Haptic Interface for Surgical Manipulator System

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Background (relevance/importance/goal):
Component wear and osteolysis, the active resorption of bone around components, are responsible for shortening life spans in total hip anthroplasty (THA) procedures. Osteolytic lesions of the bone around the implant, if not removed, may lead to complications such as born fracture or component loosening or disconnection [3].

Lesions are typically accessed through screw holes in the bone. A major challenge is fully accessing the entire volume inside the lesion in order to clean the cavity; studies have shown that on average less than half of the lesion is grafted during manual procedures using curettes and other tools [3]. Therefore, the need for a highly dexterous manipulator that can cover the majority of the volume inside the lesion is essential.

The Johns Hopkins University Whiting School of Engineering and Johns Hopkins Applied Physics Laboratory have developed a cable-driven surgical manipulator system. The snake-like cannula can access osteolytic lesions through the lumen of a larger, rigid guide cannula [3]. The actuation unit consists of a Z-Theta stage with cable drive motors, which may be controlled using keyboard commands. Path planning algorithms of the system have suggested 85–95% coverage rates of surgically relevant osteolytic cavities [3], a significant improvement from traditional manual surgical methods.

The Matlab keyboard control, however, is difficult to maneuver and lacks force feedback that allows the surgeon to "feel" his way around the cavity. Since the system does not have a navigation system that allows the surgeon to orient himself within the lesion, he can only estimate where in the cavity the manipulator is currently located.

Our goal is to develop an intuitive haptic interface for controlling the manipulator end-effector position that can relay force information to the user. We plan to create a mapping between a 6-DOF PHANTOM® Premium 1.5 haptic device and the manipulator end effector. We will build a GUI that models the motion using a simplified kinematics model of the manipulator as well as display relevant information from the encoders to the user. The improved dexterity and incorporation of feedback will give us better coverage of the lesion, which may be verified through x-rays, and decrease the total procedure time, which we plan to demonstrate through preliminary trials using a phantom.

Deliverables:
<u>Minimum</u>:

- Develop a *well-defined, mathematically formulatable* interface coupling the workspace of a PHANTOM® Premium 1.5 haptic device (SenseAble, Wilmington MA) to the workspace of the provided continuum surgical manipulator. This interface must be *reliable* and incorporate available force feedback from the provided manipulator actuation unit. This interface will be realized in hardware.
    - In this context, a *well-defined, mathematically formulatable interface* requires that the entire workspace of the fully actuated surgical manipulator is mapped (one-to-

one and onto) a subset of the workspace of PHANTOM® Premium device. Additionally, the governing equations of this mapping must be documented highlighting any/all tunable (e.g. scaling) parameters. Note that, for the purposes of this work, a simplified model of the manipulator can be used for mapping workspaces. This model can assume simplified kinematics (i.e. 14-DOF) and evenly distributed bending (i.e. a constant curvature along the manipulators length [1]).

- In this context, a *reliable* interface requires that, following documented hardware and software installation procedures, the system will "work every time." That is, upon starting up the interface, a user will be guided through the correct procedures to bring the manipulator and interface online without risk of unintended software or hardware behavior. Note that, given the overall scope and duration of this project, a fully debugged system may not be feasible. As such, all efforts must be taken to reduce, track, and document errors in the integrated system. Additionally, errors that endanger the user and/or system hardware must be addressed prior to final delivery.

<u>Expected</u>:
In addition to minimum deliverables,

- Develop and incorporate a 3D visualization of the manipulator for testing and training purposes.
- Increase interaction force estimation (utilizing simulation-based collision detection and/or additional sensors if available) to enhance/increase haptic feedback to the user.
- Schedule and document intermittent system trials with at least one mentor on a bi-weekly (i.e. every other week) basis to offer feedback on progress.
- Schedule and document a final system trial with a collaborating surgeon to provide qualitative feedback for future system enhancements

<u>Maximum</u>:
In addition to minimum and expected deliverables,

- Define and run quantifiable trials having inexperienced subjects learn to operate manipulator using the PHANTOM® interface, and perform a simple set of tasks. Compare multiple sets of scaling parameters and gestures to find best one for the specified task.
- Draft a preliminary conference paper documenting the use of this haptic interface to control the manipulator.
- Draft a preliminary conference paper describing outcome of user trials.

Milestones:

- Get PHANTOM® Premium 1.5 interfaced and running using provided SensAble software interface
    - Date: 20 Feb 2012 (~2-3 hr)
- Be able to import positional data from the PHANTOM® to MATLAB
    - Date: 22 Feb 2012 (~2-3 hr)
- Identify/create and implement test mappings from PHANTOM® to a graphical interface of the manipulator
    - Date: 24 Feb 2012 (4-6 hrs)
- Be able to control manipulator using keystrokes in MATLAB
    - Date: 28 Feb 2012 (~2-3 hrs)

- Develop initial phantom-manipulator mapping schemes incorporating haptic feedback on paper
  - Date: 29 Feb 2012 (3 days)
- Derive inverse kinematics model for the simplified manipulator model (given desired xyz coordinates of end-effector, how do we move the joints)
  - Date: 9 March 2012 (~2 wks)
- Develop dynamic 3D visualization of the manipulator (eventually to become part of PHANTOM® GUI controller)
  - Date: 28 March 2012 (~2 wks)
- Control manipulator using PHANTOM® by implementing mapping schemes
  - Be able to gather positioning/movement data from manipulator and import into MATLAB
  - Date: 28 March 2012 (~2 wks)
- Incorporate force feedback into mapping schemes
  - Date: 3 April 2012 (5 days)
- Complete preliminary testing and refine mapping scheme as necessary
  - Date: 17 April 2012 (2 weeks)
- Have surgeon provide qualitative feedback
  - Date: 20 April 2012 depending on surgeon availability (1 day)
- Testing and trials with inexperienced users
  - Date: 27 April 2012 (1 week)
- Poster presentation
  - Date: 10 May 2012 (1 day)

Technical Approach:
The first step is to understand all the system hardware and software components as well as set up and verify the working order of the hardware and the MATLAB keystroke controller for the manipulator. To allow our GUI to interface with the C++-based PHANTOM® Premium API, CISST library, and forward kinematics Robworks simuation [1], we plan to port the keystroke controller to C++.

The second step is to develop an inverse kinematics model of the manipulator so that we may map the workspace of the manipulator end-effector to the workspace of the PHANTOM® Premium. Using this information, we may then develop various Phantom-manipulator mapping schemes, each of which we will simulate using a graphic interface before implementing in hardware. We may then compare the efficacy of the different mappings and choose a single one to refine, after user trials to determine which mapping is the most intuitive.

The third step is to implement force feedback into the PHANTOM® interface to allow the user to haptically feel their way around a cavity without the use of optical feedback and/or manipulator configuration estimates.

<u>Use Case(s)</u>
Controlling manipulator using force-feedback integrated PHANTOM®
- Start GUI
- Follow instructions to turn on hardware (manipulator, Phantom)
- Move Phantom

- GUI: Maps Phantom's position (user input in xyz coordinates) to position of manipulator end effector using mapping and scaling function
- GUI: Displays simulated movement of manipulator based on inverse kinematics model of manipulator
- Manipulator moves
- User feels forces (pushback) in PHANTOM® based on position of manipulator

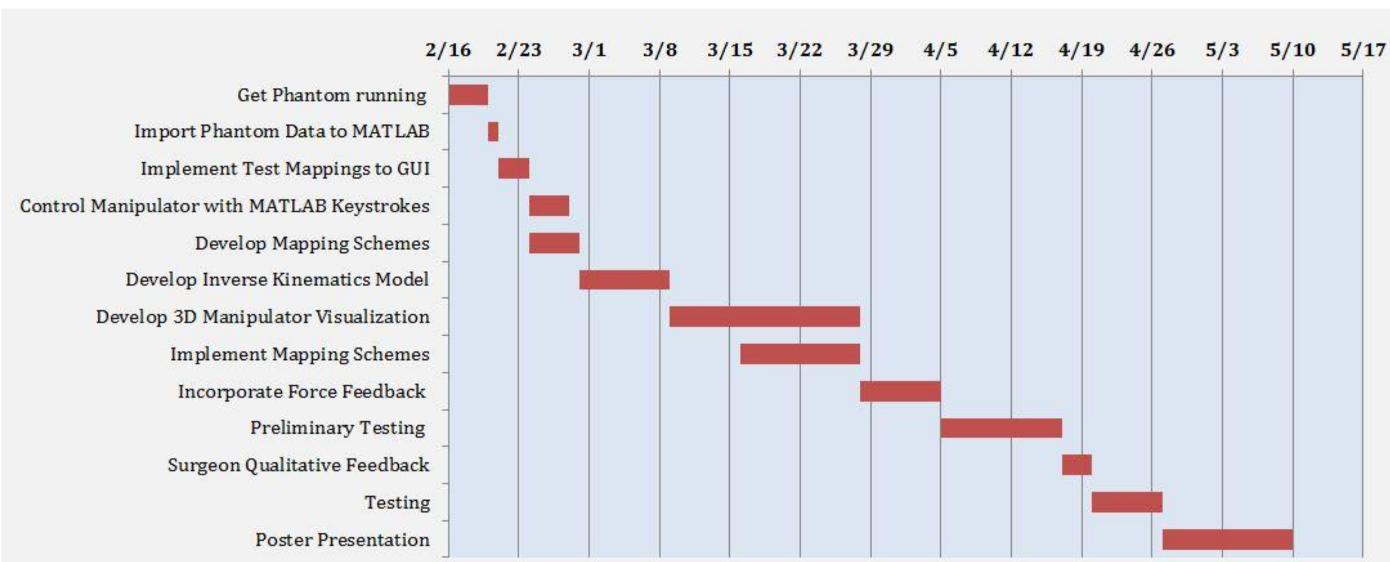
Dependencies:

- Access to BIGSS Lab
    - Resolved: Yes
    - Plan to Resolve: N/A
    - Resolved By: 14 Feb 2012
    - Contingency Plan: N/A
    - Affects: N/A
- Access to PHANTOM®
    - Resolved: Yes
    - Plan to Resolve: N/A
    - Resolved By: 14 Feb 2012
    - Contingency Plan: N/A
    - Affects: N/A
- Access to manipulator
    - Resolved: Yes
    - Plan to Resolve: N/A
    - Resolved By: 20 Feb 2012
    - Contingency Plan: N/A
    - Affects: N/A
- Access to CISST library
    - Resolved: Yes
    - Plan to Resolve: N/A
    - Resolved By: 21 Feb 2012
    - Contingency Plan: N/A
    - Affects: N/A
- Weekly meetings with mentors
    - Resolved: Yes
    - Plan to Resolve: Michael is at Homewood twice a week and available for meetings. Meetings can be scheduled with other mentors as needed.
    - Resolved By: N/A
    - Contingency Plan: Skype meetings, conference calls
    - Affects: Entire project (esp milestone 6--inverse kinematic model--and on)
- Availability of test subjects
    - Resolved: No
    - Plan to Resolve: Recruit students (easily obtainable)
    - Resolved By: 15 April 2012
    - Contingency Plan: Offer small rewards for participation (e.g. candy)
    - Affects: Expected deliverables (milestones 10--ability to refine model before presenting to surgeon--and 12--run trials with inexperienced users)
- IRB Approval for trials (if necessary)
    - Resolved: No
    - Plan to Resolve: Submit proposal to IRB
    - Resolved By: 15 April 2012

  - Contingency Plan: Talk to Mike about other ways to test device, do limited testing on ourselves
  - Affects: Expected deliverables (milestone 10-- ability to refine model before presenting to surgeon--and 12--run trials with inexperienced users)
- Availability of surgeon
  - Resolved: No
  - Plan to Resolve: Ask Dr. Mears to come to Homewood and test out robot
  - Resolved By: 19 April 2012
  - Contingency Plan: Reschedule to available date
  - Affects: Expected deliverables (esp milestone 11--have surgeon provide qualitative feedback)

Management Plan:

- Weekly in-person meeting with Michael Kutzer to check-in and ask questions along with constant email contact in lab pod depending on his availability
- Group meetings every Monday in lab pod from 8-9p to report status updates and assign tasks for the upcoming week
- Further group meetings throughout the week to work on project together
- Weekly email chain to facilitate constant contact and status updates
- Work will be done cooperatively for the most part, especially at first. In general, Jessie will mainly work with the simulation and kinetic model while Piyush and Manish work on interfacing the Phaontom and manipulator and testing various interfaces. Further delegation as project progresses will be considered as necessary.
- Revise Gantt chart and milestones as necessary



References/Reading List:

[1] W.P. Liu, B.C. Lucas, K. Guerin, and E. Plaku, **Sensor and Sampling-based Motion Planning for Minimally Invasive Robotic Exploration of Osteolytic Lesions,** in Intelligent Robots and Systems (IROS), 2011 IEEE/RSJ International Conference on, Sept. 2011.

[2] S.M. Segreti, M.D.M. Kutzer, R.J. Murphy, and M. Armand. **Cable Length Prediction for a Compliant Surgical Manipulator,** in Proceedings of the 2012 IEEE International Conference on Robotics and Automation, May 2012, in Press.

[3] M.D.M. Kutzer, S.M. Segreti, C.Y. Brown, R.H. Taylor, S.C. Mears, and M. Armand, **Design of a new cable driven manipulator with a large open lumen: Preliminary applications in the minimally-invasive removal of osteolysis,** in Proceedings of the 2011 IEEE International Conference on Robotics and Automation (ICRA2011), May 2011, pp. 2913-2920.

[4] B. T. Bethea, A.M. Okamura, M. Kitagawa, T.P. Fitton, S.M. Cattaneo, V.L. Gott, W.A. Baumgartner, and D.D. Yuh. **Application of Haptic Feedback to Robotic Surgery**. in Journal of Laparoendoscopic Advanced Surgical Techniques 14.3, 2004, pp. 191-95.

[5] A.M. Okamura, **Methods for Haptic Feedback in Teleoperated Robot-assisted Surgery**. in Industrial Robot: An International Journal 31.6, 2004, pp. 499-508.

[6] C.R. Wagner, N. Stylopoulus, and R.D. Howe, **The Role of Force Feedback in Surgery: Analysis of Blunt Dissection,** Proc. Haptics Symp., Mar. 2002.

[7] G. Tholey , G.P. Desai, A.E. Castellanos, **Force feedback plays a significant role in minimally invasive surgery - results and analysis**, Ann of Surg, 2005;241(1): pp. 102–109.