Application of image processing technology in cable detection of underwater robot

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Abstract. Manual inspection of underwater cables has many problems, such as heavy labor intensity, high operation difficulty and low work efficiency. It is more effective to use underwater camera to capture images of underwater cables than manual inspection. The addition of subsea detection and construction equipment raises bottom sediment in the water and causes the water to become turbid and cloudy, it also reduces the contrast of the underwater image and adds irrelevant background information. Therefore, a method of cable location in turbid waters based on image processing is proposed. The method firstly applies the dark channel prior dehazing algorithm. An adaptive histogram equalization algorithm is used to improve the light distribution of underwater image after defogging. Then, we use the local adaptive dynamic threshold segmentation method to achieve the rough segmentation, and the fine segmentation of cable image is carried out by selecting each connected domain region. Finally, the cable pixel coordinates are obtained by the method of center line extraction and frequency domain transformation. Experimental result shows that the proposed algorithm has good effects in terms of clarity.

Keywords: underwater image, histogram equalization dehazing, image segmentation, center line extraction, frequency domain transformation.

1. Introduction

With the development of society, the laying and maintenance of underwater cables and location detection have become important research hotspots, and the laying of underwater cables can help alleviate the energy demand in China [1]. Photography is a conventional underwater cable detection method, the literature mentions that the sight distance of underwater camera is short, but compared with magnetic method, multi-beam and side-scan sonar detection results are more reliable and easy to operate. However, in underwater environment, non-uniform optical field, shooting distance, water suspension particles, etc. make the quality and contrast of image low, and insufficient segmentation accuracy cannot correctly identify the ROI area, in this sad condition, cable equipment or underwater inspection equipment yaw. Therefore, it is very important to obtain accurate cable pixel position for underwater cable detecting.

At present, researchers have carried out a lot of work on underwater image processing. [3] applied "Two-step method" to underwater images, first by piecewise linear transformation to solve the problem of color distortion, and then using an optimal contrast improvement method for the underwater image
to prevent color offset and contrast decrease. [4] proposed a method of color compensation for underwater images based on electromagnetic theory, because the red wavelengths of light are most attenuated in water, the transmission coefficient of the red channel can be estimated by using the electromagnetic wave transmission theory, and the background light and the transmission coefficient of each channel can be effectively estimated, as a result, the image color can be compensated. [5] proposed a subwater image enhancement algorithm based on color attenuation a priori and visual salience, which effectively solved the problem of color distortion of the image with optimized transmission rate. [6] proposed a method based on improved homomorphic filtering and Retinex underwater image enhancement, which overcomes the phenomenon of halo artifacts in underwater images, eliminates the uneven lighting and improves the clarity of underwater images.

To some extent, the above-mentioned algorithm improves the quality of underwater images, but it still needs to be improved in terms of detail improvement, real-time processing and accuracy. Therefore, a simple and effective cable detection method based on image processing in turbid waters is proposed. The flow of the overall algorithm is shown in Fig.1.

![Algorithm flow](image1)

**Figure 1.** Algorithm flow.

2. Image acquisition equipment

We used the AM1481 camera to capture images of cable surface. The camera parameters are listed below: effective pixels of 768 (H) × 582 (V), a frame rate of 50fps, a lens frame of 1/3 inch, a minimum illumination of 0.0013lux, focal length of 6mm, a power supply of 24V DC voltage. The camera weighs 0.74kg in the air and 0.3kg in the water, it can dive to a depth of 500 m. The camera has four pins, the first pin corresponds to the power supply negative/shield GND, the second pin corresponds to the 24V DC power positive pole, the third pin output VBS video signal, the fourth is the test pin. The underwater camera transmits the VBS signal to the video grabber via a watertight connector, which converts VBS to a USB signal, as shown in Fig.2.

![Signal acquisition flow chart](image2)

**Figure 2.** Signal acquisition flow chart
3. Underwater image enhancement

3.1. Underwater image imaging model

Jaffe-McGrammery’s underwater optical imaging model [7] is shown in Fig. 3. From the model, it can be seen that the underwater image is mainly composed of forward scattering component, backward scattering component and direct emission component. In the imaging process, the camera is generally closer to the photographed object, consequently, the forward scattering component can be ignored [8]. The underwater imaging model can be represented by (1):

\[ I(x) = J(x)t(x) + A(1 - t(x)) \]

where \( I(x) \) is the fog image, \( J(x) \) is fog-free image, \( A \) is the value of global atmospheric light, \( t(x) \) is the transmission rate, \( J(x)t(x) \) is the direct irradiation component, \( A(1 - t(x)) \) is the backward scattering component.

3.2. Dark channel defog based on histogram equalization

The scattering of light in water causes the change of propagation direction, and the direct application of dark channel a priori dehaze theory weakened the fog-like blur caused by cloudy water, but led to overexposure of some background pixels and aggravation of the phenomenon of dark corners around it. This problem can be well solved by histogram equalization combined with [9]. The implementation steps are as follows:

1) Histogram equalization. Convert the input image to a gray-scale graph, using histogram equalization algorithm to achieve contrast enhancement.

2) Estimate underwater transmission. Divide the image into x-centric local areas \( \Omega(x) \), and the \( \Omega(x) \) is filtered with minimum value. Because the dark channel is represented as \( J_{\text{dark}}(x) = 0 \), so \( \tilde{t}(x) \) is shown in (2)

\[ \tilde{t}(x) = 1 - \omega \min_{y \in \Omega(x)} \left( \min \frac{I(y)}{A} \right) \]

\( \omega \) is used to balance the relationship between fog and brightness, we set it to 0.95.

3) Get atmospheric light intensity \( A \). Select the 0.1% brightest pixel in the dark channel and return the foggy image to find the brightest pixel in the corresponding position, we write it as \( A \).

4) Restore the defogging image \( J(x) \). According to the (3) restore the image after defogging. Introduced \( t_0 \) in order to adjust the image white field excessive, usually \( t(x) < t \).

\[ J(x) = \frac{I(x) - A}{\max(t(x), t_0)} + A \]

In this paper, a cable image under the turbid waters is selected. The method in this section is compared with other methods, the results are shown in Fig. 4.
Figure 4. Comparison of effect after algorithm improvement

As shown in Fig.4, Fig.4(a) and Fig.4(b) were the original and corresponding histograms, Fig.4(c) and Fig.4(d) were the results of the He’s algorithm and the corresponding histogram, Fig.4(e) and Fig.4(f) were the results of the processing of the algorithm for the section and the corresponding histogram. By contrast, it can be seen that the image is enhanced by histogram equalization and the dark channel a priori defog removal algorithm can obtain high-contrast underwater image, the corresponding grayscale histogram is closer to the normal distribution[10], and the result is more intuitive and reliable.

4. Segmentation of underwater cable image

Traditional methods, such as threshold method, it is easy to be affected by noise and difficult to process the image with uneven gray, it cannot split underwater images characterized by non-uniform lighting[11]. Fan[12] used the adaptive threshold segmentation method in the extraction of underwater cracks, and then ensured the complete separation of cracks under effectively reducing the impact of noise. Cai [13] divided the ore image into equal blocks and segmented the rock map with the multi-threshold algorithm. According to the above method, we used the local adaptive dynamic threshold method to divide an image into several sub-images on average, selects multiple local thresholds to achieve the rough segmentation of the image. Then, we considered from the neighborhood space, split out the interference similar to the grayscale of the target cable, and realized the fine segmentation of the image. The steps are as follows.

1) Local adaptive dynamic threshold segmentation. Divide the input image into square neighborhood blocks of 15×15 sizes, The gray value of the pixel in the An(i,j), is compared with the mean value of the pixel Anavg in the corresponding local area. Finally, we get the updated pixel A’n (i,j) in (4).

\[
A'(i,j) = \begin{cases} 
0, & A_n(i,j) < A_{avg} \\
255, & A_n(i,j) \geq A_{avg}
\end{cases}
\]

2) Connect domain marked. For more intuitive, split and reverse. And we use the eight-neighborhood connectivity domain tagging method to the two-value image marker.

3) Remove interferential information. When the connected domain area is less than 1200, it can be considered a interference, and its internal pixels are set to 0.
5. Cable position acquisition

5.1. Morphological processing
Threshold segmentation does not eliminate interference attached to the online cable boundary line. Therefore, by morphological expansion of the two boundary lines, can not only fill the holes distributed between the two edges, but also the edges of the cables are smoothed. Morphological expansion operations are shown in Fig.5. In this experiment, the size of structural core B is $15 \times 15$ elements, A is a collection of cable pixels, A expanded with respect to B is denoted by $x$. The results of the expansion are shown in Fig.6 (a).

$$A \oplus B = \{ x \mid (B)_x \cap A \neq \emptyset \} \quad (5)$$

5.2. Centerline extraction
The two-value refinement method[14] is a centerline extraction method. Started by setting a $3 \times 3$ window W. By judging the situation of pixel values around the traversal center point P1 of W, we can determine whether they are boundaries, and if yes, sets the boundary pixels to 0. The set 0 condition is mentioned in detail in [15]. Experiments showed that the method can finally obtain the center line with a vertical width of 1 in horizontal direction, and the results have shown in Fig.6 (b). It was observed that the transverse interference in Fig. 5(d) had been completely separated from the centerline.

5.3. Horizontal interference information removal
[16] notes that in fourier transformation, vertical stripes are concentrated on the horizontal axis of the fourier frequency domain energy spectrum. Similarly, horizontal directional stripes are concentrated on the vertical axis of the fourier frequency domain energy spectrum. We convert the image to FFT space, as shown in Fig.6(c). If the width of the entire image is w, a pair of center symmetrical right triangles distributed horizontally are the height as $h'$. we set the mask to a pair of axis symmetric rectangles with a width of $w/5$ and a length of $h'/2$, as shown in Fig.6(d). Lateral interference was effectively weakened after fourier reverse transformation, as shown in Fig.6 (e). Finally, according to the weakened interference at the grayscale value cannot reach 255, we can completely eliminate the horizontal interference, as shown in Fig.6 (f).
5.4. Get cable coordinates
By traversing all pixels in Fig 6(f), a total of 390 pixels with a grayscale value of 255 are counted and their corresponding pixel coordinates are recorded in Table 1.

| Index | u   | v   | Index | u   | v   |
|-------|-----|-----|-------|-----|-----|
| 1     | 1   | 420 | 195   | 218 | 451 |
| 2     | 2   | 420 | 196   | 219 | 451 |
| 3     | 3   | 420 | 197   | 220 | 451 |
| 4     | 4   | 420 | 198   | 221 | 451 |
| 5     | 5   | 420 | 199   | 222 | 451 |
|       |     |     |       |     |     |
| 191   | 215 | 450 | 386   | 449 | 507 |
| 192   | 216 | 450 | 387   | 450 | 507 |
| 193   | 217 | 450 | 388   | 451 | 507 |

6. Experimental results and analysis
In order to detect the image segmentation effect of cable under the muddy waters based on histogram equalization defog, the underwater cable image with dimensions of 640×480 is experimentally verified. The experimental environment is an i5-9300H CPU with a PC of 2.40GHz and the compilation platform is Visual Studio Code 1.51.1.

6.1. Clarity contrast
Table 2 lists the clarity evaluation price indicators for no reference images, including SMD2 (Grayscale Differential Evaluation Function and Laplacian Gradient), which correspond to the higher the value, the clearer the image.
Table 2. Clarity Evaluation Results

| Image | SMD2     | Laplacian |
|-------|----------|-----------|
| 4(a)  | 491128.00 | 12.27     |
| 4(b)  | 4012931.00| 102.09    |
| 4(c)  | 65298478.00| 171.57   |

6.2. Split effect comparison

Figure 7. Three segmented contrasts in clear and turbid waters

As shown in Fig. 7, Fig. 7 (a) and Fig. 7 (e) are cable images under clear and turbid water, respectively. Fig. 7(b) - Fig. 7 (d) are the result of global threshold segmentation, Otsu segmentation, and this article methods, respectively, in clear waters. Fig. 7 (f) - Fig. 7 (g) is the global threshold segmentation in turbid waters, the Otsu segmentation, and this paper method. The comparison showed that the underwater cable image obtained by using the segmentation algorithm was more complete and with less noise interference. It is not suitable for clear underwater environment, but for turbid underwater environment.

7. Conclusion

Based on the characteristics of under water imaging environment such as poor clarity, low contrast and complex noise in turbid waters, this paper proposes a method for obtaining cable coordinates based on image processing in turbid waters. The histogram equalization defog is used for images captured in turbid waters, and the foreground is split by threshold and neighborhood spatial characteristics, interference information on the cable is extracted by graphical expansion combined with the center line, horizontal interference is weakened in frequency domain space, and effective underwater cable
coordinates can be obtained after simple threshold processing. The method is simple and effective, and we can extract the cable pixel coordinates more accurately, thus provide the basic conditions for obtaining the cable coordinate in three-dimensional space.

References

[1] C. Feng, “Research on underwater cable detection method based on RGB channel fusion,” Harbin: Harbin Engineering University, 2019.

[2] Z. Cen, D. Jiang, W. Zhang, C. Cai. “Analysis on selection of detection technology and method for submarine cable,” J. Southern Energy Construction, vol. 4(03): pp. 85-91+96, 2017.

[3] X. Fu, Z. Fan, M. Ling, Y. Huang, X. “Two-step approach for single underwater image enhancement,”//2017 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS), 2017, pp. 789-794.

[4] Z. Jiang, Y. Piao. “Underwater image color compensation based on electromagnetic theory,” J. Laser & Optoelectronics Progress, vol. 55(08): pp. 237-242, 2018.

[5] W. Di, F. Guo, F. Huang, T. Li. “Underwater image enhancement algorithm based on color attenuation prior and visual salience,” J. Optoelectronics. Laser, vol. 31(09): pp. 891-896, 2020.

[6] H. Wang, L. Zhang, L. Wang, D. Lu. “Research on Underwater Image Enhancement Algorithm Based on Improved Homomorphic Filter and Retinex,” J. Electronics Optics & Control:1-5 (2021-03-24). http://kns.cnki.net/kcms/detail/41.1227.TN.20210113.1533.003.html.

[7] L. McGlamery. A Computer Model For Underwater Camera Systems. Other Conferences, 1980.

[8] L. Zhou, J. Zhu, Q. Wang, Y. Jiang. “Underwater image restoration method based on fog line dark channel prior,” J. Journal of Nanjing University of Posts and Telecommunications (Natural Science Edition), vol. 40(04): pp. 64-69, 2020.

[9] K. He, J. Sun, X. Tang. “Single Image Haze Removal Using Dark Channel Prior. IEEE Transactions on Pattern Analysis & Machine Intelligence,” vol. 33(12): pp. 2341-2353, 2011.

[10] C. Zhu, Z. Li, R. Pan. “Color measurement of camouflage fabric based on image technology,” J. Journal of Donghua University (Natural Science), vol. 46(02): pp. 282-287, 2020.

[11] Y. Sun, Z. Chen, H. Wang, Z. Zhang, J. Shen. “Underwater Image Segmentation Based on Level Set Fusing Region and Edge Features,” J. Journal of Image and Graphics, vol. 25(04): pp. 824-835, 2020.

[12] X. Fan, P. Wu, L. Gu, P. Shi. “Adaptive crack segmentation and extraction algorithm based on uniform light processing,” J. Science Technology and Engineering, vol. 14(07): pp. 72-77, 2014.

[13] G. Cai, L. Wang, X. Luo, Z. Jiang. “Mining Research and Development, Mining Research and Development,” vol. 40(12): pp. 153-157, 2020.

[14] K. Palágyi, A. Kuba. “A parallel 3D12-subiteration thinning algorithm.” Graph Models Image Process., vol. 61(4): pp. 199-221, 1999.

[15] J. You, L. Huang. “A ranging method based on the center line of the light strip,” J. Microcomputer & Its Applications, vol. 35(17): pp. 11-13, 2016.

[16] P. Huang, S. Su, T. Tu. “A destriping and enhancing technique for EROS remote sensing imagery.” Journal of C C IT, vol. 32(2): pp. 1-14, 2004.