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Group 5: Haptic Interface

CIS II: Paper Critical Review

Selected Paper

The Benefit of Force Feedback in Surgery: Examination of Blunt Dissection. Christopher R. Wagner, Nicholas Stylopoulos, Patrick G. Jackson, and Robert D. Howe. Presence: Teleoperators and Virtual Environments 2007 16:3, 252-262

Project Background and Paper Relevance

I am part of group 5, and our project is creating the haptic interface for a surgical manipulator. Total hip replacement surgery is an extremely popular surgery in the United States. It is not without issues, however. Over time, hip implants begin to degrade the surrounding bone and cause resorption in a process known as osteolysis. To prevent the integrity of the entire bone from being compromised, revision surgery is performed in which the surgeon inserts a tool through a screw hole made for the hip replacement surgery and removes the degraded bone. The screw hole insertion limits the surgeon's movement. Additionally, the operating site is difficult to visualize because of the minimally-invasive nature of the surgery and requires the use of fluoroscopy to update the surgeon on the progress of the surgery. This results in less than optimal coverage of the lesion. The manipulator is intended to make hip revision surgery more efficacious by allowing greater coverage of the lesion.

Currently, the issue with the manipulator is that no intuitive interface for controlling it exists. The existing method of controlling it is a keyboard controller. Our project seeks to develop a more intuitive interface using a PHANTOM Premium Haptic controller. Integral to our interface is the use of haptic, or force, feedback. Thus, the question that naturally arises is whether haptic feedback is actually a useful addition to the interface, especially as haptic feedback has been called 'trite' and 'gimmicky.' Wagner et al. seek to answer this exact question in their paper. Moreover, they seek to better understand its role in assisting surgeons. This focus on the utility of haptics feedback, including the investigation of why it works, makes this paper relevant to our project. The fact that they also utilize a PHANTOM® Haptic controller in their trials only makes this paper more so. Wagner et al. find that haptic feedback is indeed useful when it comes to robotic surgery. The larger the force feedback gain, the less tissue damage users generated on the phantom artery during mock surgery trials. Results will be discussed in greater detail later in this report.

Authors' Methods

To answer the question of force feedback's usefulness, the authors recruited subjects to perform mock surgery on a phantom of their own creation. Two PHANTOM® controllers were used as surgical devices. One was used as the surgical robot while the other was used as the controller. As with our device, the tip of the controller stylus was mapped to the tool tip of the surgical robot. The surgical robot had a 50 cm rigid shaft to which was attached a right angle hook, a surgical tool. For the purpose of trials, the shaft was passed through a fixed incision point to restrict its movement. This was done to model the actual range of motion present in a laparoscopic surgery in which entry is through a small incision.

The controller-robot system had both force feedback and position feedforward. The former was achieved utilizing a force transducer that was located on the shaft of the robot. The force that was read from this transducer was transformed to the end of the right angle hook by assuming the shaft acted as a perfect lever. This was done to allow the user to feel the force at the tool tip. Force was then scaled to either 0%, 37%, or 75% force feedback gain depending on the experimental condition.. Thus, the force that the surgical controller relayed to the surgeon was $f_{master} = g_{ff} A(x_{robot}) f_{sensor}$ where g_{ff} is the force feedback gain, $A(x_{robot})$ is the matrix used to transform the force to the tip of the right angle hook, and f_{sensor} is the force the load cell reads.. The latter part was implemented using proportional position/velocity control via the relation $f_{robot} = k_p(x_{master} - x_{robot}) + k_d(\dot{x}_{master} - \dot{x}_{robot})$ where x_{master} is the position of controller stylus tip,

x_{robot} is the position of the connection between the proximal end of the instrument shaft and the surgical robot, $k_p = [0.5\ 1.0\ 1.5]^T\ N/mm$ and $k_d = [0.0001\ 0.0010\ 0.0005]^T\ Ns/mm$. The values of the latter two parameters were selected to preserve uniform stiffness in the workspace without sacrificing the stability of the system.

Users were asked to perform a mock surgery on a phantom modeling an artery within a bed of soft tissue. The artery was modeled as a 4mm diameter cylinder with pink clay. To create the phantom, a 10cm length of artery was embedded in a block of gray clay that modeled surrounding tissue. This was then compressed to a height of 5mm. The artery and surrounding tissue were both made with clay of different stiffnesses. The artery was stiffer than the surrounding tissue. To quantify this difference, the right angle hook was embedded in the artery clay at 5mm depth and dragged along the artery. This generated a force of 3.5 N while the same action in the surrounding tissue clay generated a force of 0.5 N.

The subjects asked to perform the surgery had varying levels of skill with surgery. They ranged from graduate students with no experience to experienced attending surgeons. The subjects were asked to dissect out as much of the artery as they could in one minute—that is, they were asked to remove the tissue surrounding the artery for as much of the length of the artery as possible. They were to do this while minimizing the amount of visible damage done to the artery and surrounding tissue. Such damage would correspond to an applied force of >1.0 N. Subjects were also provided with visual feedback from a fixed surgical endoscope, camera, and light source to model the actual visual feedback a user receives during a minimally invasive laparoscopic procedure. Each group was asked to perform this task with varying amounts of force feedback gain: 0%, 37%, and 75%. The final value was the highest gain available that maintained 'high fidelity and stability' (Wagner et al.). One subject from each of the most experienced groups (a medical student, a senior resident, and an attending surgeon) performed similar trials on a porcine liver and gallbladder to show that the results from the clay phantom were relevant to tissue. Porcine liver and gallbladder were determined to correspond well to the stiffness properties of the artery/surrounding tissue clay phantom.

Data were analyzed using a nonparametric Friedman test of *k* related samples to determine the statistical significance of the different metrics (see below in 'Authors' Results and Discussion'). This particular test was chosen because of the unknown distribution of the variables being studied as well as the small sample size (n=20). Statistical significance was achieved with a *p* value of less than 0.05

Authors' Results and Discussion

In the course of the trials, the authors measured four different quantities: force generated by the user, errors during the surgery (i.e. the number of times the applied force exceeded a force threshold while the instrument touched the artery), area of tissue affected during the surgery, and length of artery dissected. The first three are measures correlating with tissue trauma, and the last is a productivity measure.

The authors found that increasing force feedback gain resulted in smaller force magnitudes generated during the mock surgery and a decreased number of errors for all groups. The former was confirmed in the porcine gallbladder trials. Because this result held for all groups, the researchers concluded that the benefit of force feedback does not diminish as users become more experienced. In contrast, the presence of force feedback did not affect the area of tissue affected during the surgery or the length of the artery dissected in a significant way. Only the surgeons had a significant increase in the amount of artery dissected, based on training.

The researchers speculated that these results mean that force feedback transforms the properties of the tissue into physical constraints for the user's motion. The user is able to differentiate between different types of tissue based solely on the force feedback. Because of this, force feedback can act as a guide for the user. This is especially true for the mock surgery because the artery and surrounding tissue had different levels of rigidity. The authors also believe that as force feedback gain level decreases, it acts less as a physical constraint and more as an additional sense of information for the user. They note that this requires more conscious thought on the part of the user to integrate the feedback into his motion than higher levels. Thus, they imply that higher levels of force feedback lead to more intuitive control schemes.

Interestingly, the group that evolved the greatest force magnitudes and durations on the phantom was the surgeons. The authors posed several possible reasons for this: One was that the surgeons did not have all the cues in the mock surgery they would expect because of their experience, including tissue color and functional change (i.e. some tissue begins to bleed as it is touched by the tool). The authors also suggested that surgeons may be more comfortable with damaging tissue as they understand the level of abuse the body can take and know that, in some surgeries, tissue damage is required. Another reason they posed were that the surgical manipulator was different than a typical surgical tool handle, preventing the surgeons from fully engaging their surgical experience and methods during the experiment. Finally, they also theorize that surgeons might have been showing off, trying to dissect as much of the artery as possible, regardless of how much they damage it.

Personal Assessment

I found this paper to be extremely relevant to our project because it justifies the addition of force feedback to our interface. First and most importantly, it shows that the addition of force feedback to a surgical interface is not meaningless. Increased force feedback significantly decreased metrics related to tissue damage (applied force magnitudes and number of errors). This is a worthwhile result because minimizing tissue damage during surgery results in fewer complications and reduces recovery time as the surgery affects fewer regions outside the target region. It is, in effect, making the surgery even less invasive. Building on this, as the purpose of our project is to create as intuitive an interface as possible, the authors' study of the nature of force feedback is useful. They claim that high levels of force feedback transform material properties of tissue into physical constraints, allowing for more unconscious and intuitive control of the surgical robot. Their conjectures have led us to consider giving users varying amounts of force feedback in the trials that we will run with our interface to investigate this effect.

This paper was a very strong and interesting paper. It was well-written and easy to understand. The authors were clear in their analysis and made the major points of the paper flow in a logical manner. Regarding their experimental design, their measuring multiple different factors (length of artery dissected, force magnitudes, etc.) helped make their analysis very strong. They were able to show that force feedback does reduce tissue damage via multiple metrics. Moreover, it allowed them to make the interesting point that force feedback does not seem to affect the productivity of the surgery, which was measured by the length of artery dissected. Another strong aspect of their design was confirming the results of the clay phantom trials with an actual biological model. This precludes the objection that the phantom the mock surgery was performed on is not a realistic biological model. Although they spend time in the paper justifying the use of the clay as a material that represents tissues that deform plastically, the addition of this confirmation strengthens the applicability of their results. The data also show a very interesting and non-intuitive result concerning the increased amount of force that surgeons applied to the phantom during the mock surgery. The authors also present a variety of reasons that could have been responsible for this observation. Finally, in their analysis of the force feedback data, the authors include a very interesting conjecture about the nature of force feedback, namely the fact that different levels of force feedback may be processed in different ways by the brain. These last two factors point to a great strength of the paper. It is not self-contained; instead, it suggests future work that should be pursued so that the nature of force feedback and the way that the brain processes it can be better understood.

As strong as the paper is, it does have some flaws, most of which are linked to the experimental design. First, only 20 users participated in trials, and these users were split across five different groups. In fact, the four more experienced groups each only had three members in them. This is a rather small sample size, and increasing it would strengthen the results and conclusions the paper presents. A second flaw is that, of the groups participating in the trials, the graduate students were meant to have the least experience with the surgery. While they had no experience with surgical technique, they did have experience with the PHANTOM®. This familiarity may have skewed the results, allowing the graduate to perform the surgery more easily or control the robot better than they would have been able to without any experience. Another issue with the paper is that the results only apply to tissue that can be plastically deformed, a function of the phantoms used for the trials. As there are multiple types of tissue in the human body, it is important to generalize study of force feedback across different tissue types to make the application of results and conclusions as broad as possible. Finally, another problem with the paper is that it only compares the lack of force feedback with two other feedback gains. The authors note that both gains were high enough to act as physical constraints for the users. To fully investigate the nature of force feedback, including the threshold required for the feedback to act as a physical constraint, more gains should be considered and tested.

Considering these issues with the paper, future study should rectify many of them. Increasing the sample size will strengthen the paper’s conclusions. Many more subjects should be included in each group. Additionally, no user should have prior experience with the PHANTOM® to ensure unbiased results. Investigating more gains would allow for deeper investigation into the nature of force feedback. Finally, performing mock surgery on more types of tissue and running further trials on biological tissue would also allow conclusions about force feedback to be even more generalizable and useful to the world of robotic surgery.