Tool Gravity Compensation for Galen Microsurgical Robot

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Background

- The Galen is a general purpose, hand-over-hand, admittance control robot developed mainly for otolaryngology.
- Initial developed as a PhD project in the LCSR but is currently being commercialized by Galen Robotics Inc.
The Problem

● The weight of the tool is also read by the force sensor
● There is no way for the force sensor to distinguish between force from the tool and force from the surgeon
Objective

- Develop static model of tool gravity for multiple tools in various configurations
- Integrate tool gravity model into the control loop of the Galen robot
- If time permits, develop and integrate model of tool torques during dynamic motion
Technical Approach: Model

\[ L = KE - PE \]

\[ \frac{f_T}{\tau} = \frac{\partial}{\partial t} \left( \frac{\partial L}{\partial \dot{x}} \right) + \left( \frac{\partial L}{\partial x} \right) \]

\[ \frac{f_T}{\tau} = M(x) + C(x, \dot{x}) + G(x) \]

\[
\begin{bmatrix}
    f_s \\
    \tau_s
\end{bmatrix} = 
\begin{bmatrix}
    R_{ST} & 0 \\
    -R_{ST} \hat{p}_T & R_{ST}
\end{bmatrix}
\begin{bmatrix}
    f_T \\
    \tau_T
\end{bmatrix}
\]

\[
\begin{bmatrix}
    f_s \\
    \tau_s
\end{bmatrix} = A \vec{b}
\]
Technical Approach: Method

- Develop an analytical model of the tool in static/dynamic cases
- Move tool to different positions, velocities, and angular velocities
- Take measurements from force sensor
- Regress unknown parameters (such as tool offset and inertial components)
- Use model to predict force sensor readings based upon tool position, velocity, and angular velocity
- Subtract predicted sensor reading from actual sensor reading
Deliverables

● Minimum:
  ○ Report with data and analysis demonstrating a model capable of predicting 6 DoF forces and torque given a tool and tool holder pose due to gravity, along with code and documentation

● Expected:
  ○ Video and data demonstrating successful integration of gravity compensation into robot control software, along with code and documentation

● Maximum:
  ○ Report demonstrating a model capable of predicting 6 DoF forces and torque given a tool and tool holder pose due to dynamic motion, along with code and documentation
  ○ Video and data demonstrating successful integration of dynamic model compensation into robot control software, along with code and documentation
# Dependencies

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>Solution</th>
<th>Alternative</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access to MockOR</td>
<td>resolved</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Access to Galen Mark 2</td>
<td>Speak with Galen Commercial team about scheduling</td>
<td>Use Galen Mark 1.</td>
<td>2/14</td>
</tr>
<tr>
<td>Access to Galen Bitbucket Repository</td>
<td>Email Barry Voorhees</td>
<td>Speak to Galen Team/Dr. Taylor. Worst Case, use old LCSR repo and mark 1</td>
<td>2/14</td>
</tr>
<tr>
<td>Get access or knowledge about previously used data collection on the Galen</td>
<td>Email Paul Wilkening</td>
<td>Read through code and write our own script.</td>
<td>2/14</td>
</tr>
<tr>
<td>Discuss tool exchange</td>
<td>Speak with Dave Levi</td>
<td>Use Galen Mark 1</td>
<td>2/14</td>
</tr>
<tr>
<td>Login Access to Galen Computers</td>
<td>resolved</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Schedule

CIS2 Project

- Familiarize Ourselves with Existing Work
- Collect Data For Static Compensation
- Analyze Data For Static Compensation
- Integrate Static Compensation into Galen
- Collect Data For Non-static Compensation
- Analyze Data For Non-static Compensation
- Integrate Non-static Compensation into Galen
- Write Final Report/Presentation
### Milestones

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Data Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Proposal submitted</td>
<td>Feb 21st</td>
</tr>
<tr>
<td>Collect all data for static compensation</td>
<td>March 4th</td>
</tr>
<tr>
<td>Create working model for static compensation</td>
<td>March 11th</td>
</tr>
<tr>
<td>Integrate static compensation model into Galen</td>
<td>April 1st</td>
</tr>
<tr>
<td>Collect all data for non-static compensation</td>
<td>April 15th</td>
</tr>
<tr>
<td>Create working Model for non-static compensation</td>
<td>April 29th</td>
</tr>
<tr>
<td>Integrate non-static compensation model into Galen</td>
<td>May 13th</td>
</tr>
</tbody>
</table>
Management Plan

- Work Together: Tues/Thurs/Fri 8:45-11:45 am
- Mentor Meetings: Fri 10:00-10:30 am
- Code updates will be pushed a branch of the bitbucket repository
- Data and Reports will be stored in jhBox


Kim, Woo Young & Han, Sanghoon & Park, Sukho & Park, Jong-Oh & Ko, Seong Young. (2013). Tool Gravity Compensation for Maneuverability Enhancement of Interactive Robot Control for Bone Fracture Reduction System.
