# 3D Reconstruction for Underwater Laser Line Scanning

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***Abstract*—Laser line scan (LLS) is one of the underwater optical imaging methods, which can reduce the detrimental effects of backscatter and forward scatter. This paper put forward a 3D reconstruction method based on the LLS system, for the purpose of underwater surveying. By direct camera calibration, a coordinate mapping relationship between 2D pix coordinate and 3D world coordinate is established, which then can be used to reconstruct 3D objects from 2D scan data. Experiments had been carried out in a pool, and underwater 3D scene can be reconstructed at millimeter scale, which demonstrated that this method can be used to underwater surveying.**

***Index Terms*—3D reconstruction, laser line scan, underwater imaging**

## I. INTRODUCTION

Underwater surveying technology takes on an importance role in ocean exploration and development. Many non-contact 3D measurement and mapping methods on land have been researched for underwater application, such as stereo vision, structured light, etc. And with the 3D data, the target can be reconstructed by 3D reconstruction methods [1][2].

Image-based 3D modeling and range-based 3D modeling are two common ways for 3D reconstruction. Image-based method usually infers 3D data from shading, edges, texture, etc. Range-based method includes triangulation, time-of-flight, etc. Laser line scan (LLS) is one of the common triangulation methods, which can reduce the detrimental effects of backscatter and forward scatter underwater [3][4]. By projecting laser stripe onto the target, the profile of targets can be inferred from the displacement of the laser scan lines [5]. And LLS system can be mounted on a ROV to survey underwater and create high resolution bathymetric maps [6]. Chau-Chang Wang [5] put forward a nonmetric camera calibration method for underwater laser line scan system, and the error of their experiment was less than 1.5mm from a distance of 1m. Chris Roman [6] used structured light laser profile imaging to create bathymetric maps of underwater archaeological sites, and some experiments had been done to compare with stereo imaging and multi-beam mapping methods.

This paper put forward a 3D reconstruction method based on the LLS system for the purpose of underwater surveying. Experiments had been carried out in a pool and the target objects can be reconstructed at millimeter scale.

## II. METHODS

### *A. Camera Calibration*

In the field of machine vision, the process of camera calibration is usually complex. The three coordinate mapping relationships are necessary: world coordinate, camera coordinate and pixel coordinate. And the calculation often involves many parameters [5][7]. But in this paper, a direct calibration method is used, which makes the process much easier.

The camera calibration process is shown in Fig.1, in which the laser and the digital camera are set up in a linear guide, and the calibration plate is placed in the laser plane. The coordinate relationship between 2D sampling data and 3D world is defined as Fig.2, in which every calibration point has a pix coordinate in the image acquired by digital camera. Both the 2D pix coordinates and 3D world coordinates of all the calibration points are stored as matrices, which can be considered as a point-to-point mapping relationship. Then it can be then used to transform the sampling data into a 3D scene.

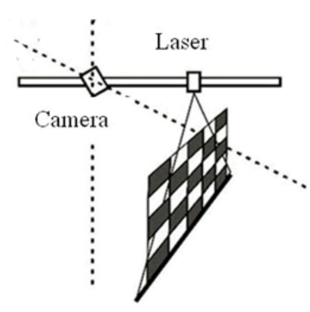


Fig.1 Camera calibration

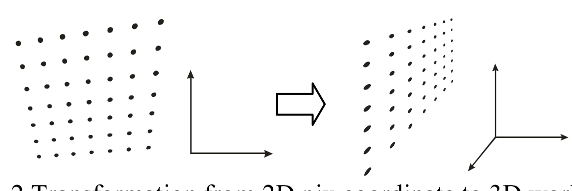

Fig.2 Transformation from 2D pix coordinate to 3D world coordinate

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*B. 3D Reconstruction*

According to the calibration, every calibration point in 2D sample data has an accurate 3D coordinate. And a 3D coordinate of other points between the calibration points can be calculated from its nearest four calibration points by proportion. The coordinate transformation equation is shown as followed:

$$\begin{cases} X = \dfrac{x-a_i}{a_{i+1}-a_i}\cdot\left(c_{i+1}-c_i\right)+c_i \\ Y = vt \\ Z = \dfrac{z-b_j}{b_{j+1}-b_j}\cdot\left(d_{j+1}-d_j\right)+d_j \end{cases} \quad (1)$$

Where $(x,z)$ is the pix coordinate of a certain point, $(X,Y,Z)$ is the world coordinate of a certain point; and $(a_i,b_j)$ represents the pix coordinate of a calibration point, $(c_i, d_j)$ represents the world coordinate of a calibration point, as shown in Fig.2; $t$ is the scanning time; $v$ is the scanning velocity which is controlled by the linear guide.

The steps of the 3D reconstruction can be summarized as followed:
a) Read the pix coordinate of a certain point;
b) Search its nearest four calibration points;
c) Calculate the proportion in pix coordinate;
d) Use (1) to transform the coordinate by the proportion;
e) Reconstruct the 3D mesh along the laser scan direction.

## III. EXPERIMENT

Experiments had been carried out in a pool, and the scanning system was set up in a linear guide. The target objects were set underwater as shown in Fig.3, in a range about 25×20 cm². And the linear guide was placed 1 meter above the target. A 532nm semiconductor laser was used as the light source, and a cylindrical lens was placed ahead of it to generate a laser line. The 2D data were acquired by a digital camera, with a resolution of 640×480 pix.

The original image data were shown as Fig.4(a). They were denoised as shown in Fig.4(b), by the method of limiting the threshold value. Equation (2) was used for calculating the center of the lines, and the result was shown in Fig.4(c). Then the pix coordinate can be read directly from the image matrices.

$$x' = \frac{\sum_x I_x \cdot x}{\sum_x I_x} \quad (2)$$

Where $x$ is the number of pix in horizontal direction, and $I$ is the light intensity in the pix position, and $x'$ represents the center pix of the laser line in horizontal direction.

The coordinates of 2D data were transformed into 3D world coordinates by (1). And the 3D reconstruction result is shown in Fig.5 at millimeter scales.

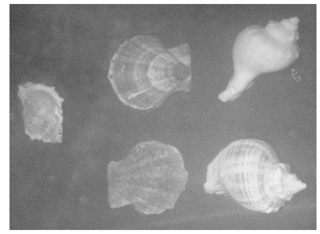
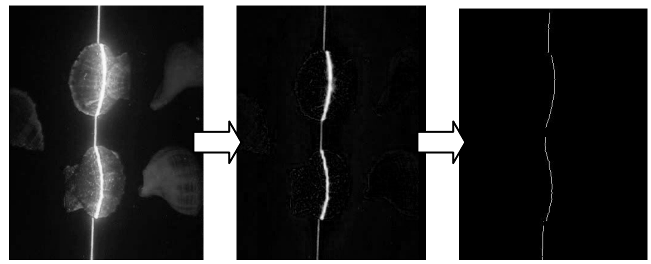
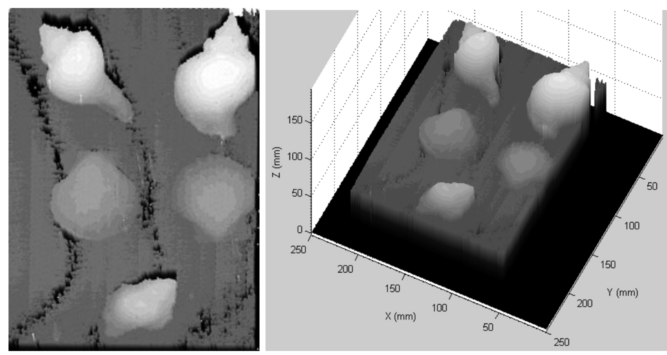


Fig.3 Image of underwater objects



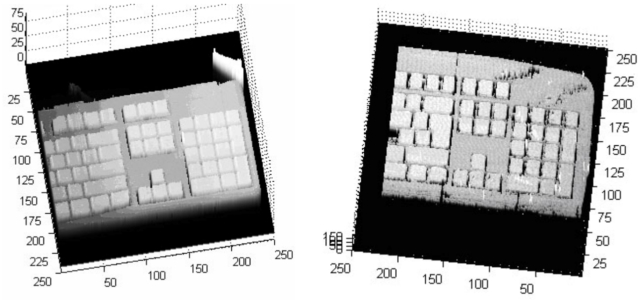
(a) (b) (c)
Fig.4 Data processing:
(a)Original data; (b) Denoising; (c) Center extraction




(a) (b)
Fig.5 3D reconstruction of underwater objects
(a) From top view; (b) From side view

## IV. DISCUSSION AND CONCLUSION

Fig.6 showed the compare of the non-underwater and underwater reconstruction results from the same method. Because of water scatter effects, the edges of underwater reconstruction objects were inaccurate, and some data were lost in places. Different materials had different light energy reflected, so it was difficult to extract the center of laser lines accurately for all kinds of materials at the same time, which was a problem need to be solved. And in these experiments, no smoothing filter method was used, because it might lose the details of the targets. As for future work, the position and orientation information of the system should be included.




(a) (b)

Fig.6 Compare of reconstruction results:
(a) Non-underwater reconstruction,
(b) Underwater reconstruction

In this paper, a 3D reconstruction method is put forward based on the LLS system, for the purpose of underwater surveying. The calibration method was much easier than common ways, and the coordinates could be calculated by proportion. The experiments demonstrated that it was a convenient and reliable method for underwater surveying.

## V. ACKNOWLEDGE

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