ME 401: Mechatronics Lab

Final Project: 3D Scanner

Titus Battisti & Rafael Romero

Section 01L

Data Collected 12/07//2021

Report Submitted 12/14//2021

Introduction:

The purpose of this project is to be able to produce a 3D scan of a location surrounding a 3D scanner itself. This will be done by having an IR sensor mounted on a platform that rotates the sensor's pitch while having a second motor control the yaw. The device can be seen in ***Figure 1***, along with its major components.

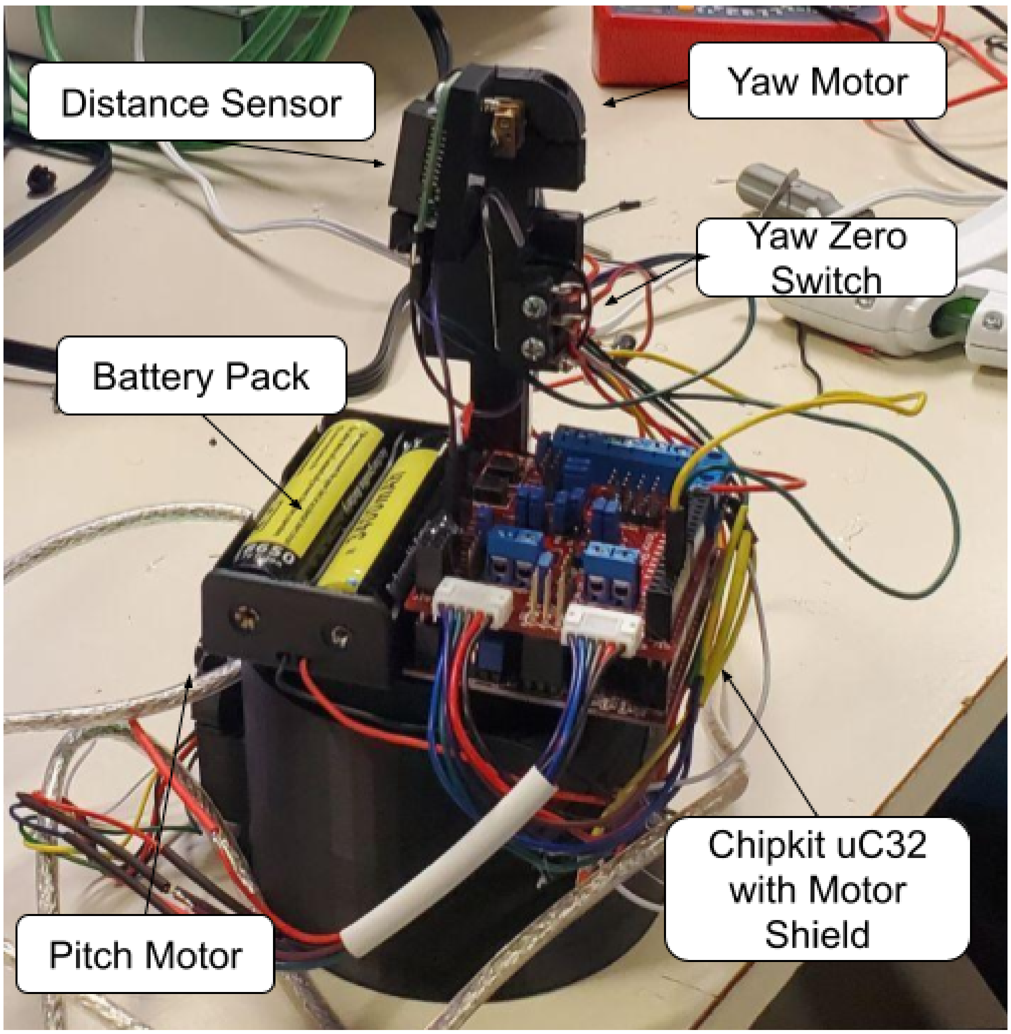


Figure 1: *An image of the 3D scanner labeling the distance sensor, yaw motor, yaw zero switch, chipkit, pitch motor, and battery pack.*

The device will create a scan that can at least create the 3D silhouette of a room. The quality of the scan is dependent on the sensor itself as well as the number of points it scans in both yaw and pitch rotations of the sensor.

Because of the IR sensor used, it works best for objects more than 0.1 m away, but less than 0.5 m. In our analysis we remove any points not within this range.

In our final project we will utilize a chipKit uc32, motor shield, batteries, two PID tuned motors that work in cahoots with an IR sensor that is mounted on a gear housing. Moving in conjunction these parts form a 3D scanner device that will scan an area around the scanner. To limit the need to make a state space approach matrix to solve the PID tuning itself, the motors can be calibrated in situ using the Ziegler-Nichols method. This way the gain is found one at a time while the machine itself is intact. The numbers and graphs generated from this calibration can be seen in **Appendix I**.

The two motors responses are shown in ***Figure I1*** & ***Figure I3***. The pitch motor has a settling time of about 4.213 ms with an overshoot of 19.5% while the yaw motor has a settling time of 1.21 ms with an overshoot of 13.78%. Overall both perform well with a gain that meets the response criteria that's needed. The values for the gain of these PID motors are shown in ***Table I1***.

The gear housing will work on a 2:1 gear ratio that utilizes a pinion and bevel gear to rotate the pitch of the IR sensor itself. The clearance of the gears themselves follow the specs shown in ***Figure 2***.

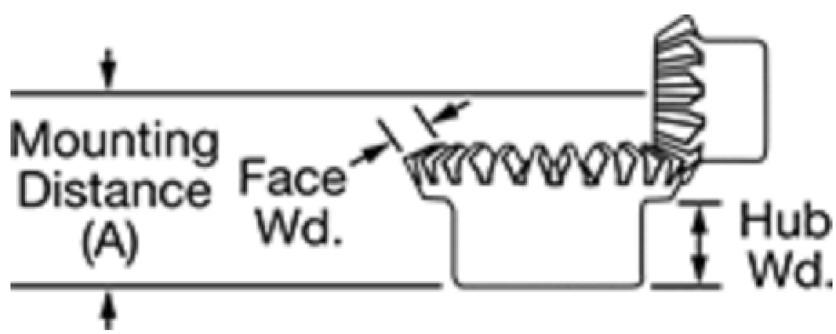


Figure 2: *Shows the clearance needed for the bevel and pinion gear, The mountain's distance (A) will be kepts at 27 mm. The horizontal gear has 20 teeth while the vertical bevel has 40 teeth. The hub height will stay at 10mm.*

The horizontal gear will be controlled by the pitch PID motor. The gear housing will have a top that has an inverted bevel gear. These two together meet the criteria shown in ***Figure 2***. The bevel gear top is shown in ***Figure 3***.

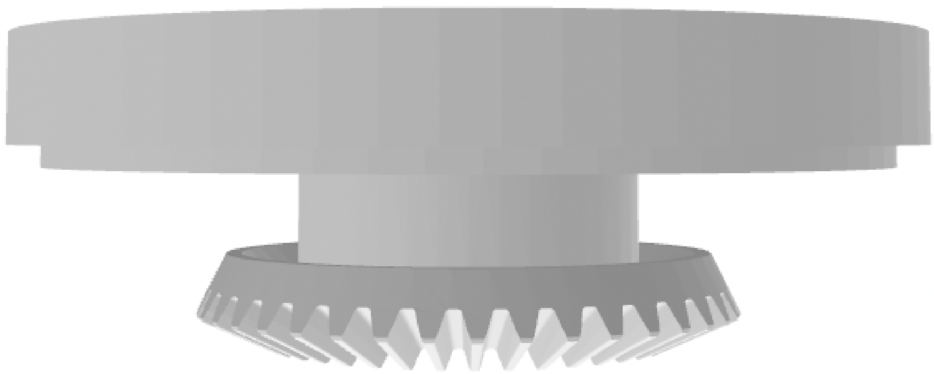


Figure 3: *The chipkit/motor shield as well as the battery, IR sensor and mount, will sit above this base that is moved by the pinion gear controlled by the pitch motor.*

The overall wiring diagram of the 3D scanner itself is shown in ***Figure 4***.

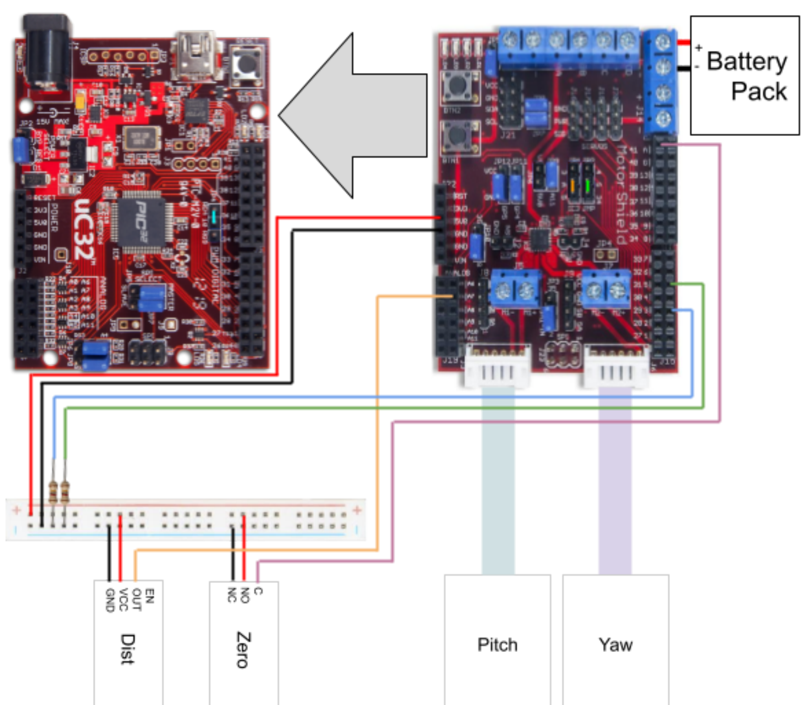


Figure 4: *Wiring diagram of the 3D scanner. The motor shield is situated on top of the uC32.*

Two separate pull down resistors are connected to the motor shield in order to stop the PID motors from initially spinning. One thing to note is that the connecting cable for the pitch motor tethers to the chip kit, crossing between the base and the rotating deck. To ensure that a scan can be completed successfully, it is therefore necessary to consider the starting angle of those two pieces, in addition to the starting angle of the sensor to the environment.

After the motors themselves are tuned, the IR sensor has to be tuned in order to get the bounds of the 3D scanner. In addition to the curve used to generate distances needed to calculate 3D coordinates. First the IR sensor range is tested from 0-5m in order to find the most effective range. ***Figure 5*** shows the first initial testing of the IR sensor.

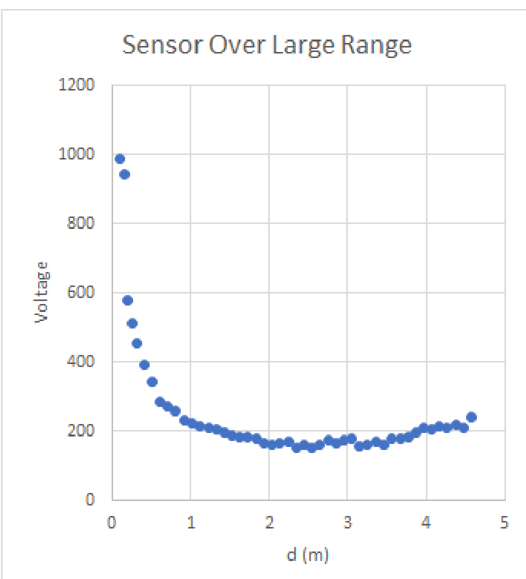


Figure 5: Measurement of voltages at expected distances.

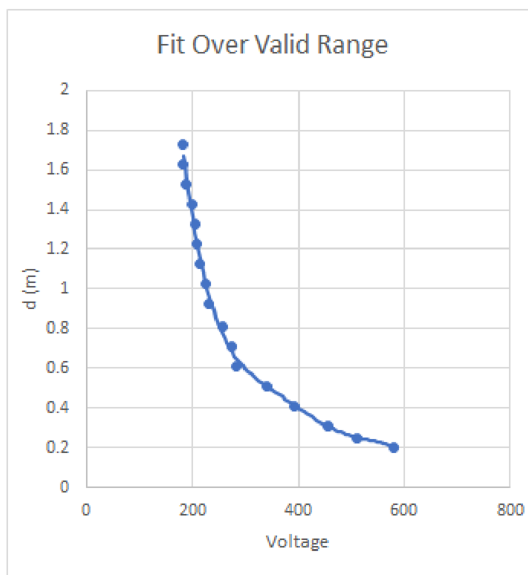


*Figure 6: Points and fit from the usable range of measurements from **Figure 5**.*

After the initial testing is done the IR sensor data shows that the measured value can only be one to one in the first two meters or so (which is necessary for generating the polynomial curve fit shown in ***Figure 6***). The data was fit in the range of 200 to 600 voltage reading which gave an output from 0.2m to

1.78m from the point of measurement. This was later reduced to 0.5m to account for other sensor inconsistencies.

Using the distance inferred from the distance sensor, and the angles gathered from the encoders on the two motors, we can transform these spherical coordinates to x, y, z coordinates with:

$$x = d\cos(\theta_{\text{pitch}})\cos(\theta_{\text{yaw}}) \qquad y = d\cos(\theta_{\text{pitch}})\sin(\theta_{\text{yaw}}) \qquad z = d\sin(\theta_{\text{pitch}})$$

We then plot these distinct three dimensional points in matlab.

Results/Discussion:

For the purpose of testing this scanner, a setup was constructed where it imaged a flat surface parallel to the yaw axis. This setup is shown in general in ***Figure II1***. In this case the scanner was put in front of a wall to scan; while having a limited pitch angle in order to only capture the wall. This data was then graphed manually through matlab and can be seen in ***Figure II2***.

Then we fit our results to a plane through the method of least squares, to analyze its deviation from the flat surface it scanned. The average error (distance between each point and the fitted plane) that the 3D scanner produced was 13.9mm. Considering the scales involved this error is considered negligible, and the sensor captured the flatness of the object fairly well.

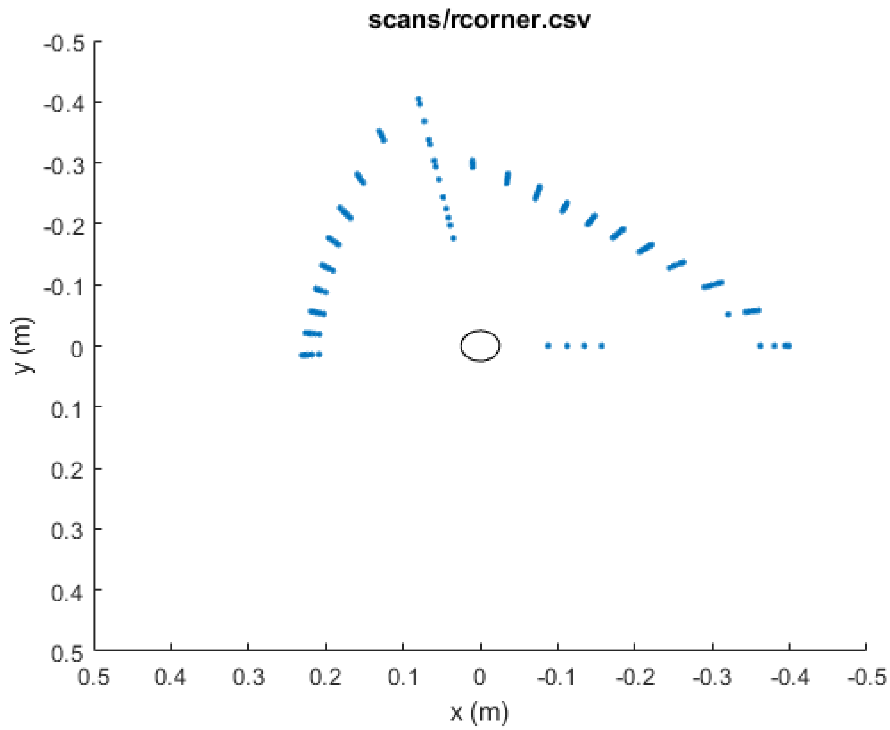


Figure 7: *A top down view of the corner.*

The second scenario, pictured in ***Figure II3***, involves demonstrating the scanner's ability to scan more complicated shapes, a corner, while also highlighting the scanner's deficiencies. In ***Figure 7*** you can see the top down view of the scan. The two lines with the most points in this image (upper left and upper right) represent the planes of the walls making up the corner as can be seen in ***Figure II4***.

The issues with the scanner become evident with the deviations. The setup of the actual scan deviated slightly from ***Figure II3*** in that there was a small gap between the two wall planes. Ideally, if the sensor looks in this gap the points should be removed from the rendering for being too far away or for being out of calibration range. However in testing it was shown that at certain distances the voltage increases despite being further away (as can be seen in ***Figure 5***.) This affects rcorner where a collection of points along the line from the sensor to the gap are calculated to be closer to the sensor than the walls. This is the line emerging between the two wall lines and coming towards the sensor in ***Figure 7***. The other odd points came from the sensor peering past the wall on the other side. This did not happen in rwall2 because the sensor was moved between trials.

This effect is also to be blamed for the failures of scans of objects at farther distances (around 2 meters) which were attempted. Those scans resulted in large variability and odd readings when the sensor was not pointing at something within a half meter or so.

Conclusion

Within its range (of 10 cm to 50 cm) the 3D scanner performed quite well. It was able to generate an image of a real plane only deviating on average by 1.4 cm or so. While it might not show measurement device levels of accuracy, it is able to give an idea of shape, as shown by both included scans.

However, outside of these ideal conditions the sensor begins to fail. When measuring a distance greater than half a meter or so, its voltages begin to become unreliable. In addition to the variability already present even in ideal scans, the first improvement for this scanner would probably be a better sensor.

The device's reliable functioning was also somewhat limited by its structure. The gearing of the yaw axis was designed in such a way that any resistance translates to unseating the deck from the base. Which messed up several scans. In addition the part production was rushed, and to make the device function, parts were altered after they were 3D printed. This led to some clearance issues (such as one with the bevel gear which made it unseat at certain angles, in addition to sudden movements.)

All in all, a more compact design with better electronics, more precise clearances, and a lighter mechanism overall would make the sensor more reliable. The 3D scanner functions, but has future work that could be done.

Appendices

Appendix I: PID Calibration for Pitch and Yaw Motors

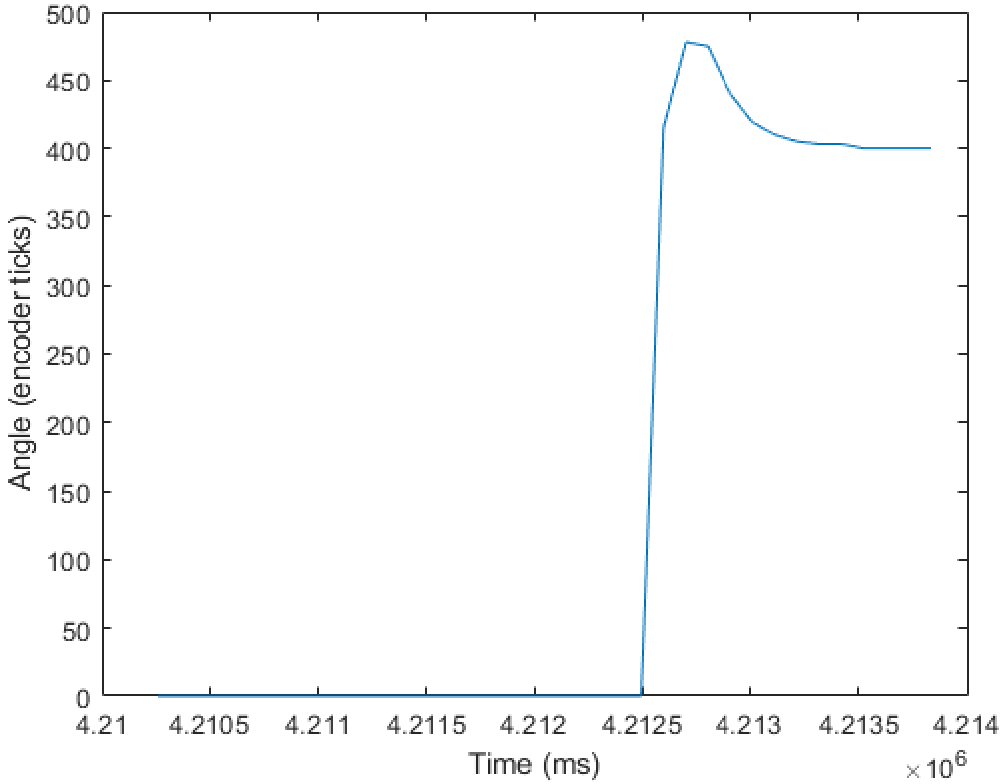
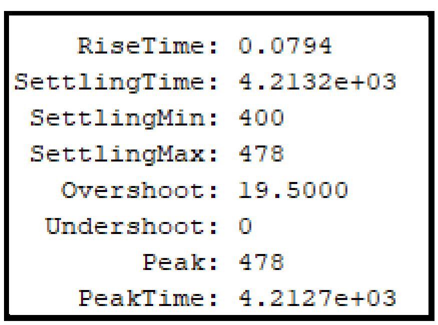


Figure I1: *Settling graph of the pitch motor PID control.*



```
    RiseTime: 0.0794
SettlingTime: 4.2132e+03
 SettlingMin: 400
 SettlingMax: 478
   Overshoot: 19.5000
  Undershoot: 0
        Peak: 478
    PeakTime: 4.2127e+03
```

Figure I2: *Settling statistics of the pitch motor PID control.*

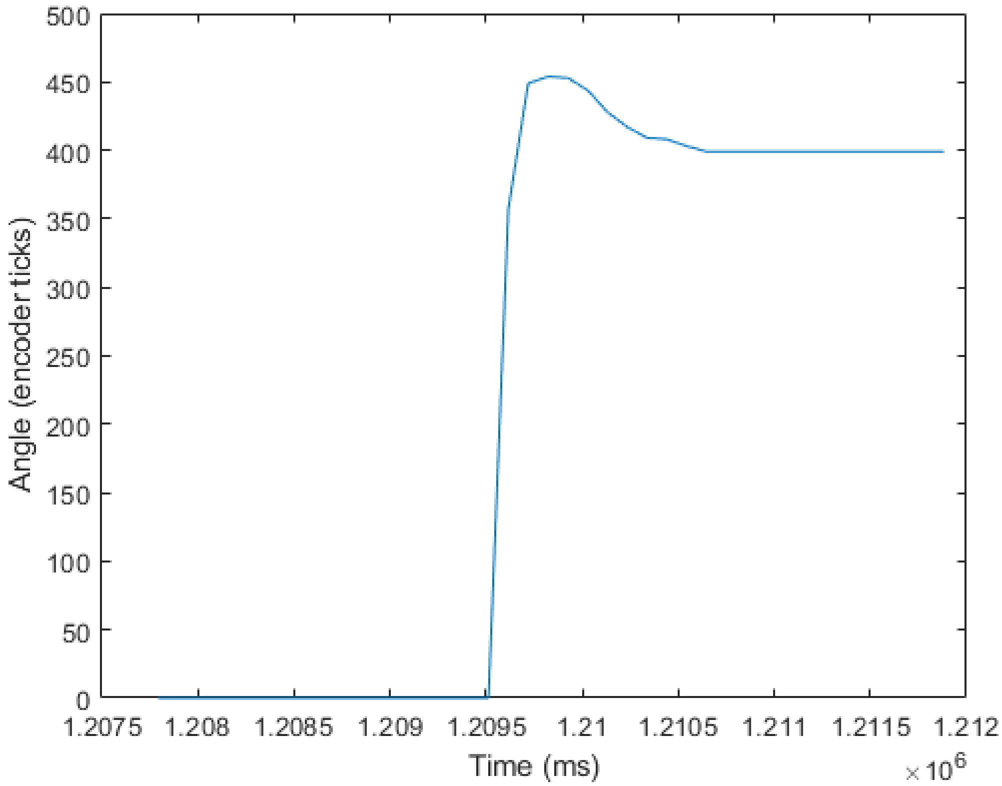


Figure I3: *Settling graph of the yaw motor PID control.*

```
    RiseTime: 0.0938
SettlingTime: 1.2105e+03
 SettlingMin: 399
 SettlingMax: 454
   Overshoot: 13.7845
  Undershoot: 0
        Peak: 454
    PeakTime: 1.2098e+03
```

Figure I4: *Settling statistics of the yaw motor PID control.*

***Table I1**: PID values from using the Ziegler-Nichols method.*		
	Pitch	Yaw
K_u	2	2.5
T_u (s)	0.3659	0.4554
K_p	1.2	1.5
K_i	6.56	6.588
K_d	0.05488	0.08538

Appendix II: Scans

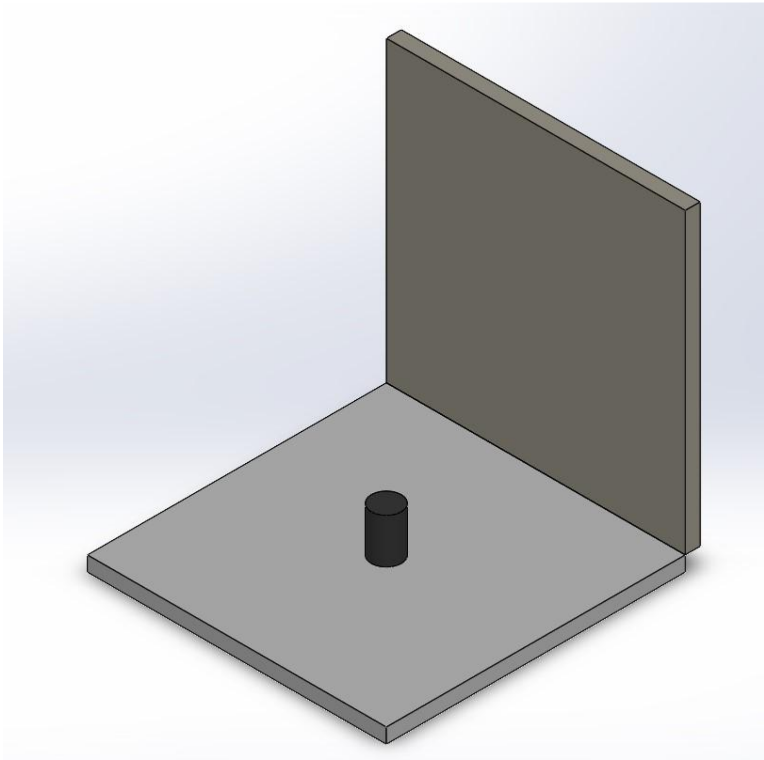


Figure II1: *Setup for scan rwall2.*

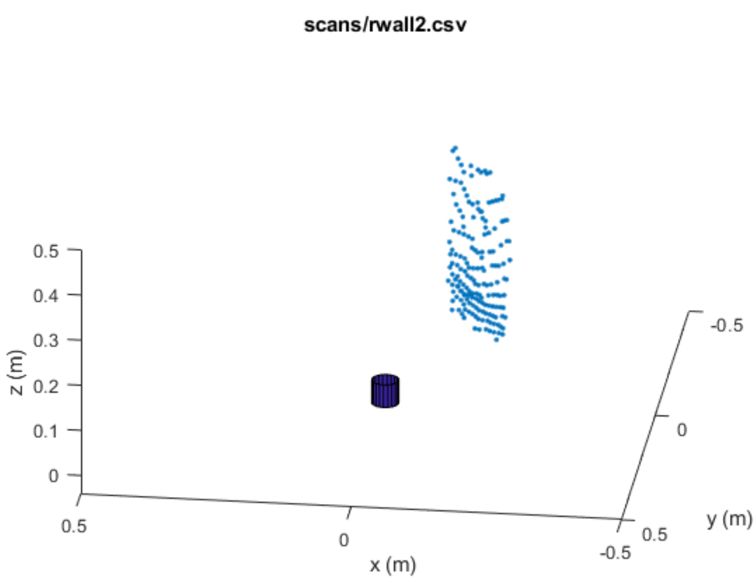


Figure II2: *Scan rwall2.*

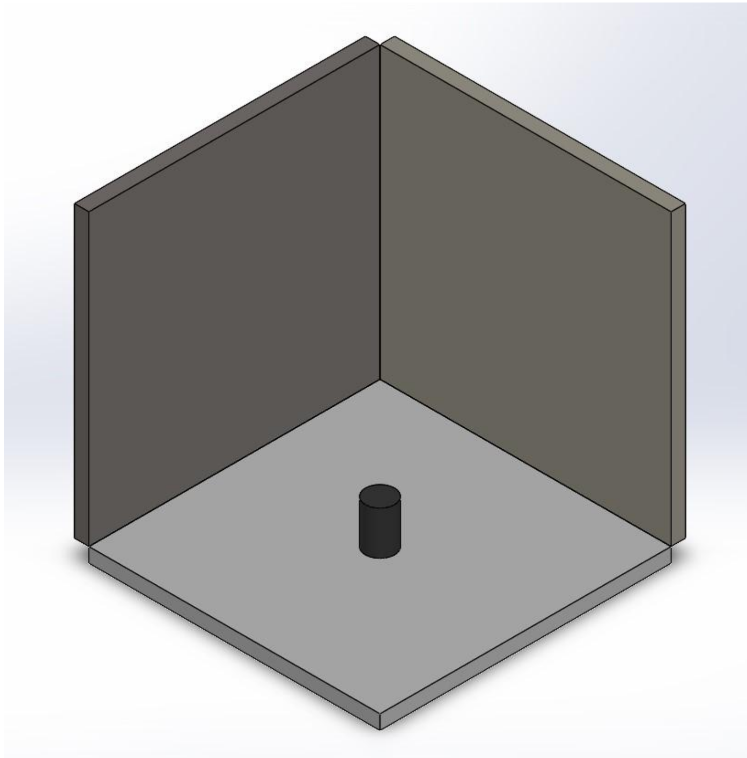


Figure II3: Setup for scan rcorner.

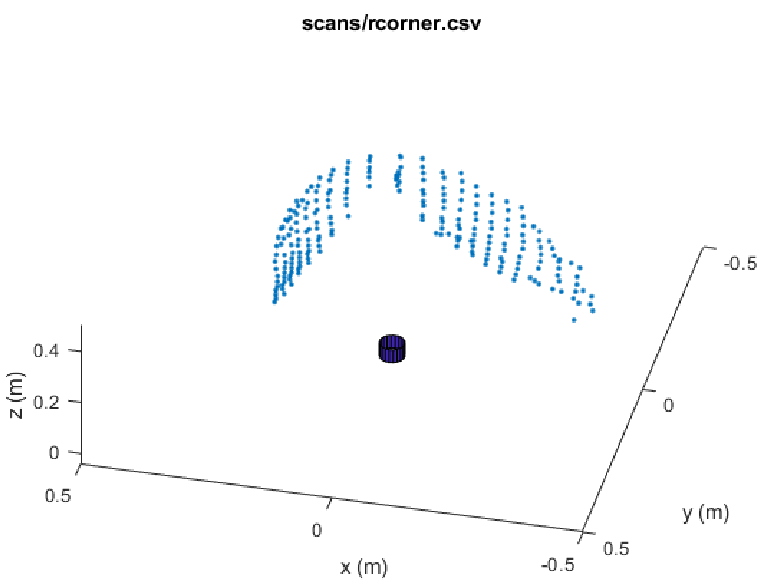


Figure II4: Scan rcorner.