600.446: **Advanced Computer Integrated Surgery**
Group 3, Final Report, Spring-2013

Interfacing APL Snake End Effector to LARS

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1. Abstract

This report describes our class project for Advanced CIS course during Spring 2013. The primary and static aim of this project is to integrate the JHU-APL Snake end effector to the LARS and achieve end point control. We have implemented controlled motion of the LARS to insert the end effector along an insertion axis. This report is *not* the final report of the project and we acknowledge a considerable amount of work is left to be done, the plan and course of action of which are explained later. A Constrained Optimization algorithm [1] is being used for the control of the LARS with vectorial entry method of the Galil controller being used for best results. The kinematics of the LARS were calculated and verified with the previous project reports. Remote Center of Motion mechanism was used for the calculations. [2]

2. Significance and Motivation

The JHU/APL Snake is a surgical manipulator intended to be used in hip osteolysis removal surgery. However, since development its potential has been realized and it is being constantly upgraded to be a self sustained surgical tool. Initially, it was controlled through mouse and keyboard only. Intuitive control interface for the manipulator, has since, been designed and integrated with the snake using PHANTOM® Premium haptic controller. The desire to further reduce human intervention for its operation and make the setup fully automated still remains. The Laparoscopic - Assisted Robot System (LARS) is an ideal platform for achieving the same due to its mobility, dexterity, and versatility of use with various end-effectors. End point control of the snake is to be achieved following the inverse kinematics of LARS with the manipulator. The demonstration of the level of achievement of the same is planned to be shown on cardboard, solid model(s) after registration and finally on cadavers; chronologically.

3. Project Management

3.1. Project Accomplishments and Division of Effort

We believe to have achieved our minimum and partially succeeded in achieving out expected deliverables. One of our minimum deliverables was fixing a LARS which we were given initially. At the condition it was handed over to us, two of its seven motors were working as expected. We managed to fix the working of four other motors. Not considering the problem of worn out gear and a broken encoder pin, we can claim that presently five of the seven motors were working as they were intended to do. Another of our minimum deliverables was to achieve end point control. The code for the same has been written and verified from previously projects dealing with the LARS. [3][4] The code for the Registration before start of operation has been written. *We are currently discussing the codes with our mentors and upon testing; they shall be added BIGSS Laboratory folder of CISST library.*

Concerning the division of our effort for the project, we worked together during initial stage of the project. Basic understanding of the Galil suite and literature review for the project was done by both of us. Both of us put efforts in repairing the faulty LARS. Piyush led the work as he was primarily responsible for the same. Ashish dedicated time for understanding the CISST libraries and using it. The kinematics and Jacobian were required for LARS motion control as well as preparing for integration of the optimization algorithm were done by Piyush. Ashish wrote the MATLAB code for registration algorithm.

The timeline of the project is shown below:

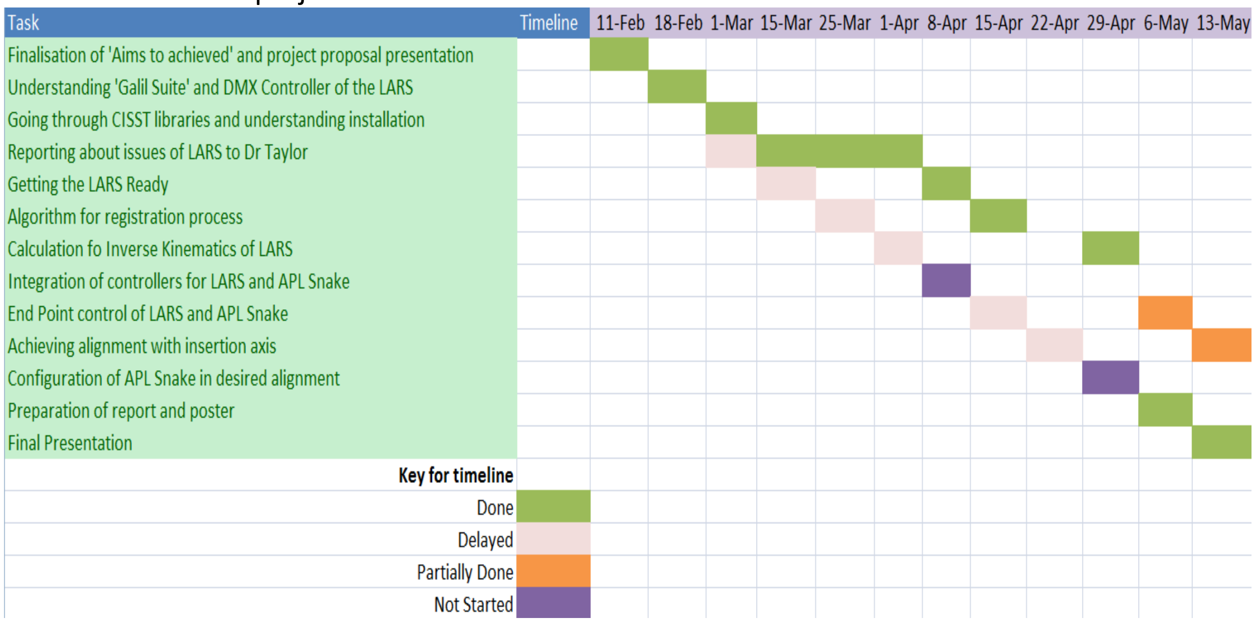


Figure 1a. Timeline of the project work

3.2. Future Work

A considerable amount of work in the project undertaken by us remains to be done. We hope to accomplish the same by end of **July 2013.** It has been discussed with our mentors and Piyush has proposed them with the expected timeline to be followed.

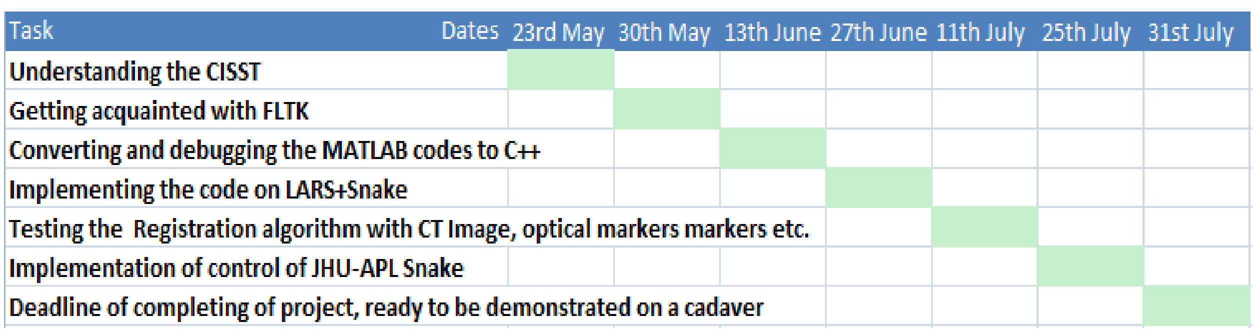
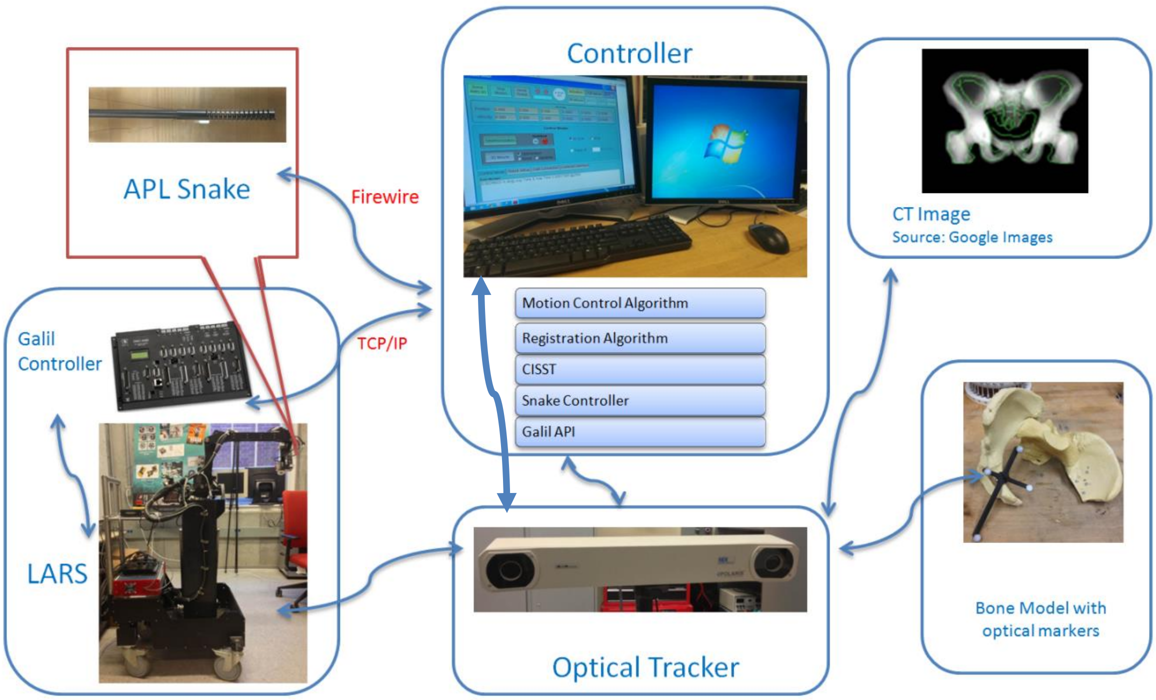


Figure 1b. Timeline for work during summer

After achieving the above mentioned checkpoints, Piyush plans to update a final report which shall be updated in the project wiki and shall be available for future reference. Also, paper(s) might be published regarding the same.

4. Process Overview

The overall process of the project can be summarized as the following in figure 2.



Process Block Diagram

Figure 2. Overall Process Block Diagram of the project

The overall process can be thought of as three modules.
Module1 – The LARS with APL Snake attached to its end effector.
Module2 – Controller
Module3 – Optical tracking module.

Module1 - The LARS with APL Snake attached to its end effector.

The LARS is 7degree-of-freedom (DOF) robot having 3 translation axes at the base and three rotational plus one translational axes at the tip. Since a position in 3D space is defined by 6 DOF, having 9 DOF (7 for LARS + 2 for JHU/APL Snake) makes the LARS + JHU/APL Snake system spatially redundant. The motion control algorithm running in the LARS Application is designed to handle this redundancy. Communication between the LARS Application and Galil controller occurs via the TCP/IP reliable connection protocol. TCP/IP is also used for communication between the LARS Application and Master Controller. At present, the robot can be controlled using a Phantom Omni haptic device that provides position-based control, or a 3D Mouse that provides rate based control.

The JHU-APL Snake Robot is a 2 DOF dexterous manipulator with an open lumen. It is cable driven and controlled by stepper motors. [5] The manipulator is constructed from two nested super-elastic nitinol tubes enabling lengthwise channels for drive cables. Notches in the nested assembly provide reliable bending under applied cable tension producing kinematics that can be effectively modeled as a series of rigid vertebrae connected using pin joints.

Module2 – Controller

The controller is presently two different operating system based system. Both the LARS and Snake codes are to be integrated to be run on Linux RTAI environment. Due to delay in our original plan of course of action this could not be achieved. The controller shall act as interface between the optical tracking system and the robotic systems of our project. The controller is expected to sense the *Action Point coordinates* (the point which through which APL snake is expected to enter the body) using the optical tracker from the CT scan and perform registration to calculate actual body coordinates of the patient. Then it should control LARS to insert the APL Snake at the action point and after insertion, should control the movement of Snake.

Module3 – Optical tracking module

The optical tracking module consists of optical tracker and optical markers placed at various points on operation table as well as base of the LARS to perform Registration. The Registration Algorithm has been discussed separately.

5. Components of Project

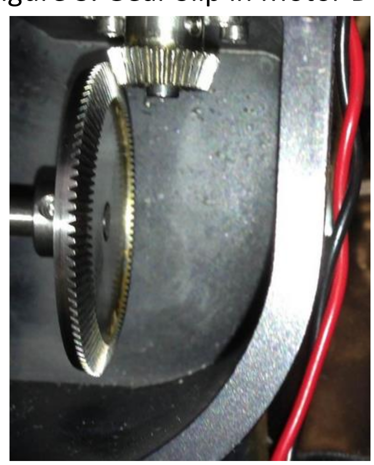
5.1. Repairing the LARS

The initial LARS given to us had considerable amount of mechanical and electrical problems to render it unusable. Baring the two base motors, none could be run as they should be, using the Galil Suite software on Microsoft Windows system. Piyush had to take care of loose wirings and wrong connections to get some response from the motors. The encoder output pins were connected in reverse order due to which they did not give proper reading. The present connection for all wirings is uniform and as follows:

Pin1 – Gnd
Pin2 - +5V
Pin3 – MA+
Pin4 – MB+
Pin14 – Lower Limit
Pin15 – Upper Limit

The above pins are input to control box of the LARS from Galil 4080 controller which is being used.

Figure 3. Gear Slip in Motor D



The encoder wires are as per the datasheet. [6]

The encoder pin for motor C is broken and new encoders have been received. The gear box of motor D and motor E produced unusual sound. Following some amount of testing it was noted that Gears of motor D have slipped out of synch and hence do not work properly. The adjoining figure shows the same. This causes the encoder reading to overshoot and hence doesn't stop the motor. The Motor E also has similar problem, but the gears haven't slipped yet.

Presently five motors are working. Two motors are not working as intended. Hence we requested Prof. Taylor to get us another LARS which was in his lab. We received the same on 10th April 2013.
The minor wiring discontinuities in this LARS were corrected and it is presently the system on which we are working upon. The other LARS shall be repaired by Piyush in summer if time permits.

5.2. Kinematics

Forward Kinematics
Even though forward Kinematics of the LARS had been calculated previously and program were written for it, *error was noted in the final report of previous project*. [3].Although it looked more as a **typographical error**, after discussion with our mentor, it was decided that we should calculate and verify the calculation with previously written codes. The forward kinematics of the LARS and APL Snake had to be combined.

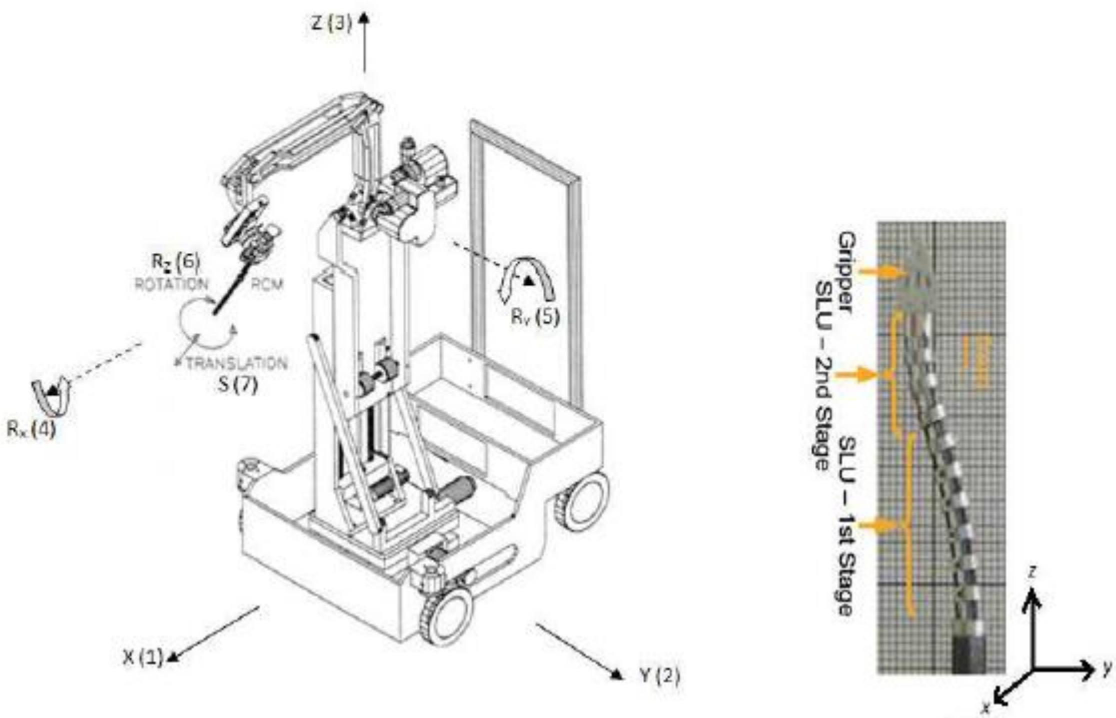


Figure 4. Axis of movements of LARS and Snake. [4]
The X and Y axes of both LARS given to us were opposite.
The Snake has to be inserted at S(7), thus it's Z and Y axis are opposite to that of the LARS.
Taking LARS's axes as basis of all calculations, the forwarded Kinematics can be calculated as follows:

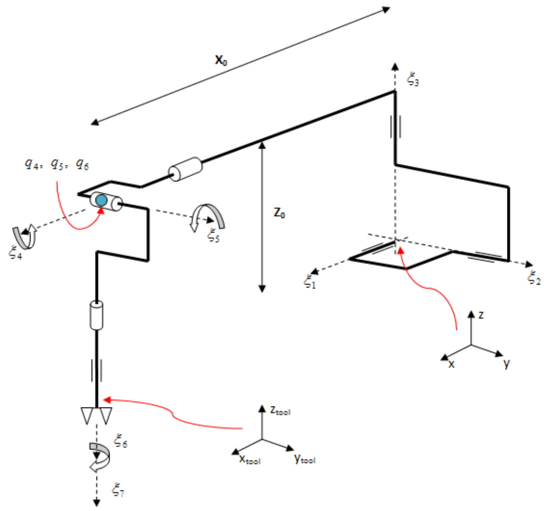


Fig 5. Twists assigned to the robot joints.[3]

$$\xi_1 = [1\ 0\ 0\ 0\ 0\ 0]^T \tag{1}$$

$$\xi_2 = [0\ 1\ 0\ 0\ 0\ 0]^T \tag{2}$$

$$\xi_3 = [0\ 0\ 1\ 0\ 0\ 0]^T \tag{3}$$

$$\xi_4 = [0\ Z_0\ 0\ 1\ 0\ 0]^T \tag{4}$$

$$\xi_5 = [-Z_0\ 0\ X_0\ 0\ 1\ 0]^T \tag{5}$$

$$\xi_6 = [0\ X_0\ 0\ 0\ 0\ -1]^T \tag{6}$$

For the above twists, for any value of theta we can calculate forward kinematics transformation of the LARS as (7)

$$g_{st} = e^{\xi 1\ \theta 1} e^{\xi 2\ \theta 2} e^{\xi 3\ \theta 3} e^{\xi 4\ \theta 4} e^{\xi 5\ \theta 5} e^{\xi 6\ \theta 6} g_0 \tag{7}$$

The net forward kinematics of the tip of the APL Snake shall be given by: $f_{tip} = f_{LARS}*f_{snake}$
Since the Jacobian of the system was already calculated previously we wish not to discuss the same in our project. [4] may be checked for better understanding.

RCM Mechanism

Remote Centre of Motion mechanism was used assuming the base of the LARS to be fixed. We plan to set a 'home configuration' of the LARS and check at the beginning of operation that LARS is at that position. Depending on the height of the patient table and its placement the surgeon shall be given an option to recalibrate the home position of the base motors. After that procedure, the base motors shall be considered fixed. And then, forward kinematics is calculated as

$$g_{st}^{RCM} = e^{\xi 4\ \theta 4} e^{\xi 5\ \theta 5} e^{\xi 6\ \theta 6} g_0 \tag{8}$$

It can be noted that the LARS reduces to a 4-DOF manipulator. Considering the 2 DOF of APL Snake, we have a 6 DOF system.

5.3. Registration Algorithm

In real life scenarios, we will know the entry point of the patient in the CT image co-ordinates. We will need to express this point in the co-ordinate frame of the LARS so that we can move the tip of the LARS to the desired point.

So we need to do a registration first between the CT image and the actual bone of the patient and then between the patient and LARS i.e. we need to find first the transformation between the CT image and the actual patient bone then the transformation between the patient bone and the LARS.

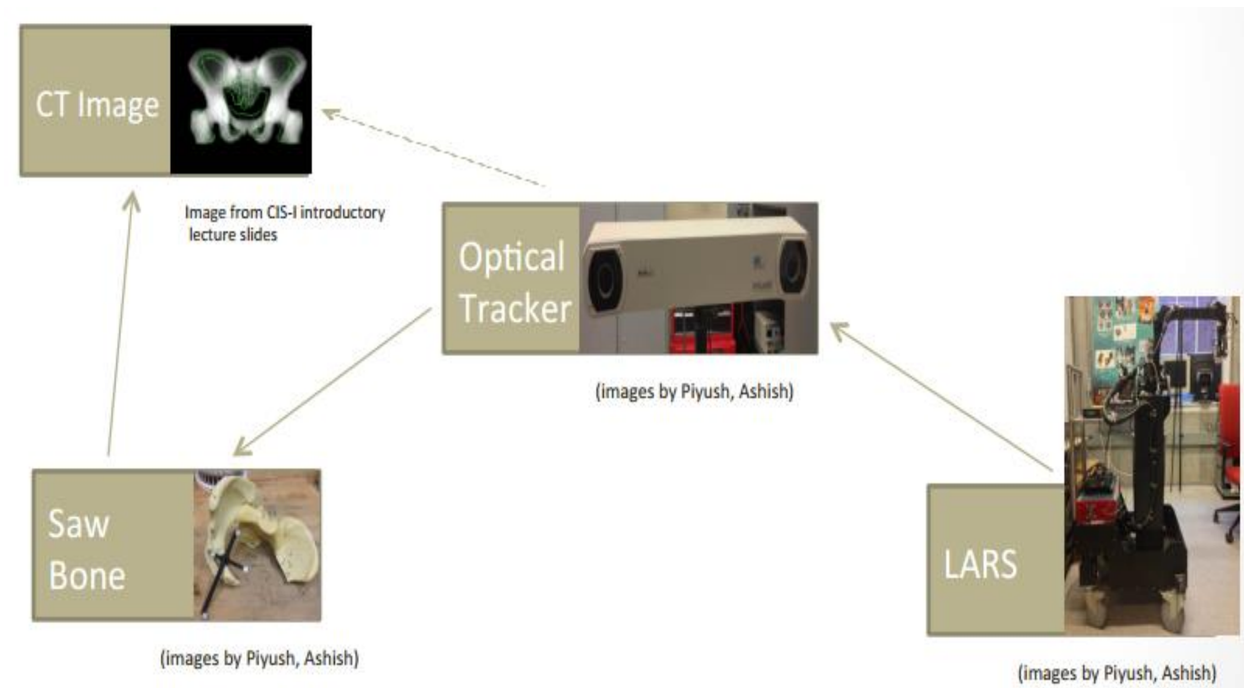


Figure 6: Block Diagram of Registration Process

This is done as explained below:

We select a few points in the CT image co-ordinate system. Then we attach a reference marker to the bone. Using anatomical landmarks, the baseline registration is obtained. Using ICP Registration the guess is refined. Markers are attaché to the base of the LARS as well as the translational part of the end effector.

These markers will help calibrate the the LARS as well as JHU/APL Snake ie we can determine the position of the same w.r.t these markers. Once we have calibrated the LARS and JHU/APL Snake we carry out registration between the LARS and patient.

This done by attaching certain optical markers to the bone as well. As already mentioned above optical markers are already attached to LARS. By tracking these two sets of optical markers through the optical tracker we can find the transformation between the LARS and the Optical Tracker and Patient and the Optical Tracker. Then combing the two transformations ie the transformation from the LARS to the Optical Tracker and from the Optical Tracker to the patient we can find the complete transformation between the LARS and the patient.

5.4. GUI for the project

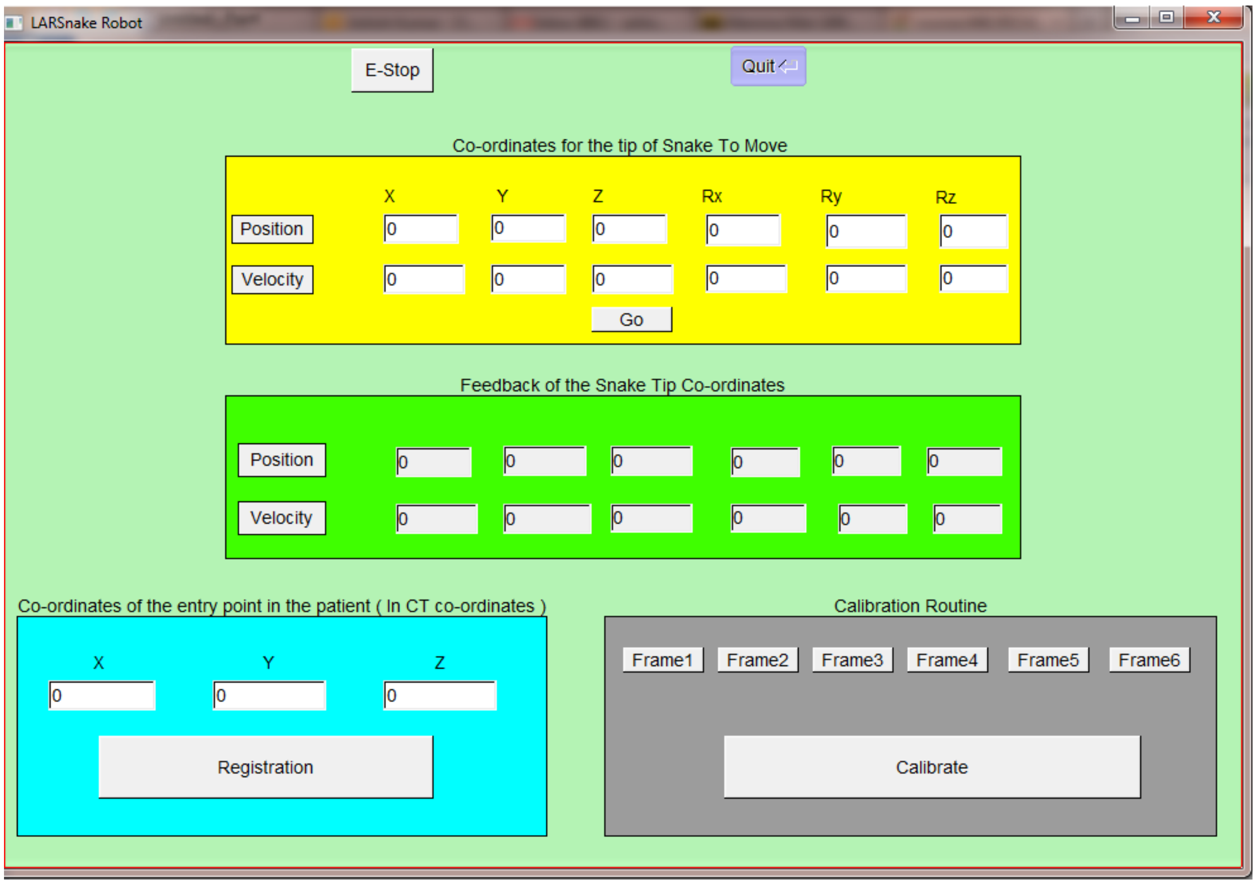


Figure 7. GUI Interface of our project

The above is the GUI (Graphical User Interface) that we have designed to tele-operate the LARS.

The different components of this GUI are explained in detail below:

1. E-Stop Button : As the name suggests, this is an emergency stop button which will shut all the motors of the LARS down in case the robot is not behaving the way it is supposed to be.

2. Quit Button: This is used to quit the entire GUI.

3. From the first box labeled 'Co-ordinates for the tip of the Snake to Move', we specify the Position (both Rotational and Translational) where the tip of the Snake is supposed to move. We also provide the velocity (again both Rotational and Translational) with which the tip of the snake is supposed to move.
The position of where the tip of the snake is supposed to move which is provided here is in the LARS Robot Co-ordinate Frame.
In real life scenarios, we will not populate the position where the tip of the snake is supposed to move manually. We will have the point of entry in the patient in the CT co-ordinates and then a registration will be done between the CT and patient and then the patient and the LARS and the position vector will be auto populated with the calculated value.
Once we have both the position and velocity vector, we press the GO button and that should take the tip of the snake to the desired position.

4. The second box labeled 'Feedback of the Snake Tip Co-ordinates', gets us the position and velocity of the tip of the snake when it is moving from its initial position to the desired position. This is done primarily for to keep track if the system is behaving as it is expected to.

5. The third box labeled 'Co-ordinates of the entry point in patient (in CT co-ordinates)' is the place where we enter the X, Y and Z of the desired point of entry in the patient. However, this point is in the CT co-ordinates i.e. the co-ordinate system of the CT image of the bone. So we need to do registration between the CT Image, the patient and the LARS so that this point can be expressed in terms of the LARS co-ordinate system. This registration algorithm is triggered when we press the Registration Button.

6. The fourth box labeled 'Calibration Routine' is used to do a pivot calibration. By pressing the different buttons from 'Frame1'... 'Frame6', the program will calculate the transformation between the optical tracker and the various different frames (from frame1 to frame 6 respectively). Once we have all the data, by pressing the 'Calibrate' button, the code will carry out the Pivot Calibration and thus calculate and store the value of the length vector the probe, which will later be used to mark points on the bone of the patient.

6. Conclusion

The project successfully meets minimum deliverables. Kinematics equations of the combined system were derived for the LARS-APL Snake combination. The inverse kinematics need to be tested. The RCM mode was understood better after going through patent application by Dr. Taylor et all [7].

This project provided a valuable learning experience concerning implementation of robot systems. The repairing of LARS clarified our fundamentals regarding functioning of motors and various intricacies like calculation of KI, KP and KD values of the system. With the help of this project we are familiarized with JHU's software support for robotic applications, including familiarity with the CISST development framework and the constrained motion control algorithm. We look forward to continuing work on this project to further enhance the robot's capabilities and increase its potential for clinical research.

7. Acknowledgement

We thank our mentors Dr. Mehran Armand, Ryan Murphy and Michael Kutzer for their guidance. Special thanks to Dr. Russel Taylor, Marissa K Tucker, Tutkun Sen, Paul Thienphrapa, Berk Gonec and Nishikant Deshmukh for their willingness to help and advice.

8. References

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