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Evaluation of haptic in robotic heart surgery

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Abstract. The introduction of telemanipulator systems into cardiac surgery enables the heart surgeon to perform sophisticated mini-invasive and endoscopic procedures with high precision under stereoscopic view. At present, the commercially available robotic surgical systems do not dispose of force feedback for the operating surgeon. The lack of haptic (force or tactile) feedback causes damage of tissue and bending or breaking of suture material. For further improvement of telemanipulated systems, we implemented haptic into a realistic experimental platform to evaluate force-feedback for robotic heart surgery.

Keywords: Force feedback; Robotic heart surgery; Haptic

1. Introduction

Endoscopic and mini-invasive telemanipulated surgery offer benefits for the patients. Reduced trauma of tissue and short times of recovery is important advantages compared to conventional operations [1]. Otherwise, telemanipulated procedures are complicated by the lack of force feedback [2]. One sophisticated telemanipulating system is the da Vinci® workstation (Intuitive Surgical®) [3], which provides full manipulability like the human wrist, a stereoscopic view and a tremor filter but no force feedback for the surgeon.

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We provide a robotic scenario, which offers the surgeon an impression very similar to common and open procedures with high immersion [4]. It enables the heart surgeon to feel for arteriosclerosis in coronary vessels, to tie surgical knots with delicate suture material and to feel the break of suture material. Endoscopic instruments are equipped with strain gauge force sensors to measure and feed back occurring forces while manipulating and operating [5,6]. The aim of this study was to establish the experimental platform for analysing the presence of haptic feedback in typical cardiac surgical procedures for the safety of the patients and for the quality in endoscopic procedures.

2. Materials and methods

2.1. Robotic system

The robotic system we built up consists of two surgical manipulators, which are controlled by two PHANTOM® input devices, and a third robot, which carries the stereoscopic camera. Each manipulator is composed of a KUKA KR 6/2 robot that bears a surgical instrument of Intuitive Surgical® as shown in Fig. 1. The KUKA robot disposes of six degrees of freedom. The manipulator is a system under Cartesian control whose position can be adjusted precisely. A magnetic switch as adapter is developed to link one instrument to the robotic arm, which is opened automatically while extremely high forces arise at the instruments or in interaction with the thorax of the patient. The modular character of this setup simplifies the adaptation of the system to technical improvements (e.g. modified surgical instruments) [7].

2.2. Instruments with force feedback and devices of haptic output

The surgical instruments provide three degrees of freedom. A micro-gripper at the distal end of the shaft can be rotated and the adaptation of pitch and yaw angles is possible.

Since the shaft of the surgical instrument is made of carbon fibre, force sensors have to be very sensitive and reliable. Therefore, strain gauge sensors are applied, which are employed for industrial force registration. The sensor gauges are applied at the distal end of the instrument's shaft near the gripper in order to display realistic forces during operation.

A B

Fig. 1. Experimental platform: (A) An overview. (B) Training thorax with two haptic instruments and one camera port.

One full bridge of sensors is used for each direction. The signals of the sensors are amplified and transmitted via CAN-bus to a PC system. Since readings of the direct sensor are associated with noise, a smoothing filter is applied in order to stabilize the results.

The surgeon controls the position and orientation of the manipulators with two PHANTOM® devices (SensAble Technologies Inc.). It provides enough space to perform surgical procedures. A stylus pen equipped with a switch is used to open and close the micro-grippers. One outstanding feature of the PHANTOM® devices is their capability of displaying forces to the user. Forces are fed back by small servomotors incorporated in the device. They are used to steer the stylus pen in a certain direction. This creates the impression of occurring forces, while the user is holding the pen at a certain posture. This version of the PHANTOM® device is able to display forces in all translational directions, while no torque is fed back.

2.3. Subjects and surgical tasks of haptic evaluation

The human subjects of the evaluation included 25 surgeons within the Clinic for Cardiovascular Surgery in the German Heart Center at the Technical University of Munich in different levels of surgical training and age. The study intended basic surgical and cardiac surgical procedures. Knot tying, breaking suture material and detection of arteriosclerosis had to be performed in a defined cycle with double blinding. These tasks imply at least basic knowledge in surgical principles. The participants dealt with three different levels of haptic feedback: no haptic, actually fed back forces and enhanced force feedback.

3. Results

3.1. Experimental surgical platform with force feedback

A novel approach of telemanipulated system is presented for mini-invasive and endoscopic heart surgery with haptic feedback. Using multi-dimensional haptic styluses, forces are measured at the surgical instruments and fed back in to the surgeon's hand. Fig. 2 shows the occurring forces while tying a knot and while breaking surgical suture

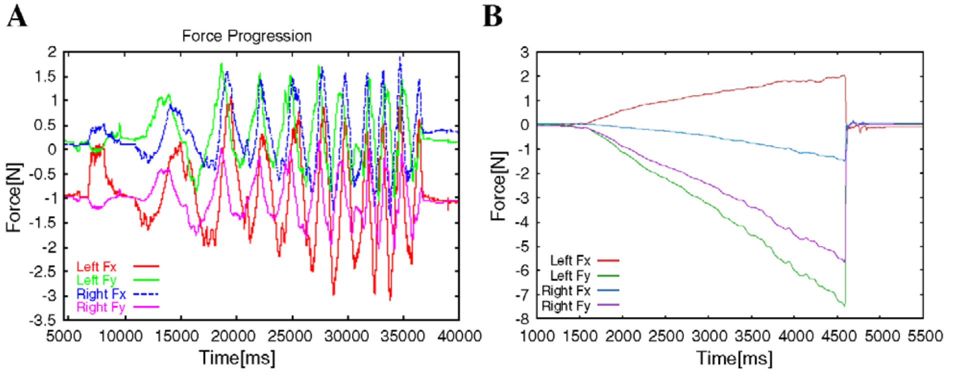

Fig. 2. Occurring forces while handling a surgical thread (Ethicon Prolene® 7/0). (A) Winding the thread. (B) Breaking the thread.

material. The application and the amount of forces can be restricted to tolerable amplitude to prevent harmful collisions not only between the instruments among each other but also between the instruments and the thorax of the patient. This platform represents a simulation environment for modelling and testing haptic interaction with a tissue model.

3.2. Evaluation of force feedback in robotic heart surgery

In all tasks without and with haptic, the occurring forces were recorded. In the knot tying task, the number of breaking the surgical thread decreases with placement of haptic. The quantity of knots tends to result in a higher number, but is not significant. In the task of breaking the suture material, the surgeons note significantly in advance the disruption of the thread with fed back haptic. The disruption of suture material and injuries to the tissue occur significantly fewer with haptic feedback for the surgeon. In detecting arterio-sclerosis, haptic feedback does not show any benefit for the participating surgeons. The stenosis was neither detected faster nor recognized better. The impression of telepresence in the experimental surgical setup was higher under the haptic environment. Nevertheless, the surgeon's subjective sensation of safeness and confidence while manipulating with implemented haptic feedback is enhanced versus non-haptic environment.

4. Discussion

We present a novel approach of a robotic system for mini-invasive and endoscopic surgery. The main purposes of the system are the evaluation of force feedback and machine learning. The performance of certain surgical tasks like knot tying while preventing the break of the suture material will profit from this feature. Experiments have shown that haptic feedback can be employed to prevent the surgeon from potentially harmful mistakes. Tension of thread material and tissue parts can be measured and displayed in order to restrict force application to tolerable amplitude. Collision of instruments can be detected and intercepted by real-time force evaluation. Perfection is planned for future evaluation to improve the set-up of the instruments and to incorporate the results of the force evaluation into the control software. A simulation environment is designed for modelling haptic interaction with a tissue model. This can be applied for offline evaluation of critical tasks.

The goal of these experiments was to examine claims about necessity of force feedback for robot-assisted surgical procedures in cardiac surgery. We present a novel approach of a robotic system for minimally invasive and endoscopic surgery. The main purposes of the system are the evaluation of force feedback. Experiments have shown that haptic feedback can be employed to prevent the surgeon from potentially harmful mistakes. The tension of thread material and tissue can be measured and displayed in order to restrict force application to tolerable amplitude. In addition, the collision of instruments can be detected and intercepted by the evaluation of real-time forces.

In this experimental platform of tasks with haptic versus non-haptic settings, the human subjects are able to distinguish different levels of feedback, so that haptic can be evaluated with this new construction and instruments. Several other experiments could be arranged and tested at the platform. In our experimental set-up, we make available and are able to demonstrate haptic feedback for surgeons in a robot scenario. Certain surgical procedures in robotic heart surgery are safer and gentler for the patient and more comfortable for the surgeon using force feedback.

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