Chapter 5

Final Model and Conclusions

My research uses a Raised 3D Pro2 printer (see Fig. 5.1) using the software ideaMaker with a precision of 0.5 mm to print the Fusion 360 models of the cam leg design. Two design iterations were printed and attached to an Antrader Dual Shaft 3-6V Motor for testing. Section 5.1 discusses the manufacturing consideration of the actuation device and the following sections test the device, the goal of which is to prove the validity of the developed simulation environment in Section 4.2.

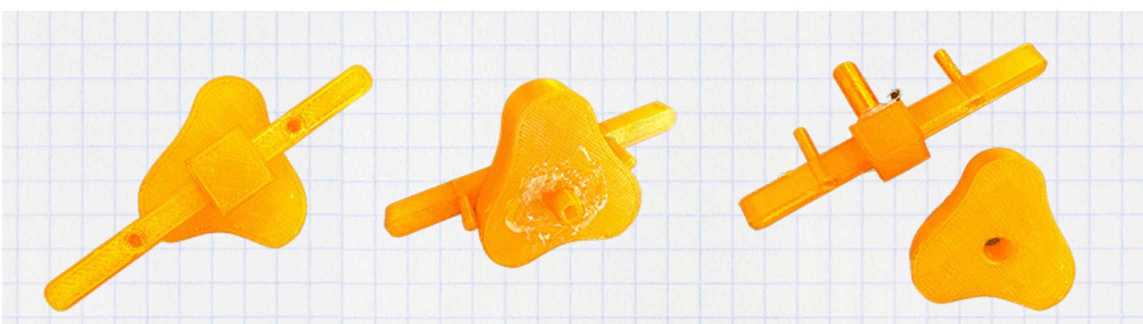

Figure 5.1: First cam print parts

5.1 Print Faults and Fixes

The specifications displayed in Fig. 3.21 define the first print of the design. The first iteration print of the design included the following faults:

- Unstable connection between the base of the rotating arm shaft and the leg insert, fixed in Fig. 5.3.

- Lack of mount. The cam had no built-in mechanism for mounting, fixed in Fig. 5.4
- Sharp contour edges, creating jerk when 3d printing. Fixed by rounding edges on the face of objects.

The second iteration of the print, the final print, proved to be sturdy after ameliorating the faults in the preceding list. To reduce print time, the interiors of the shapes contained several cardboard-like edges, in place of a complete infill, displayed in Fig. 5.2, which negligibly affected stability.

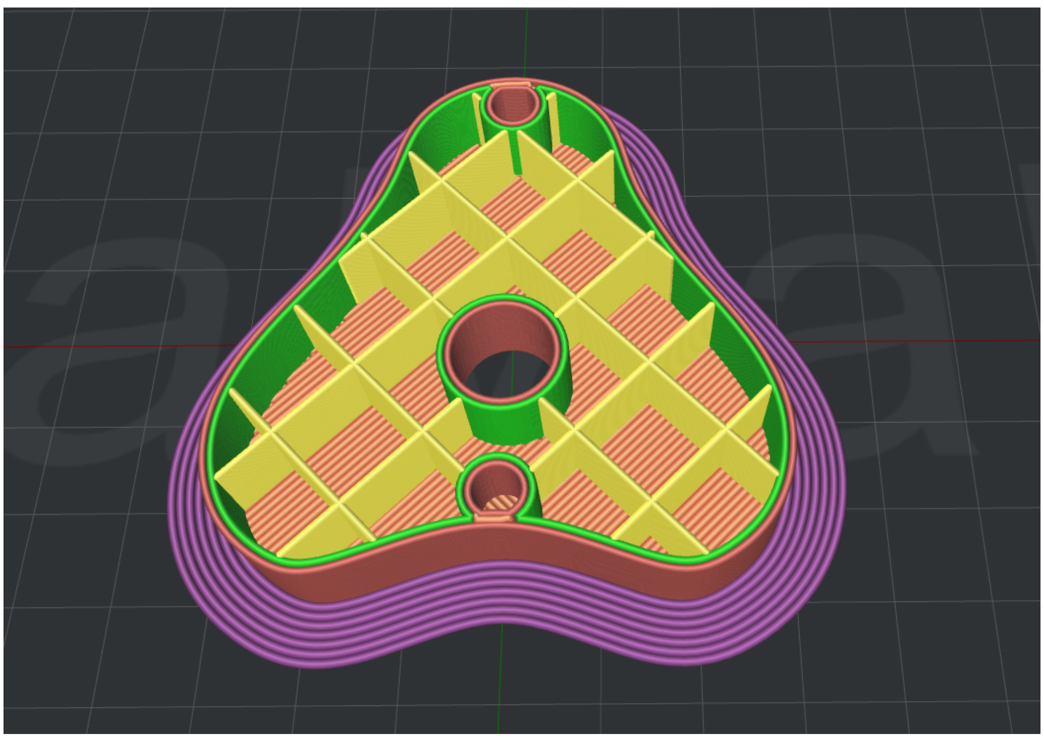

Figure 5.2: Interior slice of print. Reducing the amount of infill decreased print time while maintaining stability.

5.1.1 Conclusion on Print

Other manufacturing processes could avoid the issues that printing the mechanism created. Crow [3] manufactured a similar actuation device using metal which might be a more promising approach to build stability and the amount of material needed. Another manufacturing method might consider a multiple material design

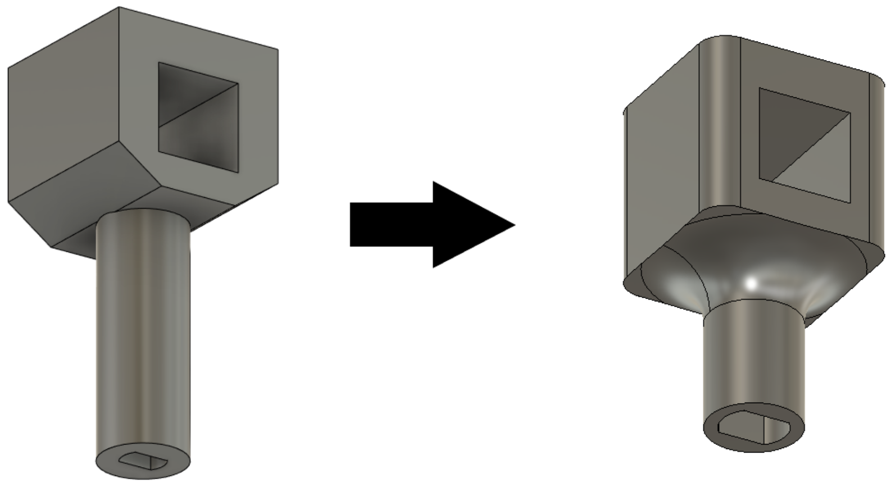

Figure 5.3: Change in rotary arm design: smoothed contour of shape, squared shape of leg slot, and added more connection material between base and shaft

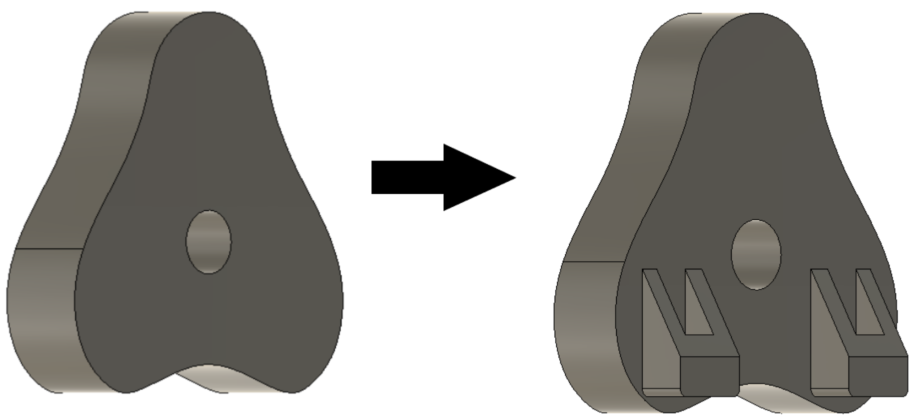

Figure 5.4: Change in cam design: decreased thickness of cam and added brackets for mounting

in which the cam is 3D plastic, and the rotary arm and legs are metal. The final print ameliorated most material issues, and the 3D plastic print proved to be exceptionally stable.

Widening the base of the rotary arm shaft created a more stable connection. Rounding the contours of the shape faces improved the consistency of print quality by reducing jagged edges, and the added mounts created a sturdy support surface. The only design change to consider is the frictional contact between the ends of the leg and the ground. In some cursory testing, frictional contact improved with glued rubber pieces to the ends of the leg. Another iteration of the design would expand on better frictional contact.

5.2 Testing of Printed Leg

The objective of testing the leg mechanism with a limited budget is to acquire experimental data compared to the simulation data. Comparable data experimentally proves the developed Simscape Multibody simulation environment concerning the type of data obtained, i.e., gait dynamics. The primary test regime of the simulation environment is limited to the dynamic gait model of an omnipede-like robot using the designed cam leg mechanism.

The trajectory of the print is analyzed in Section 5.2.2 with discussion of failed testing systems in Section 5.2.4 and a short discussion of angular velocity in Section 5.2.5.

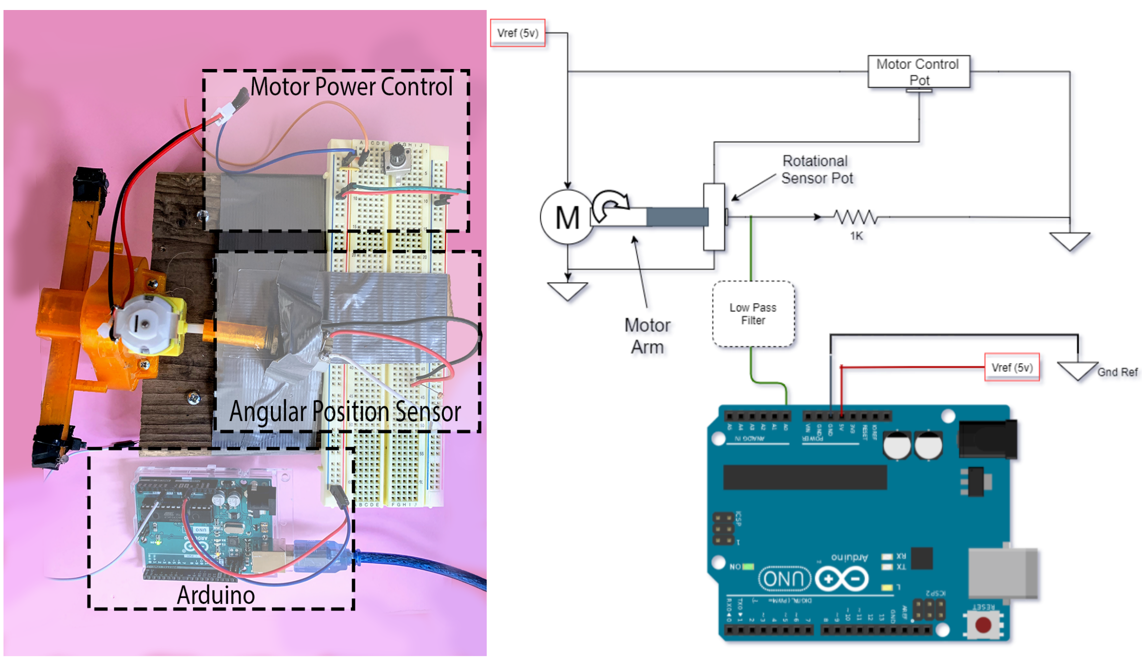

Figure 5.5: Test environment of device. On the right is the circuit diagram representation of the picture on the left. An Arduino was used for the test harness.

5.2.1 Consideration of Ideal Test Environment vs. Home-Brew Testing

As mentioned in prior sections, this research was conducted at home without laboratory equipment. This test environment limited my ability to collect rotational acceleration/position and frictional contact. Ideally, the relative angular position would be sensed with a quadrature encoder attached to the back arm of the motor, see Kano et al. [9] for some idea of how this would look. Kano's test environment mounted a motor on a surface above a conveyor belt capable of measuring thrust potential. Without the lab equipment, the attempt to measure frictional contact did not prove fruitful. The bulk of considered experimental data is dependent on the comparative trajectory analysis of the device using After Effects and the simulation data from Simscape Multibody.

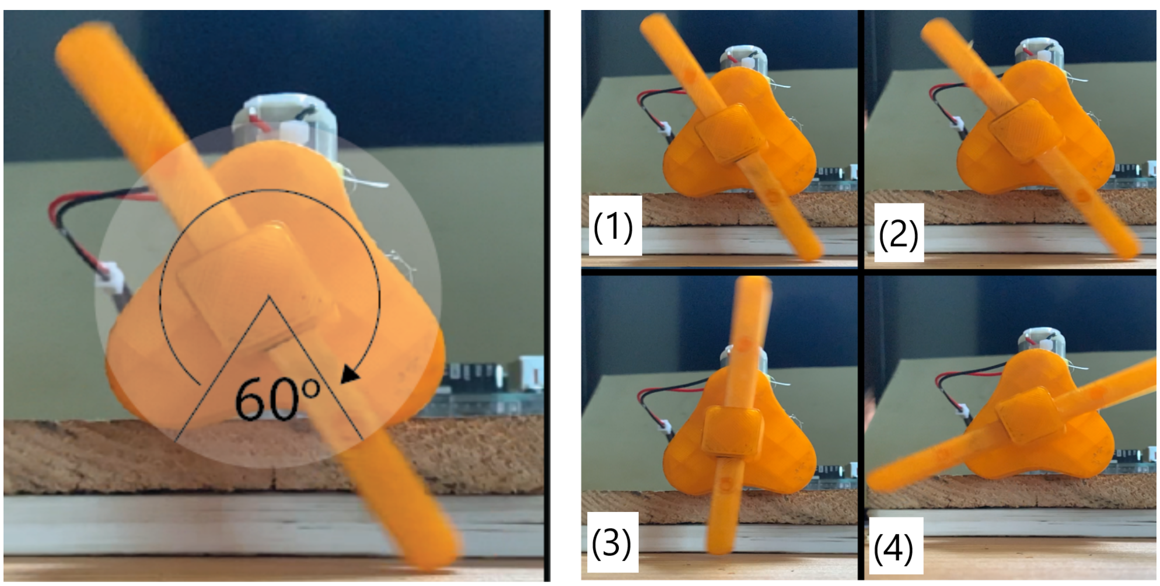

Figure 5.6: Sixty degree span of leg contact with ground. (1-4) show snapshot of the motion of the leg, which moved as initially intended.

5.2.2 Testing Trajectory

A test harness determines if the leg mechanism's trajectory is comparable to the intended orbit in the original design, shown in Fig. 3.18. The test system, shown in Fig. 5.5, is comprised of an Arduino Uno, a 10-spin potentiometer for angular position detection, and a potentiometer in a voltage divider circuit to control the speed of the DC motor. The angular position of the leg was initially determined by reading the resistance of the 10-spin potentiometer connected to the shaft of the DC motor. This data was not used in the final trajectory analysis, though, as it proved to be quite noisy, as discussed in Section 5.2.4.1.

The trajectory was measured using After Effects motion tracking of a slow-motion video of the leg mechanism, see Fig. 5.8. This motion data does not include any time data, as an iPhone 8s with custom slow-mo software captured the slow-motion video. This issue hinders capturing angular velocity, discussed further in Section 5.2.3.

5.2.3 After Effects Trajectory Analysis

Fig. 5.6 shows the motion of the 3D printed leg in motion and the span of it's propulsive state. In the first trial, the system appeared to move as intended. After Effects motion-tracked a green dot on a piece of paper attached to the foot of the cam for one rotation. Analysis ignored velocity of the leg as tracking data returns the foot's position based on the frame data from the video, which is not a source for time data because of the custom iPhone slow-motion video capture software.

Typically, cameras record at a standard rate of 30 frames per second(fps), or possibly 60 fps, but the iPhone uses software that automatically slowed down parts of the video and added inconsistencies in using the frames as a determination of time. Fig. 5.7 shows the position of the trajectory without any reference to time. Angle of the arm is determined with trigonometry i.e. $\theta = \arcsin \frac{y_{pos}}{x_{pos}}$.

The ideal analysis would capture data in millimeters. My home laboratory setup, which uses After Effects only, provides pixel data; thus, I normalize the trajectory in pixels to the known length of the leg 120mm.

As shown in Fig. 5.8 the trajectory proves to be relatively accurate. Fig. 5.9 shows an error analysis.

The maximum error is about 4.6mm between 70 to 120 degrees. This error does not significantly impact the gait of the system, as it occurs at the bottom of the foot trajectory and maintains a visually straight course as shown in Fig. 5.7. Minor improvements would include a better mounting surface as well as larger pegs on the leg. The pegs used in the test were shorter than the width of the cam and had some tendency towards skewing.