Haptic Sensing for Use in Miniature In-Vivo Robotic Grasping Tasks

Tom Frederick

Eric Markvicka

Joe Bartels

Kearney Lackas

Shane Farritor

Department of Mechanical and Materials Engineering,
University of Nebraska-Lincoln

Dmitry Oleynikov
Department of Surgery,
Medical Center University of Nebraska

1 Background

Surgical procedures have been improved greatly through the use of minimally invasive techniques. These techniques allow the surgeon access to the abdomen of the body without the necessity of a large incision. The same reasons that allow laparoscopic procedures to produce limited scarring and reduced risk of infection hamper the surgeon. Passing long rigid tools through the skin requires advanced training for accurate control of the tools. As found by MacFarlane in [1], tool choice greatly affects the surgeon's ability to palpate and grasp tissue for diagnosis and manipulation so as to minimize trauma.

An improvement on laparoscopic procedures is the implementation of surgical robots. This route can return the intuitive nature of open surgeries through providing the surgeon direct control over the tool tip, while providing a stable, reliable platform. Through these robots and their respective human interfaces, the potential for passing on haptic information, such as grasping force, can be realized. The user interface component of the system is well understood and accepted, but the initial sensing of the applied force can lead to difficulties. The da Vinci® S Surgical System (Intuitive Surgical, Sunnyvale, CA) is the most widely used system in US for gastrointestinal procedures. This robot, even with its success relies on the surgeons experience to control the level of forces applied to the respective tissues.

The da Vinci system is very large and has space if force feedback is ever desired, but in miniature surgical robots that are meant for complete insertion into the patient, space is limited. It is the forearm of a robot such as described in [2], three quarter to one inch diameter and three inches long, that a force sensing system must be made to fit. This size restriction both limits the options and requires more creativity in creating a simple, reliable design.

There have been efforts to augment the surgeons sense of touch by measuring the forces applied to laparoscopic tools under manual manipulation. The approaches in [3] and [4] have created systems that are capable of measuring the forces either directly, on the grasper itself, as well as indirectly, measured on the handle or drive system. Direct methods of sensing on the graspers can lead to unfamiliar grasper geometries as well as difficulties for sterilization. Indirect measurement is more practical for robotic applications, but due to the necessary space and the desired coupling of tool rotation and actuation, measurement of the drive rod directly can cause the overall forearm size and complexity to grow unacceptably.

When a focus on grasping force is taken, Puangmali in [5] discusses several different methods for indirect and direct sensing, including optical- and displacement-based sensing. These methods were considered for their practicality in a miniature system. Indirect measurement of the applied force was chosen for both its potential size as well as its ability to be applied on a coupled drive configuration.

In this paper, the initial testing of an in-line, self-contained force-sensing robotic grasper for use on miniature surgical robotic platforms is presented. This grasper has been tested in five different grasping situations, with the corresponding curves presented here as a measure of its effectiveness. Based on the verification presented here, the system will be adapted to a package capable of in vivo testing.

2 Methods

A testbed was created, Fig. 1, to provide proof-of-concept of the method as well as the attachment design. This testbed utilized the grasper and linkage components from an Ethicon laparoscopic grasper. The open/close of the grasper was driven by a 6 mm 256:1 brushed Faulhaber motor driven at 5 volts. The load cell used is an ENTRAN ELFS-T3E-2 L sensor capable of both tension and compression measurements. An Arduino UNO microcontroller was used to control the motor and record the sensor data. Each grasp test was driven at the same speed and power settings, and the motor was driven to stall and held at stall during the grasp. The open/close mechanism is selflocking, but continuous input from the motor was desired to create a secure grasp and maintain a bias on any system backlash.

Due to the consistent input conditions on the motor for each test, the measured force on any material results in same maximum force applied. When testing, the crucial component is how the force ramps up from no load to this full load, and the characteristic curves that result.

As shown in Fig. 2, five different closing conditions were tested; empty grasp, thick acrylic, thin acrylic, foam, and a drinking straw. These materials provide for a range of properties from fully rigid (acrylic and empty) to uniformly soft (foam). The drinking straw was chosen as a fifth to provide a common material that is fairly universal.

3 Results

Several grasps were conducted with each of the five end conditions. The measurements were recorded at 50 Hz. Each of the trials for a given condition was adjusted laterally to accommodate different times of contact. Once the matching cases were aligned laterally, each trial for a particular case was averaged. The resulting averages were then filtered using a rolling average that accounts for the previous four readings. The result of this filtering demonstrates distinct trends for each class of material, as shown in Fig. 4.

The three cases that represent a rigid end condition (empty and thin/thick acrylic) all demonstrate the same steep loading curve as

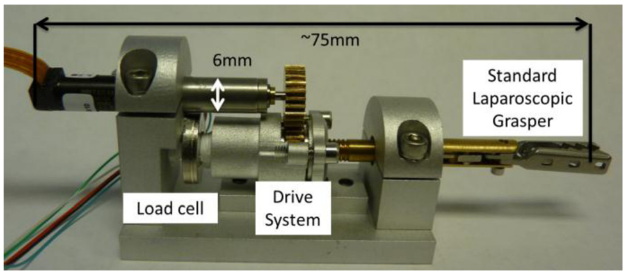

Fig. 1 A testbed was created for design validation

Manuscript received March 15, 2013; final manuscript received April 26, 2013; published online July 3, 2013. Assoc. Editor: Arthur G. Erdman.

Fig. 2 Five different conditions (empty, thin acrylic, thick acrylic, a drinking straw, and foam) were tested and shown to have both different as well as consistent readings

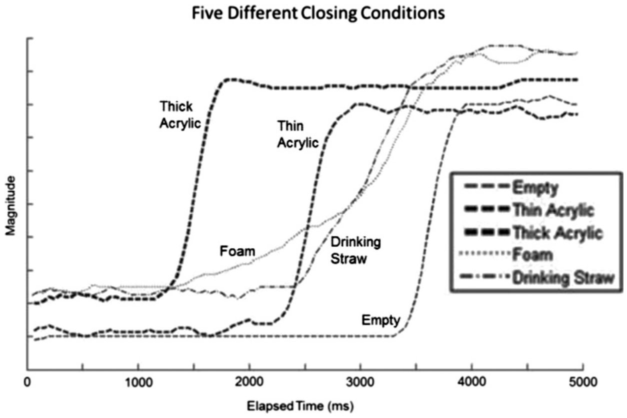

Fig. 4 Testing results provide varying compression characteristics for each type of material

would be expected. The different starting points for the curves correlate well with the relative thickness and corresponding stopping angle for the jaws at stall.

The foam shows an extended contact period with a smoothly increasing applied force. As the foam compacts, its elasticity drives the required force up. The slope of the contact portion was found to be approximately 25% of the rigid slope.

The drinking straw demonstrated a mixed mode of force profiles. The slope of the load curve right after contact is high and then it levels off to a path similar to late stage foam. This transformation can be explained by the changing physical shape of the straw as it is crushed and the mechanical stiffness that is associated with each shape. This curve can be fit closely with a line that has a slope approximately 42% of the rigid grasp.

It is important to note that the force that is measured is the amount of force used to actuate the graspers closed. While it does relate to the realized endpoint forces, that relationship is dependent on the specific grasper geometry. The force cannot be used to precisely predict the contact forces as the contact area and position cannot be accurately characterized. This information is best implemented in a relative manner combined with the surgeons experience using the system.

4 Interpretation

The characteristic slopes of these lines can help to roughly identify and classify tissue as it is grasped. The results are consistent with the results presented by Tholey, [3], for materials of different stiffness. The similarity in trends seves to verify the arrangement tested. This validation has provided the confidence in proceeding with an early embedded design as part of a miniature surgical robot.

A primary consideration with the design of a new end-effector is the overall size of the device. The present design for the robotic end-effector is of comparable size to previously successful designs. The added bulk of this design is due largely to the choice of load cell, and future versions will need to use a yet unfound smaller sensor. Upon the completion of the embedded design, the design will begin in vivo testing. This stage of testing will initially rely on a single degree of force feedback provided by a PHANToM Omni haptic device. Further versions will require a different controller or a custom pen interface with haptic feedback specifically for grasping events.

Acknowledgment

The material is based upon work support by the National Science Foundation Graduate Research Fellowship undergrant number DGE - 1041000.

References

[1] Mark MacFarlane, MD, Jacob Rosen, Ph.D., Blake Hannaford, Ph.D., Carlos Pellegrini, MD, and Mika Sinanan, MD, Ph.D., 1999, "Force-Feedback Grasper Helps Restore Sense of Touch in Minimally Invasive Surgery," J. Gastrointestinal Surg., **3**(3), pp. 278–285

[2] Wortman, T. D., Lehman, A. C., McCormick, R. L., Farritor, S. M., and Oleynikov, D., 2011, "Miniature Surgical Robot for Laparoendoscopic Single-Incision Colectomy," Annual Meeting-SAGES, San Antonio, TX.

[3] Gregory Tholey, Anand Pillarisetti, William Green, and Jaydev P., Desai, 2004, "Direct 3-D Force Measurement Capability in an Automated Laparoscopic Grasper," EuroHaptics, 478–481.

[4] Jeffrey D., Brown, Ph.D., Jacob Rosen, Ph.D., Lily Chang, M.D., Mika N. Sinnan, M.D., Ph.D., and Blake Hannford, Ph.D., 2004, "Quantifying Surgeon Grasping Mechanics in Laparoscopy Using the Blue DRAGON System," Studies in Health Technology and Informatics, pp. 34–36.

[5] Pinyo Puangmali, Kaspar Althoefer, Lakmal D. Seneviratne, Declan Murphy, and Prokar Dasgupta, 2008, "State-of-the-Art in Force and Tactile Sensing for Minimally Invasive Surgery," IEEE Sensors, **8**(4), pp. 371–381.