensively utilized in the civilian sector for maritime rescue, submarine fiber optic cable laying, maintenance, and other tasks. In 2014, the Zhejiang Hangzhou Public Security Bureau used an underwater robot to recover a murdered person's body from a reservoir with a water depth of over 100 meters. The civilian police were aided by the Wuhan Public Security Bureau's multifunctional detonation robot in safely and efficiently accomplishing rescue and detonation tasks in tough conditions. This will considerably lower the risk of work and the number of civilian police officers killed. Underwater robots are mostly utilized in scientific study for topographic mapping, seabed mineral

exploration, marine environmental studies, and marine archaeology, among other things. The "*Qianlong*" series includes two underwater robots, "*Qianlong I*" and "*Qianlong II*" which were produced by China for oceanographic study. The "*Qianlong I*" can work at a maximum depth of 6000 meters. It has a shallow stratigraphic profiler and other exploration equipment, as illustrated in Figure 6 [31], enabling fine exploration of seabed microtopography and geomorphology, as well as monitoring of seafloor hydrographic parameters. The greatest dive depth of Harbin Engineering University's "*Wukong*" reached 7709 meters in 2021, setting a new record for unmanned cableless submersible AUV dive depth and making it the second deepest in the world [32]. This is the world's second-deepest AUV.

Because there is no impact of cable and limited fluctuation in sea state parameters, AUV has significant benefits in operational capability and precision. As a result, AUV will be one of the future trends of underwater multipurpose robots with outstanding prospective application possibilities. Multi-autonomous underwater vehicle (Multi-AUV) underwater cooperative operation is now the trend and focus of underwater robot research, and because the underwater environment is complicated and changing, multi-AUV formation can better accomplish diverse duties. The literature [34] suggested an integrated algorithm for cooperative operation of Multi-AUV, which enhances search

efficiency and decreases tracking mistakes while maintaining high efficiency and flexibility. The literature [35] evaluated the impacts of the AUV model, underwater environment, and intra-AUV communication on formation transformation and recommended several difficult difficulties and future research paths for Multi-AUV formations.
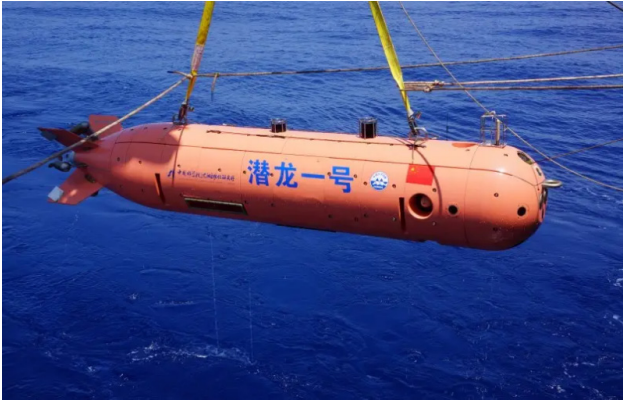

Figure 6. "*Qianlong I*" AUV [33]

2.2.2 ROV

ROV technology is the most advanced and widely utilized, with operating depths ranging from 0 to 10,000 meters and the ability to reach nearly any ocean depth. The ROV is connected by cable to the mother ship, which supplies power, energy, data transmission, and control. As demonstrated in Figure 7, ROV has better data transmission and range than AUV and is not limited by the ocean environment, making it appropriate for substituting people in a variety of industries to complete some dangerous duties. Japan's "Trench" ROV and the U.S. "Poseidon" ROV have reached the deepest place on Earth - the Marianas Trench. In 1985, China's first large underwater robot, the Sea Man One ROV, was developed to conduct scientific research. ROVs can also be utilized in police applications such as underwater suspicious object detection and rescue, underwater security, and underwater disposal, and can replace frogmen in risky, sensitive, or long and repetitive labor. The literature [36] uses ROVs for underwater inspection of ship hulls or marine debris, etc., equipped with cameras and sensors such as GPS, temperature, depth and pressure to achieve protection of the marine environment as well as underwater species. ROVs are used to do maintenance inspections of coastal berms or coastal buildings, according to the literature [37]. Virtual reality (VR) technology is used in the literature [38] to remotely operate ROVs, which can let users feel as if they are in a risky scenario without having to be physically present. ROV sensor data is converted into human-perceivable experiences using a VR sensory simulator. The hurdles to person-in-the-loop

ROV teleoperation are reduced by allowing substantial human engagement in ROV teleoperation.
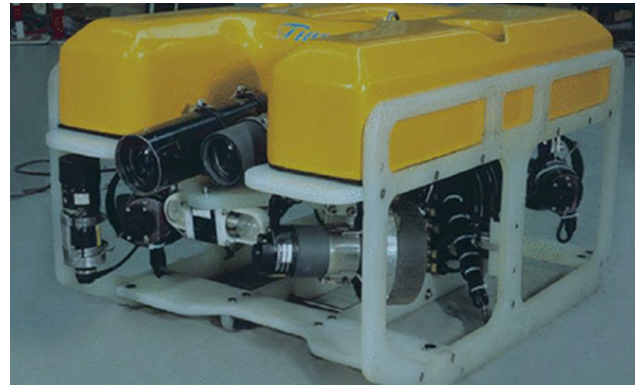

Figure 7. ROV [39]

There is still more opportunity for AUV development than ROV due to the limits of related technology development levels [40]. The ROV system is the most established, frequently utilized, cost-effective, and practical submersible [41]. ROVs are classified as observation or operational, and the water-based automatic security marking platform uses an observation level ROV with underwater thrusters and underwater camera systems as its core components, which are sometimes supplemented by navigation, depth sensors, and other conventional sensors.

The ROV body is smaller, lighter, and carries a reduced burden. One of the trends in the development of ROVs is improving the operational synergy between the surface control system and the underwater observation operation system, increasing data processing capability and speed, and improving the overall ROV operational control level and operational performance [42]. ROVs use umbilical cords to provide data, control commands, and energy to the surface platform. The length of the loaded umbilical cable is proportional to the underwater robot's dive depth and operational radius, which is overly reliant on the surface USV, resulting in a limited range of activities and a dive depth that has to be enhanced. The umbilical cable has a particular rigidity and buoyancy, and its contact with the ROV can impact the underwater robot's operational precision to some amount. As a result, one of the most important research concerns in the future will be decreasing the cable's impact on the underwater robot or creating AUV technology. The combination of AUV and ROV to form a water-based automatic security marking platform is an important development direction and hot spot for future safety in complex waters, and they both play their respective irreplaceable roles in complex waters considered for detection, complementing the characteristics of AUV and ROV to improve the efficiency of underwater operations.

2.3 Research on Underwater Multi-sensor Information Fusion

Because the underwater environment is complicated and varied, individual sensors are less dependable, hence underwater data fusion is critical. The correlation and fusion of information and data acquired by each sensor in time and space to remove redundant information and produce a consistent interpretation and description of the observed object so that the obtained information is fully utilized are referred to as multi-sensor information fusion. Fusion can be classified into three types based on the structure of the data: data-level fusion, feature-level fusion, and decision-level fusion [24]. A summary of USV challenges, research issues, and the current state of the art is presented in Figure 8.

The literature [43] designed a submarine pipeline detection method based on multi-sensor information fusion, capable of collecting acoustic profiles and topography above and below the water in the area of the pipeline route. Inspection of underwater infrastructure, such as bridges, water supply systems and oil rigs, requires divers to be in the water to perform the task. Because underwater habitats are complicated and all environments are unknown and harmful to divers, the employment of underwater robots to create maps of the environment and locate them can lessen the risk to divers. The literature [44] combined vision, inertial, acoustic and pressure sensors using SLAM algorithm to achieve simultaneous localization and mapping in underwater environment. In the literature [45], data fusion using sensors such as IMU, pressure and optical flow was used to achieve underwater centimeter-level localization using an extended Kalman filter fusion algorithm to improve localization accuracy and achieve optimal navigation [46]. This underwater robot localization method with a modest processing capacity is useful for operational duties in unfamiliar underwater environments. Because GPS is

no longer applicable in unknown complex underwater environments, which is extremely dangerous for divers, it is necessary to use underwater robotic detection and real-time map construction, i.e. positioning, as well as to quickly correct the course at any time based on changes in motion sensors and navigation parameters. Although the present multi-sensor data fusion detection technology is advanced, its use in the underwater environment is still uncommon. Some essential technologies, including as high-level representations of data fusion, target tracking identification, and its fusion algorithms, still require improvement [47].

The lowest level of fusion is data-level fusion, which is the direct data fusion of the raw data obtained by each sensor for the detection target, without any pre-processing [48]. As demonstrated in Figure 9, data-level fusion is commonly employed for data fusion of the same type of sensor [49].

Pre-processing the original information obtained by each sensor first, extracting representative features in the information for feature fusion, and then performing target recognition based on the fused features is what feature-level fusion is all about. This fusion method preprocesses the original data and eliminates redundant data, which improves the sensing system's real-time performance. However, as illustrated in Figure 10, certain critical information may be lost in the preprocessing, resulting in perception system misjudgment.

As shown in Figure 10, decision-level fusion is a high-level fusion that complements (integrates) data-level and feature-level fusion. To accomplish optimal target detection, each sensor first detects the target to obtain its judgment results, and then these decisions are correlated and integrated, as illustrated in Figure 11. Decision-level fusion can make the best use of the data collected, but it requires a lot of processing power. The literature [50] proposed the use of Bayesian fusion method for underwater

Multi-sensor Information Fusion		
Key Questions for Research	**Challenge**	**Status of Technology**
Data-level Fusion	**Basic Theory Research**	**Widely used in Military and Civilian applications**
Feature-level Fusion	**Citation of Artificial Intelligence Technology**	**A complete Theoretical System has not been formed so far**
Decision-level Fusion	**Real-Time**	
Algorithms for Fusion	**The Problem of Associative Duality**	**Multidisciplinary Intersectional Areas**

Figure 8. The summary of the current status of Multi-sensor Information Fusion research

multi-sensor information fusion, where each sensor makes a decision before submitting it to the fusion center to make the final decision, this fusion reduces the data transmitted by the underwater robot like the data center, reduces the computational complexity of the fusion middle row, and facilitates the underwater transmission.

The multi-functional underwater robot uses a decision fusion mechanism to judge and make decisions on targets by integrating multiple sensors such as sonar, electromagnetic detection, and high-definition cameras and then passing the results of the decisions to the fusion center, where they are fused. The accuracy of sonar detection of various water quality, the use of electromagnetic detection to determine the type of target, the capacity to study and judge high-risk zones and send alerts, and the use of the hull to indicate the danger area are all investigated. Because the extracted features are directly related to the decision analysis, the fusion results can maximize the feature information required for decision analysis, considerably boosting the system's efficiency. However, each sensor in this distributed fusion process determines only its data information, and the correlation between data is not taken into account [51]. The data correlation isn't properly taken into account.
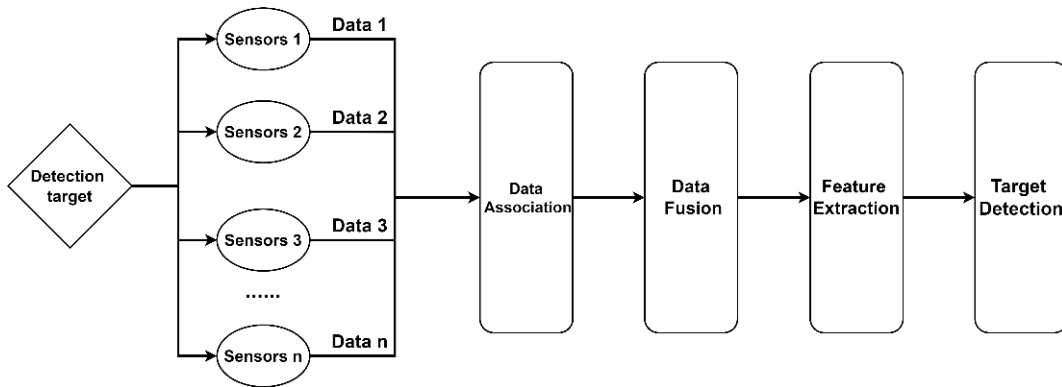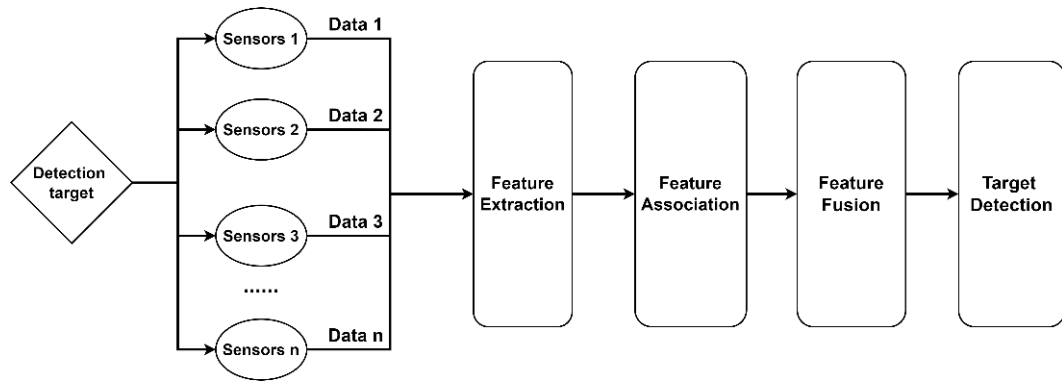

Figure 9. Data-Level Fusion

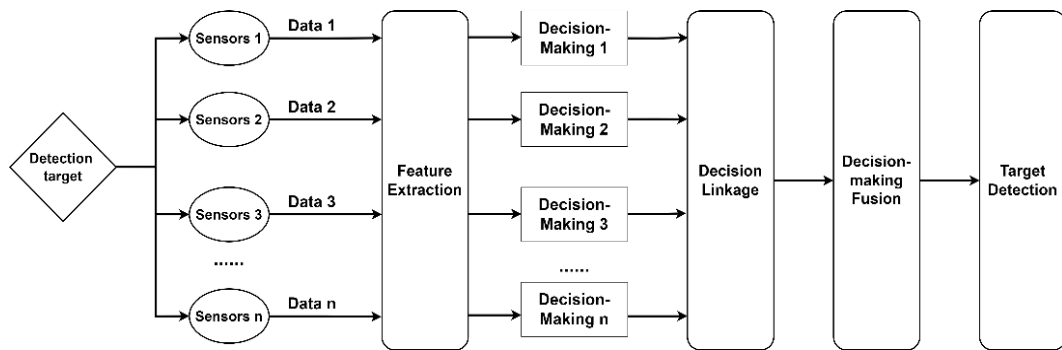**Figure 10.** Feature-Level Fusion

Figure 11. Decision-Level Fusion

3. Conclusions

The water-based automatic security marking platform by integrating a range of systems, such as ROV, USV, and surface control and launch recovery system, to achieve high-risk area research and marking. To prevent civilian casualties, the creation of a fully automatic security inspection platform on the water could replace civilian police in poisonous and hazardous operations such as reconnaissance, detonation, rescue, and other jobs. Underwater and surface control command and data transfer, underwater robot range and operating capabilities, high-precision motion control capability, environment perception capability, and positioning capability are the important technologies. The underwater robot is a critical component of the water-based automatic security marking platform on the sea, offering substantial mobility, flexibility, and endurance. Underwater robots combine modern technologies in mechanics, materials, energy, fluids, computer control, and other domains. Underwater multifunctional robotics development is critical for military, civic, and scientific study. This paper researches and summarizes the key technologies involved in the water-based fully automated security marking platform, which provides a certain reference for the research in the field of water safety and is of great significance for reducing casualties.

Despite the fact that research on the USV-ROV collaborative system is growing, it still has significant issues to address due to the unique nature of its working environment and application context. Satellite communication currently covers practically the whole globe, however it cannot be utilized underwater. One of the most important components of a USV-ROV utilized for underwater operations is the communication system, which increases underwater communication performance in three ways: efficiency, dependability, and safety. The water-based fully automated security marking platform should be able to make intelligent autonomous decisions in a tough environment. In the event of a communication failure, it may self-adopt a series of coping mechanisms to establish autonomous route planning and control capacity for underwater operations.

Acknowledgments

Conflict of Interest

There is no conflict of interest.

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