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RadVision integration with TRUS robot for Brachytherapy

600.446 Computer Integrated Surgery II

Final Report

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Abstract

The main goal of this project is to integrate the RadVision treatment planning software with the (Trans-Rectal Ultrasound) or TRUS robot. The TRUS robot is used in place of a physical template for placing the radioactive seeds in prostate brachytherapy, a treatment for prostate cancer. This integration should allow the surgeon to position the needle of the robot more accurately with the new system.

In addition to the integration with RadVision, I conducted a study in which the accuracy of the TRUS robot in needle placement will be assessed. The protocol for this accuracy study will be used to evaluate other prostate brachytherapy robotic systems. The first part of the accuracy study involved testing the 2-dimensional accuracy of the robot's needle placement with graph paper. The second part of the accuracy study was designed to study the 3D accuracy of the robot's needle placement and it involved inserting fake radioactive seeds into a phantom gel. Once all of the fake seeds were inserted the phantom gel was scanned using a CT scanner, and the accuracy of the needle placement was determined from these scans.

The Problem

The American Cancer Society reports that 240,890 cases of prostate cancer are diagnosed and about 33,720 men die from it annually [1]. Prostate Brachytherapy is a minimally invasive radiation therapy used to treat prostate cancer. The therapy involves the injection of radioactive seeds directly into the prostate near the tumor using fine needles. Unfortunately, attaining the level of accuracy required to achieve optimal positioning often takes the surgeon more than one

attempt at inserting the needle. Increasing the accuracy of the needle insertion with a robotic system would allow faster surgeries with better results.

The conventional approach uses a grid of holes (template) located over the prostate to position and guide the needle for insertion. The needle itself is monitored in real-time by an ultrasound probe positioned below the prostate. Since the seed insertion must be very accurate and the final location of the end of the needle cannot be predicted, the surgeon often must insert the needle multiple times using multiple holes in the grid. The TRUS robot replaces the function of the template by using two 2-dimensional servo mechanisms to position and guide the needle. The two dimensional grid allows the user to control both the 2 dimensional insertion location as well as the angle of the needle.

While there have been a few robots that have been designed for prostate brachytherapy practically all of them simply have the surgeon specify the location to put the needle. At the same time there exists planning and simulation software for prostate brachytherapy that surgeons are able use such as RadVision. Integrating the planning and simulation software with the robotic system will allow the surgeon to specify the location where the needle should be placed and then the robot will place the needle guide in the correct position.


RadVision screen 1

While robotic, branchytherapy systems have proven to be quite accurate in the tests developed by their developers. There is no standardized testing protocol that has been developed

for testing the various systems, so that they may be directly compared to each other. Danny Song has developed a protocol that he believes will fulfill this need. The second part of this project is to test the TRUS robotic system with the protocol.

Technical Approach

The TRUS robot is a semi-autonomous 4 degree of freedom robot. Two degrees of freedom come from each of the two 2-axis Galil servo mechanisms. The two servo mechanisms are connected to each other and each holds one end of a aluminum tube that holds the needle. This setup allows for both 2D needle positioning as well as orientation. While the robot holds and guides the needle it is semi-autonomous, but it does not insert the needle or the radioactive seeds. The base of the robotic system consists of a pivot that allows the whole system to be manually pivoted. On top of the pivot mechanism lies the ultrasound probe. Since the ultrasound probe is being held at a fixed distance from the servo mechanism, the mechanism can be registered to the robot.
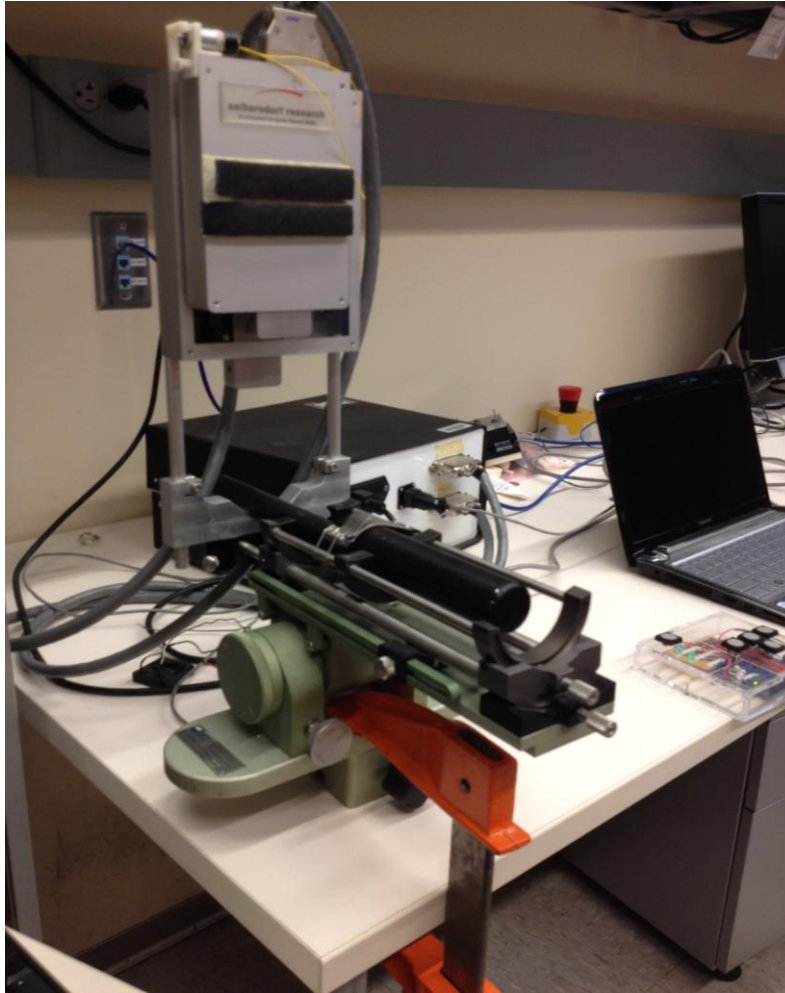
TRUS robot 1

The first step in the project was to rebuild the setup for the TRUS robot currently in the robotorium. Since I chose to use my laptop as the computer to complete this step, I had to install all of the necessary drivers and resolve any compatibility issues between my laptop and the TRUS robot. Since my laptop runs Windows 7, and the old Galil drivers were not compatible with Windows 7, I was forced to rewrite the CISST wrapper for the new Galil drivers. In general, I simply modified the code that interfaced with the old drivers in order to make the software compatible with the new drivers. While most of the functions and data formats remained the same because the hardware was the same, there were a few major changes between the new drivers and the old drivers. Perhaps the biggest change was the coding paradigm. The old drivers used a procedural approach while the new drivers used an object-oriented approach. While modifying the code did take a little bit of trial and error, it was completed fairly quickly.

The second step in this project was to integrate the software that currently controlled the TRUS robot with the RadVision software. The RadVision software provides the target positions for the robot. It was our original intention to interface the button controller with RadVision, so

that the surgeon could give commands to RadVision using the button controller rather than having to do so at a computer console. Unfortunately, we were not able to implement this feature because it would require modifications to RadVision, which only the company could do since it did not provide us with the source code. The button controller will still interface with the robot control software, thus allowing the button controller to interface with the robot directly.

Communication between the robot control software and Radvision will be handled by the OpenIGTLink version 2 protocol.   The protocol did not have all of the commands needed in our project, but the protocol allows for additional commands to be added. In order to use the protocol for our application we added the MOVE_TO, the GET_STATUS, and the GET_COORDINATE commands. The MOVE_TO command has a 28 byte body that consists of three 32-bit floats that specify a position, and four 32-bit floats that specify an orientation quaternion. The MOVE_TO command is sent by the RadVision software to the program that controls the robot to specify the position and orientation to which the robot needs to move the needle guide. Communication between the computer and the robot is handed by an Ethernet link.
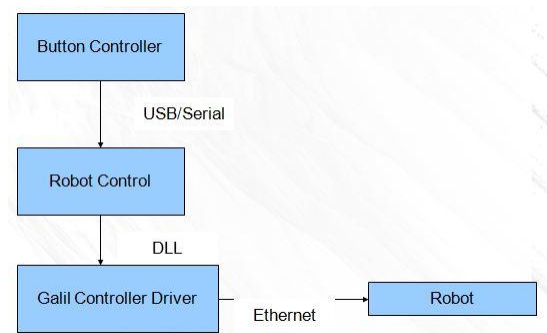
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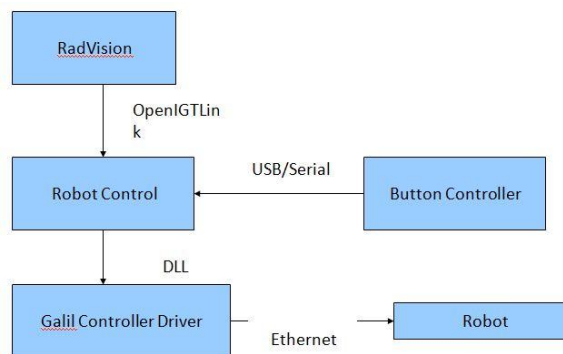
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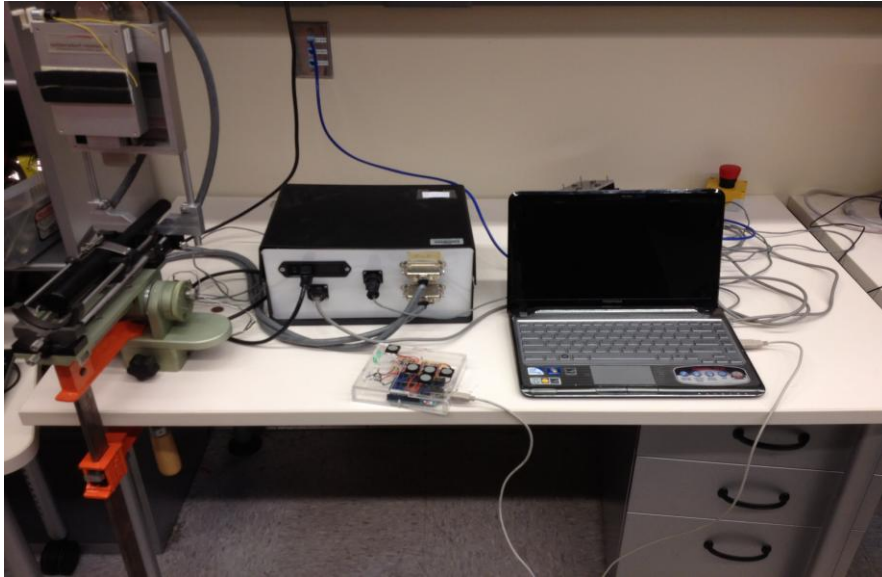
Entire system 1

The accuracy study we decided to engage in had us test the robot according to a protocol developed by Danny Song. The protocol could be divided into two separate experiments. The first experiment was designed to test the two dimensional accuracy of the needle placement of the system.

In the first experiment, graph paper was taped onto a board of styrofoam, which itself was taped to a box. The function of the styrofoam was to reinforce the graph paper and hold it in place. The styrofoam was tapped to a box, so that it along with the graph paper was held vertically in place. The whole apparatus was placed so that the graph paper was parallel to the actuators of the robotic system, but perpendicular to the needle guide. The protocol called for a distance of 3 cm between the needle holder and the graph paper. In order to maintain the 3 cm standoff distance, other pieces of styrofoam were placed in between the robot and the graph paper. The protocol called for the needle guide to execute a zig-zag pattern in a 4x4 grid. The grid was to be 2 cm in length and width. The robot was to have the needle's end touch each position in the grid for a total of 16 different positions. The needle was be inserted so far as to touch the graph paper, but not so far as to deform or puncture the graph paper. Since the robot did not have an actuator for inserting the needle, the needle insertions needed to be done manually. In order to determine the positioning accuracy, a HD camera system was used to photograph the needle while it was touching the paper in the correct position. Using the lines in the graph paper as a reference point, the location of the needle tip on the two dimensional surface of the graph paper could be determined with high accuracy after the experiment. The protocol called for this zig-zag pattern to be repeated 100 times in order to test the reliability of the system

as well as the accuracy. Unfortunately, in the time I had to do this part of the project I was only able to do 20 such iterations of the zig-zag pattern.

The second experiment in the accuracy study protocol involved placing fake radioactive seeds into a phantom gel. Since the accuracy study is meant to be performed on a number of different systems for experimental control, the protocol instructs us to get the phantom from Thomas Jefferson University. Having all the phantoms come from the same source ensures quality control by ensuring that different phantom compositions will not contribute to differences in the experimental results. Unfortunately, at the time of the writing of this report we had not received the phantom for the study. We did do a trial run of the experiment with a phantom designed to represent breast tissue. We also used pencil lead as a replacement for the fake seeds. We inserted our fake seeds into the phantom in the same way we would for the experiment in the accuracy study. We took the result to the small animal CT scanner at JHU hostipal, and scanned the phantom with the CT scanner. The resulting scan had a resolution of less than one millimeter. Using Slicer, we could then decipher the image and calculate the accuracy of the seed placement in the gel.

Outcome

RadVision was successfully integrated with the TRUS robotic system. We are now able to move the robot through RadVision by entering in quaternions into RadVision. We have conducted a number of tests where we provide a quaternion to RadVision to see whether or not the robot travels to that position. We had hoped to do a full test of the entire system including the ultrasound sensor using a prostate phantom. Due to the lack of availability of an ultrasound system and prostate phantom, it was notpossible to perform this test.
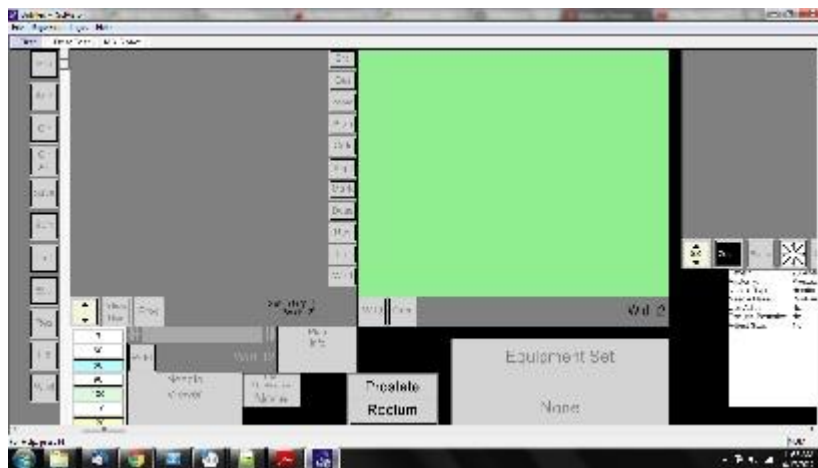

Integrated RadVision 1

The graph paper portion of the accuracy study went pretty well. We have not done the full test of 100 samples in accordance with the accuracy study protocol, but we did a test with 20 samples. After we loaded all the images we analyzed them in Matlab. We calculated the

average error, standard deviation in error, etc. of the needle in the HD pictures. The results are in the following table.

Error in needle position			Repeatability in needle position		
Axis	Average	SD	Axis	Average	SD
X	.8	.2	X	.3	.2
Y	.8	.3	Y	.3	.2
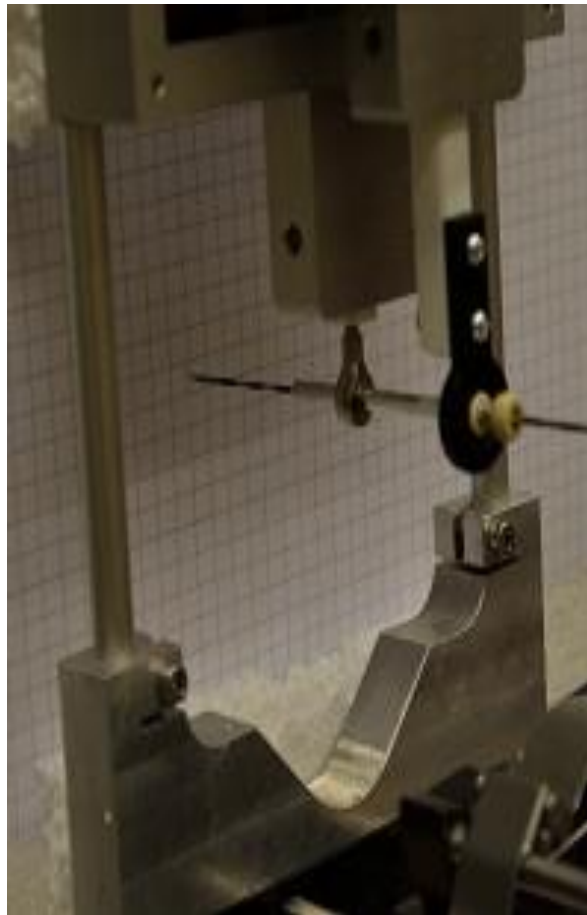
Picture taken of graph paper experiment 1

The trial run involving the breast phantom went as planned. We executed the tests, and inserted the fake seeds into the gel and ran a CT scan on it. The whole experiment went as planned, except the x-ray attenuation of the graphite seeds was not sufficient to clearly

distinguish them in the CT image. In order to do an accurate assessment of the accuracy of the seed placement, the seeds in the image must be clearly visualized.

Phantom gel implantation 1

Management Summary

Since I was the only one working on this project, I did most of the work. My advisor helped a great deal, especially in obtainingthe resources I needed to complete the project.

We met the minimum project deliverables with the integration of RadVision and TRUS, including completion of the accuracy study. We had originally intended to make our own phantoms, but later discovered that the protocols designer intended for us to use phantoms with another university where all the phantoms for all the robots was produced for the purpose of consistency and standardization. For other expected deliverables, we were unable to demonstrate the integrated system with ultrasound because we were unable to acquire an ultrasound system in time. We were also unable to integrate the button controller with RadVision as we intended because the company did not give us access to the RadVision source code itself. Our maximum deliverable was to get IRB approval for a clinical trial involving the system. This objective would only have been possible if we received RadVision relatively early in the semester. Unfortunately, we received the software well after the deadline for IRB submission.

Having integrated the RadVision treatment and planning software with the TRUS robot, it would probably make sense for us to redesign the robot for automated needle and seed insertion. A high precision servo mechanism for needle insertion will likely be more precise than manual needle insertion, so automating this part of the robot would probably increase the accuracy the of system overall.

At the moment, the robot still uses the robot's encoders and forward kinematics to determine the needle's location. Unfortunately, this method is vulnerable to error caused by bending of the structures in the system, especially the needle. When the needle is inserted into a surface that is not perpendicular to the needle itself, bending can occur. Since the robot is unable to detect the bending of the needle, the location the system believes the needle is in and the actual location of the needle might differ significantly. Ultrasound could help solve this problem by providing the system with the location of the needle independent of the encoders. One could in theory improve the accuracy of this system by processing the image from the ultrasound to discover the actual location of the needle. In theory this method of determining the needle location would not be vulnerable to the distortions mentioned earlier.

Conclusion

Overall the project was fairly successful. Radvision was successfully integrated with the robot. We completed as much of the accuracy study as we could in the time we had with the resources we were given. We had hoped that we would be able to demonstrate the entire integrated system with ultrasound, but we were unable to get the ultrasound equipment. We also had hoped to do the second stage of the accuracy study with the standardized phantom gel, but the people who were suppose to synthesize it for us were unable to do so by the end of the semester. This technology has great potential to achieving superior results in prostate branchytheapy.

Reading List

- Gabor Fichtinger, Jonathan P. Fiene, Christopher W. Kennedy, Gernot Kronreif, Iulian Iordachita, Danny Y. Song, Everette C. Burdette, Peter Kazanzides, Robotic assistance for ultrasound-guided prostate brachytherapy, Medical Image Analysis, Volume 12, Issue 5, October 2008, Pages 535-545, ISSN 1361-8415, 10.1016/j.media.2008.06.002.

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  Keywords: Medical robotics; Image guided surgery; Prostate cancer; Brachytherapy

References

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