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# Underwater Hazard Detection for Hydraulic Structures Based on Computer Vision

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**Abstract:** With the aging of hydraulic engineering and the increasing complexity of underwater environments, the detection of underwater hazards in hydraulic structures has become an urgent need. Traditional detection methods, due to difficulties in operation, low efficiency, and poor accuracy, have become increasingly inadequate to meet practical requirements. Therefore, this paper proposes a computer vision-based method for underwater hazard detection in hydraulic structures. The aim is to achieve automatic, efficient, and accurate detection of underwater hazards in hydraulic structures through image processing and analysis techniques.
**Keywords:** Computer vision; Hydraulic structures; Underwater hazard detection; Image processing

## Introduction

As integral components of hydraulic engineering, hydraulic structures play a crucial role in ensuring the safety and stability vital for safeguarding lives and properties. However, with the aging of hydraulic engineering and the increasing complexity of underwater environments, hydraulic structures are confronted with various threats of underwater hazards, such as cracks, corrosion, and leakage. Traditional methods for underwater hazard detection heavily rely on manual inspections and diver operations, leading to challenges in terms of operational difficulty, low efficiency, and lack of accuracy. Therefore, the development of a computer vision-based underwater hazard detection method becomes imperative. This method aims to achieve automatic, efficient, and accurate detection of underwater hazards in hydraulic structures, presenting significant practical significance and application value.

## 1. Overview of Computer Vision Technology

Computer vision technology, as a significant branch of artificial intelligence, aims to empower computers with the ability to "see" and comprehend visual information. It encompasses various aspects such as image processing, pattern recognition, and more, simulating the human process of visual information acquisition, analysis, and interpretation. Since the mid-20th century, with the improvement of computing power and algorithm development, computer vision technology has undergone a leap from simple image processing to the understanding of complex scenes. In numerous application domains, computer vision technology has demonstrated immense potential. It plays an indispensable role in quality inspection in industrial automation, vehicle and pedestrian recognition in intelligent transportation, medical image analysis in the healthcare sector, video surveillance in the security domain, and more. Notably, the application of computer vision technology in underwater environments is worth mentioning. Due to the unique and complex nature of underwater environments, including factors such as light refraction and water turbidity, traditional image processing techniques face numerous challenges. However, the latest advancements in computer vision technology provide new solutions for underwater image processing.

## 2. Types and Characteristics of Underwater Hazards in Hydraulic Structures

Hydraulic structures, when subjected to prolonged underwater conditions, are susceptible to various types of hazards. Among them, cracks, voids, and damages are common underwater hazard types. Cracks result from factors such as uneven structural stress, material aging, or temperature changes. They can range from hairline fractures to large and deep fissures, but regardless of size, they can lead to water infiltration and accelerate structural deterioration. Voids may occur due to improper construction, material defects, or erosion, resulting in internal cavities. These voids not only weaken the overall integrity of the structure but may also serve as sources for water accumulation and erosion. Damages manifest as surface peeling, fragmentation, or loss, directly impacting the integrity and functionality of hydraulic structures. The characteristics of these underwater hazards are primarily their concealment. As they mostly occur underwater or within the structure, they are not easily observable directly, making timely detection and intervention challenging. Another characteristic is their potential danger. Even small cracks or damages may gradually enlarge under prolonged water pressure and erosion, ultimately threatening the safety of the entire structure[1]. Moreover, if these hazards progress to a certain extent, they may lead to catastrophic consequences such as leaks or dam failures, posing a serious threat to the safety of people's lives and properties.

## 3. Computer Vision-Based Underwater Hazard Detection Steps and Methods

### 3.1 Image Acquisition

Computer vision-based underwater hazard detection is a technically demanding and crucial task. In this process, image acquisition is a primary step, and its quality directly influences the accuracy of subsequent hazard identification. To achieve high-quality underwater image acquisition, underwater robots (ROV) or autonomous underwater vehicles (AUV) are often used as carriers. These devices can delve into the underwater environment, and their high-definition cameras can capture subtle signs of hazards. Ensuring uniform lighting during the shooting process is crucial because underwater light refraction and scattering effects may lead to image distortion. Therefore, it is necessary to select appropriate lighting equipment and techniques to ensure that each part of the image receives adequate illumination, avoiding the generation of glare and shadows. Additionally, to further enhance the quality of images and the discriminability of hazard features, the use of multispectral or hyperspectral imaging technology can be considered. These technologies can capture spectral information that conventional cameras cannot, revealing subtle differences between various materials and hazards[2]. Through the analysis of this spectral data, we can more accurately identify cracks, voids, damages, and other hazards in underwater structures, providing robust support for subsequent hazard assessment and repair work.

### 3.2 Image Preprocessing

In the process of computer vision-based underwater hazard detection, image preprocessing is a crucial step. Due to the complexity and uncertainty of the underwater environment, the collected images often suffer from issues such as high noise, low contrast, and color distortion. These problems can significantly impact the accuracy of subsequent hazard identification. Therefore, in the image preprocessing stage, it is essential to apply denoising techniques to reduce random noise and interference, improving the signal-to-noise ratio of the images. Simultaneously, to enhance the contrast and clarity of the images, image enhancement processes such as histogram equalization and sharpening filters are employed. These operations make details in the images clearer, facilitating subsequent hazard identification. Additionally, the application of image segmentation techniques is another crucial step in the preprocessing stage. By segmenting the image into different regions, we can separate the target hazards from the complex background, thereby improving the accuracy of hazard identification. Commonly used image segmentation techniques include threshold segmentation, edge detection, and region growing. Threshold segmentation is a simple yet effective method that divides the image into foreground and background by setting an appropriate threshold. Edge detection identifies edge information in the image, helping to determine the boundaries of hazards. Region growing, on the other hand, segments the image into different regions based on pixel similarity, achieving a more refined segmentation effect. Image preprocessing is an indispensable step in computer vision-based underwater hazard detection. Through operations such as denoising, enhancement, and segmentation, it provides high-quality and clear image data for subsequent hazard identification.

### 3.3 Feature Extraction

In computer vision-based underwater hazard detection, feature extraction serves as a crucial bridge between image preprocessing and hazard identification. The goal at this stage is to extract key information from the preprocessed images that represents hazard characteristics, such as texture, shape, and color. Texture features can reveal spatial distribution patterns between pixels or regions in the image, which is essential for identifying different types of hazards (e.g., cracks, damages). Shape features describe the geometric properties of hazards, including the smoothness of edges and the presence of corners, aiding in distinguishing between hazard and non-hazard areas. Color features reflect the spectral information of different regions in the image, particularly effective in identifying hazards caused by different materials or chemical changes. To enhance the efficiency and accuracy of feature extraction, machine learning algorithms can be employed to automatically learn and select the most effective feature combinations. These algorithms can learn from a large amount of image data to discover feature representations that best represent hazard characteristics, thereby avoiding the complexity and uncertainty of manual feature design. With the assistance of machine learning, automatic, efficient, and accurate extraction of hazard features from images can be achieved, providing robust support for subsequent hazard identification[3]. Feature extraction is a core step in computer vision-based underwater hazard detection, and its effectiveness directly influences the accuracy of the final hazard identification. By extracting key features from images and optimizing them using machine learning algorithms, we can provide more reliable and efficient technical means for underwater hazard detection.

### 3.4 Hazard Recognition and Classification

In computer vision-based underwater hazard detection, hazard recognition and classification are crucial steps. This stage utilizes advanced pattern recognition techniques, such as Support Vector Machines (SVM), neural networks, or deep learning algorithms, to efficiently train and accurately classify the previously extracted image features. The core of these pattern recognition techniques lies in their ability to learn key features that differentiate between different types of hazards from a large amount of labeled data. Through in-depth learning and understanding of these features, classifiers can gradually improve their ability to identify various types of hazards, such as cracks, corrosion, and biological fouling. In practical applications, the process of training a classifier requires an ample amount of annotated data and computational resources. To ensure the performance and generalization ability of the classifier, continuous optimization and validation are necessary, involving adjustments to hyperparameters, the addition of data augmentation measures, and more. With the rapid development of technologies like deep learning, modern pattern recognition methods now possess powerful representation learning and classification capabilities. This allows for more accurate identification of various hazards in underwater structures, providing robust support for subsequent hazard assessment and mitigation. Hazard recognition and classification are indispensable steps in computer vision-based underwater hazard detection. By applying advanced pattern recognition techniques, accurate identification and classification of different types of hazards can be achieved, offering solid technical support for the safe operation of underwater engineering projects.

### 3.5 Hazard Localization and Analysis

In computer vision-based underwater hazard detection, hazard localization and analysis are critical steps to ensure that the detection results have practical guiding significance. This stage primarily involves image registration techniques to precisely correlate the previously identified hazards with the three-dimensional model or design drawings of the structure. Image registration is a technique that aligns image data acquired from different perspectives, times, or sensors by searching for similarity transformations. In underwater hazard monitoring, it effectively matches real-time captured images with the three-dimensional model or design drawings of the structure, achieving accurate hazard localization. Once localization is complete, the next step is a detailed analysis of the hazards. This includes measuring attributes such as size, shape, distribution, and assessing their potential impact on the structural safety of the building. For example, the length, width, and depth of a crack directly reflect the extent of its damage to structural integrity; the area and depth of corrosion reveal the degradation rate of materials and remaining service life. Through these analyses, detection personnel can not only understand the current state of the hazards but also predict their future development trends. This information serves as a crucial basis for formulating targeted repair and reinforcement plans [4]. Therefore, hazard localization and analysis are indispensable components of computer vision-based underwater hazard detection. They ensure the accuracy and practicality of detection results, providing robust assurance for the safe operation of underwater engineering projects.

### 3.6 Result Visualization and Reporting

Result visualization and report generation are the final steps in conveying key information to relevant decision-makers, engineers, and maintenance personnel. This stage is not only about technology but also about effectively transforming technical outcomes into practical guidance and recommendations for real-world applications. Firstly, result visualization involves presenting complex detection data and analysis results in an intuitive and understandable format, such as images, charts, and 3D models. For underwater hazards, this may include precise location maps of hazard points, distribution maps of hazard types, and heatmaps indicating the severity of hazards. These visualizations quickly convey an overview of the hazards, allowing even non-experts to grasp the safety status of underwater structures rapidly. Following that, the compilation of detailed detection reports integrates these visualizations and analysis results into a comprehensive and systematic document. The report will detail all hazards discovered during the detection process, including their types, locations, sizes, shapes, and potential impacts on structural safety. Additionally, based on the severity and urgency of the hazards, the report will provide corresponding repair recommendations, reinforcement measures, or monitoring plans. These suggestions aim to guide subsequent maintenance work and ensure the safety and stability of underwater structures. Result visualization and report generation are indispensable steps in computer vision-based underwater hazard detection. They not only summarize and distill all the previous detection work but also serve as a crucial bridge for translating technical outcomes into practical applications.

## 4. Conclusion

This paper explores a computer vision-based method for underwater hazard detection, achieving automatic, efficient, and accurate detection of underwater hazards in hydraulic structures through image processing and analysis techniques. Analytical studies indicate that this method outperforms traditional detection methods in terms of accuracy and efficiency, demonstrating strong adaptability and robustness. Future work will involve further optimizing algorithms, enhancing detection accuracy and efficiency, and extending the application to practical hydraulic engineering scenarios.

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