EVALUATION OF HAPTIC FEEDBACK IN AN EXPERIMENTAL TELEMANIPULATOR SYSTEM

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Abstract: The introduction of telemanipulator systems enables the heart surgeon to perform sophisticated minimally invasive and endoscopic procedures with high precision under stereoscopic view. The lack of force-feedback is considered as major drawback of currently available telemanipulators used for minimally invasive cardiothoracic surgery. It was hypothesized, that haptic informations could increase the quality of surgical procedures and decrease exhaustion of the surgeon. The following experiment was performed to evaluate the impact of haptic information on the quality of surgical procedures.

Introduction

Endoscopic and mini-invasive telemanipulated surgery offer benefits for the patients. Reduced trauma of tissue and short times of recovery are 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.

We provide a robotic scenario that 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.

Materials and Methods

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 figure 1.

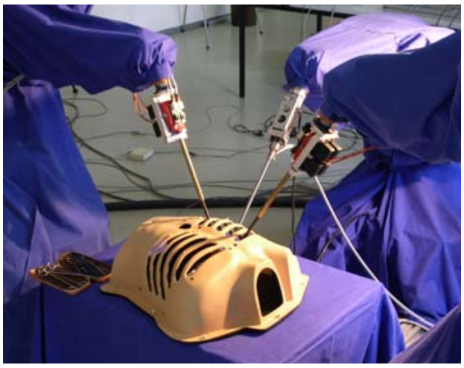

Figure 1: Experimental platform: Training thorax with two haptic instruments and one camera port

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].

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 (figure 2), 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. 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.

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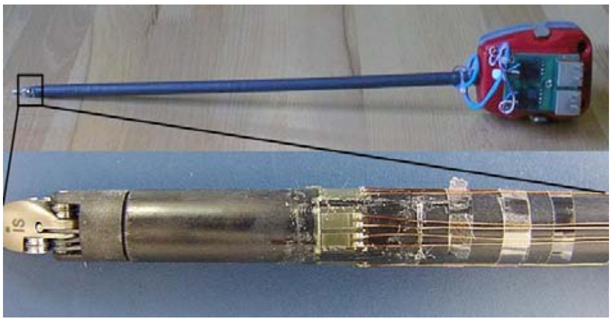

Figure 2: Modified Da Vinci® instruments with strain gauge sensors coated with protective cover (above).

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.

The human subjects of the evaluation included 25 surgeons within the Clinic for Cardiovascular Surgery in the German Heart Centre 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. . Experiments were evaluated recording speed and precision, visual exhaustion of the surgeon using the critical flicker fusion-test and were rated according to a scale by independent observers. Statistical analysis was done by analysis of variance or nonparametric tests, where appropriate.

Results

Breaking suture material: The effect of haptic becomes particularly apparent in the test of breaking suture material. In this task of immersion, the forces were continuously recorded. Therefore, the force difference between the feeling of breaking the thread and the real break of the thread could be analysed with and without haptic. With haptic feedback the surgeons noted disruption significantly better.

In increasing the haptic feedback the force difference decreased (*p<0,05, figure 3), which signifies the precision of the estimated force while breaking the thread.

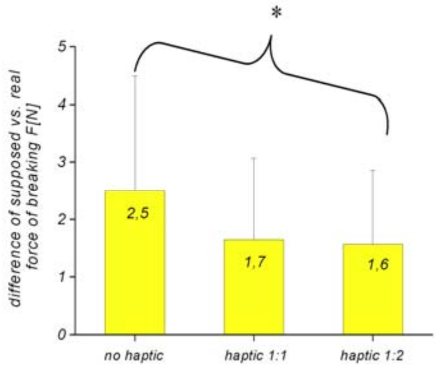

Figure 3: The difference of the supposed and the real force while breaking a surgical suture decreases significantly with haptic feedback

Surgical knot tying: In surgical knot tying force feedback influences the application of forces significantly (*p<0,05): with increasing force feedback, the applied forces are reduced (*p<0,05, figure 4).

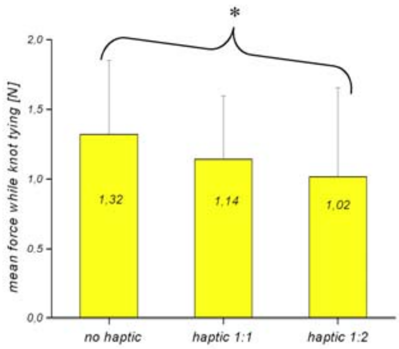

Figure 4: Forces while knot tying. With increasing haptic feedback the applied forces decrease significantly

Robotic surgeons apply significantly less forces while knot tying with doubled force feedback (figure 5).

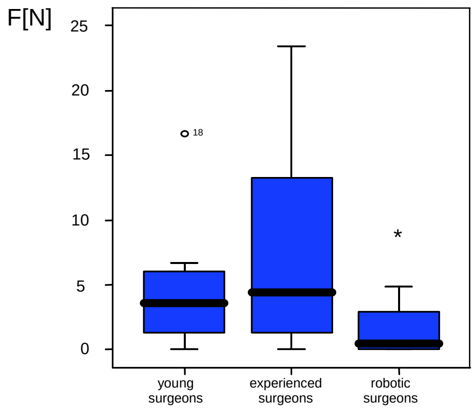

Figure 5: Robotic surgeons apply significantly less forces while knot tying with haptic feedback

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The robotically experienced surgeons showed a significantly higher speed of motion in no haptic and 1:2 haptic fed back skills (figure 6).

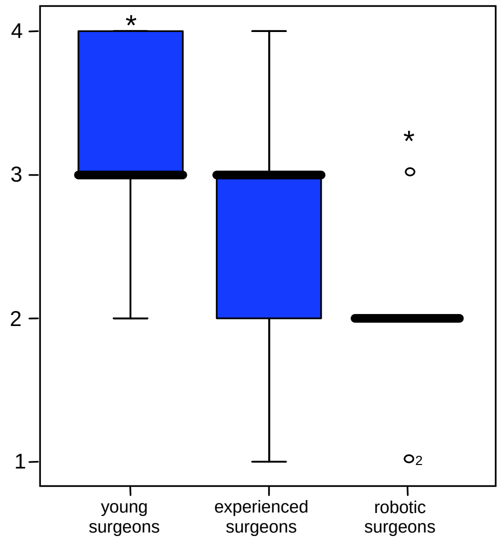

Figure 6: The speed of motion (1=fast, 4=slow) is significantly higher in robotic surgeons while knot tying (haptic 1:2)

Haptic feedback does not show any influence on the quality of surgical knot tying (p=0,05). The number of knots does not increase. Haptic feedback does not show any superiority concerning coordination and velocity of motion while knot tying in one of the three groups of surgeons. While knot tying the surgeons did not damage significantly less tissue. The breakage of suture material did not decrease significantly.

Detecting stenosis: Haptic feedback does not increase the number of correctly detected stenosis, but the forces decrease significantly with the increase of haptic feedback (figure 7).

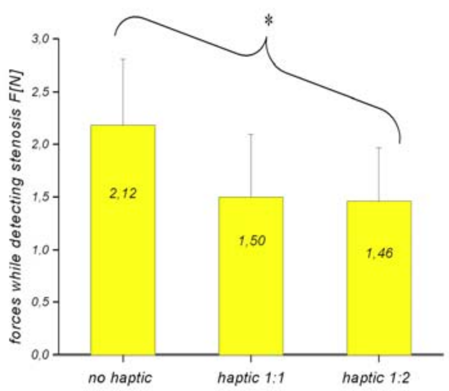

Figure 7: Detecting arteriosclerosis. The applied forces decrease significantly with the increase of haptic feedback

Critical flicker fusion frequency: Haptic feedback resulted in a tendency to decrease the visual stress and fatigue for young, experienced and robotically experienced surgeons (figure 8) measured by the critical flicker fusion frequency CFF.

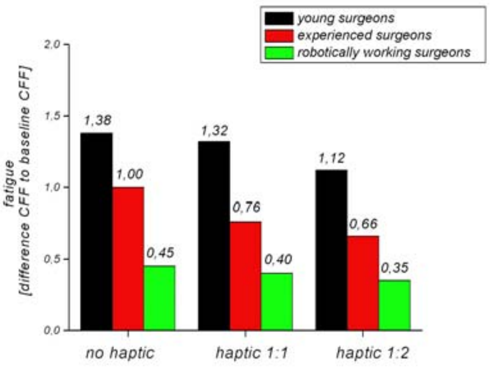

Figure 8: The critical flicker fusion frequency CFF. The visual fatigue decreases with increasing haptic feedback in young, experienced and robotic surgeons

Discussion

Intuitive Surgical® intended to create with the Da Vinci® Surgical System a conception of a surgeon-robot interface so transparent to the surgeon that his set of skills can be used in a natural and instinctive manner. Its excellent 3D-visualisation system allows compensating the lack of force feedback to a certain point.

The haptic feedback is currently limited to interact with rigid structures, such as tool-on-tool collisions, not soft tissues. This requires the surgeon to rely on visual feedback in tasks such as suturing. Especially for fine suture material approaches began in research groups to analyse haptic feedback, but the evaluating setup is not fulfilling the special medical interest for heart surgeons. The basic consideration in our work is to offer the heart surgeon an accessory sensory channel in addition to the visual channel not only to avoid breakage of surgical suture material and tissue, but also to decrease visual fatigue.

Conclusions

We present a novel approach of a robotic system for minimally invasive and endoscopic surgery. The main purposes of the system are evaluation of force feedback and machine learning. Experiments have shown that haptic feedback can be employed to prevent the surgeon from potentially harmful collisions. Tension of thread material and tissue parts can be measured and displayed in order to restrict force application to a tolerable amount. In addition, the collision of instruments can be detected and intercepted by the evaluation of real-time forces. Using multi-dimensional haptic styluses, forces are measured at the surgical instruments and fed back into the surgeon's hands. Force-feedback leads to enhanced surgical carefulness. Obviously, the lack of haptic information can partially be compensated by visual control, which leads to faster visual exhaustion.

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For the future clinical use, optimisation is planned by improving the setup of the instruments and by incorporating these results of the 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. In our experimental setup, we are able to demonstrate that the surgical procedure in robotic heart surgery is not only safer and gentler for the patient, but also more comfortable for the surgeon using force feedback.

Consequently, we require haptic feedback for surgical robotics to increase the safety of patients, to increase the ease of handling for the surgeon in a complex surgical environment, to relieve the surgeon's fatigue and possibly to increase the number of indications for surgery and the variety of robotic applications for surgery.

Future surgical systems with integrated haptic feedback could be used to train young surgeons for exercising and teaching critical and difficult steps of surgical operations by the system as simulator.

Acknowledgement

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