Individual Lab Report - 10

Autonomous Reaming for Total Hip Replacement

HIPSTER | ARTHuR

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1 Individual Progress

1.1 MRSD Project

The last two weeks after PR10 has been all about complete system integration. I have completed the development of the watchdog module as we were also able to finalize the development of the other subsystems. The watchdog now acts as a health monitoring system and also as an information filter between the perception, controls, and end-effector subsystems. After the last PR, the watchdog was yet to be integrated with end-effector controls and the User Interface. The end-effector is sharing information on the reamer speed, the current drawn, reaming percentage, and the load applied. The watchdog sends a command to the end-effector to start the reaming operation if all critical parameters are healthy and stops the processes if anything goes wrong. The watchdog logs all errors in a text file as seen in Fig. 2.

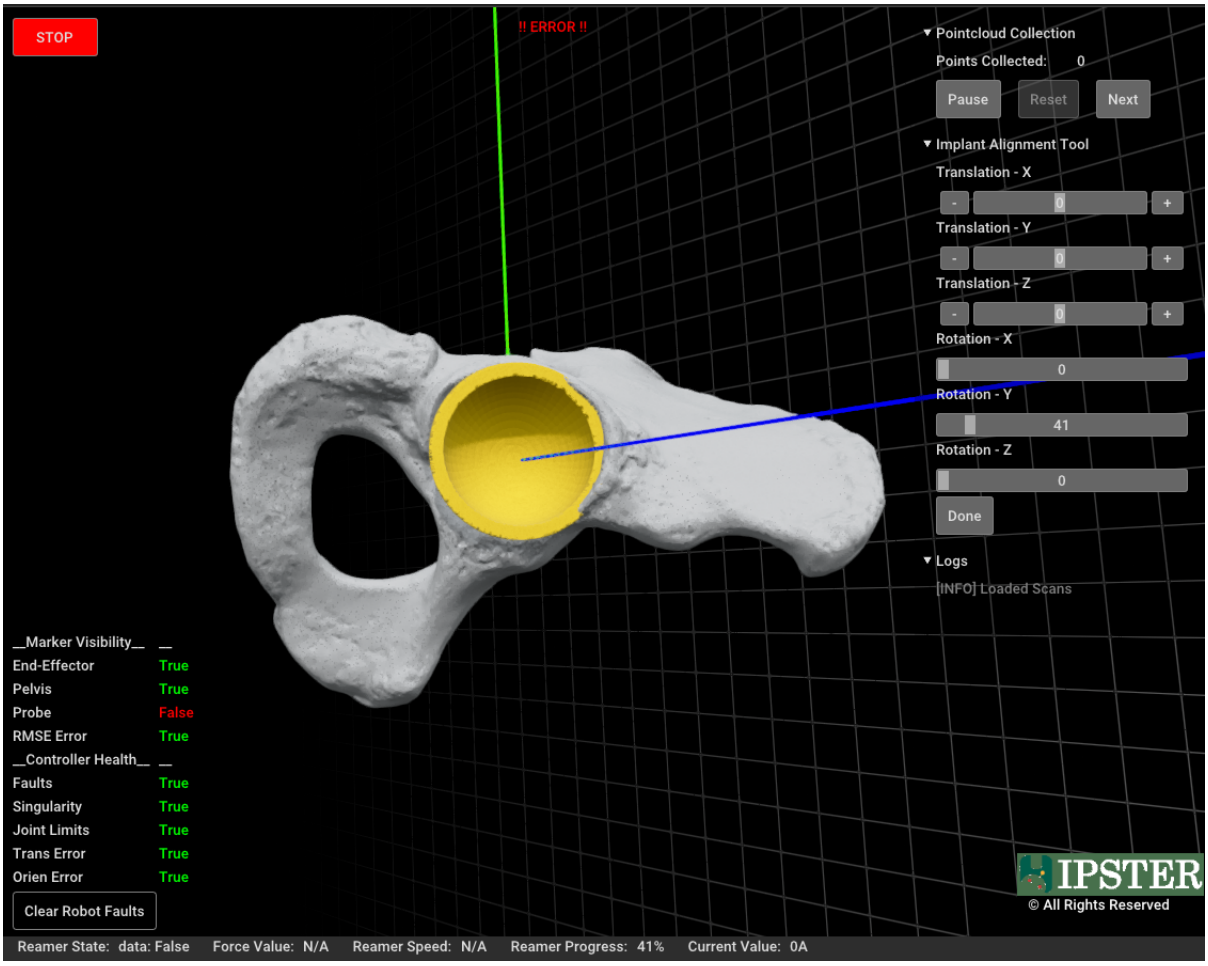

Figure 1: Watchdog as seen on the UI

I worked with Gunjan to display all the parameters on the User Interface and thought through the process of how a surgeon/user would use the system as seen in Fig 1. We incorporated a clear faults button that allows the user to correct the faults detected by the watchdog in 10 seconds. If the faults are not cleared within 10 seconds, the arm goes back to e-stop, prompting the user the

press clear-faults again. I also incorporated a controller clear faults in the watchdog that resets the master controlle if it detects a fault.

```
1 Date: 22-11-17  Time: 07:41:43    Pelvis marker is not visible
2 Date: 22-11-17  Time: 07:41:43    End-effector marker is not visible
3 Date: 22-11-17  Time: 07:41:43    Controller flag couldn't be set to true because downstream processes are unhealthy
4 Date: 22-11-17  Time: 07:41:43    Controller error publisher dropped below 30Hz
5 Date: 22-11-17  Time: 07:41:43    Controller singularity publisher dropped below 30Hz
6 Date: 22-11-17  Time: 07:41:43    Controller joint limits publisher dropped below 30Hz
7 Date: 22-11-17  Time: 07:41:43    Controls translation error is high
8 Date: 22-11-17  Time: 07:41:43    Controls orientation error is high
9 Date: 22-11-17  Time: 07:41:43    Arthur at singularity
10 Date: 22-11-17  Time: 07:41:43    Hardware flag set to true
11 Date: 22-11-17  Time: 07:41:43    Pelvis is visible
12 Date: 22-11-17  Time: 07:41:43    End-effector is visible
13 Date: 22-11-17  Time: 07:43:27    Controls translation error is within limits
14 Date: 22-11-17  Time: 07:43:27    Controls orientation error is within limits
15 Date: 22-11-17  Time: 07:43:27    Controller flag set to true
16 Date: 22-11-17  Time: 07:43:27    Arthur out of singularity
17 Date: 22-11-17  Time: 07:43:27    Hardware flag set to false
18 Date: 22-11-17  Time: 07:43:27    Controller flag couldn't be set to true because downstream processes are unhealthy
19 Date: 22-11-17  Time: 07:43:27    Controls translation error is high
20 Date: 22-11-17  Time: 07:43:27    Hardware flag set to true
21 Date: 22-11-17  Time: 07:43:33    Pelvis marker is not visible
22 Date: 22-11-17  Time: 07:43:33    Pelvis is visible
23 Date: 22-11-17  Time: 07:43:39    Controller flag set to true
24 Date: 22-11-17  Time: 07:43:39    Controls translation error is within limits
25 Date: 22-11-17  Time: 07:43:39    Hardware flag set to false
26 Date: 22-11-17  Time: 07:47:47    Pelvis marker is not visible
27 Date: 22-11-17  Time: 07:47:47    Controller flag couldn't be set to true because downstream processes are unhealthy
28 Date: 22-11-17  Time: 07:47:47    Hardware flag set to true
29 Date: 22-11-17  Time: 07:47:47    Pelvis is visible
30 Date: 22-11-17  Time: 07:47:47    Controller flag set to true
31 Date: 22-11-17  Time: 07:47:47    Hardware flag set to false
32 Date: 22-11-17  Time: 07:47:48    Pelvis marker is not visible
33 Date: 22-11-17  Time: 07:47:48    Controller flag couldn't be set to true because downstream processes are unhealthy
34 Date: 22-11-17  Time: 07:47:48    Hardware flag set to true
35 Date: 22-11-17  Time: 07:47:50    Pelvis is visible
36 Date: 22-11-17  Time: 07:47:50    Controller flag set to true
37 Date: 22-11-17  Time: 07:47:50    Hardware flag set to false
38 Date: 22-11-17  Time: 07:57:48    Pelvis marker is not visible
39 Date: 22-11-17  Time: 07:57:48    End-effector marker is not visible
40 Date: 22-11-17  Time: 07:57:48    Controller flag couldn't be set to true because downstream processes are unhealthy
41 Date: 22-11-17  Time: 07:57:48    Hardware flag set to true
```

Figure 2: Watchdog logging in a text file

I spent a lot of time experimenting with different tools for our FVD evaluation metric. I started with CloudCompare to replicate the placement of the acetabular cup as in the User Interface. For this, we save the transformation from the acetabular cup to a local point on the pelvis. Using that transformation, I translate the acetabular cup to fit an unreamed pelvis. Post this, I subtract the mesh of the cup front he mesh of the pelvis to get a theoretically reamed pelvis. After we have conducted an experiment of reaming the pelvis with our system, we scan the reamed pelvis at our sponsor's office. With this scan, I compare the meshes on CloudCompare and generate a number for the difference between the two meshes using an inbuilt plugin, which should be less than 2mm. I also spent some time making a ballistics gel mould for FVD. For FVD we plan to use a larger pelvis bone which needs a bigger box than the one we used last time. Hence, I had to make twice the amount of ballistics gel to cast the bone which also took twice the amount of time.

2 Challenges

2.1 MRSD Project Challenges

Our current challenges are all to do with the integration of all the subsystems. The end-effector controls has the most challenges due to the uncertainties in various parts of the system that affect the parameters such as current. For example, the configuration of the arm changes the current drawn by the end effector motor as gravity is sometimes opposing the configuration and sometimes aiding. One issue we faced during the integration of the watchdog with the end-effector is the difference in the frequency of the two nodes. Watchdog being a critical system runs at a much

higher rate, 1000Hz, than the other subsystems. Since the end-effector waits for a command front the watchdog and the watchdog sends the command at 1000Hz, the Arduino used in the end-effector gets blocked by this call and was causing issues. Similarly, we had to identify all the cases when we would have to initiate emergency stop and how we would clear those faults to let the user correct the error. I had to think through and realize from testing all the edge cases where the information flow failed and accounted for them. Finally, to have our system perform optimally, we have a lot of parameters to tune which is still a work in progress.

3 Team Work

3.1 Anthony Kyu

Anthony worked with me to integrate the arm controller with the watchdog module. He also worked with Kaushik to integrate the arm controller with the end-effect controller. He spent time along with Parker to identify the sources of misalignment and manually corrected those eros in our URDF. He spent a lot of time 3D printing the end-effector cover and ensuring it snapped to the end-effector.

3.2 Kaushik Balasundar

Kaushik worked on implementing various controllers for our end-effector, specifically a position and velocity controller for the two motors in our end-effector. He worked with Gunajn to transform the reaming pose from the UI to the camera's frame of reference, and fixing other integration issues with perception. He worked with me to integrate end-effector controls with the watchdog and ran lots of test to validate the system.

3.3 Gunjan Sethi

Gunjan completed the development of the UI and integrated uI with the watchdog. She worked with Kaushik to debug to correct perception bugs and sent the cup transform from the UI. She worked with the entire team to perform dress rehearsal and debug overall system integration issues.

3.4 Parker Hill

Parker redesigned to electrical subsystem to be adapted onto a single 3D-printed part and created custom connectors to interface with the motors. He worked with Anthony to determine sources of misalignment error and hand-tuned the base positioning. He worked with me to validate the system performance by comparing meshes and helped test the entire system.

4 Future Plan

The next few days before FVD will be spent in preparing for the demonstration and optimizing the performance of our system. We are trying to keep the system as bug free as possible and are thinking through the entire process. For FVD encore we would continue improving the performance of the system as necessary. We will see you at FVD and FVD Encore!