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Outline of the thesis

Development of a Robot System for Supermicrosurgery

The study aims to develop a robot system for supermicrosurgery with an improved operating precision. The robot system adopted a leader follower operation. The robot system was designed to enable the precise manipulation of the leader manipulator and achieve the precise motion of the follower manipulator. The realization of improved precision is expected to contribute to the advancement of the surgical procedures and the targets of supermicrosurgery. In addition, the robot system includes a force feedback function, which is the challenge of the general surgical robot system and is not properly realized yet, by enabling the force displaying in the leader robot system and the force detection in the follower robot system.

In Chapter 1, we introduced the background that a robot system, which has an improved precision for supermicrosurgery, is desired. The performance of supermicrosurgery, which requires greatly high precision, is limited by precision and dexterity of the microsurgeon's hand.

Surgical robot system using a leader follower operation may facilitate use of this technique. To realize a desirable surgical robot system for supermicrosurgery, the improved precision is required through the advancements of these two processes: motion input by precise manipulation of a leader manipulator, and motion output based on superior operating precision of a follower manipulator.

In Chapter 2, we proposed a combined grip scheme to establish a more effective manipulating method of a leader manipulator in a leader follower operation for supermicrosurgery. We designed the combined-grip-handle that is adjustable in the distance and the direction of the fingertips for a pinch grip motion around the holding axis of a power grip motion during the operation, mainly to compensate for the disadvantages of the conventional gripping types.

We conducted a pointing experiment for the combined grip and the conventional gripping types with the leader follower operation under several manipulating conditions. The results showed that the condition of using the combined grip recorded fewer failures and required shorter time and length of trajectory drawn by the follower manipulator under the same condition in scale factors and forearm fixation. Moreover, the participants preferred the combined grip over the conventional types. We verified that the positioning operation could be performed better with the combined grip than with the conventional gripping types. Additionally, with the combined grip, it is possible to perform precise work at lower scale factors.

Chapter 3 presents a leader manipulator, which integrated the motion input and hand rest functions and adopted a combined grip scheme. The hand rest function, which generates the stable pivot point, was realized by switching the impedance value in admittance control with a simple operation of the interface, such as a foot switch, in the translation section of the leader manipulator. The leader manipulator enables force feedback at the gripping fingertips on a stable hand condition with a hand rest function.

With leader follower operation, we verified that the position of the hand rest in the direction of gravity could be arranged at the intended position in the evaluation experiment. Additionally, we conducted a pointing experiment for evaluating the manipulating method during precise positioning by focusing on the conditions of the hand rest function on a plane perpendicular to the direction of gravity under several conditions in terms of time required, number of failures, length of trajectory, and preference. We verified that the optimal manipulating condition of the leader manipulator was the condition that the hand rest function adopted sufficiently high impedance and did not fix the hand rest completely and the operator could use the finger movement on the basis of the hand rest. Furthermore, we verified that the condition of using the force feedback on the hand rest function applied the smallest force to the experimental target during operation through the 8-drawing experiment. As a result, we presented the feasibility of the force displaying method on the hand rest function, and verified the hand rest function contributed to effective force feedback.

Based on the Chapter 3, we established a leader robot system for supermicrosurgery.

In Chapter 4, we established a follower robot system for supermicrosurgery. Chapter 4 presents a follower manipulator that enables to achieve the improved positioning precision in precise motion with extended orientation range in larger motion of supermicrosurgical procedures. For this, this study proposed and adopted a semi-decoupled mechanism which selectively follows a coupled kinematics for larger motion and a decoupled kinematics of translation and orientation for precise motion, as needed. Furthermore, the follower manipulator implemented the force sensing ability for force feedback.

We identified the workspace which enables all designated range of orientation using the MATLAB simulation. Then, we experimentally evaluated positioning precision by microscopic measurements and force sensing precision by comparing the measured force information in the external force sensor. We verified that the specifications of the follower robot system surpass the requirements of microsurgery, and is adequate to supermicrosurgical procedures.

In Chapter 5, we constructed the robot system with a leader follower operation which consists of the leader and follower robot systems established in this study. The robot system involved the leader follower operation, three-dimensional visual system and force feedback function.

With the leader follower operation, we conducted a needle driving experiment using an artificial vessel with a diameter of 0.2 mm, to verify the feasibility of the robot system for supermicrosurgery. In the experiment, all participants including a microsurgeon and novices completed the experimental tasks without impairing the vessel after sufficient practice. Then, we performed a vessel transporting experiment with the artificial vessel to evaluate a force feedback function during the leader follower operation. The results suggest the possibility that the gripping and contact force feedback functions contribute to the improvement of surgical performance of supermicrosurgery, by reducing the force applied to the surgical subject.

Based on the results, it can be assumed that the leader robot system can contribute to effective supermicrosurgery ultimately, by enabling precise manipulation of the leader manipulator, and that the follower robot system showed the performance capable of performing supermicrosurgical procedures. Accordingly, it also indicates the feasibility of the developed leader follower robot system for supermicrosurgery.