Application of Force Feedback in Robot Assisted Minimally Invasive Surgery

István Nagy, Hermann Mayer, and Alois Knoll

Technische Universität München, 85748 Garching, Germany,
{nagy|mayerh|knoll}@in.tum.de,
WWW home page: http://wwwknoll.in.tum.de/index.html

Abstract. Currently deployed systems for robot assisted, minimally invasive surgery come with no force feedback. This is one of the main reasons for prolonged operation time and collateral tissue trauma. We present an experimental setup for an endoscopic robot system, that is capable of both, measurement and reflection of forces. We have evaluated certain tasks known from endoscopic surgery within this scope. First results have shown, that force feedback reduces most of the difficulties inherent to minimally invasive surgery without haptic feedback.

1   Introduction

Adoption of minimally invasive surgery has had a significant impact on both, patients and surgeons. Patients profit from this new possibility of intervention because of considerably reduced tissue trauma and, on that account, shorter recovery times. On the other hand, minimally invasive operations complicate working conditions for surgeons. They have to cope with an 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 *daVinci* workstation (cf. [1]). It restores full manipulability of the instruments by means of a telemanipulator and provides the surgeon with stereo vision of the operation environment. Another system, which has already been employed for delicate operations, like coronary artery bypass graft, is the *ZEUS* system (cf. [2] and [3]). Despite the mentioned advantages of robot assisted minimally invasive surgery, all research groups involved in agree about the fact, that the lack of force sensory and force feedback are the biggest drawbacks of currently available systems (cf. [10]). Consequently two major 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 inclusion of force sensory and feedback, the other is implementation of full Cartesian control of the end effector. The latter is indispensable for calculating exact directions of forces in a known coordinate system. Therefore one of our main research interests is the

prototypical construction and evaluation of force sensory/feedback in realistic scenarios of robotic surgery. In particular we focus on instrumental (as different from conventional manually executed) suturing and knot-tying. We present in the next sections several measurements with two instruments equipped with force sensory.

2   Previous Work

Since the interesting field of robotic surgery has attracted many researchers, there is a variety of systems with different features implemented by other groups. At the University of California, Berkeley, a robotic system was developed, which has already been used to perform certain surgical tasks like suturing and knot-tying ([7]). The Korean Advanced Institute of Science and Technology has developed a micro-telerobot system that also provides force feedback ([5]). In Germany two systems for robotic surgery were built at the Research Facility in Karlsruhe ([6]) and at the DLR in Oberpfaffenhofen ([4]). While the first system provides no force feedback, the latter system is equipped with *PHANToM* devices for haptic display. There is also some work available dealing with analysis of knot-tying. At Johns Hopkins University, Kitagawa et al. [8] have evaluated occurring forces during knot-tying. They did not measure forces directly at the instruments and during realistic operations, but with a specially designed measurement contrivance. Cao et al. [9] have analyzed a variety of surgical tasks (among other things knot tying) and decomposed them into subtasks. They did knot include force measurement.

3   Materials and Methods

The motor part of our system consists mainly of two major parts: A low pay-load robot that carries an adapter with an Oldham coupling for flanging the instruments. This contrivance can accept different exchangeable surgical instruments (Fig. 1). To address the aspect of intuitive operability of the user interface, we apply the concept of so-called *trocar kinematics*: the manipulator has to pass through a fixed hole ("port") in the the patient's body. This restricts the degrees of freedom of the instrument. Feed (translation) and rotation axes must always intersect with the fixed port.

We have equipped all surgical instruments for our setup with strain gauge sensors. They are applied by means of adhesive sealing and heat shrink tubing. Strain gauge technique is well-approved in other areas (like crash testing) and provides solutions for multifarious requirements (like high temperature, moisture and corrosive environments). Raw signals acquired from the gauges are preprocessed with high-precision amplifiers. They are finally transferred to the control computer by means of a *DeviceNet* bus. For user input and force reflection we employ two *PHANToM* devices, capable of force-feedback in all translational directions. Since we precisely know the geometry and kinematics of our system,

we can transform measured forces to be displayed with the *PHANToM*s.

With the help of this setup we have performed different tasks known from surgical practice and evaluated the impact of force measurement. Our hope is, that haptic feedback contributes to a better performance of systems for robotic surgery by preventing force-induced damages. Examples for such harms are breaking of thread material, ripping tissue and strangulate sutures.
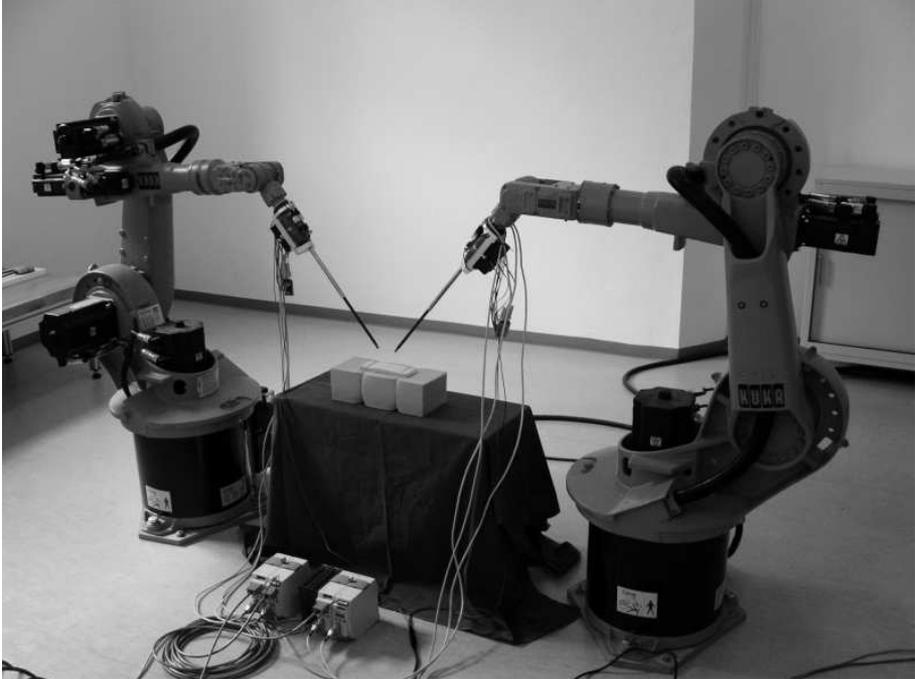
Fig. 1. System Setup

3.1 Winding

The first operation sequence we evaluated was winding thread during knot tying. Forces are acquired only in the XY–Plane perpendicular to the instrument shaft, as our 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 (cf. [9]), 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. Fig. 2 (left) shows
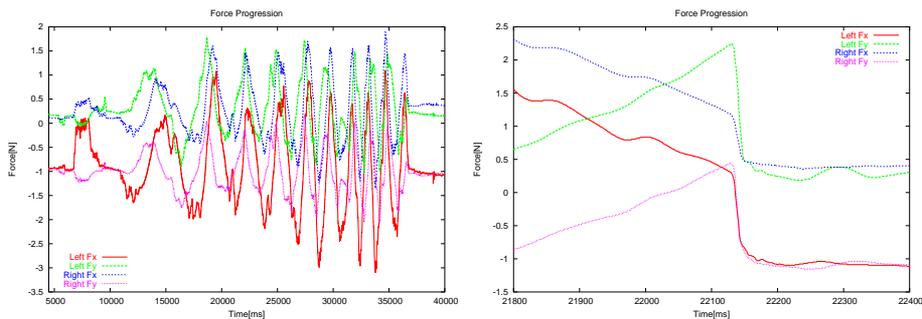
**Fig. 2.** Winding a thread to make loops

the force progression during a winding process. The frequency of force peeks in a certain direction grows, as the suture material gets shorter. Nevertheless the forces are quite constant during the whole manipulation. Figure 2 (right) shows a magnified view of an accidental break of the thread during a further winding process. Due to the high time resolution (1 ms) the instant recognition of such suture breaks is possible, preventing the robotic system from unexpected behavior.

3.2   Preventing Suture Material Damage

The tensile strength of absorbable and non-absorbable sutures is critical both during and after surgical procedures. Breaking strength can be measured using either a "straight pull" test or a "knot pull" test. Having the breaking strengths of all used sutures enables us to prevent suture material damage by limiting the applicable forces to adequate maximal values. Fig. 3 (left) shows the progression of forces while trying to break original surgical suture material, in this case Ethicon PROLENE (7/0, Polypropylen, not absorbable). Fig. 3 (right) shows breaking the thread (PROLENE 7/0) while tying a knot. As expected, the thread was broken at the knot position by significantly less force impact.

3.3   Collision Detection

Avoiding the collision of the instruments in robot assisted minimally invasive surgery is not an easy task. Therefore a symbolic representation of the whole robotic system, including both the instruments and the arms, were necessary. 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 will not prevent collisions, but an early detection can avoid from damaging the instruments. Figure 4 shows the forces recorded while an instrument collision, the instrument velocities were within ranges typical to this scenario. We observe,
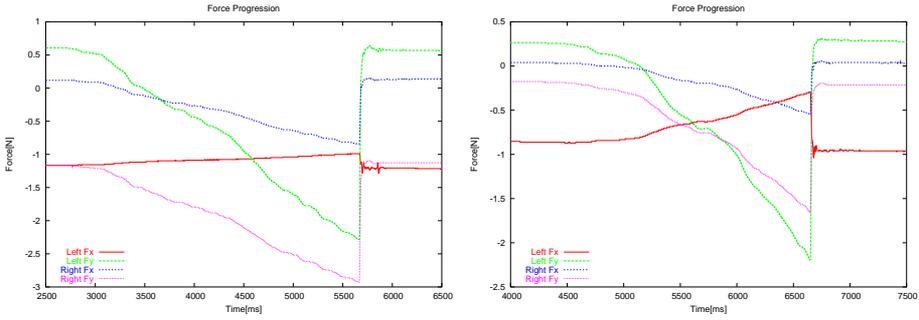
Fig. 3. Breaking Ethicon 7/0 by normal pulling (left) and knot tying (right)

that the highest peak (Y-force component of the left instrument) arises in approximately $35ms$. With a robot arm interpolation of $12ms$ there are nearly 3 interpolation periods to react when such a situation appears, providing a satisfactory collision interception.
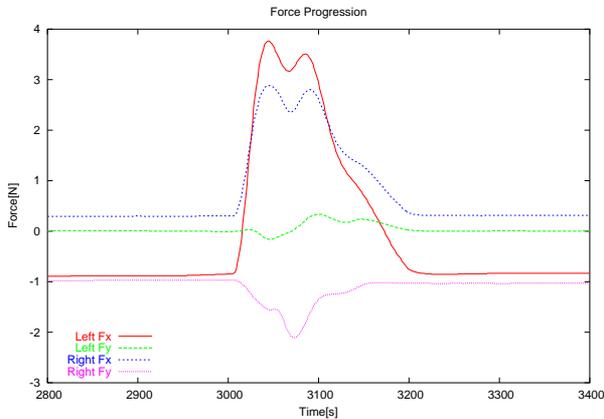
Fig. 4. Colliding instruments

4 Conclusion

We have presented a system for robot assisted, minimally invasive surgery that is capable of force measurement and haptic feedback. 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 a tolerable amplitude.

Collision of instruments can be detected and intercepted by real-time force evaluation.

The future plans for the system include measurement of torques and their incorporation in the control loop of the system. Currently we are also working on a simulation environment that can be used to simulate haptic interaction with a tissue model. This can be applied for off-line evaluation of critical tasks.

References

1. G. S. Guthart, J. K. Salisbury: The $Intuitive^{TM}$ Telesurgery System: Overview and Application, IEEE ICRA, San Francisco, CA, April 2000.
2. A. Garcia-Ruiz, N. G. Smedira, et al.: Robotic surgical instruments for dexterity enhancement in thoracoscopic coronary artery bypass graft, J Laparoendosc Adv Surg Tech 7(5), pp. 277-283, 1997.
3. D. H. Boehm, H. Reichenspurner, et al.: Clinical use of a computer-enhanced surgical robotic system for endoscopic coronary artery bypass grafting on the beating heart, Thorac Cardiov Surg 48, pp. 198-202, 2000.
4. R. Konietschke et al.: Optimal Design of a Medical Robot for Minimally Invasive Surgery, *2. Jahrestagung der Deutschen Gesellschaft fuer Computer- und Roboterassistierte Chirurgie (CURAC)*, Nuernberg, Germany, 2003.
5. D. Kwon et al.: Microsurgical Telerobot System, *IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 945-950, 1998
6. U. Voges et al., Evaluation of ARTEMIS: the Advanced Robotics and Telemanipulator System for Minimally Invasive Surgery, *Proceedings IARP 2nd Workshop on Medical Robotics*, pp. 137-148
7. M. Cavasoglu et al.: Robotics for Telesurgery: Second Generation Berkeley/UCSF Laparoscopic Telesurgical Workstation and Looking towards the Future Applications, *Industrial Robot, Special Issues on Medical Robotics*, Vol. 30, no. 1, 2003
8. M. Kitagawa, A. M. Okamura et al.: Analysis of Suture Manipulation Forces for Teleoperation with Force Feedback, Technical Report, Johns Hopkins University, Baltimore MD, USA, 2002
9. C. Cao, C. MacKenzie and S. Payandeh: Task and motion analyses in endoscopic surgery, Proceedings ASME Dynamic Systems and Control Division, pp. 583-590, Atlanta, USA, 1996
10. M. Mitsuishi, S. Tomisaki et al.: Tele-micro-surgery system with intelligent user interface, IEEE International Conference on Robotics and Automation, pp. 1607-1614 San Francisco, CA, April 2000.