EVALUATION OF FORCE FEEDBACK IN MINIMALLY INVASIVE ROBOTIC SURGERY

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Abstract— *Despite the fact that minimally invasive robotic surgery provides many advantages for patients like reduced trauma and shorter recovery times, the lack of force feedback complicates the application of available surgery systems. We present an evaluation platform which emulates the functionality of such a system. Additionally it is extended by a high fidelity force sensory and feedback. For evaluation purposes we focus on instrumental knot-tying and linked problems like accidental suture material breaking and instrument collision. The manual execution of certain surgical tasks profits from a high-fidelity haptic feedback. The experiments show that this auxiliary feature prevents the surgeon from potentially harmful mistakes like tissue damage or yarn or needle break.*

Keywords— *force feedback, robotic surgery, minimally invasive surgery*

Introduction

A significant impact arose from the implementation of minimally invasive surgery for both, patients and surgeons. Patients benefit from this new possibility of intervention because of considerably reduced tissue trauma and thereby shorter recovery times. Otherwise minimally invasive operations complicate the working conditions for surgeons. They have to cope with unaccustomed kinematics of surgical instruments, since all operations have to be accomplished through a small port ("key-hole") in the patient's body. In addition, visual impressions and lighting conditions are limited.
By the application of robotic systems in this field, limitations were partially removed. A sophisticated example for such a system is the da Vinci® workstation [1]. Full manipulability of the instruments is restored by means of a telemanipulator and provides stereo vision of the operation environment to the surgeon. Despite the mentioned advantages of robot assisted minimally invasive surgery, all research groups involved agree about the fact, that the lack of force sensory and force feedback are the major drawbacks of currently available systems. Consequently two key problems arise in such procedures: increased tissue trauma and frequent suture material damage. In order to overcome these hitches, two crucial issues have to be solved. One is the inclusion of force sensory and feedback, the other is the implementation of full intuitive control of the end-effector. Therefore one of our main research interests is the prototypical construction and evaluation of force sensory and feedback in realistic scenarios of robotic surgery. In particular we focus on instrumental (in comparison with conventional manually performed) suturing and knot-tying.

Materials

Similar to other systems, our setup comprises an operator-side master console for in-output and a patient-side robotic manipulator that directly interacts with the operating environment. As shown in Figure 1, our system has one stereoscopic 3D-camera and two manipulators, which are controlled by two input devices. Each manipulator is composed of standard industrial robot that bears a standard surgical instrument. We developed an adapter to link the robotic arm with the instrument. The surgical instruments dispose of 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. All movable parts of the gripper are driven by steel wires. Their motion is controlled by four driving wheels at the proximal end of the instrument, one for each degree of freedom (two for yaw of the fingers).

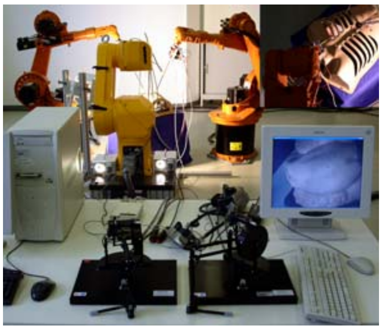

Figure 1: System Overview

The entire system offers 8 degrees of freedom. Therefore, with certain restrictions, the end-effector can reach every position and orientation through a fixed port (trokar kinematics). Position and orientation of the manipulators are controlled by two PHANTOM® devices. The model we use has a working space of approximately 20×25×40 cm, which provides enough space to perform surgical procedures. The user controls a stylus pen equipped with a switch to open and close the micro-grippers.

Methods

The most interesting feature of the PHANTOM® devices is their capability of displaying forces to the user. Forces are fed back by small servo motors 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. The force sensors were applied directly on the shaft of the instrument. Since the shaft of the surgical instrument is manufactured from carbon fiber, force sensors have to be very sensitive and reliable. Therefore strain gauge sensors were applied, which are employed for industrial force registration. Since direct sensor readings are blurred with noise, digital filters are applied to stabilize the results.

With the help of this setup different tasks are performed known from surgical practice and the impact of force measurement is evaluated. The expectation is that haptic feedback contributes to a better performance of the systems for robotic surgery by preventing force-induced damages to tissue and material.

Results

Winding: The first operation sequence evaluated was winding thread during knot tying. Forces are acquired only in the *XY*-Plane perpendicular to the instrument shaft, as the current setup does not yet allow the measurement of forces along the shaft. Winding thread to form loops is a subtask in instrumental knot tying [2], and if executed by a surgeon only very low forces arise, since a human operator easily copes with this task using only visual feedback. However in robot assisted surgery scenarios high fidelity force sensory is indispensable, as the visual modality is very difficult to interpret. Accordingly, robotic winding can be accomplished only in a force-controlled manner. On the one hand forces are preferably to be kept constant; on the other hand suture break must be avoided. Figure 2 shows the force progression during a winding process. The frequency of force peaks in a certain direction grows, as the suture material gets shorter. Nevertheless the forces are quite constant during the whole manipulation.

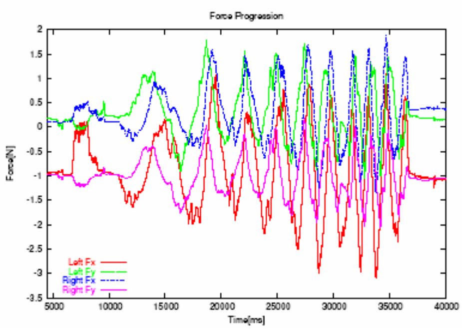

Figure 2: Winding during knot-tying

Collision Detection: Avoiding the collision of the instruments in robot assisted minimally invasive surgery is a challenging task. Therefore a symbolic representation of the whole robotic system, including both the instruments and the arms, were essential. Furthermore exact position control and a collision detection software subsystem are indispensable. Most setups however do not provide the above mentioned infrastructure. A human operator will easily avoid instrument collisions, but in an autonomous mode other solutions are necessary. A force controlled setup does not prevent collisions, but an early recognition prevents damage to the instruments. Figure 3 shows the forces recorded during an instrument collision, the instrument velocities were typical within ranges in this scenario. The highest peak (*Y*-force component of the left instrument) arises in approximately 35 ms. With a robot arm interpolation of 12 ms there are nearly 3 interpolation periods to react in such a situation, providing a satisfactory collision interception.

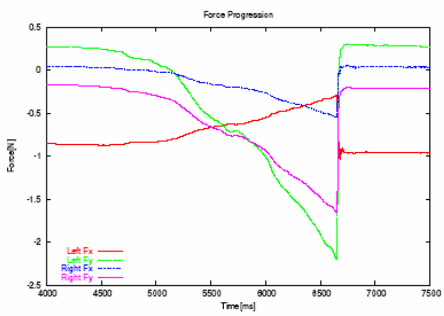

Figure 3: Forces during instrument collision

Discussion

A new robotic system is presented implementing force feedback for minimally invasive surgery. The main purpose of this system is the evaluation of basic surgical tasks by means of force feedback. The manual execution of certain surgical tasks profits from a high-fidelity haptic feedback. This feature has the capability to prevent potentially harmful actions performed by the surgeon. Tension of suture material and tissue can be measured and displayed in order to restrict force application to tolerable amplitudes. The collision of instruments can be detected and intercepted by real-time force evaluation. Forces are measured at the surgical instruments and fed back into the surgeon's hands using multi-dimensional haptic styluses. Long-term tests are initiated to evaluate a postulated reduction of surgeon’s fatigue by force-feedback.

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