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Three Dimensional Measurement of Shark Body Based on Monocular and Binocular Vision

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Abstract. To provide precise configuration reference for the engineering bionics, high accuracy detection in large field of view on the natural biological body is a prerequisite. Targeting the streamline body of *carcharhinus brachyurous*, 3D (three dimensional) measurement was carried out with monocular and binocular vision inspecting system based on sinusoidal structure light. By means of moving the vision sensor driven by a stepper motor, fringe patterns with variable fringe spacing were projected to every parts of the shark body, then the point clouds of different parts of the whole shark body were obtained. Using the quaternion method to joint the edges of these point clouds together, surface reconstruction was conducted. Finally the digital model of the low resistance body of shark was achieved. It would be useful reference for the configuration design of underwater vehicles, especially microminiature biomimetic underwater vehicles.

Introduction

In order to increase the voyage and mobility of the underwater vehicles especially the microminiature ones, low resistance and streamlined body design is a high efficient way [1]. Marine organisms, such as shark and tuna, provide mankind with abundant perfect configuration resources. Therefore, it is undoubtly a convenient and efficient biomimetic method to adopt the body shapes of those creatures directly into underwater vehicle design. The micro-morphology scanning of shark scales has been investigated in the preceding research [2,3], based on which the high precision three-dimensional (3D) shark-scale groove has been obtained. Whereas, according to the large size nonrigid organism body, the 3D large field of view imaging and modeling methods with high precision remain to be solved. In this paper, the streamlined body of shark was measured in 3D by means of a monocular and binocular vision inspecting system based on sinusoidal structure light so as to explore the measuring and modeling methods of the macroscopic shape of low-resistance marine organisms.

3D Measurement System

System Components. Fig. 1 shows the monocular and binocular vision system based on sinusoidal structure light. The contact probe of the traditional contacting coordinate measuring machine (CCM) is replaced with the vision sensor, which is composed of two charge coupled devices (CCD) and one projector. The vision sensor is fixed in a stepping motor with five degrees of freedom, which can realize translating along x-axis, y-axis, z-axis and rotating around x-axis and z-axis.

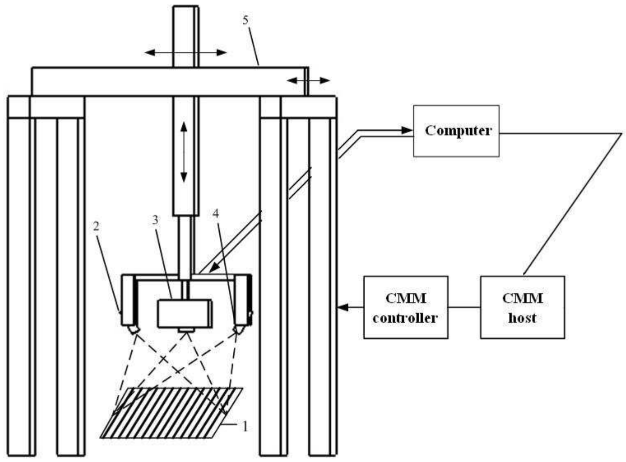

Fig.1. Illustrations of the 3D measurement system

1. Projected grating 2. Left CCD 3. Projector 4. Right CCD 5. CMM

The projector is used to project sinusoidal gratings, and the CCD cameras are used to acquisite distorted grating images caused by the differences of the measured object surface in height. If necessary, the left or right CCD camera and the projector can separately constitute a monocular measurement system which would compensate for the data missing caused by occlusion, shadow and so on.

The standard deviation of the above measurement system is 36 μm and the maximum deviation is -76 μm by calibration, which indicates that the measurement accuracy can meet the measurement requirements in this paper.

Working Principle. The vision inspecting system mainly bases on the method of phase detection of projected grating, and it has the advantages of large measuring range, non-contact measurement, fast measuring speed, good adaptability and temperate precision [4]. The working principle is that when sinusoidal fringes are projected on the surface of the measured object, its phase will be modulated by the height of surface, thus the fringe image taken by CCD camera will certainly contain the height information of the object. Among them, the monocular measurement method directly obtains the height of objects by the phase value, while the binocular measurement method is based on the parallax of corresponding points. By acquisiting the matching points of both cameras and calibrating the locative relations between the structure parameters and them, the 3D coordinate of the measured object surface can be obtained by means of the least squares method [5].

The combination of binocular and monocular vision measurement can maintain the high precision and high robustness characteristics of binocular vision measurement. Meanwhile, for the areas which can't be measured by binocular vision can be compensated by means of monocular vision.

As to the measured object in larger size, this 3D measurement system can only irradiate a local each time. To get the the whole 3D structures, 3D splice in large field of view is necessary. The 3D splice was carried on by means of the quaternion method in this paper. Firstly, move the vision sensor until all parts of the measured object can be irradiated, then move all coordinate systems to a common coordinate system, thus the 3D splice in large field of view can be realized [6].

3D Measuring Experiment of Shark Body

Pretreatment of Shark Body. The shark used in this experiment is *Carcharhinus brachyurous*, 1.4 m in length, about 25 kg in weight, purchased from Beijing Marine Fishery Company.

Shark is a kind of large and nonrigid species. Inevitably, the measuring accuracy would be affected due to the deformation caused by any movement and flip if it is measured directly. Therefore, pretreatments are necessary before measurement. First, wash the skin of the fresh shark and flush away bloodiness, soil and so on; second, put it in refrigerator and keep horizontal after drying at room temperature; third, freeze the shark body at -15°C. To keep its shape in natural state, the pectoral fin, caudal peduncle and caudal fin should be propped up before frozen.

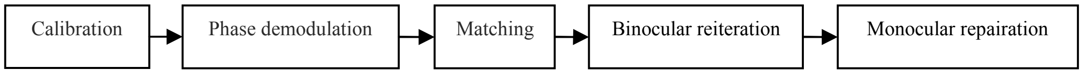

Fig.2. Flowsheet of the 3D measurement process

Measurement Process. Fig. 2 shows the flowsheet of the 3D measurement process of shark body. The basic processes are as follows [7-10]:

(i) Calibration. Monocular and binocular calibration are conducted separately, while the monocular calibration aims to get the position parameter between the two CCD cameras and the projector, and the binocular calibration aims to obtain the internal and external parameters of the two cameras.

(ii) Phase demodulation. Unwrap the phase of raster image taken by the left and right CCD cameras, and unify both of their phase values to a common reference. Meanwhile, to reduce the influence of the background and noisy region, the background distinguish method based on the modulation depth can be used to filtered out them from the phase maps.

(iii) Matching. Search for the corresponding matching points in the left and right cameras through the equal phase value and limit constraint, and mark the mismatching points in phase maps at the same time.

(iv) Binocular reiteration. After getting the matching points in the left and right cameras, the 3D structures of the objects can be reconstructed by using the internal and external parameters of the cameras.

(v) Monocular repairation. The mismatching points in the phase maps, except those which are distinguished as the background, all only appear in one camera's field of view and they can not be matched due to occlusion, shadows and so on. Therefore, it need to establish two monocular measurement systems with the projector and each CCD camera, by means of which the corresponding 3D coordinates of the mismatching points in each CCD camera can be obtained and unified to the binocular measuring coordinate.

During the experiments, by means of moving the vision sensor driven by a stepper motor, fringe patterns with variable fringe spacing were projected to every part of the shark body, and then the data clouds of different surfaces of the whole shark body were obtained. Fig. 3 and Fig. 4 respectively show the measuring photographs of the back and the caudal fin of shark body in the experiments.


Fig.3. Measuring photograph of the back of shark body

Fig.4. Measuring photograph of the caudal fin

Results and Analysis

With the surface point clouds of every parts of the shark scanned by the monocular and binocular vision measuring system, the 3D data registration of its complete body shape was achieved by using the quaternion method. Fig. 5 and Fig. 6 respectively show the reconstruction results of the shark's complete body shape and the caudal fin shape, which were dealt with 3D integration in large field of view.

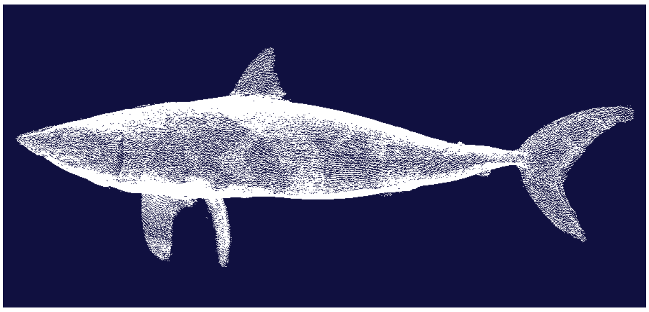

Fig.5. Reconstruction result of the 3D shark body shape

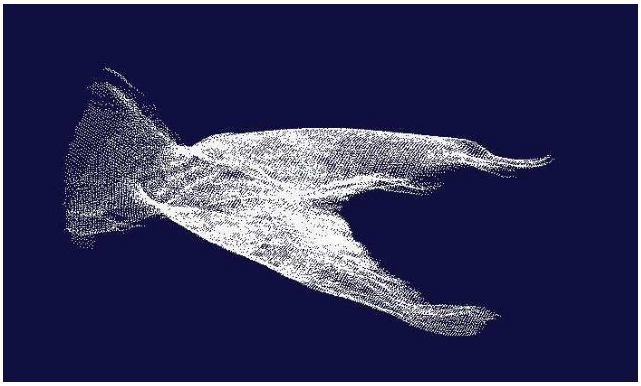

Fig.6. Reconstruction result of the 3D caudal fin shape

The follows are what we can see from Fig. 5 and Fig. 6: (i) Due to the combining of monocular and binocular vision systems, the missing data caused by the occlusion of the fins and the skin folds in the binocular vision measurement was filled up by the monocular vision measurement, which effectively improves the integrity of the measuring results. (ii) Since such measures as freeze and fixation have been taken in and before the measurement, the spliced point clouds in the shark body shape have a smooth transition, which effectively ensures the integrity of the streamlined 3D shark body.

In addition, some reverse engineering softwares were used to deal with the spliced point clouds so as to reconstruct the surface of the 3D shark body. Fig. 7 shows the surface reconstruction result of the shark caudal fin.

Fig.7. Surface reconstruction result of the shark caudal fin

It can be seen from Fig. 7 that the surface reconstructed on the crescent caudal fin is continuous and smooth, and that the skin texture is clearly visible, which fits the biological template well. This demonstrates that the monocular and binocular vision inspecting system based on sinusoidal structure light used in the 3D shark body measurement can well ensure the measuring accuracy. Nevertheless, the edge surface of the caudal fin deforms after splicing, which makes it difficult to fit the biological template. The reason is that it is difficult to keep the thin edge of the caudal fin frozen for the whole experimental time. Thus the shape of the caudal fin edge deformed inevitably when it was fliped from one side to the other side. Therefore, If the measuring accuracy requirement of this part is not high, the measurement results above may meet the biomimetic needs to some extent. However, if the requirement to the details of this part is higher, the caudal fin must be measured in priority when it is in the frozen state.

Conclusions

(i) The pretrated shark body has appropriate mechanical strength and approximately rigidness, which makes it suitable to be taken as the messured object in the the 3D large field of view imaging and modeling.

(ii) Targeting the body of *Carcharhinus brachyurous*, 3D measurement was carried out with monocular and binocular vision inspecting system based on sinusoidal structure light, by means of which the digital shark body model with high accuracy was achieved.

(iii) The direct measurement on large-sized low resistance biological body is proved to be feasible, which provides a convenient and efficient way for the configuration design of underwater vehicles, especially for the microminiature ones.

Acknowledgments

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