IMPROVING THE TRANSPARENCY OF THE GALEN ROBOT

CIS-2 Plan Proposal by Vishnu Kolal

I. INTRODUCTION

The Galen Robot (Mk-2) is a prototype Stewart Platform based robotic manipulator intended for surgical use. It comes equipped with a 6-axis F/T sensor mounted between the robot and the end effector. The sensor provides vital information which is used to control the robot in a hand-over-hand control mode where a surgeon and the robot, both, hold the tool together. The surgeon controls the tool path directly while the robot provides a steady platform by eliminating hand tremors and enforcing hard or soft limits. The tool is typically a surgical drill intended for cutting bone. The robot has great potential to improve the safety and efficacy of certain surgical procedures including Laryngeal surgery, Stapes Surgery, Mastoidectomy, etc. However, the robot is a prototype and needs significant improvement before it is ready for use in an OR.

Figure 1: Galen Robot Mk2. Image curtesy www.galenrobotics.com

II. PROJECT GOALS

The goal of this project, as stated, is to improve the transparency of the Galen hand-over-hand surgical robot i.e. to make the tool feel ‘weightless’ in the hands of the operator. Currently, the feel of the tool while used in the hand-over-hand control mode is sub-par and sluggish. This project aims to improve this ‘feel’ and make the robot more responsive to operator force input.

III. PERSONNEL

Team Members: Vishnu Kolal
Mentors: Dr. Russell Taylor, Dr. Adnan Munawar

IV. POTENTIAL IMPACT

The Galen hand-over-hand surgical robot has potentially limitless applications such as eliminating hand tremors, imposing virtual fixtures that prevent the operator from damaging sensitive organs, drilling out of pockets in bone structures with near prefect precision, automated guided biopsies and maybe even fully automated surgery in the not-so-distant future.

There are also other ongoing projects in LCSR that aim to further develop the Galen robot such as the force sensing drill project, the force sensing forceps project, virtual reality guided skull base surgery, etc.

All of these potential applications and projects would benefit greatly from an improvement in the transparency of the robot control.

V. TECHNICAL APPROACH

This project is fairly open-ended in terms of the possible technical approaches and outcome. There are multiple approaches to improve the transparency of the robot. Some of the approaches could potentially be used in conjunction with each other to significantly improve the robot's performance, whereas other approaches may be detrimental to the performance.

Nevertheless, before any of these approaches can be attempted, an objective metric to determine improvement in the transparency must be established. The most straightforward way to accomplish this would be to measure the magnitude of the forces and torques on the wrist F/T sensor. A higher magnitude of forces would mean more sluggish/less transparent control of the robot and lower magnitude of force would result in more fluid control as the robot moves freely with the operator's control.

Another useful method to determine improvement in the transparency would be to design an experimental setup where and operator is required to trace a fixed path with the tool in 2D/3D space and measure the amount of time taken from start to finish. A shorter time would imply that the robot motion is more fluid and the tool is more 'weightless'.

Once a reliable metric for transparency is established, we can use some of the below outlined approaches to improve the robot's performance.

- Increasing admittance gain: The mid-level control loop of the Galen utilizes an admittance controller to supply motor torques to the low-level controller (Galil). The gain for this admittance controller has already been tuned to allow for safe operation. Increasing this gain will improve the responsiveness of the robot to force inputs but at the same time, may induce some instability that causes the controller to diverge or crash. This instability would have to be nullified using other means.

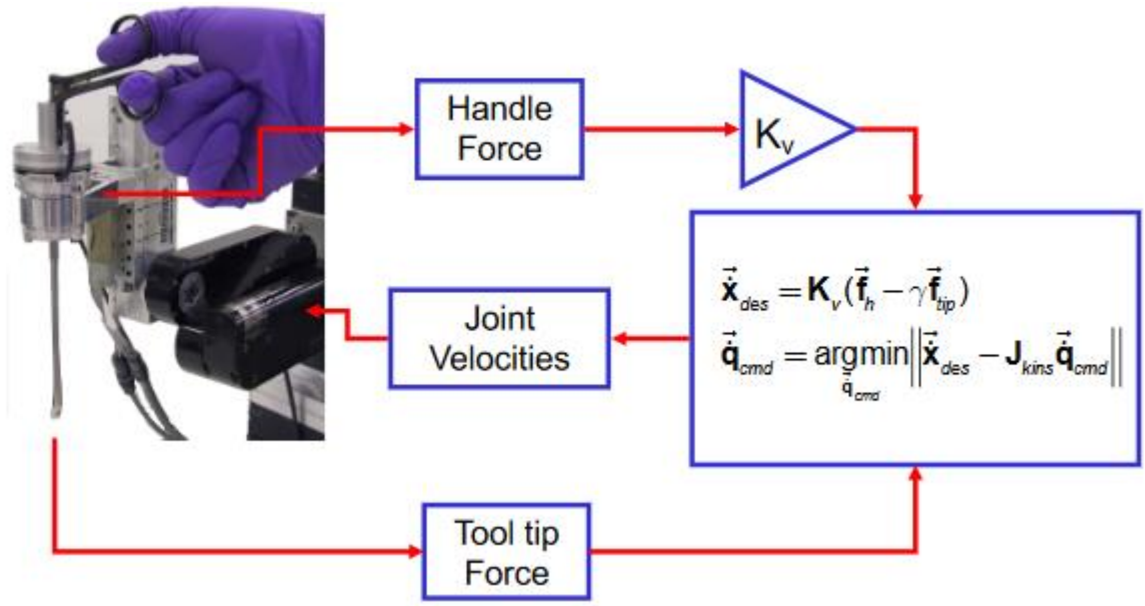

Figure 2: Admittance control block diagram. Source: CIS-1 lecture notes, R.H. Taylor

- Filtering sensor data: The Galen robot's hand-over-hand control loop relies on sensor input from the wrist F/T sensor. The data generated by the sensor directly influences the motion of the robot and any noise or inaccuracies in the data can affect the stability of the robot. Moreover, with higher admittance gain and greater acceleration and deceleration of the robot, the sensor is likely to pick up forces resulting from the inertia of the tool. This could result in further instability and undesirable oscillations. Therefore, the sensor data would need adequate filtering before is fed into the control loop. A filter for the sensor data has already been implemented, however there is scope for improvement and the filter parameters can be tweaked.
- Adaptive gains: Since the Galen surgical robot has a broad range of potential applications, a 'one size fits all' approach to setting the gains may not be the most feasible way improve performance. Higher gains may be better suited to applications such as drilling out large pockets or manipulating tissue with forceps whereas smaller gains may be much better suited to drilling intricate parts around sensitive tissue or steady hand holding. The ability to adjust the admittance gain automatically on the fly is highly desirable in a platform such as the Galen robot. In order to accomplish this, the surgical profile/task must first be sensed, its required gain must be determined and then the gain must be slowly transitioned without resulting in any instability, loss of control or undesired behavior
- Mid-level control loop timing and refresh rate: One hypothesis for why the hand-over-hand control of the robot is sluggish is the fact that the mid level controller may not be sending commands to the low-level controller at fixed intervals. This could result in a reduced responsiveness to inputs, especially at higher admittance gain. A good way to rectify this would be to send commands to the low-level controller at the start of every iteration and then perform computations for the next iteration. Increasing the rate at which these commands are sent would also help improve the responsiveness of the robot.
- Better dynamic model: The robot mid-level controller uses a mathematical model of the robot dynamics to compute the required motor torques. Implementing a more accurate/up-to-date dynamic model will inevitably improve the robot's performance.

❖ Tool tissue force compensation: During operation, the tool attached to the hand-over-had control robot is expected to experience some reaction force from the tissue being operated on. An ongoing project in LSCR titled 'Force Sensing Drill' aims to isolate and measure the amount of force between the tool and tissue. As these measurements become available to the robot, the logical next step is to account for the tool-tissue force in the control loop to further allow for control over the amount of force the robot exerts on bone and tissue. To accomplish this, the resultant force from both the sensors would have to be used in the numerical solver. Depending on the operation, a limit can be enforced on the tool-tissue force as well. This will ensure that a constant, uniform force is applied on the tissue and ensure that the force applied on the tissue does not exceed acceptable limits.

VI. DELIVERABLES:

- Minimum:
  1. Code cleanup & corrected control loop timing
  2. Tuned admittance gain at maximum stable limit
- Expected:
  1. Mean sensor forces reduced by 50%
  2. Experimental data and operator testing result analytics
- Maximum:
  1. Mean sensor forces reduced by 75%
  2. Implemented adaptive gains control loop
  3. Control loop with wrist force and tool-tissue force

VII. TIMELINE

Schedule:

Activity - Week	1-2	3-4	5	6	7	8	9	10	11	12	13	14	15	16+
Project definition & preparation														
Literature review, plan proposal, presentation														
Increasing & Tuning admittance gains + Testing														
Code cleanup & frequency increase														
Spring break														
Sensor Data Filtering														
Adaptive gains implementation														
Improved dynamic model														
Tool-tissue force inclusion														
Final posters & report														
Continued work, missed goals														

Milestones:

1. Mar 15th: Established transparency metrics
   Collected data to establish baseline
2. Mar 27th: Experiments show improved transparency by 20%
3. April 10th: Transparency improved 50%
4. April 26th: Transparency improved 75%
   Tool-tissue force compensation implemented

VIII. DEPENDENCIES

Dependency	Contact	Status	Plan of action	Expected date	Consequence if not fulfilled	Contingency
Functioning robot, PC	Dr. Taylor	Fulfilled	-	-	Project cannot continue	New project to fix robot/use Mk1
Access to Mock OR, code repos, documentation	Dr. Taylor, Florin	Partly fulfilled	Contacted Florin for code access	Mar 4th	Prevented from code access at home	Access code and documentation from Mock OR
Functioning tool for robot	Anna, Adnan	Fulfilled	-	-	None	Will use different tool
Availability of robot	Anna	Ongoing	Book time on robot in advance	-	Restricted to WFH, limited testing & feedback	Use sharepoint to schedule time
Availability of mentors and surgeons for testing	Dr. Galaiya, Adnan	Ongoing	Schedule time in advance	-	Unable to get constructive feedback	Test robot with mentors, peers

IX. MANAGEMENT PLAN

1. Weekly progress report meetings with Dr. Taylor on Wednesdays.
2. Short weekly meetings on Fridays with Adnan to discuss technical details and next steps.
3. All code managed in existing BitBucket Repo.
4. Documentation and presentations to be stored in JHU Galen OneDrive.
5. Communication with mentors and peers via slack.

X. READING LIST

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