Proceedings of EuroHaptics 2004, Munich Germany, June 5-7, 2004.

Direct 3-D Force Measurement Capability in an Automated Laparoscopic Grasper[1]

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Abstract. Advancements in robotics have led to significant improvements in robot-assisted minimally invasive surgery. The use of these robotic systems have improved surgeon dexterity, reduced surgeon fatigue, and made remote surgical procedures possible. However, commercially available robotic surgical systems do not provide any haptic feedback to the surgeon. This paper describes our design of an automated laparoscopic grasper with tri-directional force measurement capability at the grasping jaws. The laparoscopic tool can measure grasping forces, as well as, lateral and longitudinal forces, such as those forces encountered in probing and poking of tissue. Initial testing of the prototype has shown its ability to accurately characterize artificial tissue samples of varying stiffness.

1 Introduction

The introduction of robot-assisted surgery into the operating room has revolutionized the medical field. The uses of these systems not only have the advantages of traditional minimally invasive surgery (MIS), such as reduced patient trauma and recovery time, lower morbidity, and lower health care costs, but they also eliminate surgeon tremor, reduce the effects of surgeon fatigue, and incorporate the ability to perform remote surgical procedures. However, current systems lack the capability of providing haptic feedback to the surgeon. Several researchers in this field have proposed solutions to incorporate force feedback into current laparoscopic tools or new tools or surgical systems [1-4]. In addition, researchers have also incorporated a direct sensing method for tissue characterization through pressure measurement normal to the surface of the jaws [5]. However, these methods are expensive, non-sterilizable, and not modular, which make them difficult to incorporate into laparoscopic tools.

In this paper we present our results on design, development, and testing of an automated laparoscopic grasper that can provide tri-directional force feedback. Our design focuses on the direct measurement of the tool/tissue interaction forces for both grasping and probing tasks. This paper will discuss: (1) design and development of the laparoscopic grasper, and (2) evaluation of the laparoscopic grasper in characterizing artificial tissues.

[1] We would like to acknowledge the support of National Science Foundation grants: EIA-0312709 and CAREER Award IIS-0133471 for this work.

2 Materials and Methods

The prototype of a laparoscopic grasper with force measurement capability has incorporated the advantages of our previous designs with the addition of a direct force measurement and a more compact modular design [4]. The design has included a grasping jaw with force sensors that have the ability to measure the grasping forces in three directions, namely F_x, F_y, and F_z. Another key advantage of our design is the modularity of the end-effector to convert between a grasper, cutter, and a dissector.

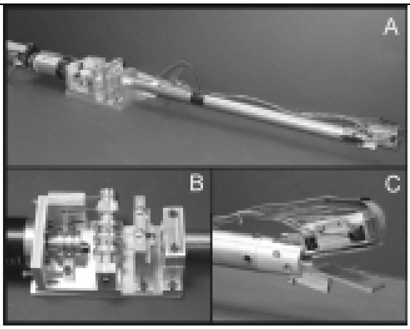

Fig 1: A) Laparoscopic grasper prototype. B) Cable transmission. C) Prototype jaws (top with sensors, bottom without sensors)

The prototype consists of a DC motor (manufactured by Maxon), cable-driven pulley system, and grasping jaw with sensors (See figure 1, part A). The jaws consist of one jaw with sensors for tri-directional force measurement (normal, lateral, and longitudinal forces to gripping surface) and a second jaw without sensors. This prototype is the initial design and future versions will be smaller and encapsulate the electronics and route the wiring through the hollow tool shaft.

The system comprises of the laparoscopic grasper actuated by a DC motor with encoder. The motor control is achieved by using the dSpace DS1103 controller board (manufactured by dSPACE, GmBH). We have developed a program using the dSpace interface that allows a user to input a desired position of the jaws while also measuring the forces from the jaw sensors. We have implemented a PD controller to control the position of the jaws.

3 Experiments

3.1 Characterization of Artificial Tissue Samples

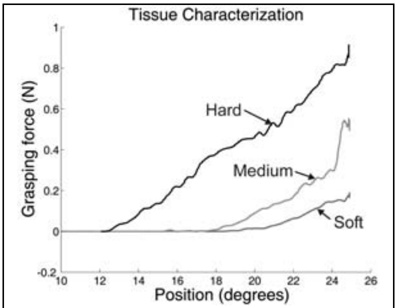

Figure 2: Characterization of artificial tissue samples using the grasper

Our first experiment with the laparoscopic grasper was to evaluate the forces detected by the tool when grasping tissue samples of varying stiffness. For this experiment, we developed several artificial tissue samples made up of Hydrogel material of varying stiffness. The tissues were numbered from 1 to 6 with sample 1 being the softest tissue while sample 6 was the hardest tissue.

For the experiment, we selected three (1, 3, and 6) of the Hydrogel samples that had a significant variation in stiffness such that they would be easily differentiated by direct exploration with one's fingers. Each tissue sample was fully grasped by the tool and the normal force on the jaw was recorded.

The final position of the jaws was held constant and each of the samples was of the same thickness. In Figure 2, we plotted the norm of all three forces in three independent directions as sensed by the force sensors in the grasper. As shown by the results in figure 2, the grasper can distinguish between samples of different stiffness. The soft, medium and hard Hydrogel samples showed peak forces of 0.2 N, 0.55 N, and 0.9 N respectively. As the tissue samples become stiffer, the required force to achieve the same compression also increases. Therefore, the grasper's capability of differentiating between tissues of varying stiffness has been shown.

3.2 Direct vs. Indirect Force Measurements

This experiment with the grasper involved the comparison of direct force sensing and indirect force sensing technique. Direct force sensing involves using a force sensor at the exact location where the measurement is desired while indirect force sensing might involve placing the sensor away from the location of the measurement (for example, determing the grasping force based on the motor current driving the jaws through the cable transmission). The direct method in this experiment used a thin film force sensor located on the jaw of the grasper and the indirect force estimation method involved calibration of the motor torque relative to the end effector force.

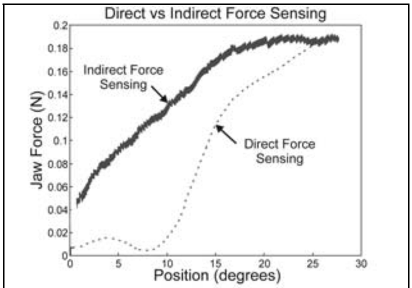

Figure 3: Direct vs. indirect force sensing using the laparoscopic grasper.

The soft Hydrogel sample (sample 1) was grasped while recording the sensor readings, the motor torque, and the position of the jaws. Then the two methods of obtaining the force (direct and indirect) were plotted and compared. As shown in figure 3, there was significant difference between the two methods. While the indirect method showed a linear force curve from the calibration, it significantly overestimated the tissue grasping force by an order of magnitude compared to the direct force sensing method. However, both methods arrive at approximately the same value of 0.18 N at the final jaw position. This experiment validates the requirement for direct force sensing. It is also important to note that indirect force sensing is significantly governed by the calibration procedure and the accuracy of the calibration equipment involved.

3.3 Soft-Tissue Probing using the Laparoscopic grasper

Our final experiment using the grasper focused on the probing ability of the tool and the accuracy of the forces measured. The experimental setup to measure the normal probing force consisted of a rigid object attached to the force sensor on one side and probed by the laparoscopic grasper on the other side. We used a rigid object for this experiment because we wanted to confirm the accuracy of the force measurement capability of the laparoscopic grasper by making certain that the probing force exerted on the rigid object is directly transmitted to the force sensor on the other side.

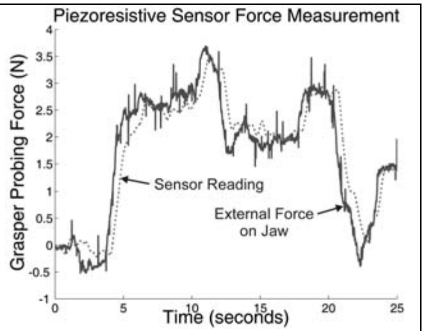

Figure 4: Longitudinal force measurement using the grasper compared to the actual forces during a probing task.

A load cell (MLP-10, manufactured by Transducer Techniques) was used in this experiment. The grasper was pushed forward towards the rigid object to simulate a typical probing task. As shown in figure 4, the force measured by the load cell and the piezoresistive force sensor in the grasper jaws is of similar magnitude. There was very little error between the actual probing force (load cell) and the measured force by the grasper piezoresistive force sensors with the configuration in which they were places in the jaw. A similar experiment was performed to measure the lateral forces. Therefore, the capability of the grasper to be used to probe soft tissues or organ surface is a natural extension of this experiment.

4 Conclusion

This paper discusses the design, development, and testing of an automated laparoscopic grasper with force measurement capability in three directions. Experiments were conducted and have shown the grasper's capability to characterize artificial tissue samples, to compare the difference between direct and indirect force sensing methods, and to evaluate the grasper's ability to measure probing forces. Future work with this prototype will consist of attaching the prototype to a robotic arm and transmitting the forces measured by the grasper to a haptic interface device, such as the PHANToM, for telemanipulation experiments involving animal tissues. Also, future versions of this prototype will involve packaged electronics, only three force sensors, and a smaller design for usability in laparoscopic procedures.

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