ME 401: Mechatronics Lab

Final Project: 3D Scanner

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Section 01L

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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 a sensor mounted on a platform that rotates the sensor's pitch while having a second motor control the yaw of the sensor itself. The device itself can be seen in ***Figure 1***.

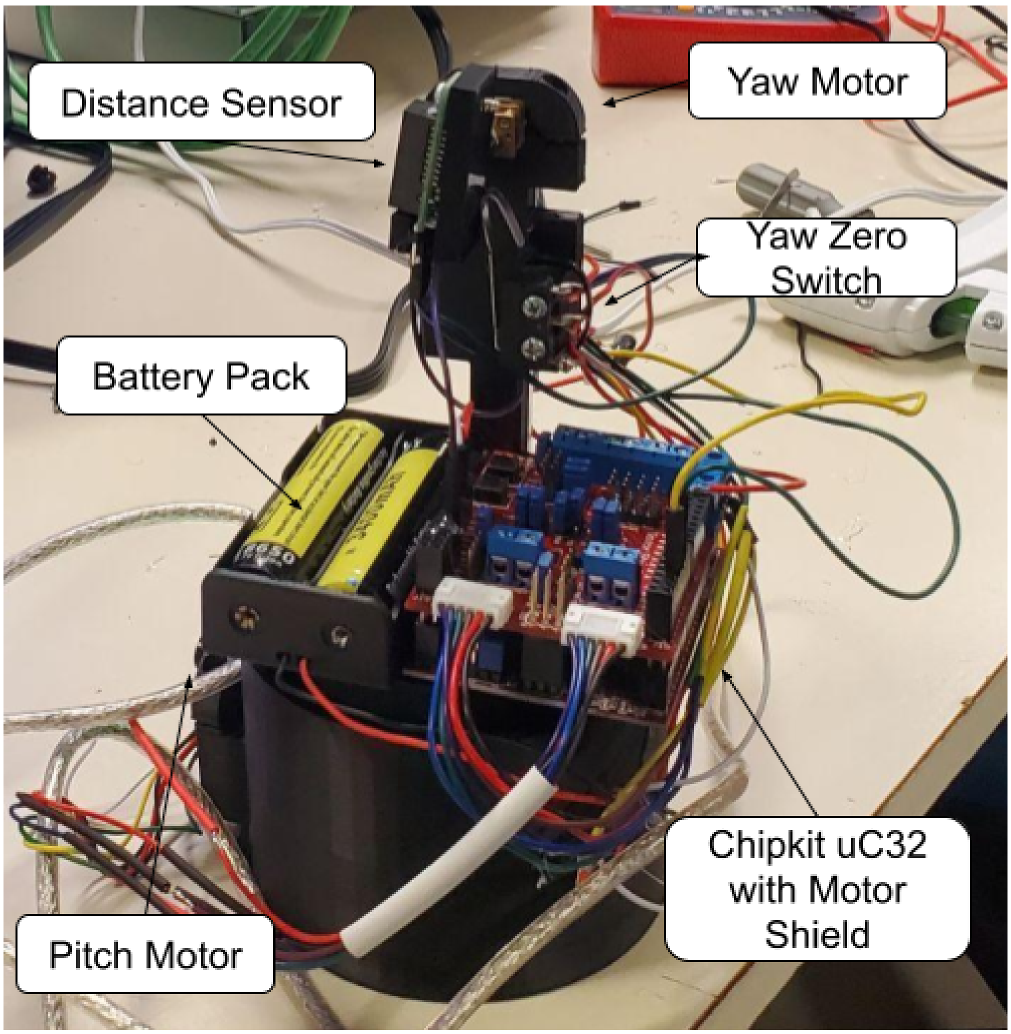

Figure 1: *An image of the 3D scanner labeling the distance sensor, yaw motor, yaw zero switch, chipkit, pitch motor, and battery pack.*

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 can scan 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 1.75 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 itself. 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***.

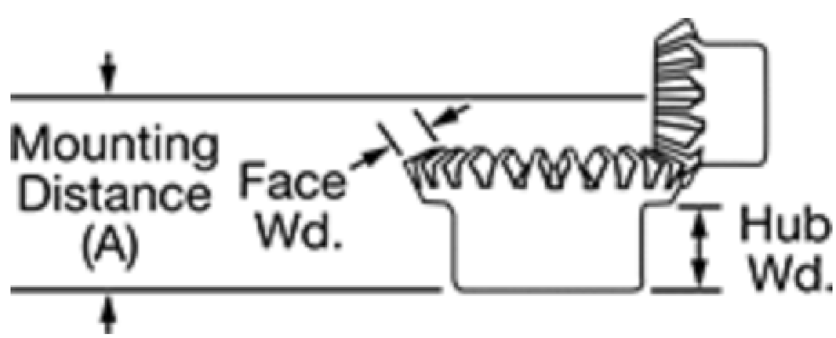

Figure 2: *Shows the clearance needed for the bevel and pinion gear, The mountain's distance (A) will be kepts at 27 mm. The horizontal gear has 20 teeth while the vertical bevel has 40 teeth. The hub height will stay at 10mm.*

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***.

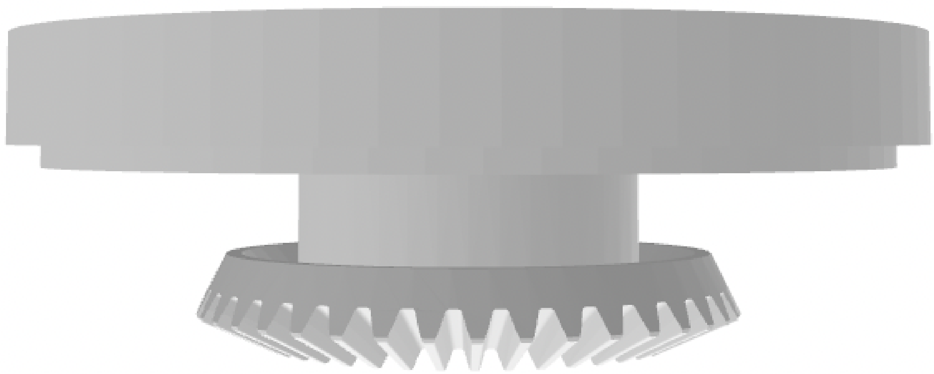

Figure 3: *The chipkit/motor shield as well as the battery, IR sensor and mount, will sit above this base that is moved by the pinion gear controlled by the pitch motor.*

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

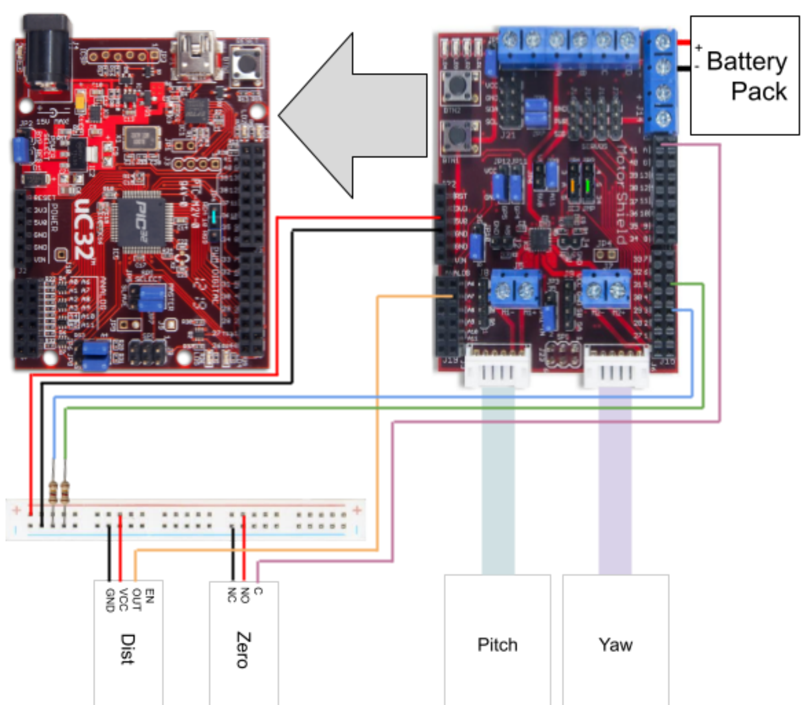

Figure 4: *Wiring diagram of the 3D scanner. The motor shield is situated on top of the uC32.*

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 on top. To ensure that a scan can be completed successfully, it is therefore necessary to set the angle of the chipkit from the pitch motor at 90 degrees clockwise, so that after it finishes its 180 degree rotation the chipkit only reaches 90 degrees counterclockwise.

After the motors themselves are tuned, the IR sensor itself has to be tuned in order to get the bounds of the 3D scanner itself. 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.

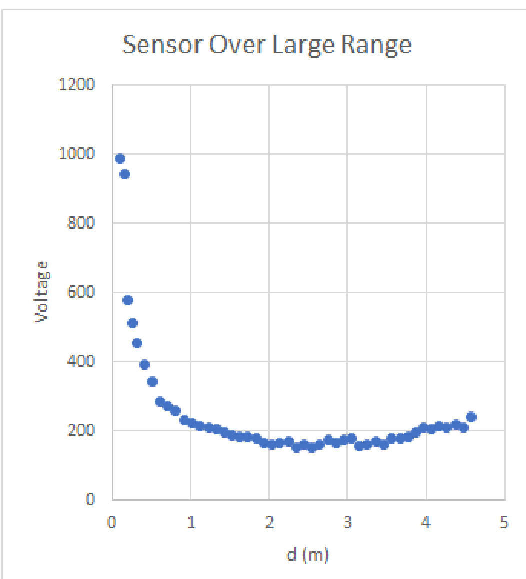

Figure 5: *Measurement of voltages at expected distances.*

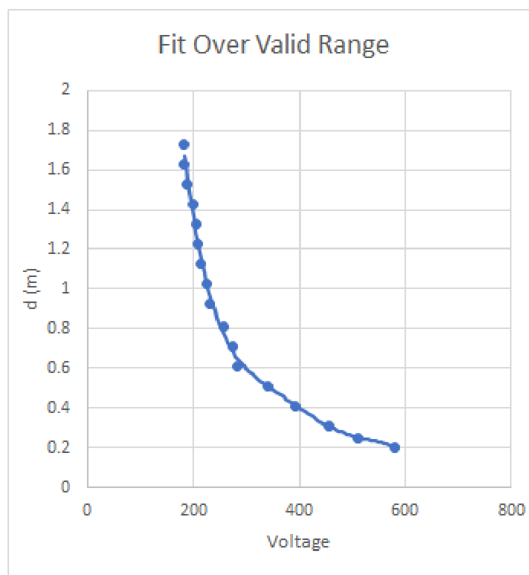

Figure 6: *Points and fit from the usable range of measurements from **Figure 5**.*

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.

These distances when combined with the angles of the motors can then be used to calculate the cartesian coordinates of whatever the sensor observed, in 3D space. In our scans (in **Appendix II**) these points are not shown (as it makes it difficult to infer 3D shape from one perspective), instead lines are drawn between consecutive points in the scan and colored according to their z coordinate.

Results/Discussion:

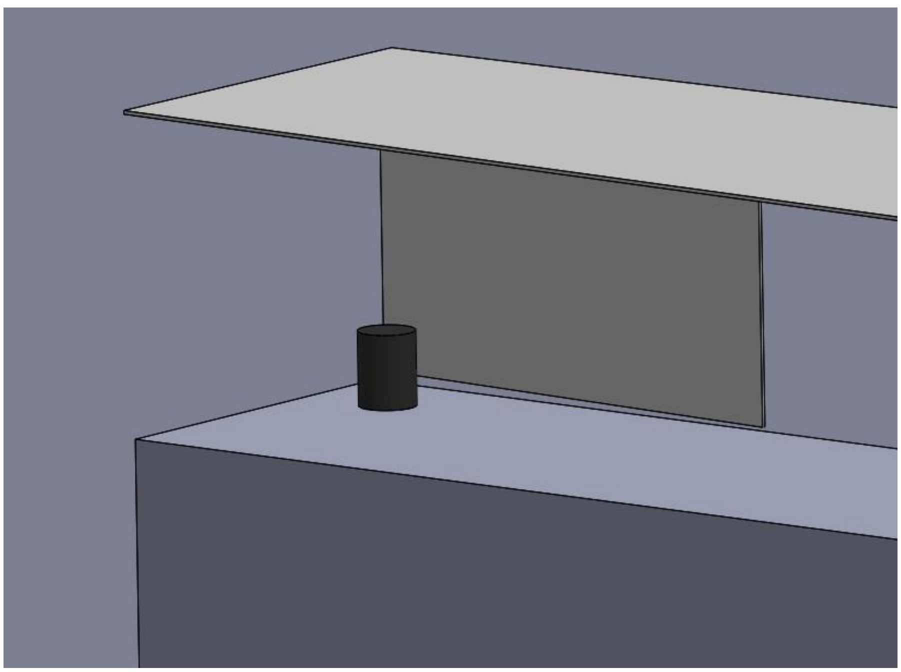

Figure 7: *An approximation of the situation surrounding the fourth scan, "corner".*

As an evaluation of our 3D scanner we performed 4 3D scans in different shaped environments. These four scans were scan1, walls, under, and corner. The images of the sensor in these locations for the first three can be seen in ***Figure II1***, ***Figure II3***, and ***Figure II6***. The fourth scan, corner, has no picture, but was a situation approximated by ***Figure 7***.

The first scan, scan1, was done at the lowest used resolution of 20. It can be seen in ***Figure II2***. Resolution was a number specified in our programming which decided how many distinct points the pitch and yaw motors ranges would be divided into. Because of the nature of the code, the number of points, P, which follows from a resolution, R, will be as follows:

$$P = R^2 + 2R + 1$$

In addition to having the lowest resolution, scan1 was done in a mostly open environment. As points outside of the IR sensor's calibrated range are deleted, the overall environment shown in ***Figure II2*** is indistinct.

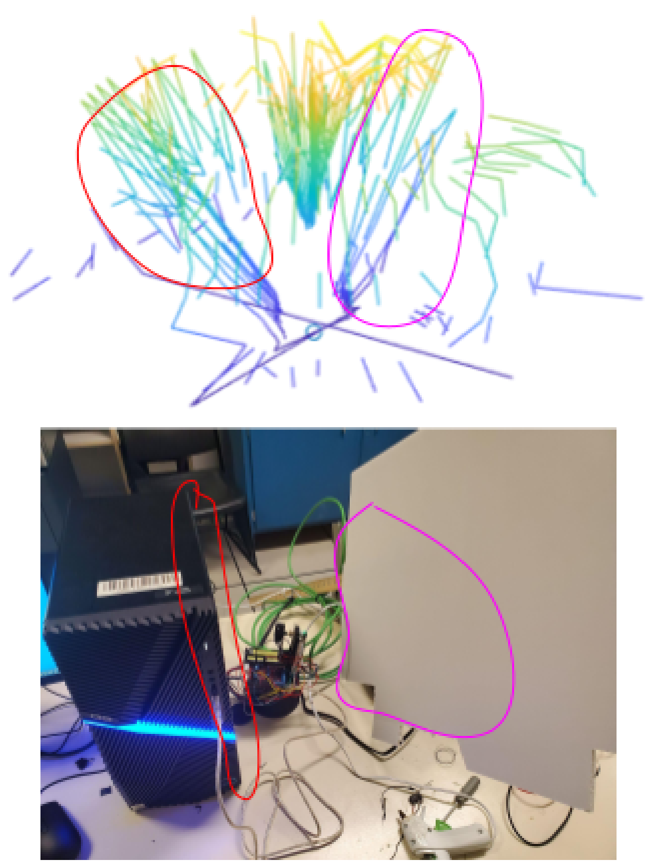

Figure 8: *An attempt at highlighting common features from the scan to the real world.*

The second scan, walls, was done at a resolution of 30, and in an environment more suitable for its sensor. ***Figure II5*** shows the scan at a similar angle to the picture taken in ***Figure II3***. ***Figure 8*** attempts to connect features seen in the scan to real life, although the scan features something between the red and magenta circles which doesn't seem to be there in the picture.

This might be due to the nature of the scanner. Objects a certain distance away begin increasing the output voltage for a time before it falls back off to zero. It is possible that the ceiling in this scan is at that distance and so interpreted to be closer, but in an odd shape. It could also be due to the foam core wall moving significantly at some point in the scan.

The third scan, under, again seems to roughly correspond to reality as shown in ***Figure II6***. These images (***Figure II7-II9***) seem to feature one shallow plane and one harsher plane. These might correspond to the underside of the table and to the back of the chair.

The fourth scan was done at a much higher resolution (of 100), and in a more suitable environment. This scan took the longest at about half an hour, but produced obvious walls and possible ceiling, best seen in ***Figure II13***. The glitches in the ceiling were likely due to operator error, as the experimenter was holding the ceiling there and it likely moved quite a bit in the experiment.

The walls were more stable, and had a slightly different error. They seemed to curve as they went up. This was likely due to faults in calibration. As a failure to correctly observe a straight line as straight implies the sensor saw points near where it should have, but slightly off in a way that became more pronounced af farther distances.

Conclusion

The 3D scanner functioned reasonably well. The design could be improved by changing how the pitch motor operates, as it was able to become unset from rapid turning. In addition, all the mass rotating caused the device to move a bit on the desk during testing, and likely at least a little during the actual scans. A much more compact device where the motors only move what is needed and all the electronics are simply set off to the side would probably function better and would require less 3D printing. Although, a more secure cabling method would probably be needed.

In addition the sensor could be replaced with a better one with a higher range. Or it could be calibrated more diligently. Also, some parts of the code which were meant to wait until the device was in position did not do so and likely needed more tweaking. Finally for future testing, the sensor needs a better scanning environment. Perhaps a cardboard bow with a known size placed over the sensor would function as a more reliable scanning environment.

Appendices

Appendix I: PID Calibration for Pitch and Yaw Motors

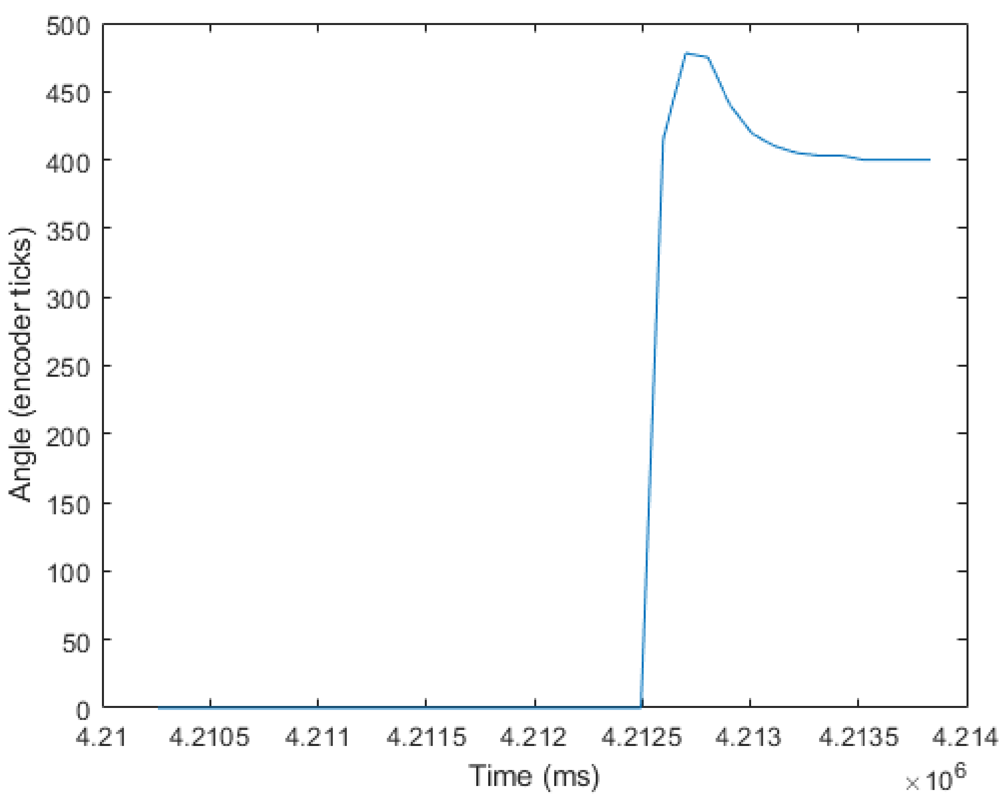

Figure I1: *Settling graph of the pitch motor PID control.*

```
     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.*

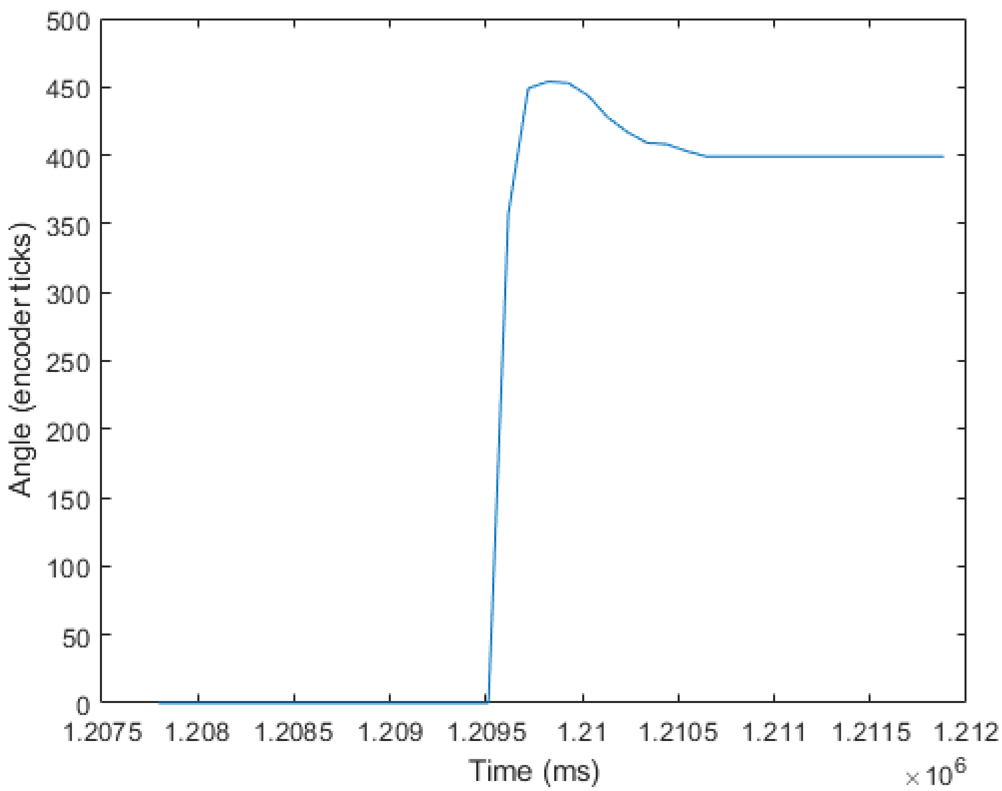

Figure I3: *Settling graph of the yaw motor PID control.*

```
    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

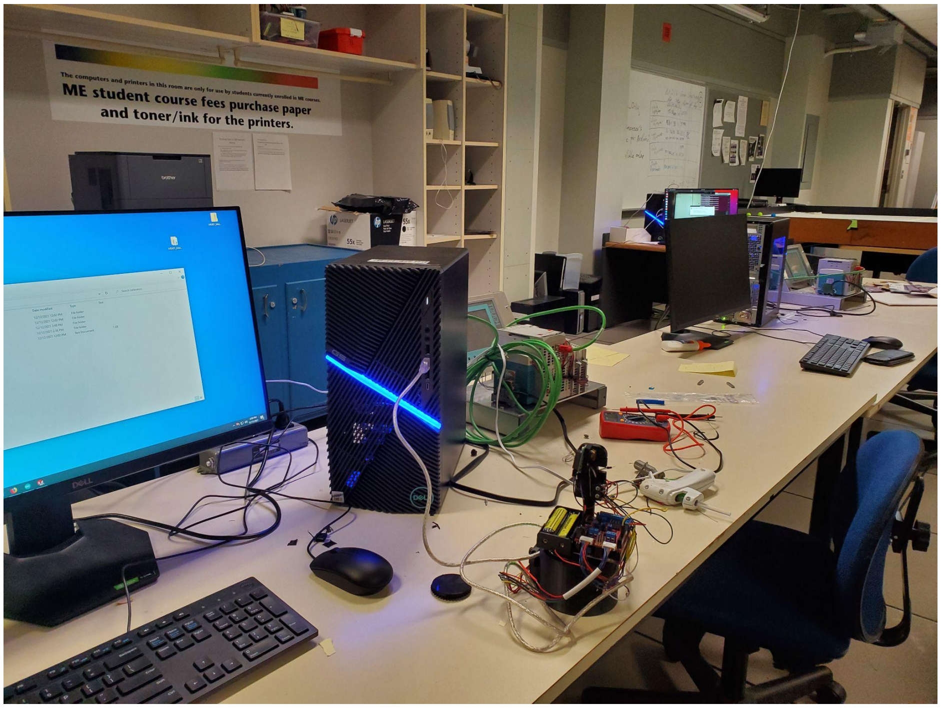

Figure II1: *Location of first scan, "scan1".*

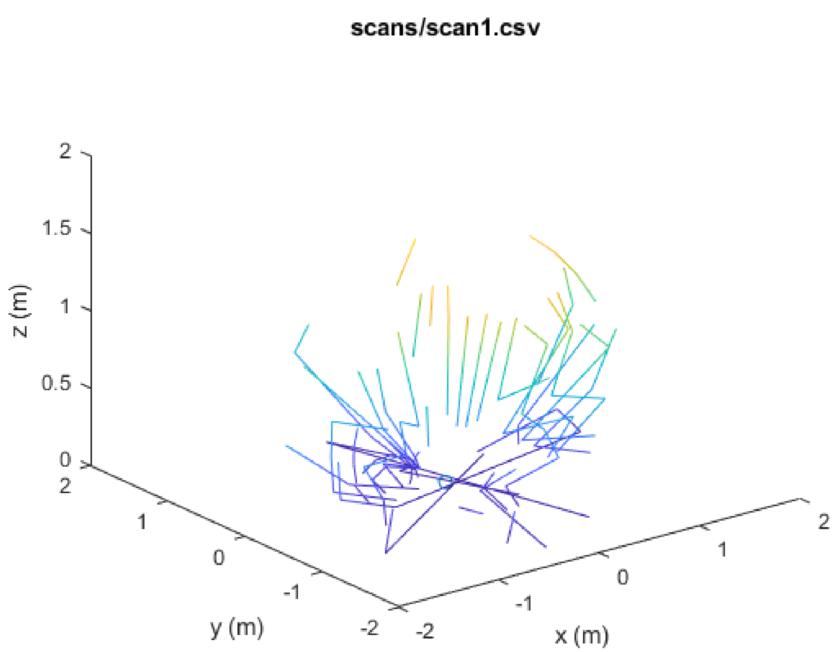

Figure II2: *First scan, "scan1". The resolution was set to 20 (441 points) on this one, and not much can be seen.*

Figure II3: *Location of a scan between two walls, “walls”.*

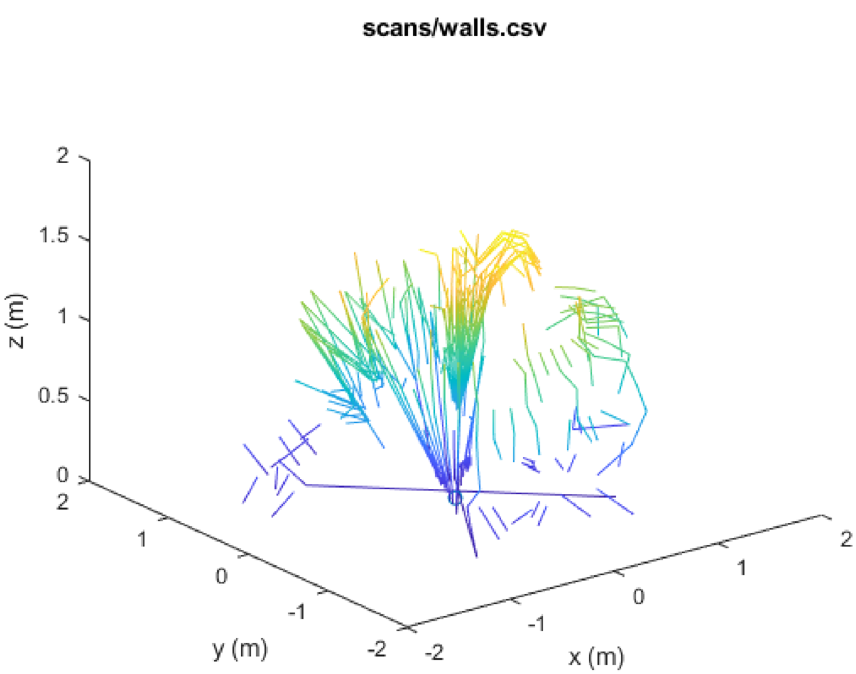

Figure II4: *Scan of “walls”. The resolution was set to 30 (961 points).*

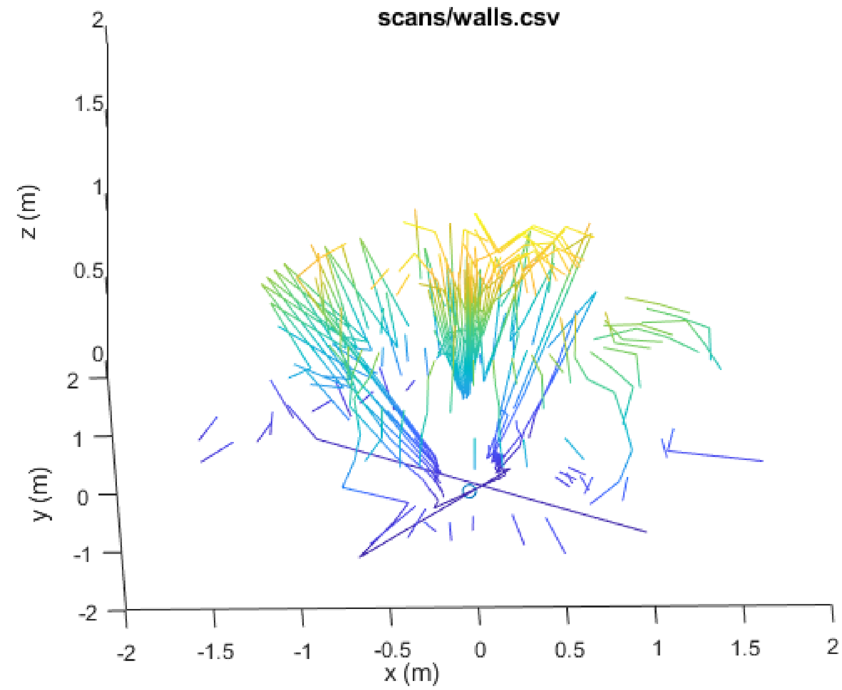

Figure II5: *Another angle of "walls" with the walls more visible.*

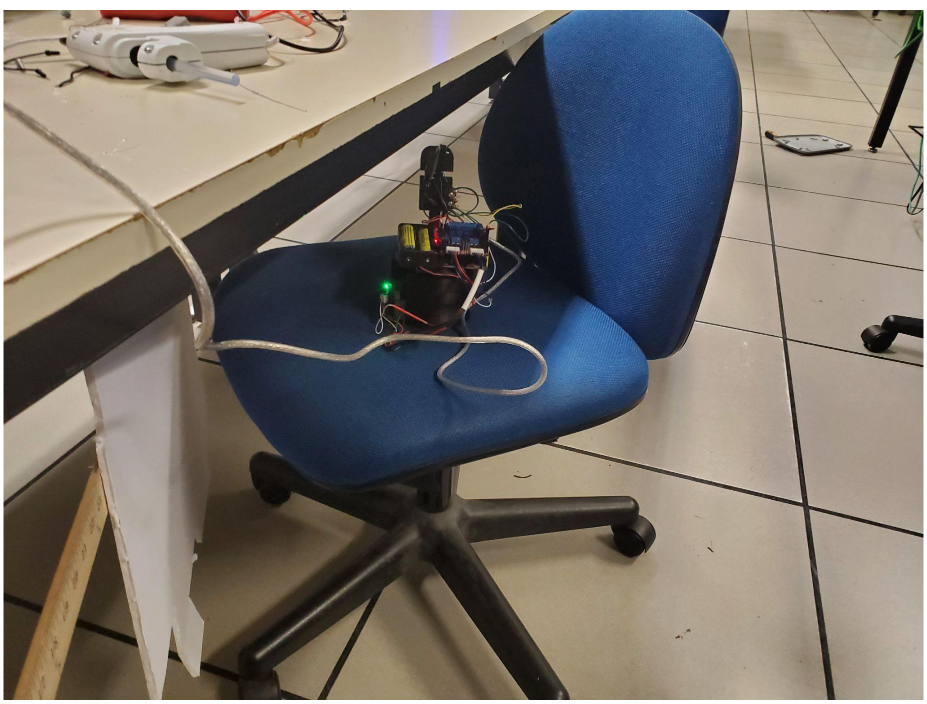

Figure II6: *Location of a scan with a partial ceiling, "under".*

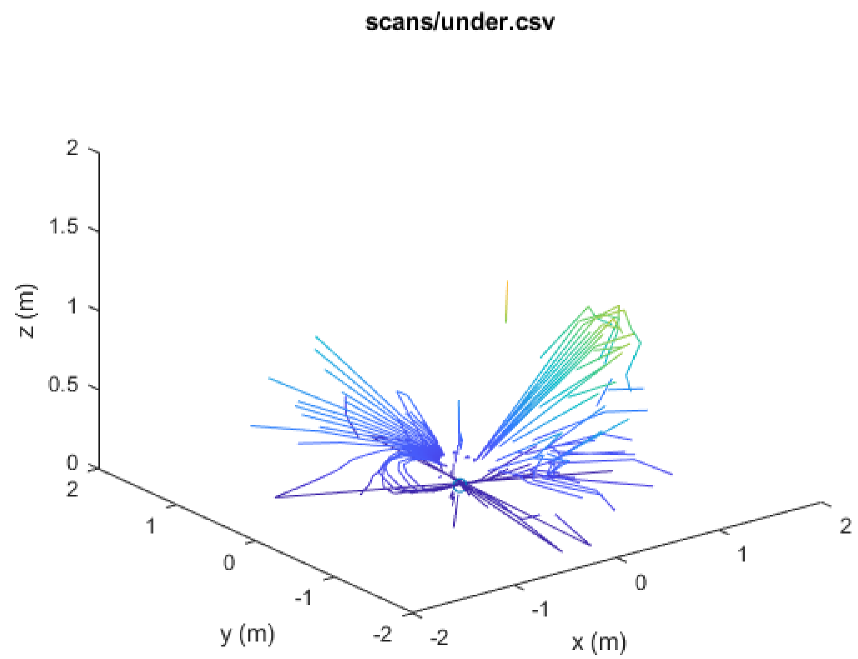

Figure II7: Scan of "under". The resolution was set to 40 (1681 points).

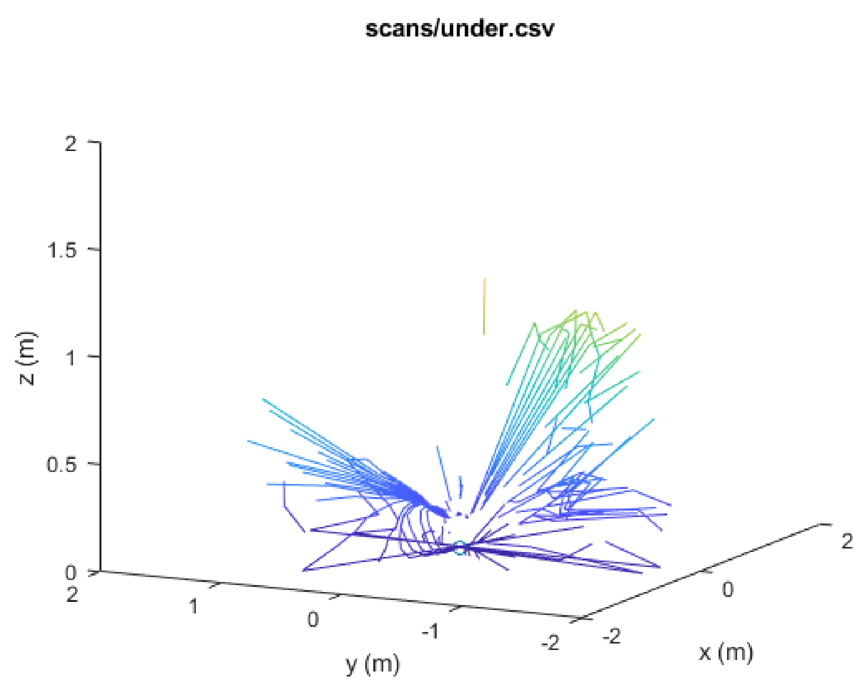

Figure II8: Another angle of "under".

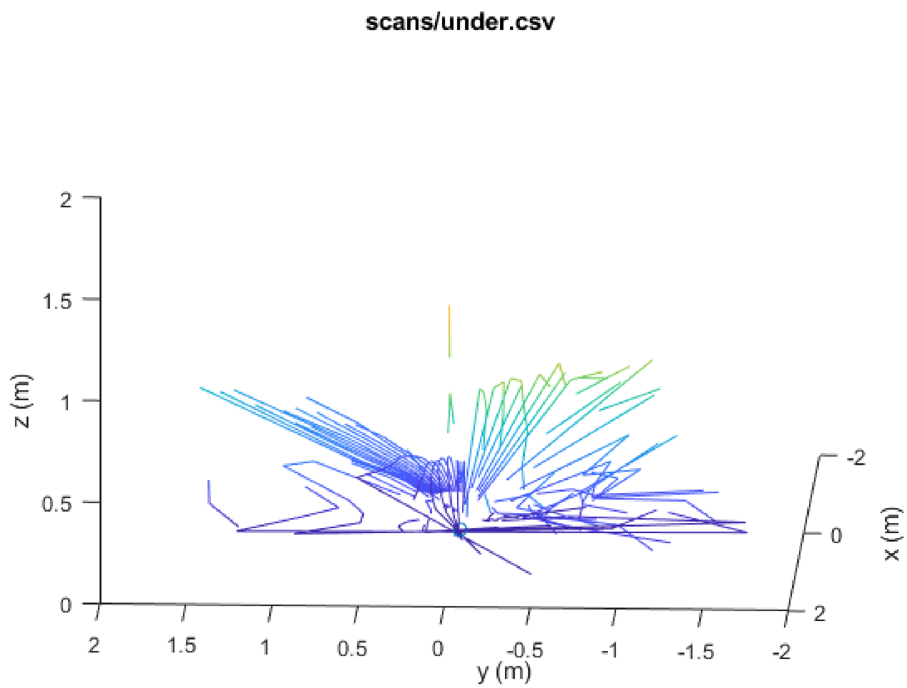

Figure II9: *An angle of "under" highlighting the underneath captured.*

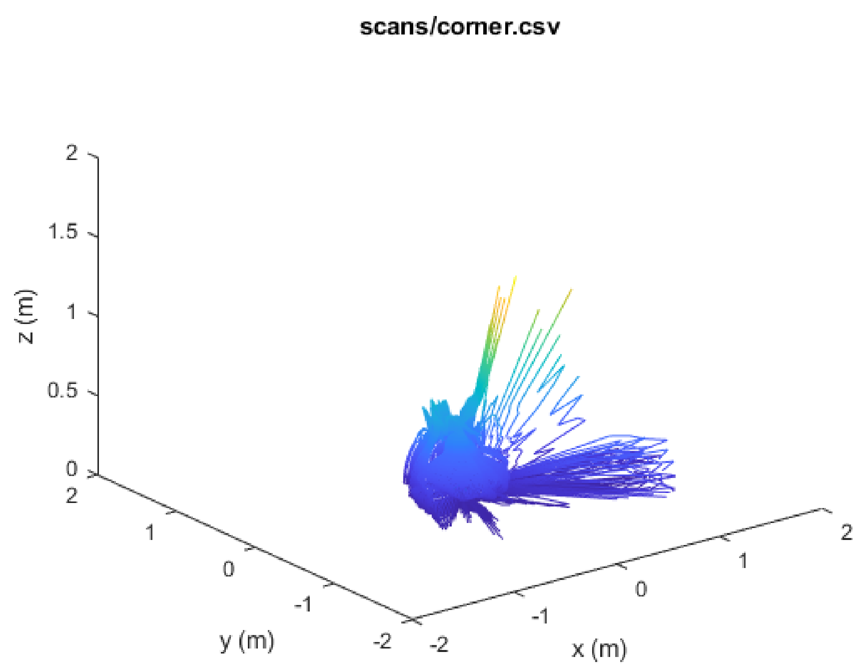

Figure II10: *A scan of "corner". There is no image for this one, but it was in a corner with two walls, a floor, and a ceiling done at a resolution of 100 (10,201 points).*

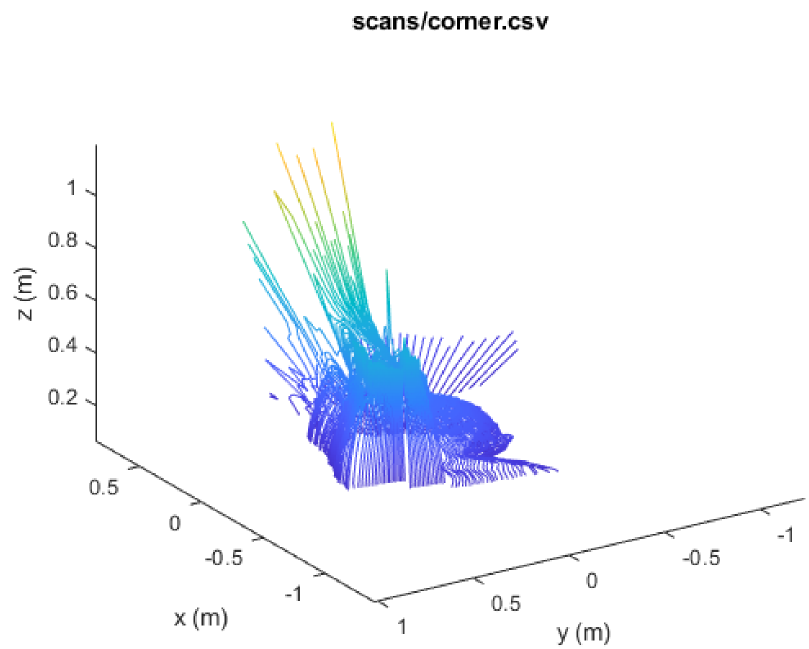

Figure II11: *Another angle of "corner" showing the intersection of the walls..*

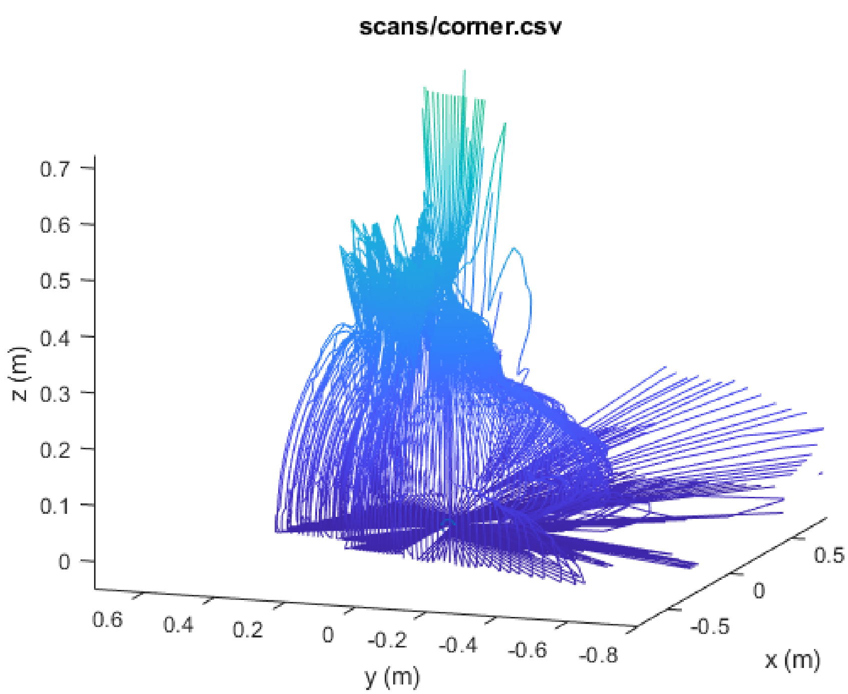

Figure II12: *Another angle of "corner showing a clear floor, two walls and a ceiling. The walls are a bit disturbed and the ceiling more so, likely because it was a 30 minute long scan with the environment being held up by hand..*

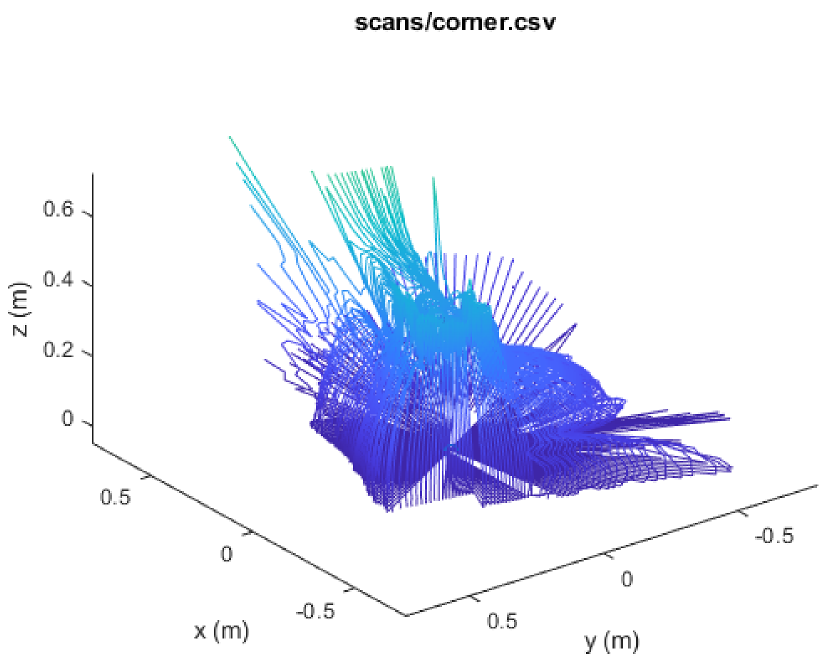

Figure II13: *Another angle of "corner", from the perspective of the corner..*