ABSTRACT
Existing ocean visualization studies are usually conducted independently using either sonar or optical imaging. However, the two methods have their own shortcomings in different engineering applications. Acoustic imaging is not comprehensive enough to show the details of the target, and the perspective of optical imaging is not extensive enough. Combining the advantages of optics and acoustics, this paper proposes a joint imaging method with acoustic communication-assisted decision-making and optical image stitching, aiming to improve information acquisition efficiency in the ocean visualization process. The joint imaging method relies on sonar technology as the decision-making layer to obtain the position information, then it sends instructions to AUV by acoustic communication and get the details of the target by the AUV-mounted camera which forms the executive layer. Finally, it conducts smoothing and mosaic processing on the optical image. The system can efficiently obtain complete, comprehensive, and detailed ocean visualization information through the advantages of agility of acoustic and accuracy of optics.

KEYWORDS
Underwater imaging, acousto-optical fusion, image enhancement, image mosaic

1 Introduction
Along with the development of ocean exploration and reconnaissance, the need for ocean visualization has been growing fast. Through ocean visualization systems, we can explicitly envisage the underwater environment and the motion states of the targets. Ocean visualization information is needed for many applications, such as underwater oilfields detection, valuable minerals exploration, distributed tactical surveillance, archaeological salvage, and wreck salvage.

The acoustic wave is the only known energy form that can propagate over a long distance in water. With the new developments in recent decades, sonar technology has been widely applied in rapid information acquisition of underwater targets. In [1], researchers use a low-cost acoustic sensor, scanning imaging sonar, to build a feature-based map of the environment by using SLAM. In [2], researchers design an RSS measurement model for locating a single target node.

Optical imaging can provide detailed information of the target. With underwater cameras constantly upgrading in definition and pressure resistance, there has been some research in applying optical imaging in underwater visualized exploration and detection. Due to the complexity of the underwater environment, the information acquired from underwater cameras encounter multiple distortion situations, such as absorption and scattering. These situations will cause contrast reductions for optical images. Underwater scenes captured by cameras are plagued by poor contrast and spectral distortion, which are the result of the scattering and absorptive properties of water. At the same time, the characteristics of optical imaging limit the visual angle of the camera, and a single AUV with a camera can only obtain limited distance and limited angle of view information. Although the use of AUV clusters for target detection can expand the detection range and perspective, they can consume a lot of time and resources, making them not worthwhile for users. [3]
In view of the acoustic and optical imaging limitations and the characteristics of long-distance underwater transmission of acoustic waves, this paper presents a marine information visualization system based on acousto-optic fusion and preliminarily studies the image processing algorithm in the execution layer of the system. The system uses sonar as the decision-making layer to first detect and locate the target, and then uses the AUV mounted with camera as the execution layer to enhance the image of the target and visualize the image mosaic. The two layers can be combined to more efficiently obtain the underwater visualization information data, and acquire a complete and detailed underwater image.

Section 2 introduces the general method of sonar target detection and location, and Section 3 shows the structure of the ocean information visualization system based on acousto-optic fusion. Section 4 introduces the image preprocessing method used in execution layer of the system and the image mosaic algorithm. Section 5 contains the test results and analysis of the execution level of the system. Section 6 contains summary and prospect.

2 Sonar Target Detection and Localization

One of the difficult parts of the Search task is the detection and localization of the target. Usually researchers use time-of-arrival, time-different-of-arrival, angle-of-arrival, and received-signal-strength to obtain target localization. Some researchers use side-scan sonar to obtain subsequent image target segmentation and recognition.

Above all, sonar systems have been conventionally optimized for the detection of “point” targets. Thus, more complex and more accurate targets can be identified by the optical method.

3 System Structure

The ocean visualization detection system based on acousto-optic fusion proposed in this paper is mainly divided into two layers: the decision-making layer for target detection and location and the executive layer for image processing and mosaic. The following will illustrate a case study in regard to detecting an underwater lost contact ship or crashed aircraft.

First, the decision-making layer uses the main ship with sonar positioning and navigation system to detect and locate the target. Then the AUV route is made and driven to leave the main ship using the position information of the target, or the AUV cluster is notified by underwater acoustic communication, and the underwater vehicle nearest to the target in the cluster is used to collect an optical image of the target.

Next, the execution layer will process a series of underwater optical images captured by the camera mounted on the AUV twice. The first time involves the preprocessing of a single image with image denoised, color balance, enhancement, and other processing. The second time involves image mosaic processing. In this paper, the SURF algorithm is used to find the eigenvalues of adjacent images to match, filter out the unmatched eigenvalues, and fuse these matched images two by two until they are connected to an image with complete target information. Finally, the complete image information of the target is transmitted back to the main boat through AUV recovery or underwater acoustic communication. The main flow chart of the system is shown in Figure 1.

![Figure 1: The main flow chart of the ocean visualization detection system.](image)

4 Image Processing

4.1 Image Mosaic Technology

Image mosaic technology is a technology that combines a group of partially overlapped images into a large, high-resolution image with more complete information. Image mosaics are widely used in remote sensing image processing, medical image analysis, and so on.

Image mosaic technology includes three parts: feature points extraction and matching, image registration, and image fusion. To improve the accuracy of the image mosaic, the SURF algorithm is used to extract and match the feature points of the image sequence. SURF uses the Hessian Matrix to extract feature points and calculates the Euclidean distance between the two feature points to determine whether the matching is successful[5]. RANSAC, Random Sample Consensus, is used to screen the mismatching points in the image registration module[6]. According to the transformation matrix between the images, the overlapping areas between the images can be determined by transforming the corresponding images. The images to be fused are mapped to a new blank image to form a mosaic map. Then the weighted smoothing processing is carried out on the image mosaic to obtain the final mosaic image.

Because of the scattering of light and ambient noise, there are fewer feature points that can be correctly matched, and the matching success rate is low in the image mosaic. The matching success rate of the feature points will directly affect the image quality, so the underwater image mosaic needs pre-processing: underwater image enhancement processing. [7] [8] [9]
### 4.2 Underwater Image Enhancement Processing

The water medium can scatter and absorb light, which will cause the attenuation of light energy, resulting in low contrast, large chromatic aberration, and noise in underwater optical imaging. To improve the image quality after image processing, we need to preprocess the acquired optical images.

The images we obtained from the underwater cameras have horizontal strap-like patterns. To mitigate the edges between adjacent straps, we adopt a variation of average filtering algorithm. Considering the straps are perfectly horizontal, the filter kernel we use is one by three, which is not a common setup. By smoothing the image in the vertical direction, we wish to slightly blur the edges of the straps.

Here we compare the variation with a three by three average filtering algorithm and median filtering algorithm. The basic principle of median filtering is to replace the value of a pixel in a digital image with the median value of each point in the neighborhood of the point, so that the surrounding pixel values are closed to the true value, and the isolated noise points are eliminated.

In fact, the images obtained from underwater cameras are already blurry, there isn’t any salt noise, standard average filter and median filter will only sabotage the clarity of the image, and the horizontal strap patterns still exist. With our variation median filtering method, the strap patterns are slightly mitigated, without losing too much clarity.

The contrast and color of the underwater images still have some defects after smoothing. If so, the Retinex algorithm is used to enhance the contrast and color display of the images. Retinex is a compound word, and its composition is retina (retina) + cortex (cortex).

Edwin Land, an American physicist, argued that the human visual system performs some processing of information during the transmission of visual information, eliminating a series of uncertainties, such as the intensity of the light source and the uneven illumination, while retaining only information reflecting the intrinsic characteristics of the object. The basic content of Retinex is that the color of an object is determined by its ability to reflect long (red), medium (green), and short (blue) light, not by the absolute intensity of the reflected light. The color of objects is unaffected by the non-uniformity of illumination, which means that Retinex theory is based on color consistency (color constancy). [10]

In the Retinex algorithm, the image can be expressed as a formula

\[
S(x, y) = R(x, y) L(x, y)
\]

(1)

\( R(x, y) \) is the reflected light, \( L(x, y) \) represents luminance image, and \( S(x, y) \) shows the image obtained by the viewer.

The illuminated image \( L(x, y) \) is obtained from the original underwater image, and then the reflected image \( R(x, y) \) of the object surface is obtained to enhance the image. After median filtering and Retinex enhancement, underwater images with high contrast, color, and clarity can be obtained. The image preprocessing flow chart is shown in Figure 2.

### 5 Tank Test

To verify that the image mosaic and enhancement algorithm selected in this paper can process complete and detailed underwater images, we carried out a pool experiment.

The sinking ship model is used to simulate the real detection target in the pool experiment. The pool experiment was conducted in a pool of 4 m\(\times\)3 m\(\times\)1 m, and the water depth of the pool was 0.5 m. The underwater camera was a rotating camera that takes pictures under natural light. The position of the underwater camera is fixed and set to a uniform rotation mode. During the rotation process, the underwater target is photographed, and the image is intercepted at an equal time interval. The experimental environment and equipment parameters are shown in Table 1, and the pool scene is shown in Figure 3.

**Figure 3: The pool scene.**

**Table 1 The Experimental Environment and Equipment Parameters**

| Parameters of pool | Pool specification | 4 m\(\times\)3 m\(\times\)1 m |
|--------------------|--------------------|-----------------------------|
| Water injection depth | 0.5 m |

| Parameters of wreck model (consisting of two parts) | Parameters of bow broken block | High 25 cm, wide 25 cm, long 44 cm |
|-----------------------------------------------------|---------------------------------|----------------------------------|
| Parameters of stern broken block | High 27 cm, wide 23 cm, long 38 cm |

| Parameters of underwater camera | Definition | 800 TVL |
|---------------------------------|------------|---------|
| Viewing angle | 92 ° |
| Power input | DC12V 1A |
| Working temperature | -20 °— +50 ° |

**Figure 2: The flow chart of image preprocessing.**
We have two sets of results of the optical imaging: one involves no enhanced splicing test results, which is the mosaic the original underwater optical image, and the other is uses the Retinex algorithm to enhance the image.

5.1 Image Mosaic Technology

Figure 4 shows the six original images captured continuously during the pool test. The six sunken ship images in Figure 4 are mosaicked using the mosaic algorithm described in Section 3. The process is shown in Figure 5, and the mosaic results are shown in Figure 6. As can be seen from Figure 5, there are only 24 feature points that are successfully matched.

Figure 6 is a complete image of an underwater target (sunken ship model). We can intuitively see that the picture shown in Figure 6 is low contrast and low definition. This is due to the absorption and scattering of light by water molecules and substances in the water, resulting in the attenuation of light propagation in the water medium, which results in the poor image quality of the underwater camera when shooting for Figure 1.

Figure 4: The original underwater optical image.

Figure 5: adjacent feature points matching pictures (feature points 24).

Figure 6: Image mosaic results.

Figure 7: R/G/B histogram of Figure 4.

Figure 8: Underwater optical image after image enhancement.

Figure 9: Feature points matching of adjacent pictures (feature points 41).

5.2 Enhanced Splicing Test Results
Figure 10: image mosaic results.

Figure 11: R/G/B histogram of Figure 11.

Figure 8 shows the image created through processing using enhancement and the denoising algorithm, as described in Section 3. Compared with the original underwater optical image in Figure 3, the processed image has higher definition, lower color difference, and better image quality.

Compared with the 24 matched feature points in Figure 5, the number of successful matched feature points in Figure 9 increased to 41, indicating that image enhancement processing will play a great positive role in the image mosaic. Figure 10 is a complete image of the wreck obtained by splicing the enhanced image. Figure 11 is the R/G/B histogram of Figure 10. Comparing Figures 11 and 7, the R/G/B histogram of Figure 11 has pixels in the range of 0-255 pixel values, and the pixel values are evenly distributed. From another point of view, the contrast of the underwater optical image is improved, the color is enhanced, the image quality is high, and the detail of the target image is better.

6 Conclusion and Directions For Future Work

In this paper, a marine information visualization system based on acousto-optic fusion is proposed, which mainly studies the image enhancement and mosaic processing of optical underwater images. The image enhancement and mosaic methods used in this paper can effectively improve the quality of underwater optical images. In the future, we will devote ourselves to the realization of ocean information visualization systems based on acousto-optic fusion, including underwater acoustic positioning and navigation, AUV cluster communication, and the cross-layer optimization of AUV communication networks.

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