Underwater 3D Target Positioning by Inhomogeneous Illumination based on Binocular Stereo Vision

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***Abstract*—This paper presents a new approach for underwater 3D target positioning by inhomogeneous illumination based on binocular stereo vision. Based on the theory of inhomogeneous illumination field, we build underwater binocular stereo vision system to measure the distance between the target and the detector (CCD receiver) as well as the 3D information of the target, which can be used to the further 3D reconstruction of underwater scene. The underwater experiments show that our system can get the depth as well as posture information of the targets accurately, especially in turbid water.**

I. INTRODUCTION

The key point of underwater target detection is to solve the backscattering problem which is generated by the suspended particles during the light transmission. [1][2] In fact, for underwater homogeneous illumination or laser, the strong backscattering is mainly generated at the range close to the detector, yielding low visibility. Therefore, we proposed a new approach for underwater target detection by inhomogeneous illumination, which intensity distribution relates to the attenuation pattern of light transmission with an inverse form as illustrated in Fig. 1. Our approach was tested and verified by the underwater imaging experiments, showing that it is effective to decrease the backscattering within a wide field of view (FOV) to increase the detection distance, especially through turbid water as well as other turbid media. [3][4]

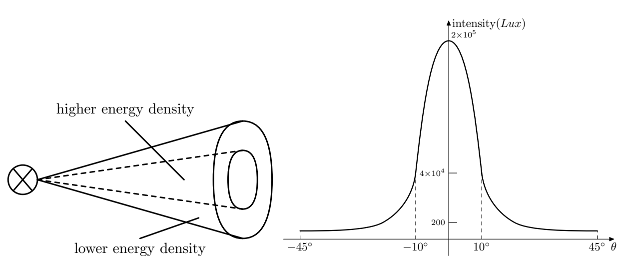

Fig. 1. The intensity distribution of light source.

This paper presents a new approach for underwater 3D target positioning by inhomogeneous illumination based on binocular stereo vision. Based on the theory of inhomogeneous illumination field, we build underwater binocular stereo vision system to measure the distance between the target and the detector (CCD receiver) as well as the 3D information of the target, which can be used to the further 3D reconstruction of underwater scene.

The underwater binocular stereo vision system concludes image acquisition, camera calibration, feature extraction, stereo matching, and calculation of three-dimensional coordinates. [5] The system can acquire images with good contrast visibility by inhomogeneous illumination as discussed above, which is good for the further work such as feature extraction, stereo matching and calculation of three-dimensional coordinates. Based on Zhang's method of camera calibration, [6][7][8] we calculate the matrix of structural parameters R and t by equations $R = R_{right}R_{left}^{-1}, t = t_{right} - R_{right}R_{left}^{-1}t_{left}$. As for stereo matching, according to the study of the image matching technique based on Scale Invariant Feture Transform (SIFT), we adopt a new matching method which combines feature matching and region matching as well as edge feature and corner feature, which can reduce the matching time and improve the matching precision. To calculate three-dimensional coordinates of the points in underwater scene accurately, we use projection transformation matrix of three-dimensional coordinates solved by least squares method, which can correct ideal binocular stereo vision model.

We build the underwater binocular stereo vision system within the inhomogeneous illumination field and realize the algorithms based on OpenCV (C/C++). The underwater experiments show that our system can get the depth as well as posture information of the targets accurately, especially in turbid water.

II. THEORY OF INHOMOGENEOUS ILLUMINATION

The image quality obtained by an underwater imaging system depends mainly on contrast visibility. Increasing the illumination power results in increased backscattering, therefore this will not improve the image quality. Since most underwater imaging system use a uniform illumination source, strong

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backscattering at short distances is inevitable. Therefore, we propose using an inhomogeneous illumination field where the power density is inversely proportional to the light attenuation in water.

As illustrated in Figure 2, a concentrated light beam illuminates the area underwater by a reflector. A CCD detector is located at a distance S_0 from the axis of rotation of the reflector. The receive axis is parallel to the concentrated light beam axis OO'. The reflector directs the light beam which passes through the inhomogeneous illumination field to the target C. The cooridinate system (X, Y, Z) originated at C, and Z is the detection axis MN. Y is vertical to the plane XCZ. YCX is the detection plane whose center is the light center. Because the brightness at all agnles follows an exponential decaying distribution, the intensity of illumination (illumination field E) in the plane YCX has an exponential decaying distribution in both the X and Y directions. This system will provide a small-angle, high density, illumination power at large distances. The detection axis MN intersects the beam at a short distance D where the light power density is low, as shown in the figure.

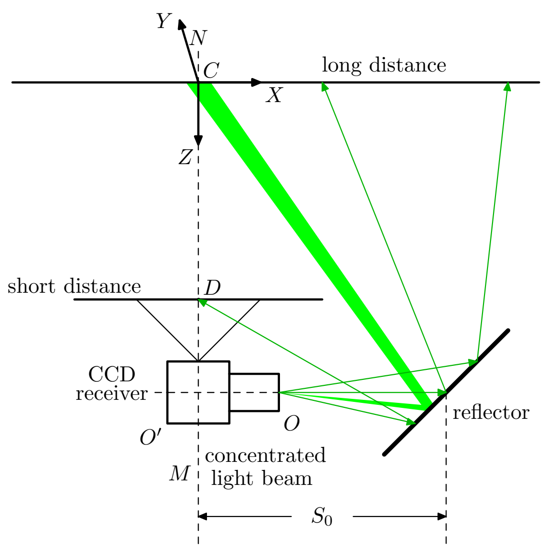


Fig. 2. The inhomogeneous illumination field.

Within the inhomogeneous illumination field, the backscattering light is weak at short ranges because of the low power density, while larger ranges have a higher power density. The scattering light will be attenuated and thus be too weak to have a significant effect on the receiver.

This approach to sensing is independent of the view angle and depth of field. In addition, the detector can cover the entire FOV with no blind spots.

III. Underwater Binocular Stereo Vision System

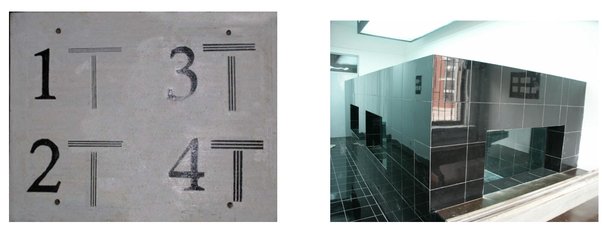
Underwater binocular stereo vision system is composed of inhomogeneous illumination part and binocular stereo vision part. The inhomogeneous illumination part include light source connected with the controller by the underwater cable shown in Fig. 3. And the binocular stereo vision part include dual cameras (as shown in Fig. 4 controlled by the program on PC.

(a) The light source and controller. (b) The cable.

Fig. 3. The inhomogeneous illumination.

Fig. 4. The dual cameras.

We put the board (Fig. 5(a)) into the pool (Fig. 5(b) with full of water as the target.



(a) The board. (b) The pool.

Fig. 5. The target board and pool.

A. Synchronous Image Acquisition

The CCD of dual cameras can be synchronized by the signal generated from the PC with special program, where the synchronous images can be acquired as shown in Fig. 6.

B. Camera Calibration

The Ti-times chess board (Fig. 7) for camera calibration has the size of $40 \times 30cm$ with 12×9 array with $30mm$ of every element, which accuracy can be $\pm 0.001mm$.

Based on Zhang's method of camera calibration, we calculate the matrix of structural parameters R and t by equations $R = R_{right} R_{left}^{-1}, t = t_{right} - R_{right} R_{left}^{-1} t_{left}$.

(a) The left image.　　(b) The right image.

Fig. 6. The synchronous images.

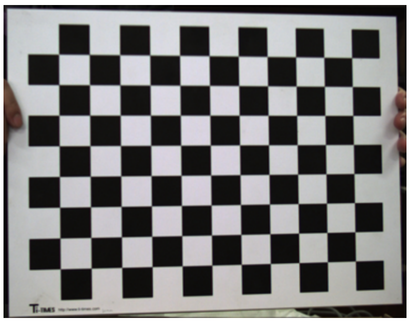


Fig. 7. The Ti-times chess board.

C. Feature Extraction and Stereo Matching

Before feature extraction and stereo matching, image preprocessing can normalize the images to eliminate the brighness difference as well as improve the image texture. The stereo matching method based on feature and region is adopted to reduce the matching time and improve the matching precision.

The basic idea of improved regional realted matching algorithm is based on the distributed similarity of sub-region or distance measure function as the basic criteria, which is processed by adjustable SAD (Sum of Absolute Differences) window. And the detail is as follows (Fig. 8):

1) for every feature of left image, search the corresponding line of right image to find the best match;
2) after rectification, get the epipolar lines on both left and right image;
3) then reduce the amount of searching disparity by limit the matching length to decrease the matching time.

The rectified image can be better matched of left and right images. And the gray-level describes the depth of target.

D. Calculation of Three-Dimensional Coordinates

For underwater target, the size and the distance can be calculated.

As shown in Fig. 8, the point of three-dimensional coordinates (x, y, z) is calculated by clicked using the mouse. The X coordinate of point on left edge and point on right edge can show the size of target.

IV. Experimental Results

A. One Board

We use only one board to measure the distance between target and CCD as well as the width of target. Table I shows the real distance, the measure distance and the error. It is shown that the error is growing with farther and farther away, which can generate light attenuation. Table II shows the measured width of board (with $50.5cm$ width) on different distance. And the error is at most $1.5cm$, which is accurate on different distance.

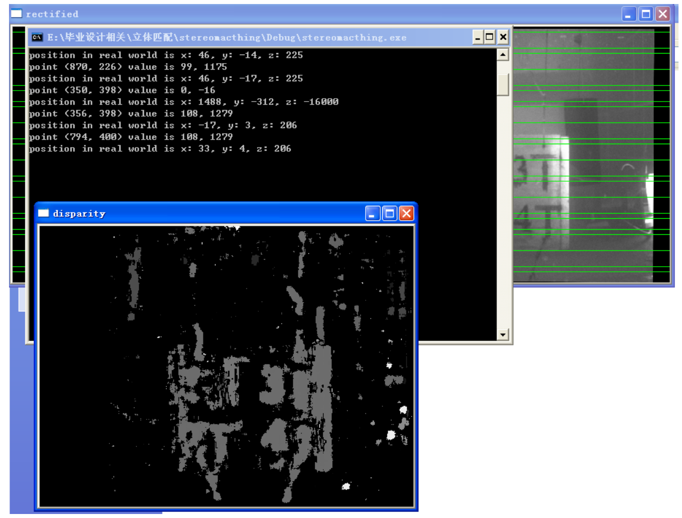


Fig. 8. The stereo matching and calculation of three-dimensional coordinates.

TABLE I
DISTANCE MEASUREMENT.

real distance(cm)	155	186	216	246
measure distance(cm)	152	174	195	218
error(cm)	3	12	21	28

TABLE II
WIDTH MEASUREMENT WITH $50.5cm$ AS THE REAL WIDTH.

real distance(cm)	155	186	216	246
left X(cm)	-11	4	-9	-17
right X(cm)	40	46	40	33
measure width(cm)	51	50	49	50
error(cm)	0.5	0.5	1.5	0.5

TABLE III
TWO BOARDS WITH FIXED SPACING $30cm$.

real distance(cm)	186, 216	216, 246	246, 276
measure distance(cm)	164, 184	185, 208	206, 230
measure spacing(cm)	20	23	24
error(cm)	10	7	6

B. Two Boards

We use two boards to measure the spacing beween these two boards as shown in Fig. 9.

Table III shows the experimental results while two boards with fixed spacing $30cm$. And Table IV shows the experimetal results that one board is fixed while another board is moved.

The results show that the error is growing with farther and farther distance as well as spacing.

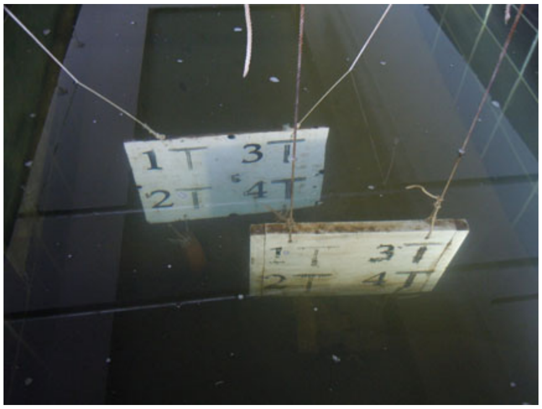


Fig. 9. Two boards.

TABLE IV
TWO BOARDS WITH UNFIXED SPACING.

real distance(cm)	$155, 165$	$155, 175$	$155, 181$
measure distance(cm)	$142, 153$	$142, 158$	$144, 163$
real spacing(cm)	10	20	31
measure spacing(cm)	11	16	19
error(cm)	1	4	12

V. CONCLUSION

This paper presents the underwater 3D target positioning apporach by inhomogeneous illumination based on binocular stereo vision. The expemerimetal results show that it is effective to decrease the backscattering within the inhomogeneous illumination field, and the accurate distance as well as width of target (3D information) can be acquired by the system. Because of the light attenuation, it's also hard to detect target beyond 3 metres.

ACKNOWLEDGMENT

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