Underwater Surface Reconstruction of Narrow Space by Endoscope and Optical Fiber: Application to Minimally Invasive Surgery

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Abstract— **In this paper, we propose a system to reconstruct the 3D surface of a synthetic knee using an endoscope and optical fiber under the water. It is able to scan the knee joint's profile even in narrow operated space and provide surgeons with 3D surface reconstruction in real time, which is very small in size, for the application of Mosaicplasty surgery from the surgical standpoint. Several sets of experiments were carried out to assess the proposed method, and it turned out that the accuracy was 0.56 mm with a standard deviation (STD) of 0.261 for plane reconstruction and 2.47 mm (5.04% difference) for surface reconstruction.**

I. Introduction

Numerous clinical studies have been made to elucidate the application of Mosaicplasty, a surgery for the osteochondral transplantation of the knee, using navigation systems. Some researchers have used invasive reference marker [1, 2], which was viewed as giving further harm to the patient's knee. Hence, this research was meaningful for minimally invasive surgery (MIS) by recovering the knee joint profile without any invasive instrumentation.

II. Methodology

A. System Setup

A lens with one side of the optical fiber was fixed to the light projector. And the other side, a 1 mm diameter fiber tip, was connected to a prism designed with a certain angle. As shown in Fig. 1, an endoscope with a diameter of 3.9 mm was attached to the prism with a baseline of 6 mm. As a result, the total diameter of the scanning tip of this system was 8 mm.

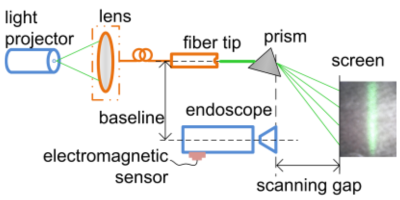

Figure 1. System setup of the endoscope and optical fiber.

B. Measurement Device

In order to calculate and record the position of the laser beam, a 6 DOF electromagnetic device (LIBERTY, Polhemus) was used. The device consists of one transmitter and two sensors. The sensors were fixed to the endoscope and the scanning object.

III. Results and Discussion

A planar surface was scanned underwater manually with a different scanning gap. The distance of each point from the ideal plane was measured and the detailed result is given in TABLE I. The maximum error was 1.08 mm on group #1, while the other groups were less than 0.70 mm. The average STD was 0.261 mm with the mean of error being 0.56 mm, which showed that the proposed system had a higher precision than those of [3] on plane reconstruction. For surface reconstruction, a cylinder model with 49 mm in diameter was chosen as the scanning object shown in Fig. 2(a). Since our system aimed at narrow space, a partial scan of the model surface was necessary. Using a comparative method described in [4], we can assess the average error was 2.47 mm compared with the ideal diameter, Fig. 2(b). Fig. 2(c) showed the synthetic knee (9 x 6 x 2 mm), and the reconstructed effect was depicted in Fig. 2(d).

In summary, the proposed system can potentially be used as a 3D profile acquisition technique of the knee joint for clinical application but it requires more research. In the future, we will expand the present study to navigate a normal vector for the reconstructed knee joint surface.

TABLE I. Result of Plane Reconstruction.

Group	***#1***	***#2***	***#3***	***#4***	***#5***	***#6***
Scanning gap (mm)	***10***	***12***	***14***	***16***	***18***	***20***
Measured value (mm)	11.08	12.70	14.39	16.28	18.52	20.40
STD	0.258	0.256	0.254	0.259	0.331	0.207
Error (mm)	1.08	0.70	0.39	0.28	0.52	0.40
Average (mm)	0.56					

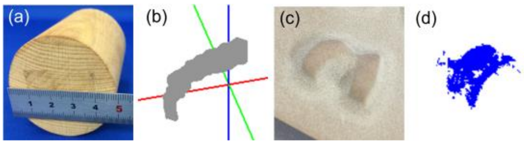

Figure 2. 3D reconstruction result of the cylinder and synthetic knee.

*Research supported by Grant-in-Aid for Young Scientists (B) from the Ministry of Education, Culture, Science and Technology of Japan (No. 25870273).

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