3D Tracking System Using Endoscope for Narrow Space

Zhongjie Long, Kouki Nagamune

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***Abstract*— This paper presents a real-time arthroscopic system that uses an endoscope and optical fiber to navigate a normal vector for the reconstructed surface of the knee joint. Navigation experiments using a synthetic knee joint were performed underwater. Compared to the freehand technique, navigational accuracy of the proposed system was significantly improved from at least 12.6° to 9.5°.**

I. Introduction

The mosaicplasty method was conceived in 1991 and applied to vigorous animal trials before the clinic application started in the next year [1]. Since then, there have been large numbers of case reports on the use of fresh autogenous cylindrical osteochondral grafts, either single or multiple, for the treatment of osteochondral lesions in the knee joint. Such procedure is not an easy task, especially when it is being performed with the arthroscopic technique. One of the crucial technical procedures during mosaicplasty surgery is congruity of the cartilage thickness between donor and recipient side [2]. Numerous case reports have been carried out to address this problem. For example, Bobic [3] pointed out that grafts harvest and insertion should be perpendicular to the articular surface, resulting in promising uniform results. Another clinical study [4] on the treatment of osteochondritis dissecans also emphasized that perpendicular access to the lesion was critical to obtaining maximize surface congruence in the open or arthroscopic technique.

Thus, this paper proposed a computer-aided arthroscopic system to navigate a *normal vector* for the knee joint surface, which seeks to provide the surgeons with more precise and predictable operation during the mosaicplasty surgery.

II. Proposed System

The fiber-based endoscopic system is presented in Fig. 1. 3D surface reconstruction was accomplished by calculating the spatial locations of the laser beam based on the stereo triangulation principles. The endoscope tube was small in size, 8 mm diameter, to allow it to be performed even in the narrow operating field. Our proposed navigation method adopted an electromagnetic device (LIBERTY, Plohemus Inc., USA) to accurately locate the harvester's 6-DoF position and orientation. 3D navigation will automatically run in real time when the harvester tip touches the reconstructed knee joint.

Research supported by the Ministry of Education, Culture, Science and Technology of Japan (No. 25870273); National Natural Science Foundation of China (No. 51275052); and Beijing Natural Science Foundation (No. 3131002).

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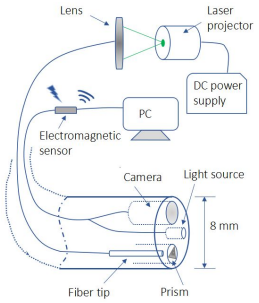

Figure 1. Configuration of the fiber-based endoscopic system.

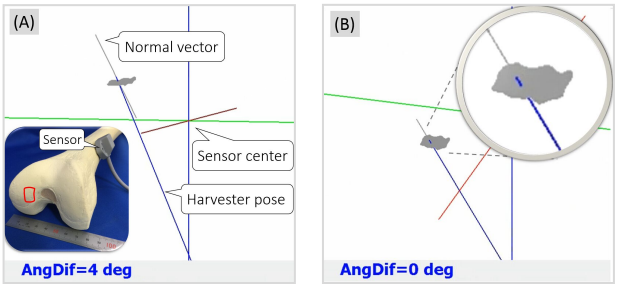

Figure 2. 3D navigation of a normal vector of the reconstructed surface.

III. Results and Discussion

Our previous study showed that accuracy of the proposed system was 0.56 mm for plane reconstruction and 5.04% difference for surface reconstruction [5]. Fig. 2(A) shows the normal vector navigated on a synthetic femoral bone surface. Harvester poses overlapping the normal vector is viewed as the optimal pose, Fig. 2(B). The navigation results revealed that our system had an average navigated error of 9.5° in the range of 5°-17°; standard deviation (StD) 2.86°. In contrast, the error of two cites of the freehand technique [6] performed in arthroscopic surgery was 14.8° in the range of 6°-26°; StD 7.53°, and 12.6° in the range of 4°-17°; StD 3.98°. Statistical analysis showed significant difference ($P = .001$ and $P = .0024$) between the navigated technique ($N = 30$) and the freehand technique ($N = 20$).

This study is meaningful for the mosaicplasty surgery by navigating a reconstructed knee joint surface without using invasive intra-osseous reference markers. Further, the position and orientation of the harvester can be tracked exactly, and each position on the surface can be navigated a normal vector in real time by using the proposed method.

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