Robone: Next Generation Orthopedic Surgical Device

Final Report

Team Members

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Mentors

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Background:

Total hip replacement surgery requires cutting into the femur bone so that an artificial hip implant can be inserted. Non-robotic assisted methods can be inaccurate, resulting in misalignment of the implant or other complications.

Robotic assisted systems were introduced to cut a more accurate implant shape into the femur bone. Robodoc, now called TCAT, is an existing computer assisted orthopedic surgical device for hip replacement surgery. The existing device isn't perfect and requires the patient to be fixed to the robot, an invasive and time consuming process. In addition, if the bone shifts during the surgery, in most cases the surgery must be the continued manually. In some cases, the Robodoc system can be registered again with rigid fixation from the robot to the patient.

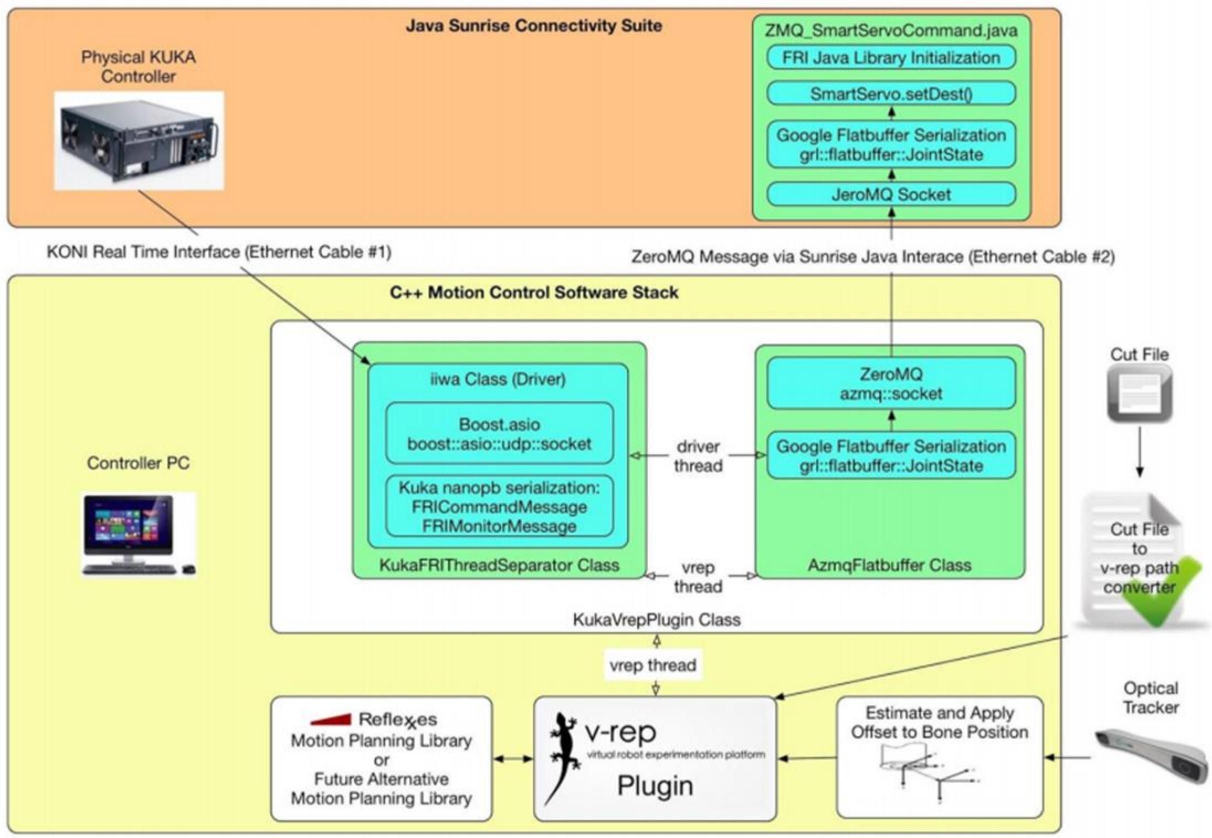
Problem:

Lost registration and increased surgical time greatly increase the cost of the surgery. The cost of the physical device and the increased time for robotic hip replacement surgical procedure makes it difficult to convince doctors of the viability of existing robotic surgical devices. The existing robotic surgical systems also have additional invasive steps required for registration that involve cuts outside the primary surgical region. These steps are not required by traditional surgery.

Approach:

We aim to streamline the surgical procedure and reduce the cost to make robotic hip replacement surgery a more viable product. Our next generation system makes real time position adjustments using a device such as an optical tracker so the invasiveness and time required for the fixation is substantially reduced.

We developed a C++ motion control software stack to control the movement of the KUKA LBR iiwa robot. The V-REP simulation suite calculates the robot's next target position and our software commands the motion of the robot end effector. The motion controller can also monitor the real time information of the joint angles of the robot. The software design is illustrated in flowchart below.

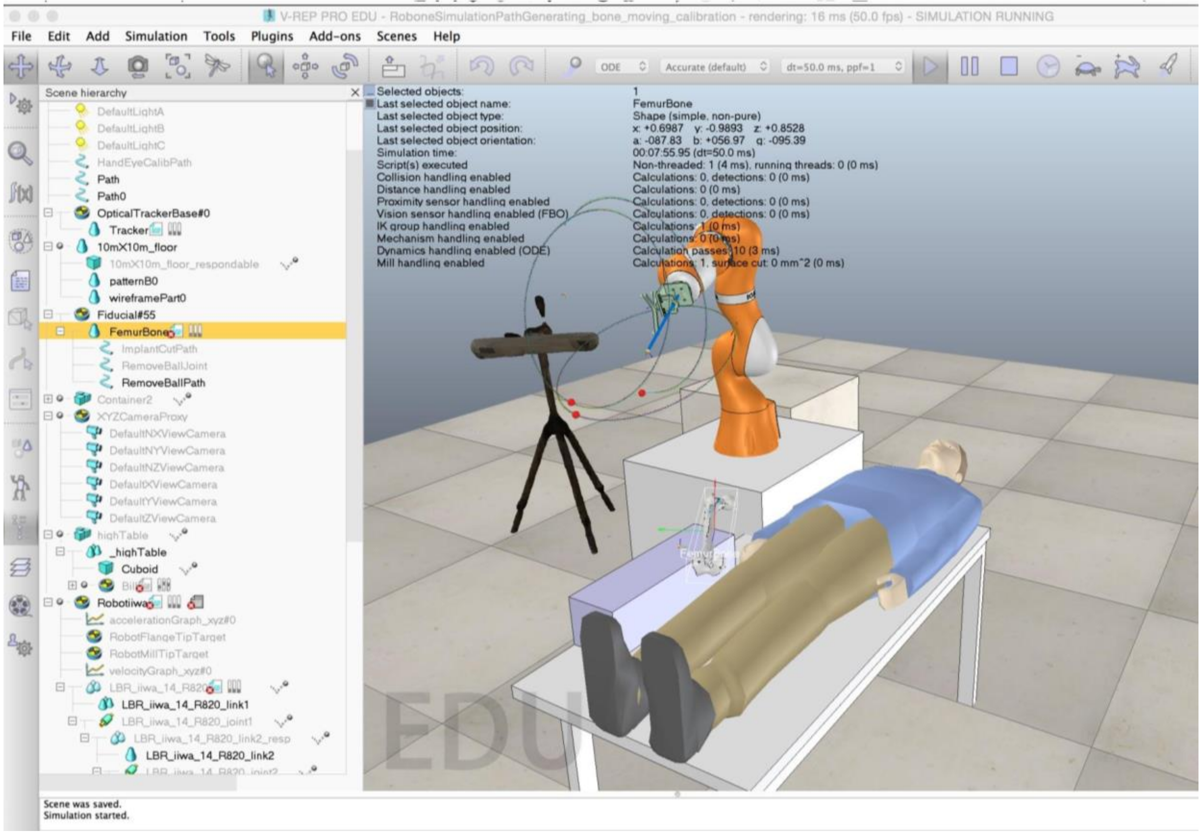


The V-REP simulation is used to visualize and test the movement of the KUKA arm in reference to the bone. Cut file paths are read into the simulation as the preoperative planned path for the KUKA to follow. Real time positional data of the target bone is sent to simulation from the optical tracker to estimate and apply offsets to the KUKA's path in accordance to bone movement.

Results:

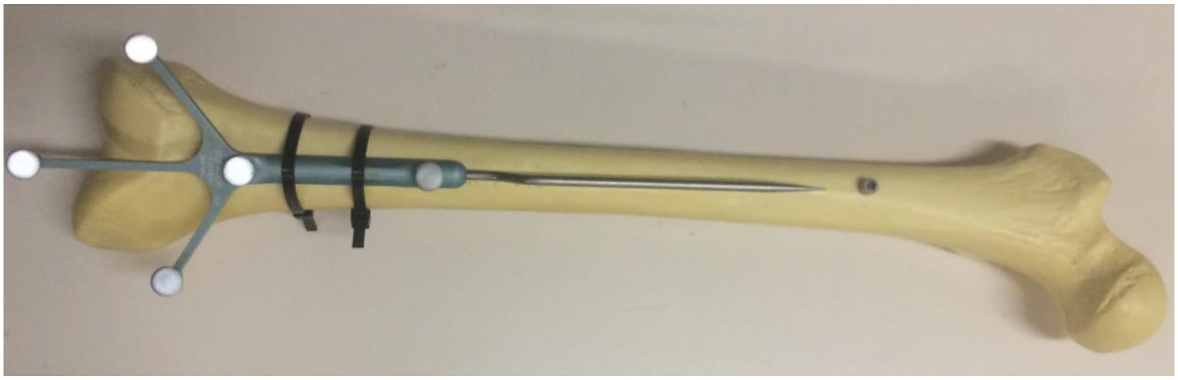
Our project resulted in a prototype system that follows a planned surgical cut path and can make real time adjustments to the path based on movement of the target bone. First, we load surgical cut file paths into the simulation. A picture of the processed cut file path overlaid over a femur bone in simulation is shown below:

Next, we added a mill to the end of the robot in simulation and have the tip of the mill follow along the cut file path. As the robot followed the path in simulation, simulation joint angles are sent to the physical KUKA robot and it follows the path.



To account for movements of the bone during surgery, we added an optical tracker to the system. A fiducial was attached to the end effector of the robot to calibrate the distance between the optical tracker and the robot. A picture of the implementation is shown below.

We also attached a fiducial to a 3D printed bone to track the real time position and orientation in the optical tracker frame. A picture of the implementation is shown below. A final product will use a more efficient and appropriate attachment mechanism.



The final design resulted in a live demo of the KUKA arm following a cut path with respect to the bone and making real time positional adjustments to the path according to movement of the bone.

Significance:

The main significance of our project is to improve the outcomes for patients of hip replacement surgery. Our project increases the accuracy from manual surgery and also reduces the invasiveness from robotic surgery. Further development could lead to a viable option to replace current methods of total hip replacement surgery.

The components of the system can be used in the application outlined above in addition to a variety of other applications outside the scope of this paper. If the combination of cost, effectiveness, and surgical time combined favorably.

Management Summary:

Below is a list of deliverables that we planned to complete on the project throughout the semester:

Minimum

-Receive arm state in real time
-Read in cut file specifying shape of implant
-Drive both simulated and physical KUKA arm along
    -simulated cut file path
    -real cut file path

Expected

-Receive optical tracker position in real time and adjust cut path accordingly
-Characterize performance

Maximum

-Milling Physical Simulation
-Investigate arm motion planning
-Milling Device Integration

We completed all of the planned minimum deliverables. We also completed the expected deliverable to receive optical tracker data in real time and adjust to the cut path according to how the bone moved.

We were not able to complete the other expected deliverable or any of the maximum deliverables. At the end of the semester, we were working on a way to calibrate the system so we could characterize the performance of the path adjustments using the real time optical tracking. This work will be continued in the future to ensure that the reaction time of our system is within the requirements given to us by our sponsors. Work towards the maximum deliverables will also be continued in the future to continue development of a system that can help during total hip replacement surgery.

We split the project up according to the different strengths of our group members so our system could be developed efficiently. Andrew developed C++ motion control software stack and the plugins. Shahriar the created V-REP simulation and designed the hardware attachments. Alex integrated the surgical CUT files and developed KUKA software control code. The project taught us the processes involved in integrating a variety of sensors and actuators towards the solution of a real world problem. We also learned the fundamentals underlying a variety of algorithms crucial to robotic systems.

Technical Appendices:

All of our publically available code is stored in the GRL and Robone git repository:
https://github.com/ahundt/grl
https://github.com/ahundt/robone