FEASIBILITY OF USING DIGITAL PHOTOGRAPHY FOR ENVIRONMENTAL MONITORING OF ANIMALS IN AN ARTIFICIAL REEF

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ABSTRACT :

Both acoustic and optical methods can be used for environmental monitoring of marine ranches. However, acoustic methods are more commonly used for underwater environmental surveillance. This paper presents the results of a study of the feasibility of using digital photography for monitoring the animals in an artificial reef. Animal monitoring studies enable us to characterize the behavior of aquatic animals and to derive parameters essential to further studies, such as fork length, swimming speed, and the relative orientation of fish, in addition to providing a quantitative acoustic assessment. A charge-coupled device (CCD) camera was calibrated in a laboratory tank by direct linear transformation (DLT), and then the accuracy of the three-dimensional (3D) reconstruction was tested. Grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) were studied to determine the parameters of fish behavior. The mean absolute deviations in *x, y*, and *z* directions were 2.0 mm, 2.2 mm, and 2.2 mm, respectively, with maximum values of 3.9 mm, 4.3 mm, and 3.5 mm, respectively. The error in estimation of fork length was about 1 cm. Our results indicated that it is possible to use digital photography for optical monitoring of a reef.

1. INTRODUCTION

Recent developments in sea fishery, such as fish farming and ranching, have made it possible to restore and protect the near-shore ecological environment as well as to recover fishery resources. Marine ranch environmental monitoring includes acoustic and optical monitoring, and acoustic methods are more commonly used for underwater environmental surveillance. Although regular underwater photography has been adopted in the study of artificial reefs, this method has a number of disadvantages, including short observation time and C mode optical measurement that converts the spatial signal to a plane signal. The dynamic changes in marine life around the reef cannot be captured with regular photography. With advances in digital photography and image processing techniques, it is now possible to obtain a three-dimensional (3D) reconstruction of an object by calibrating the spatial coordinates of the camera. This study was performed to develop an underwater optical surveillance system for artificial reefs by photogrammetry, in which the image information recorded in the camera can be used to calculate various parameters, such as fork length, body obliquity, swimming speed, and migratory time of fish, as well as the diurnal variations in certain parameters. Thus, the environmental changes in an artificial reef can be monitored. A reasonable acoustic evaluation of the reef can be performed using a quantitative echo sounder in tandem, and it is possible to determine the fork length and relative positions of fish with respect to the sensor.

2. UNDERWATER CAMERA CALIBRATION

A direct linear transformation(Abdel-Aziz, 1971) was used to calibrate the camera in the photogrammetry process. A 3-D sample block as shown in Fig. 1 is required for direct linear transformation (DLT) analysis. A box measuring 50 cm×50 cm with a cellophane aperture of 5 cm×5 cm is placed in the water tank.

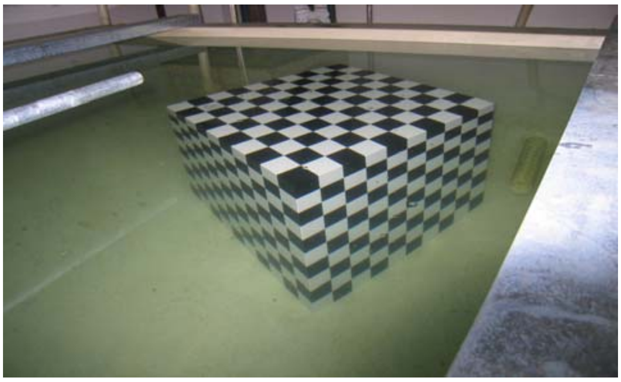

Figure 1. 3-D sample block

Regardless of nonlinear distortion, the corresponding relations between image points and spatial control points are:

$$u = \frac{L_1 x + L_2 y + L_3 z + L_4}{L_9 x + L_{10} y + L_{11} z + 1}$$
$$v = \frac{L_5 x + L_6 y + L_7 z + L_8}{L_9 x + L_{10} y + L_{11} z + 1} \quad (1)$$

where *x*, *y*, and *z* are the coordinates of the control points in the object space, *u* and *v* are the corresponding coordinates of the control points in the image, and L_1–L_{11} are the undetermined parameters in DLT. At least six control points in the 3-D sample block are required for calibration. Several methods for geometric camera calibration are presented in the literature(e.g. Tsai, 1987, Janne, 1997). A two step methods was used here, the initial parameter values are computed linearly and the final values are obtained with nonlinear minimization(Melen, 1994).

3. D RECONSTRUCTION

The camera calibration is followed by 3D reconstruction, which enables retrieval of the spatial coordinates of the undetermined point from the corresponding image coordinates(Chen, 1994). For DLT, we have:

$$\begin{bmatrix} \frac{L_9^{(1)} - L_1^{(1)}}{R^{(1)}} & \frac{L_{10}^{(1)} - L_2^{(1)}}{R^{(1)}} & \frac{L_{11}^{(1)} - L_3^{(1)}}{R^{(1)}} \\ \frac{L_9^{(1)} - L_5^{(1)}}{R^{(1)}} & \frac{L_{10}^{(1)} - L_6^{(1)}}{R^{(1)}} & \frac{L_{11}^{(1)} - L_7^{(1)}}{R^{(1)}} \\ \frac{L_9^{(2)} - L_1^{(2)}}{R^{(2)}} & \frac{L_{10}^{(2)} - L_2^{(2)}}{R^{(2)}} & \frac{L_{11}^{(2)} - L_3^{(2)}}{R^{(2)}} \\ \frac{L_9^{(2)} - L_5^{(2)}}{R^{(2)}} & \frac{L_{10}^{(2)} - L_6^{(2)}}{R^{(2)}} & \frac{L_{11}^{(2)} - L_7^{(2)}}{R^{(2)}} \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \frac{L_4^{(1)}}{R^{(1)}} \\ \frac{L_8^{(1)}}{R^{(1)}} \\ \frac{L_4^{(2)}}{R^{(2)}} \\ \frac{L_8^{(2)}}{R^{(2)}} \end{bmatrix} \quad (2)$$

Where $R^{(i)} = L_9^{(i)} + L_{10}^{(i)} + L_{11}^{(i)} + 1$

Here, the superscripts i=1 and i=2 indicate the left and right cameras, respectively. Fifteen control points were chosen at random and the results of the comparison between the real and the reconstructed coordinates are shown in Table 1.

x	y	z	X	Y	Z
4.7981	-0.1420	4.7676	5.0	0.0	5.0
9.8261	-0.2163	4.7181	10.0	0.0	5.0
14.8592	-0.0987	4.8191	15.0	0.0	5.0
4.7584	-0.2238	9.7780	5.0	0.0	10.0
5.1023	0.0942	15.2084	5.0	0.0	15.0
10.0579	-0.0492	9.9360	10.0	0.0	10.0
15.2817	0.1487	15.2531	15.0	0.0	15.0
4.7914	4.7852	-0.1221	5.0	5.0	0.0
10.0873	10.1320	0.0223	10.0	10.0	0.0
9.9898	4.9041	0.0673	10.0	5.0	0.0
4.8142	10.1552	-0.0792	5.0	10.0	0.0
-0.1278	4.8197	4.8013	0.0	5.0	5.0
-0.3866	9.5710	9.6520	0.0	10.0	10.0
-0.0754	10.2131	4.7831	0.0	10.0	5.0
-0.0739	4.8155	9.9076	0.0	5.0	10.0

Table 1. Comparison between real (X,Y, Z) and reconstructed(x,y,z) points with centimeter unit.

The mean absolute deviation in the x coordinate was 2.0 mm with a maximum absolute deviation of 3.9 mm. The mean absolute deviation in the y coordinate was 2.2 mm, while the maximum absolute deviation in the same direction was 4.3 mm. The mean absolute deviation in the z coordinate was 2.2 mm and its maximum absolute deviation was 3.5 mm. The values measured in this study were for the close view where the base length of the two cameras was shortened to keep the size of the whole system small. The CCD camera used in this experiment was a simple and inexpensive non-metric camera the parameters of which are unknown and unstable, which degrades the imaging and the resolution ratio of digital images. The system also suffers from significant quantization errors and non-linear distortions in the camera lens.

4. MEASUREMENT OF PARAMETERS OF FISH BEHAVIOR

4.1. Fork Length

We used 15 grass carp (*Ctenopharyngodon idella*) and 15 common carp (*Cyprinus carpio*) in this study. The fish were placed in a water tank and monitored using the calibrated cameras. The pictures shown in Fig. 2 were captured at the same instant by two cameras on either side of the tank.

Figure 2. Images of sample fish captured by two cameras simultaneously

The larger fish in Fig. 2 are common carp, while the smaller fish are grass carp. It is possible to obtain a rough estimate of the fork length of the fish by determining the world coordinates of the head and tail(Beddow, 1996a, Beddow, 1996b, Harvey, 2003). We randomly picked six grass carp and six common carp and estimated their fork lengths (Fig. 3).

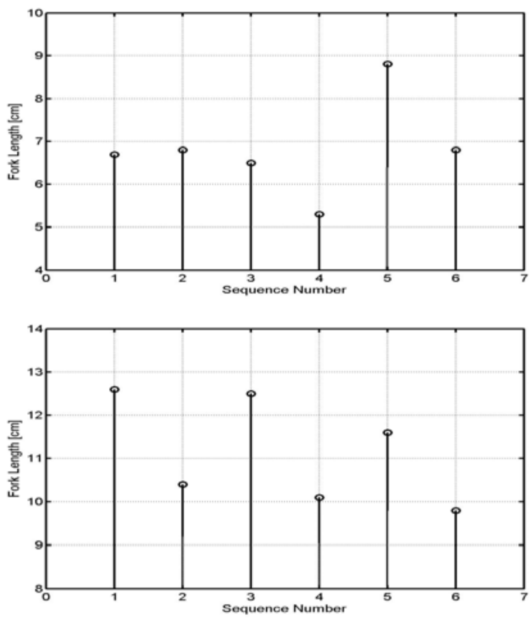

Figure 3. Fork lengths of grass carp(upper) and common carp(lower), respectively.

The real fork length of grass carp and common carp is about 6-8cm and 10-12cm, respectively. The results indicated that the uncertainty in the measurement of the fork length is 1 cm. We believe that it is possible to improve the measurement accuracy. As the 3-D sample block is reconstructed in units of mm, the uncertainty in fork length is due to arithmetic error and not the DLT process itself. First, it is important to choose the control points on the fish carefully, *e.g.*, the same point on the head or tail at the same time. Second, fish are not necessarily straight objects; instead of simply taking the straight line from the head to the tail as the fork length, the arithmetic must be different for calculating the fork length of a straight or twisted body.

4.2. Swimming Speed

The digital hard disk video recorder used in this experiment can record only nine pictures in 2 s. To determine the swimming speed, the positions of the fish, as indicated by certain features on the body, are obtained from the different pictures. Figure 4 shows six continuous pictures taken with the camera on the right side.

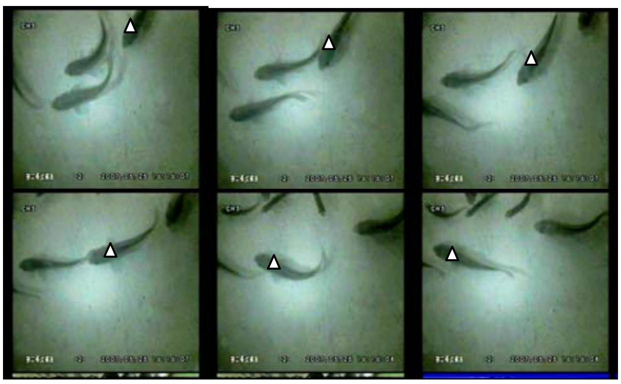

Figure 4. Six pictures recorded with the right camera. The white triangle marks the same fish.

By 3-D DLT reconstruction of the world coordinates of a certain feature in the fish using multiple pictures from both cameras, the swimming speed of fish for five different time intervals were calculated as 23.2, 24.6, 22.4, 25.6, and 26.1 cm/s.

4.3. Orientation

The coordinates of the camera in the 3D object space can be retrieved using the DLT parameters:

$$\begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} = \begin{bmatrix} L_1 & L_2 & L_3 \\ L_5 & L_6 & L_7 \\ L_9 & L_{10} & {}_{11} \end{bmatrix}^{-1} \begin{bmatrix} -L_4 \\ -L_8 \\ 1 \end{bmatrix} \qquad (3)$$

Therefore, the orientations of two cameras and the relative position of the fish with respect to the camera can be determined using the camera's DLT parameters. The orientation in object space of the cameras and the ten randomly chosen fish are shown in Fig. 5.

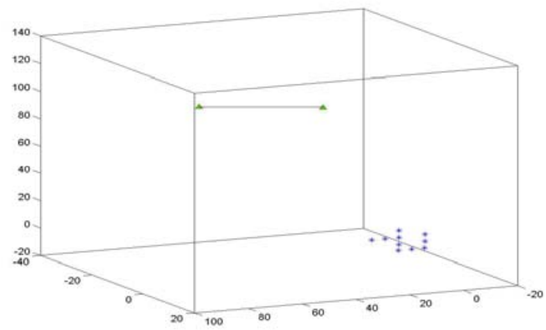

Figure 5. The orientations of cameras and fish in object space. Blue triangles indicate the camera and blue stars represent the fish.

5. CONCLUTIONS

Digital photogrammetry can withstand longer periods under water than regular underwater photogrammetry. A 200 GB hard disk can record continuous images for seven days and nights, and these images can then be used to study the habits of animals living around an artificial reef. This paper discussed the feasibility of applying digital photogrammetry to monitoring the animals living around an artificial reef. Parameters such as the fork length of the fish and the swimming speed as well as the position of the fish can be retrieved by measuring sample fish in a water tank. There is scope for improvement in the accuracy of calibration and feature-matching. Preliminary tests indicate that using digital photogrammetry to monitor aquatic life around the reef is a feasible means of evaluating fish behavior.

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