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# An Underwater Robot Inspection Anomaly Localization Feedback System Based on Sonar Technology

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**Abstract:** This article introduces an underwater robot inspection anomaly localization feedback system comprising a real-time water surface tracking, detection, and positioning system located on the water surface, while the underwater robot inspection anomaly feedback system is housed within the underwater robot. The system facilitates the issuance of corresponding mechanical responses based on the water surface's real-time tracking, detection, and positioning, enabling recognition and feedback of anomaly information. Through sonar technology, the underwater robot inspection anomaly feedback system monitors the underwater robot in real-time, triggering responsive actions upon encountering anomalies. The real-time tracking, detection, and positioning system from the water surface identifies abnormal conditions of underwater robots based on changes in sonar images, subsequently notifying personnel for necessary intervention.

**Keywords:** Underwater robots; Positioning feedback system; Sonar real-time tracking

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## 1. Introduction

Underwater robots are mainly divided into autonomous underwater vehicles (AUV) without cables and remotely operated underwater vehicles (ROV) with cables. These two types of underwater vehicles have been widely used in many fields [1-5]. The underwater robotics and applications (URA) laboratory at the University of Tokyo has developed many AUVs with different functions, such as "Twin-Burger", "PTEROA 150", and "PTEROA 250" [6]. A small intelligent underwater autonomous navigation robot is currently being developed by Northwestern Polytechnical University in China. In recent years, underwater positioning and navigation have been a technology that provides information on the posture, speed, position, and other aspects of underwater robots [7]. It is a prerequisite for underwater robots to complete various underwater tasks. In the report of the 18$^{th}$ National Congress of the Communist Party of China, the goal of building a maritime power was proposed [8]. However, the existing national spatial and gravity benchmarks have not effectively covered the ocean. The ocean geodetic benchmarks and navigation technology are lagging behind the national social, economic, and defense strategies [9]. The development of underwater terrain matching methods based on sonar image processing technology is very important for expanding the underwater application range of terrain matching and improving the error correction ability of underwater navigation systems [10]. Sonar sensors are devices based on sound signals, including matching positioning technology based on seabed terrain and landform information. The technology is based on the detection, recognition, and classification of environmental features [11]. Side scan sonar has the advantages of a long operating period, wide coverage, strong penetration ability, and large data collection [12]. Since the 1980s, scientists produced various types of sonar products, and through optimizing their performance in various aspects, preliminary research has been conducted on sonar detection equipment that can display seabed topography and landforms [13]. Due to the complex and variable underwater environment in which the robot is located, it is prone to instantaneous positioning failure [14]. Several universities and research institutions, including the Shenyang Institute of Automation, Chinese Academy of Sciences, Harbin Engineering University, and Shanghai Jiao Tong University, have increased their investment in manpower and resources and strengthened their research efforts in underwater robot technology, especially in core navigation algorithms [15].

## 2. Overall design plan

As shown in **Figure 1**, the underwater robot inspection anomaly localization feedback system includes a real-time water surface tracking, detection, and positioning system set on the water surface, whereas the anomaly feedback system is housed inside the underwater robot. The underwater robot system sends corresponding mechanical signals for the water surface system to recognize and provide feedback on anomalies. The underwater robot inspection anomaly feedback system uses sonar to track the underwater robot in real-time. When the underwater robot encounters an anomaly, the system responds with appropriate actions. The real-time tracking, detection, and positioning system on the water surface identifies the types of anomalies in the underwater robot through changes in sonar images and notifies the staff to handle them. The real-time tracking, detection, and positioning system is installed on the hull to continuously monitor the underwater robot.

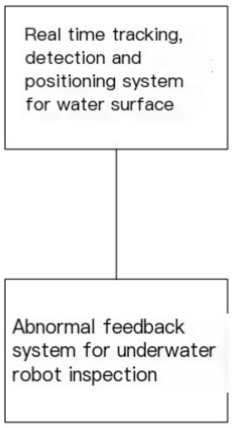


**Figure 1.** The overall design of the underwater robot inspection anomaly localization feedback system

## 3. Design scheme of underwater robot sample collection and processing subsystem

As shown in Figure 2, the underwater robot sample collection and processing subsystem includes an underwater robot image acquisition unit, an underwater robot image processing unit, and an underwater robot contour map summary encoding unit.

The image acquisition unit is responsible for deploying the underwater sampling robot into the deep sea and determining its precise position through manual positioning. It collects sonar images from the seabed in a flat sea area using a sonar collection vessel. The vessel performs a circular motion around the underwater robot, with the radius of the motion increasing gradually. Images collected during each circular motion are saved separately, corresponding to the radius and seawater depth.

The image processing unit processes all sonar image sets, recognizing contours and edge lines to create a set of contour maps. Manual marking of the contours of the underwater sampling robot is performed, retaining the internal lines within the contours.

The contour map summary encoding unit organizes the collected contour maps into folders, encoding the specific azimuth and position information of the underwater sampling robot. Each contour map corresponds to a collection point relative to the robot's location. This unit also places each image on a two-dimensional coordinate axis, with the contour of the underwater sampling robot as the center point at the origin. Points on the contour are set as integer multiples of 64, and their polar coordinates are extracted. The polar coordinate function is obtained for all encoded contour maps, resulting in a polar coordinate function that represents the number of encoded contour maps and is a positive integer. If n is a positive integer greater than or equal to 1, all polar coordinates are used to derive the polar coordinate function. This results in a polar coordinate function for all encoded contour maps, with the number of encoded contour maps being a positive integer.

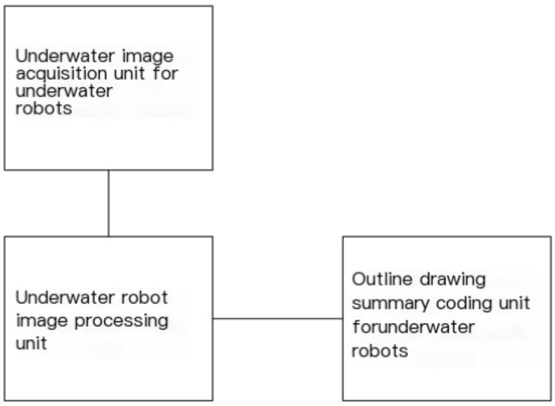


**Figure 2.** Sample collection and processing subsystem for underwater robots

## 4. Anomaly feedback system for underwater robot inspection

The underwater robot inspection anomaly localization feedback system includes an underwater robot unit, an anomaly category determination unit, and a shape change anomaly feedback unit, as shown in Figure 3. The underwater robot unit is the operating body of the underwater robot. The anomaly category determination unit is located inside the underwater robot unit, while the shape change anomaly feedback unit is situated on the outer layer.

The anomaly category determination unit continuously monitors images or videos from the underwater robot unit during inspections to identify any abnormalities. It also assesses the electrical power and overall performance of the underwater robot unit in real-time. If a fault occurs or a predefined abnormal object is detected during inspection, the anomaly category determination unit alerts the shape change anomaly feedback unit.

The shape change anomaly feedback unit responds by altering the shape of the shell or extending a marking action rod based on the type of abnormality detected. This change is then communicated to the real-time tracking and detection positioning system on the water surface.

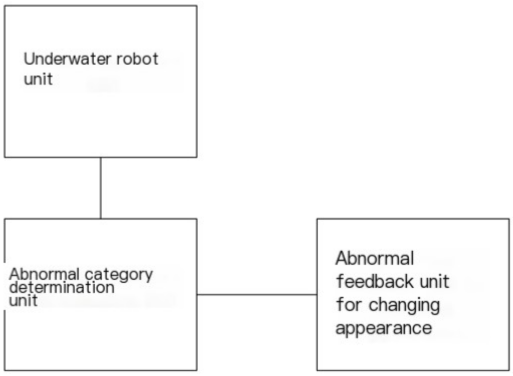


**Figure 3.** Abnormal feedback system for underwater robot inspection

## 5. Summary

This article presents the design of an underwater robot inspection anomaly localization feedback system consisting of a real-time water surface tracking, detection, and positioning system. This integrated system facilitates the acquisition of comprehensive underwater contour data for robots, offering a streamlined calculation process enabling real-time positioning and tracking capabilities.

## Disclosure statement

The authors declare no conflict of interest.

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