Precise Automated Kinematic Calibration of RCM Robots

Topic and Goal

The Revolving Needle Driver (RND) is a needle driver which can be attached to the end of an AcuBot, a remote center of motion (RCM) module with five stages: Bridge-mount > Linear pre-positioning stage (XYZ) > Support Arm > RCM > RND. The RND excels at orienting, inserting and spinning a needle; it is also capable of measuring force.

As it currently stands, there is a small but noticeable error in the location of the RCM. The RCM's two axes of rotation are neither perpendicular nor intersecting, which causes it to move upon revolving either axis. This completely defeats the purpose of having an RCM, which offers the benefit of having a stationary pivot point around which it is possible to work. Since any error in the location of the RCM will cause even more errors to propagate along the linkage of the robot, a small displacement in the location of the RCM could lead to a very large displacement in the tip of the surgical device attached.

The goal for this project is to quantify and correct the RCM of the RND robot. We hope that by being able to track the tool tip very accurately with an optical tracker, we will be able to determine how precise a surgery may be performed using an RCM module, and also learn how to build more precise and accurate RCM's in the future.

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Mentors: Dr. Stoianovici,

Relevance and Importance

Many surgical robots today, such as the well-known da Vinci, have either mechanical or virtual RCM's which allow them to operate in small spaces. By placing the RCM at the entry point in the patient, surgeons are able to obtain a very wide range of motion from a very small incision, which minimizes collateral tissue damage, blood loss, recovery time, scarring and infection.

How much error is acceptable in the RCM is very much dependent upon the type of surgery being performed. For example, a 1mm difference in some sort of belly surgery is likely to be much less disastrous than a 1mm difference in ocular surgery. If RCM's can be consistently and accurately maintained, surgeries requiring high precision will become much safer and easier to perform.

Technical Approach

1. *Polaris Tracker Accuracy Quantification*

   The manufacturer of the Polaris tracker states that the device has an error of 0.3mm, but they do not specify to what this 0.3mm refers to (overall displacement? Displacement in each cardinal direction?) Furthermore, they state nothing about the orientation of the markers.

   In order to determine a more accurate understanding of the capabilities of the tracker, we will use a highly accurate CNC machine to move the markers and give us a reference point. By placing static markers within the CNC workspace as well as markers

on the “tool”, we can measure the relative motion and compare the results of the optical tracker to the CNC’s readings. By using the CNC’s readings as the “expected” values (as the CNC has an accuracy on the order of a micron), we can better quantify the accuracy of the optical tracker. Furthermore, we will attach active markers in order to better understand the orientational accuracy of the device.

At each location within the CNC, numerous readings (a number which has still yet to be determined) with the tracker will be recorded. By doing so, the values can be denoisified and averaged to give a more accurate result that is unaffected by mechanical vibrations in the room. Furthermore, we hope to quantify the effects of taking readings at the trackers “sweet spot” and compare them to readings taken from other locations.

An extensive analysis on precision and accuracy, as well as repeatability of these tests will be performed. We also hope to test different types of trackers using our CNC method and compare the results.

2. *RCM Error Quantification*

Using the Polaris tracker, the RCM of the module will be observed in order to quantify the errors generated in the current state of construction. Markers will be placed at the tool tip, as well as a base reference, in order to more easily see the motion of the robot and its RCM. With the markers attached, the robot will be moved to several poses and orientations, taking measurements in a method similar to those of the CNC-comparison procedure.

After performing these readings, we will have to two RCM axis locations relative to the tool tip in tracker space. We then want to compare these axis locations with the axis locations in our original CAD model.

3. *Mechanical Dissection of the AcuBot*

The RCM of the RND robot will be partially disassembled and analyzed in order to study which factors contribute to the RCM error. The components of the robot, its link parameters, and axes of motion, will be compared with the ideal counterparts of the CAD model and corrected as much as possible, given the current design of the robot.

4. *Kinematic Parameter Identification Based on Polaris Measurements*

New link parameters will be identified based upon the Polaris measurements, and a new kinematic model will be developed using a simplified version of Denavit-Hartenberg. By rotating the axes of the robot around the RCM, we can look at tool tip location based upon Polaris readings and compare it to the expected location based upon encoder readings, joint angles and needle depth. By observing the errors, we can determine if the robot has a high precision and a low accuracy, which can likely be fixed by a calibration of some parameters (link length, joint angles, etc), or if it has low precision and high accuracy, in which case the kinematic model will need to be rewritten. This step will need to be repeated several times in order to achieve a high accuracy.

Deliverables

- *Minimum*
  - Write a technical report on the accuracy and precision of the Polaris tracker
- *Expected*
  - Include in the technical report a comparison of multiple types of optical trackers.
  - Quantify the RCM error of the RND robot
  - Mechanical dissection and analysis
- *Maximum*
  - RCM fixed based upon mechanical construction corrections
  - Develop a new, more accurate kinematic model for the robot
  - Simplified systems identification (one or two parameters)

Key Dates

Task	*Start*	*Finish*
Project plan presentation	14-Feb	14-Feb
Optical tracker accuracy quantification	21-Feb	10-Mar
Paper seminar	6-Mar	
Quantify the RND's RCM error	11-Mar	18-Mar
Mechanical dissection and analysis of the RND	26-Mar	1-Apr
RND modification and reassembly and RCM reanalysis	2-Apr	15-Apr
Project checkpoint	5-Apr	
Full kinematic model of the RND developed	10-Apr	25-Apr
RCM precision and accuracy testing	26-Apr	5-May
Poster presentation	10-May	
Final Report	10-May	

	Task	Assigned To	Start	End	Dur	%	2012 Feb	Mar	Apr	May
	Project		2/14/12	5/10/12	62	9				
1	Project Presentation	ALL	2/14/12	2/14/12	1	100				
2	Optical Tracker Accuracy Quantification	Changhan ,Ryan	2/21/12	3/10/12	14	30				
3	Paper Seminar	ALL	3/6/12	3/6/12	1					
4	Quantify the RND's RCM Error	Alex, Ryan	3/11/12	3/18/12	5					
5	Mechanical Dissection and Analysis of the RND	Changhan ,Ryan	3/26/12	4/1/12	5					
6	RND Modification and Reassembly and RCM Reanalysis	Alex,Changhan	4/2/12	4/15/12	10					
7	Project Checkpoint	ALL	4/5/12	4/5/12	1					
8	Full Kinematics Model of the RND developed	Changhan, Alex	4/10/12	4/25/12	12					
9	RCM Precision and Accuracy Testing	Alex, Ryan	4/26/12	5/5/12	7					
10	Poster Presentation	ALL	5/10/12	5/10/12	1					
11	Final Report	ALL	5/10/12	5/10/12	1					

Assigned Responsibilities

- Alex
    - RCM error analysis
    - RND robot dissection, analysis, correction and reconstruction
- Changhan
    - CNC control and programming
    - Kinematic modeling of the RND robot
- Ryan
    - Optical tracker error analysis
    - Serial port communications for optical tracker and CNC

Dependencies

- Time in URobotics Laboratory.
    - Effect if not resolved: All equipment and software needed for this project is located in the laboratory. We cannot do significant work without access.
    - Plan for resolution: We have key access to the lab.
- CNC Machine Time - Needed to quantify the tracker accuracy.
    - Effect if not resolved: Our entire project will be pushed back if we do not have time on the CNC machine, as the tracker is needed to quantify the RCM error.
    - Plan for resolution: We have talked to Doru Petrisor and scheduled CNC time for the week of February 20th. We will acquire the data needed for the optical tracker paper during this time.
- Time with Revolving Needle Driver - Needed to analyze, dissect, and fix RND.
    - Effect if not resolved: All milestones and steps dealing with RND will be pushed back while we do not have access to the robot. Other items, such as correcting unknown error in the Revolving Needle Driver robot, will be unaffected.
    - Plan for resolution: We have talked to Dr. Stoianovici and secured time with RND throughout the semester.

Member Dependencies

- GCode for Marker Tracking: Changhan must write the GCode for each marker tracking test using the CNC machine. Needed to run the CNC optical tracker tests.
- Serial Communication - Ryan must develop a program to allow the CNC machine and the optical tracker to communicate. Needed to run the CNC optical tracker tests.
- RCM error analysis – The optical tracker error analysis needs to be done before the RCM error analysis can be performed.

Management Plan

- Team meetings Tuesdays and Thursdays 9am – 12:45pm
- Team meetings Saturdays 12pm-3pm
- Changhan and Ryan meet Mondays and Fridays 1pm-5pm, Alex by email
- Mentor meetings Tuesdays 10am – 11am

- Individual work 6 hours/week at own discretion

Reading List

- Evaluating Remote Center of Motion for Minimally Invasive Surgical Robots by Computer Vision ,IEEE/ASME 2010
- Classification and type synthesis of 1-DOF remote center of motion mechanisms, G.Zong2007
- Comparing Accuracies of a RFID_based and an Optical Tracking System for Medical Navigation Purposes, M. Broll 2011
- Virtual Remote Center of Motion control for needle-placement robots, M. Boctor 2004
- Rohling R - Accuracy assessment and interpretation for optical tracking systems, D Wiles 2004
- Rasool Khadem - Comparative tracking error analysis of five different optical tracking systems, 2000
- AcuBot: A Robot for Radiological Interventions, D. Stoianovici IEEE 2003
- A Modular Surgical Robotics System for Image Guided Percutaneous Procedures, MICCAI, 2003
- Andrew D. Wiles - Accuracy assessment and interpretation for optical tracking Systems, Medical Imaging 2004
- Haggard P – Assessing and reporting accuracy of position measurements made with optical tracking systems