論文の内容の要旨

論文題目　Force Feedback Augmentation and the Corresponding Forceps Action Determination for the Laparoscopic Cholecystectomy
（腹腔鏡下胆嚢摘出術における力帰還強調提示と鉗子動作自動認識に関する研究）

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Commonly in the minimally invasive surgery tele-surgical system, position information from the master manipulator operated by a surgeon is transmitted to the slave manipulator. Visual information from the endoscope is fed back to the surgeon in the opposite direction. With no force information feedback, the probing, gripping, and tactile sensations are lost. Unfortunately, these are, in general, crucial in accomplishing the operation. Therefore, force feedback is introduced as a mean to augment the natural sense of the surgeon's hand-eye coordination while performing a surgical task. It provides the feeling of the reaction force at the forceps back to the surgeon. This information is expected to substitute the lack of the tactile sensation and to repair the imperfection of the visual feedback system.

Perception of reaction force is vital in accomplishing the interaction with the objects in addition to the spatial information. Unfortunately, reaction force in the surgical operation is sometimes too small to perceive due to the tissue properties. Moreover, due largely to the tissue characteristics and the forceps tool tip, interaction force during the operation is quite complex such that it hides the essence of the simple but significant reaction force of the intended action. Yet it has been observed that, during the operation, the surgeon often needs to concentrate on the reaction force in specific directions, in accordance with his intended action, than others. Force components in some directions, which account for the complexity of the resultant force, may not be so important.

A method of force feedback augmentation to improve the force perception is proposed. It brings the mentioned aspects of the minimally invasive surgical procedure into consideration. For this purpose, the analysis of the laparoscopic cholecystectomy procedure, a typical and well-known case in the laparoscopic surgery, is first studied. The procedure is broken down and analyzed for the necessary forceps actions based on the degrees of freedom of the surgical tool and the task to be performed. There are seven necessary forceps actions for this system.

Force feedback augmentation amplifies the small reaction force naturally according to the forceps action. In particular, the force components along the ideal reaction force directions resulted from the forceps action will be amplified while those in other directions will be sent as usual. As a result, only the simple but significant reaction force patterns are emphasized. Complex behavior of the reaction force, which may distract or deteriorate the intended action, is attenuated. Furthermore, the PI gain scheduling local force feedback controller is used to compensate for the inertial and gravitational force of the master manipulator. The force perception in the initial stage of the contact is improved because the integral control action makes the displayed force respond to the feedback reaction force more rapidly. The real reaction force at the forceps can be felt more realistic.

To automate the force feedback augmentation process, it is necessary to determine the action online. The framework in determining these actions automatically based on the force signals

pattern and the motion of the forceps is outlined. First the real-time reaction force and the motion pattern of the forceps are identified. Then the forceps action is determined from the current force/motion pattern, their history, and the previous action. Force/motion pattern identification and action determination algorithms have been proposed. After the forceps action is known, the corresponding force feedback augmentation can be performed on the measured slave-tissue interaction force.

Experiments were conducted to show the validity of the proposed methods. Limitations of the developed methods were evaluated through the experiments.