Haptic Interface for Surgical Manipulator

Piyush Poddar, Manish Mehta, Jessie Young
Mentors: Michael Kutzer, Ryan Murphy, Dr. Mehran Armand
The Johns Hopkins University, Baltimore, MD 21218

Abstract

A surgical manipulator, the JHU/APL snake, intended for use in hip osteolysis removal surgery has been developed. It is capable of translating, rotating, and bending and is currently controlled with a keyboard and mouse. This project concerns the successful development and implementation of two distinct interfaces for the manipulator using a PHANTOM® Premium haptic controller with the goal of increasing intuitiveness of control. The first interface allows the user to select a target position towards which the manipulator moves. The second allows the manipulator to continuously update the input position. We also discuss our various enhancements to the base interfaces, including the use of force, audio, and visual feedback.

Significance

- Areas within pelvis are hard to reach during surgery: in manual procedures, there is less than 50% coverage of the cavity[8]
- Dexterous manipulator allows for 85-95% coverage[2]
  - But lacks an intuitive control interface and force feedback

Implementation

- Control the end-effector position, *not* individual joint angles
- Develop and implement simplified inverse kinematics model
- *Primary Input:* Position of PHANTOM haptic device
- *Primary Output:* Position of manipulator end-effector
- Force feedback using PHANTOM's simulated spring force to indicate center of rotation
- C++ and MATLAB program run simultaneously to get input position and control manipulator, respectively


Haptic input device


JHU/APL snake manipulator

References

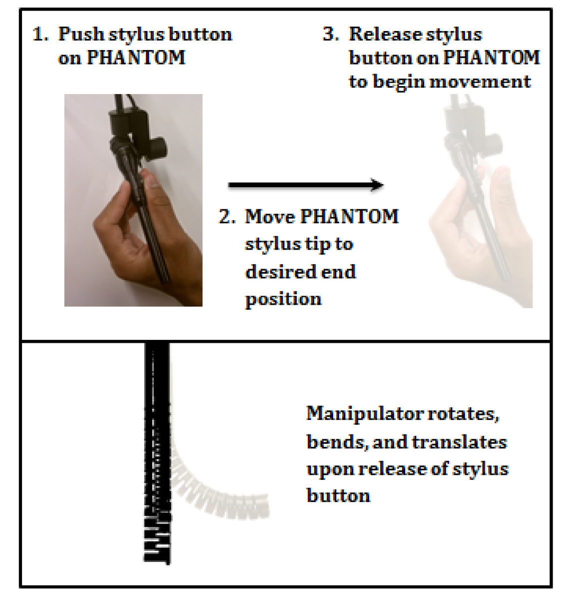
[1] W.P. Liu, B.C. Lucas, K. Guerin, and E. Plaku, **Sensor and Sampling-based Motion Planning for Minimally Invasive Robotic Exploration of Osteolytic Lesions,** in Intelligent Robots and Systems (IROS), 2011 IEEE/RSJ International Conference on, Sept. 2011.
[2] S.M. Segreti, M.D.M. Kutzer, R.J. Murphy, 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.
[8] C.A.Engh, Jr.,H.Egawa,S.E.Beykirch, R.H.HopperJr., and C.A. Engh, **The quality of osteolysis grafting with cementless acetabular component retention**, in Clinical orthopaedics and related research, vol. 465, pp. 150–154, Dec. 2007.

Approach: Interfaces

1. Keyboard Controller

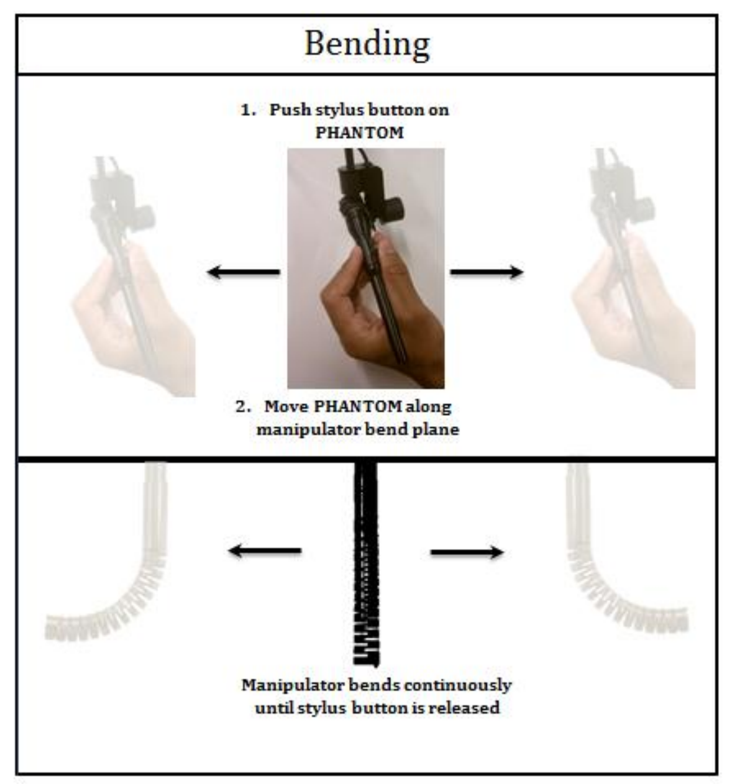
Controls each degree of freedom separately using keystrokes/mouse

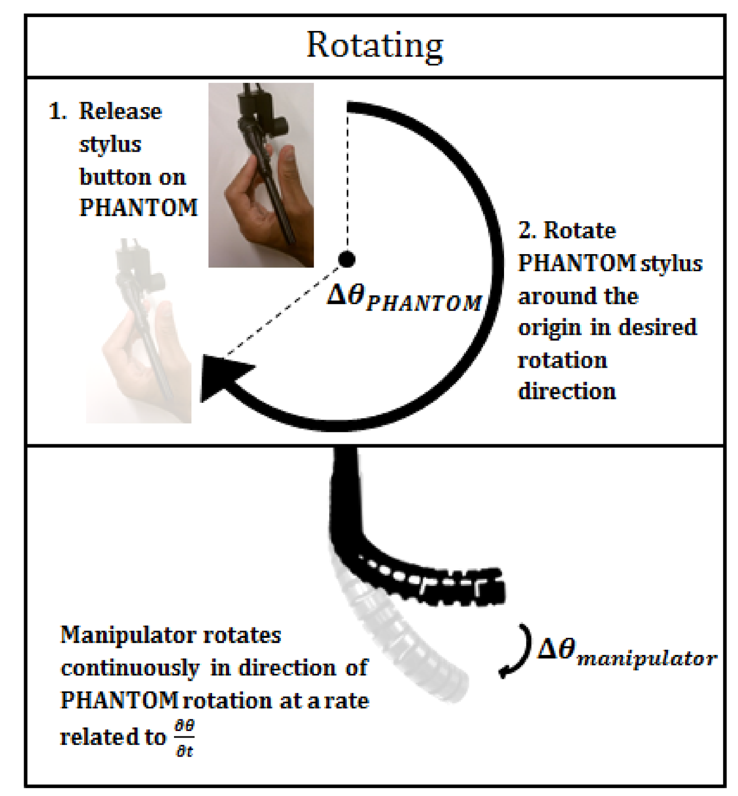
2. Point/Click

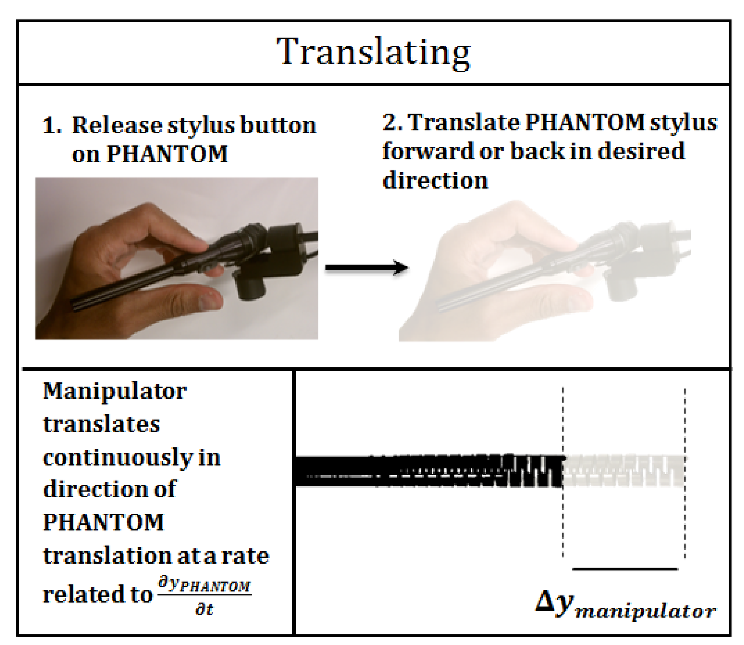


Since there are two paths to reach any target location (bend left and rotate or bend right and rotate), program decides optimal path by that which precludes rotation of greater than 135°

3. Continuous





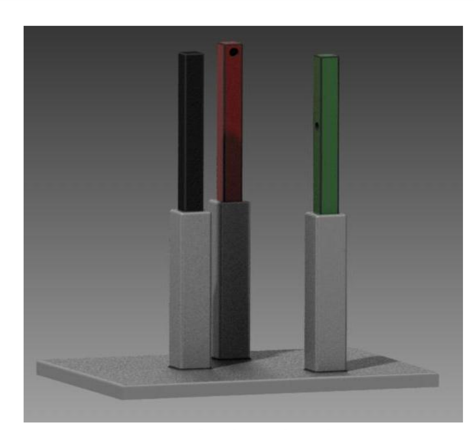


$$\frac{d\theta}{dt} = \frac{x * \dot{z} - z * \dot{x}}{x^2 + z^2}$$

Calculation of angular velocity for rotation using x, z position and linear velocity

Approach: Task

- Touch manipulator tip to holes located at different heights on posts as quickly as possible in prescribed order
- In future, will use suspended hanging targets to protect manipulator tip/cables


CAD model of phantom

Approach: Feedback

1. Force Feedback

- Spring force pulls PHANTOM stylus to current origin

2. Audio Feedback

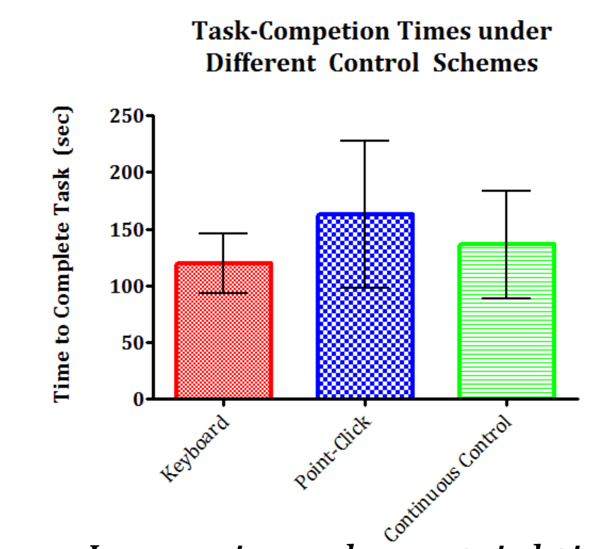
- Tone frequency proportional to deviation of cable forces from expected forces

3. Visual Feedback

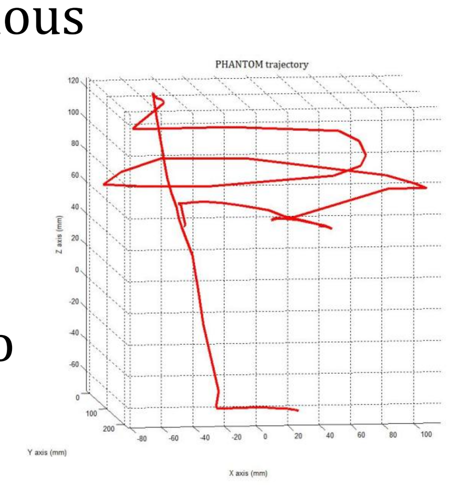
- Displays 3D position of tip

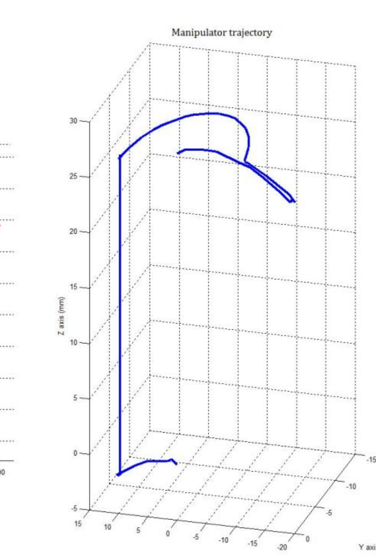
Results

- **Inexperienced user** trials (IRB-approved) to measure speed, learning curve inconclusive
- Using qualitative feedback, interfaces were updated:
  - Direct PHANTOM-manipulator mapping for point/click mode
  - Decoupled rotation and translation for continuous mode
- Subsequent preliminary trials using the updated system with **experienced users** showed point/click to be fastest, followed by continuous control



Above: Inexperienced user trial times





Left: PHANTOM trajectory
Right: Manipulator trajectory

What We Learned

- How to interface MATLAB and C++ via the MATLAB engine
- Simpler solutions may work effectively for given constraints
- Use stable system for subject trials

Future Work

- Further **inexperienced user** trials using updated system
- Obtain qualitative feedback from surgeon
- More sophisticated 3D visualization
- Continued integration of sensory information with interfaces

Acknowledgements: We would like to acknowledge Dr. Russell Taylor, Dr. Simon Mears, Blake Lucas, Haluk Tokgozoglu, and our test subjects for their generous assistance during the course of this project