Autonomous Bicycle Team

Final Research Report, Mechanical Sub-Team

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Goal

The goal of the Autonomous bicycle team is to design, fabricate and test a bicycle capable of autonomous and semi-autonomous operation. The first benchmark to achieve this goal is producing a bicycle that can drive itself in a straight line. The second is to produce a bicycle that is capable of remote radio control by an operator, and the third is to convert the bicycle to “fly-by wire”, wherein an operator on the bicycle itself drives with a controller that does not have a direct mechanical linkage to the steering wheel. Further iterations on the fly-by wire design include additional stabilizing controls implemented by the bike’s onboard computer to observe whether or not a human is capable of riding a “smart bike” that will respond to user input but do its best to stay upright at the same time.

There are two reasons motivating this project. First, many of the electrical components used in the bicycle will eventually be applied to the bipedal robot that is the primary focus of the lab. These will require a significant reservoir of experience to be put into operation. Also, working with them on this project will expose their limitations and may alter the overall design approach of the robot. In a sense the bicycle is a test run of the bipedal robot’s computing capabilities, but with a much smaller overhead.

Second, the far reaching implications of a semi-autonomous robot bicycle can be seen through a commercial lens. Ideally, a highly refined version of this project would be available to assist young children and those with inner ear (balancing) disabilities in learning how to ride a bicycle. It provides a middle ground to the safety of training wheels and the efficiency of a regular bicycle that would normally have to be provided by a human running alongside it. It can fill part of the learning curve that is generally fraught with injury and accelerate the overall process.

Division of Work

Each member of the team will be submitting an individual report describing their contribution for the sake of overall clarity.

Abstract

This report covers the progress made towards completing the mechanical portion of the BioRobotics and Locomotion Lab Autonomous Bicycle project. As of the completion of this report, the bike is mechanically functional but has yet to have all of its electrical components wired together and tested. Testing of the bike will necessitate some fine tuning but for all intents and purposes the bike should be able to move and steer itself.

Initial work centered on building team competency with preliminary CAD design. After selecting a bicycle, work progressed to designing around the unique structure of the Dahon Classic III frame, and the semester finished with fabrication and the integration of the steering assembly. Unexpected trouble with mounting the potentiometer necessitated the design and fabrication of a flexible coupling to attach it to the fork.

This project served as an introduction to group work for the freshmen on the team (Arundathi and Mert), who I instructed in CAD modeling and basic fabrication techniques. They are responsible for the electronics box and several of the designs included in this report, both of which I oversaw work on.

Summary of Work

Preliminary Design

The focus of the mechanical sub-team is to design and fabricate all of the components related to the physical movement of the bicycle. The most complex and challenging design within this project is the steering motor, which must turn the front fork while integrating sensors to measure turn angle and rate. Notably, the cost of components from other sections of this project presented a unique challenge in that funds were extremely limited for these parts, and as a result the steering component is built entirely of scrap from the lab.

Early in this semester the team expected to be using a new and full size adult bicycle, so preliminary sketches were completed in anticipation of purchasing one. Figure 1 shows the earliest design, with a motor attached to two rigid clamps on the front tube. The positions and sizes of all components are relatively sized and intended for concept only.

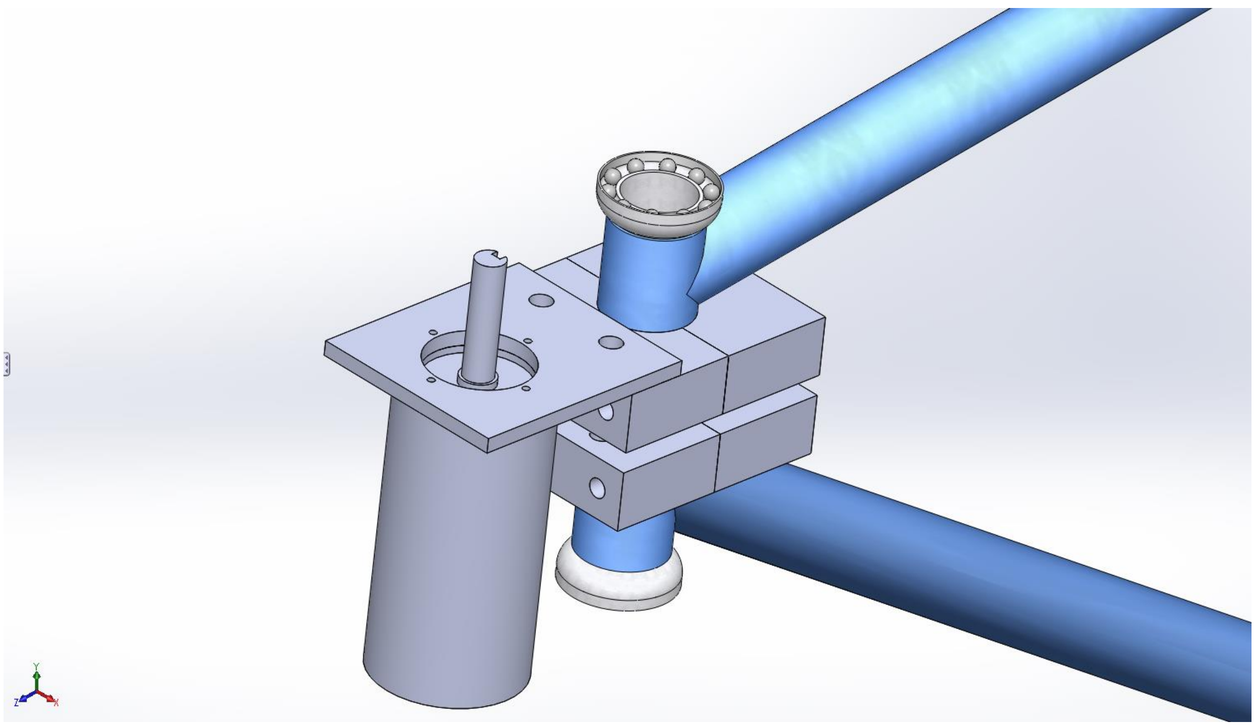


Figure 1: Early design for steering motor on a full size bicycle. The shaft on the motor would have been connected with a gear train to the fork to actuate motion.

This design later evolved to include a mounting scheme for the potentiometer used for detecting steer angle. The potentiometer design was intended to be easily integrated onto any bicycle by being able to change the angle at which the potentiometer shaft was inserted into the fork, as there is significant variation in the orientation of front tubes between bicycle models. A rigid link from the sides of both clamps would have been included in a more mature design to prevent the clamps from rotating about their respective tubes. The second design is shown in figure 2.

Both of these designs doubled as teaching tools for the freshmen on the team, who were guided through basic CAD techniques.

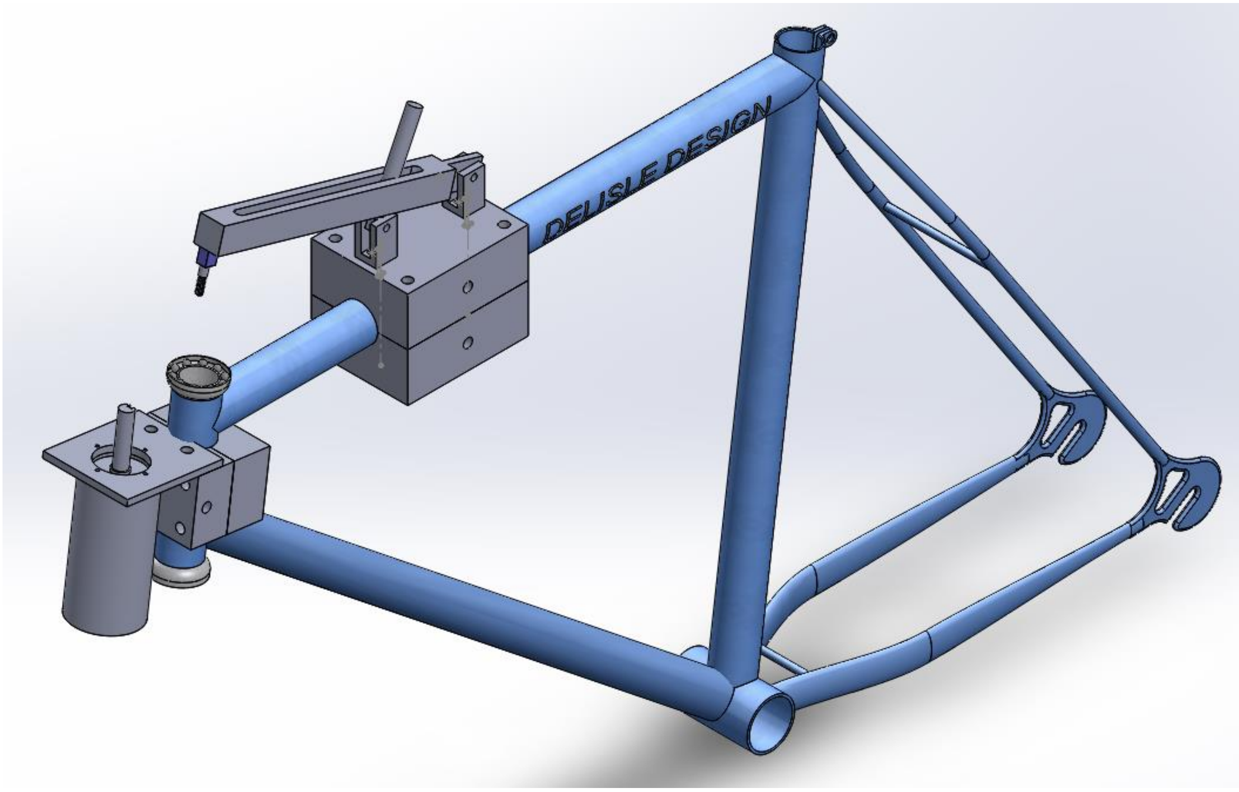


Figure 2: Second design concept for full sized bicycle, including the potentiometer assembly.

Bicycle Selection

Intervention by Professor Ruina midway through the semester scrapped previous plans in favor of using a much smaller folding bicycle. The final design bicycle is a Dahon Classic III, shown in figure 3. Figure 4 shows the portions of the bicycle that remained after removing components deemed not necessary for the final design, though the seat would eventually be repurposed for mounting the electronics box.

Figure 3: Bicycle selection, the Dahon Classic III.

Figure 4: Stripped down bike.

The Classic III is an older model of folding bicycle that was donated to the lab and maintains numerous advantages over a full sized bicycle for our purposes. While it appears more suited for small children than college students both the handlebars and seat are adjustable up to normal height for an adult. The U-shape that this arrangement creates makes it easier for a rider to dismount in the event of an accident. Also, the smaller wheels (16" as opposed to 29") reduce the torque required to steer the bike.

The only significant hurdle with using this bike is the awkward front tube structure which is unique to this model. Not only is the front tube extremely small relative to other designs, it is also canted at an angle dissimilar to both of the tubes it connects to. This makes any simple mounting scheme difficult and is why the current setup could benefit from revision. The close proximity of the tube to the wheel also invalidated the earlier design that oriented the motor shaft upwards.

The propulsion for this bike is provided by a Magic Pie 2X brushless hub motor. It was selected on account of its appropriate size for the wheels and its power output of 250W, which is comparable to a human cyclist. It runs on 24V like the steering motor.

Steering Assembly

The steering assembly consists of two major components: the steering motor and the potentiometer used for indicating turn angle. They are attached to the bike through a stack of three aluminum plates and an improvised U-bolt around the front tube joint. Each of these plates can be adjusted to optimal height with nuts that are spaced on four main structural bolts (all ¼"-20 hardware). The completed assembly is shown in figure 5. Drawings for each of the plates are located in the appendix of this report.

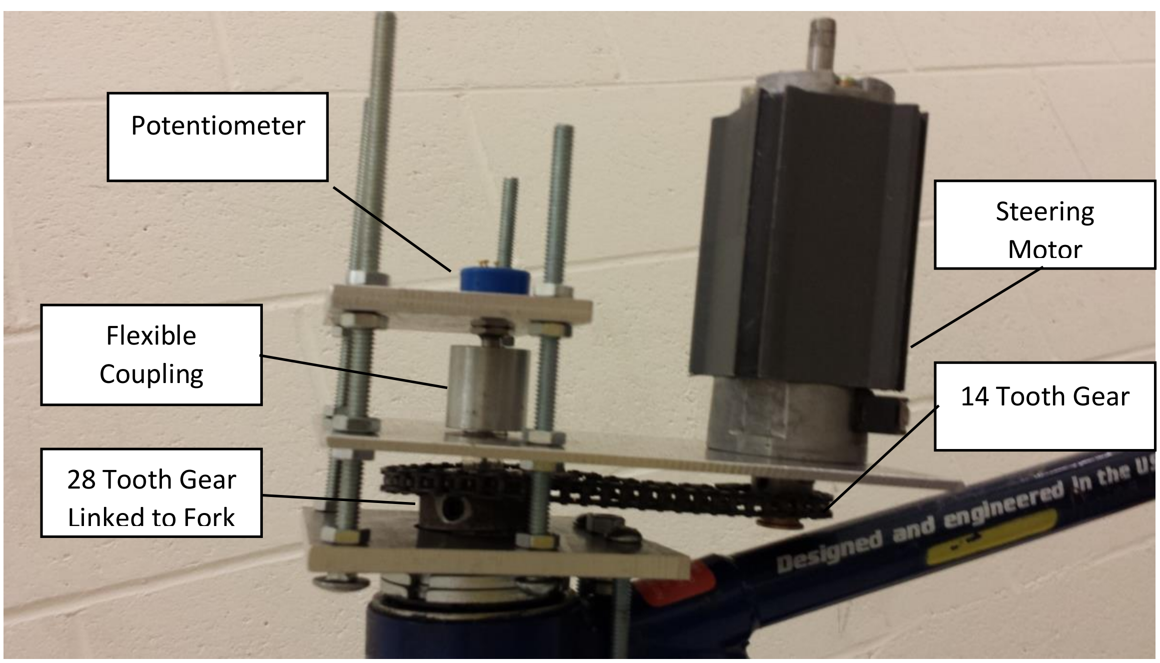


Figure 5: Annotated steering assembly as mounted on bike.

The motor is a Yasakawa Minertia Type J02L, a 24V DC motor that outputs 0.35 Newton meters of rated torque. The 2:1 gear ratio that the assembly uses doubles this to 0.7 Nm, which is far more than the 0.12 Nm necessary to turn the front wheel. Arundathi experimentally determined this requirement by sitting on a bike and pulling on the handlebars with a fish scale to determine the force needed at a given distance from the fork's axis of rotation. I personally tested the completed setup and found it functional with no rider aboard, though the motor gear has a tendency to slip if not screwed on tightly enough.

The potentiometer is a 1 turn, 10K Ohm variable resistor. Turning the fork changes the value of the resistance through a flexible coupling. Initially, it was intended for the potentiometer to be directly connected to the fork, but the fork is not a precise mechanical component and the aluminum cylinder we manufactured to go inside it and connect to the steering system does not align with its axis of rotation. Ariam designed the flexible coupling on the current design which uses simple PVC tubing and an aluminum collar to connect the two components.

Future Work

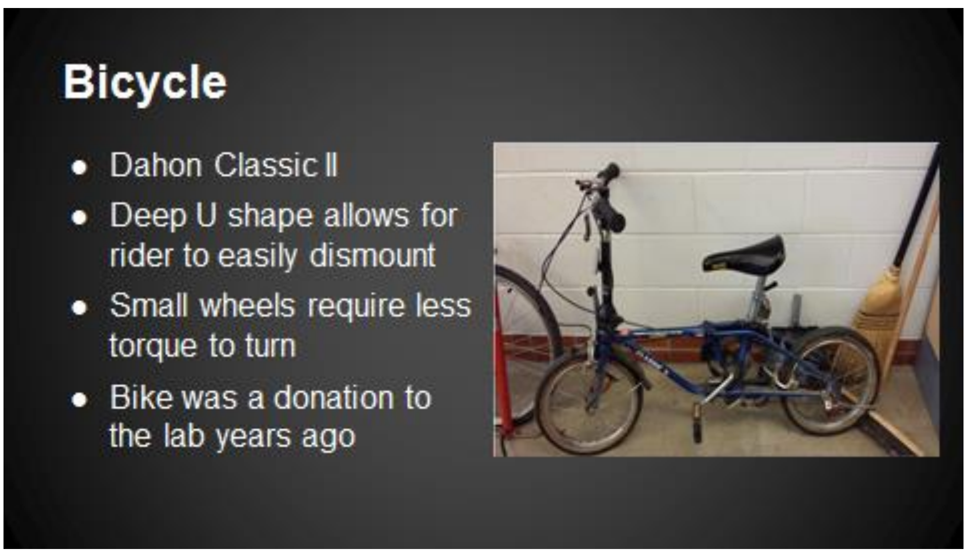
I will not be returning to Cornell in the near future due to a commitment with the US Army and the likelihood of returning before the completion of this project is quite low. A sufficiently skilled junior or senior mechanical engineering student would be capable of finishing this portion of the project in less than a semester. The only major flaw that is likely in need of remedy is the connection of the assembly to the frame. While stable for short periods of use, the bottom plate can rub against and dislodge the spacers on the fork after prolonged usage. Another component that displaces the bottom plate from this area and better affixes it to the frame would greatly improve this system's reliability.

With regards to the more far reaching goals of this project, the middle plate was designed to be wider than the others so it could accommodate a large bearing assembly and handlebars for a fly by wire system. The unforeseen necessity of the top plate for the flexible coupling may now prove an obstacle to that goal, but the overall modularity of the plate-stack design means that only a redesign of one plate may be necessary to accommodate future improvements.

Additional work on mechanical subsystems should not pose an obstacle to the overall completion of the project. Given a few weeks and functional electrical hardware, this bike should be able to run smoothly.

Appendix A: Final Presentation

This appendix contains the slides from the mechanical hardware portion of the presentation (i.e. those relevant to this report).



Propulsion

- Magic Pie 2X
- 250W 24V Brushless motor
  - Comparable power to an average cyclist
- Throttle replaced with outputs from BBB
- Hall sensors for measuring speed
- Comes with 16" wheel
- External motor controller: replaced easily

Steering Motor

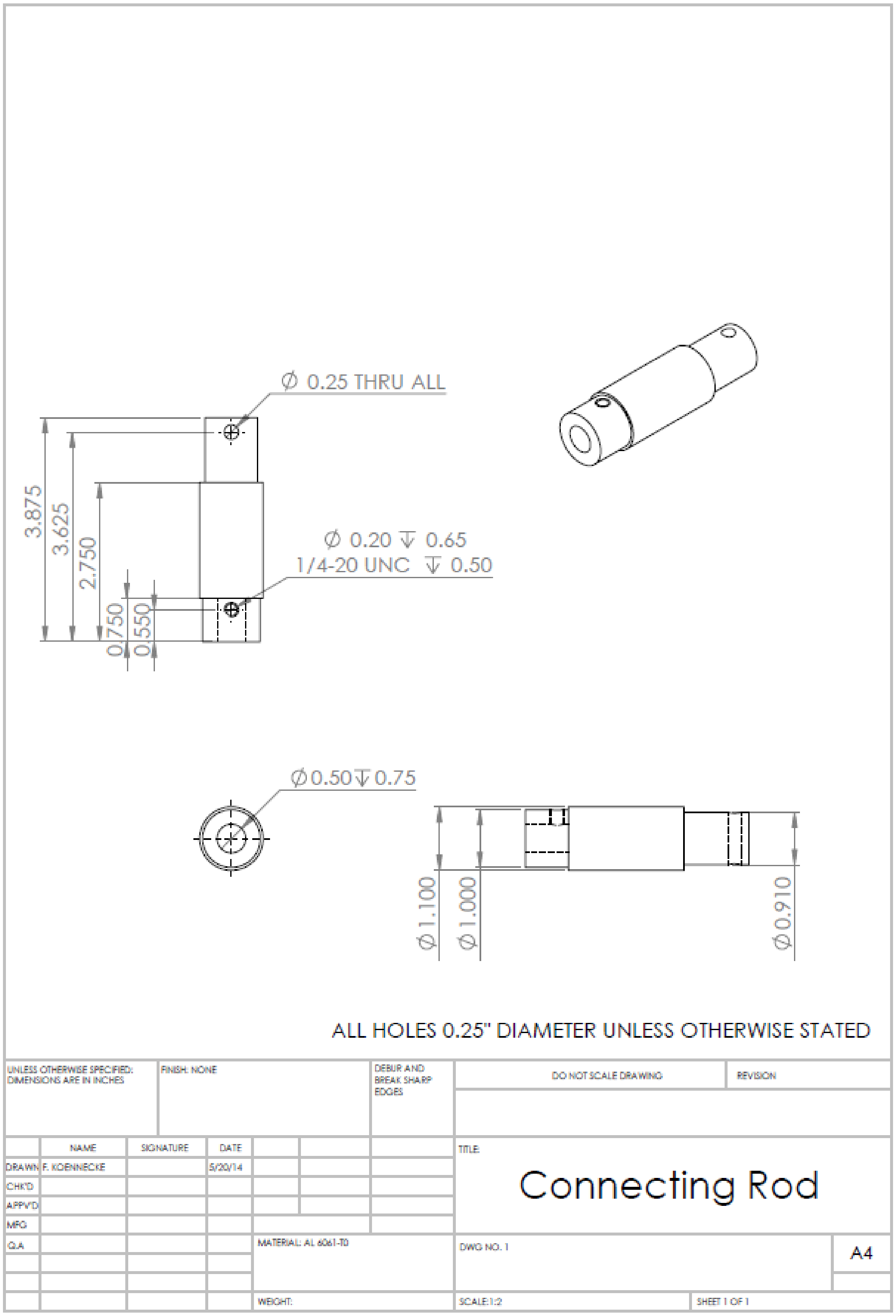
- Yasakawa Minertia Motor (Type J02L)
- 24V
- 50oz in rated torque
  - 17oz in required to turn handle (empirically determined)
  - Gear ratio of 2:1 in mounting scheme

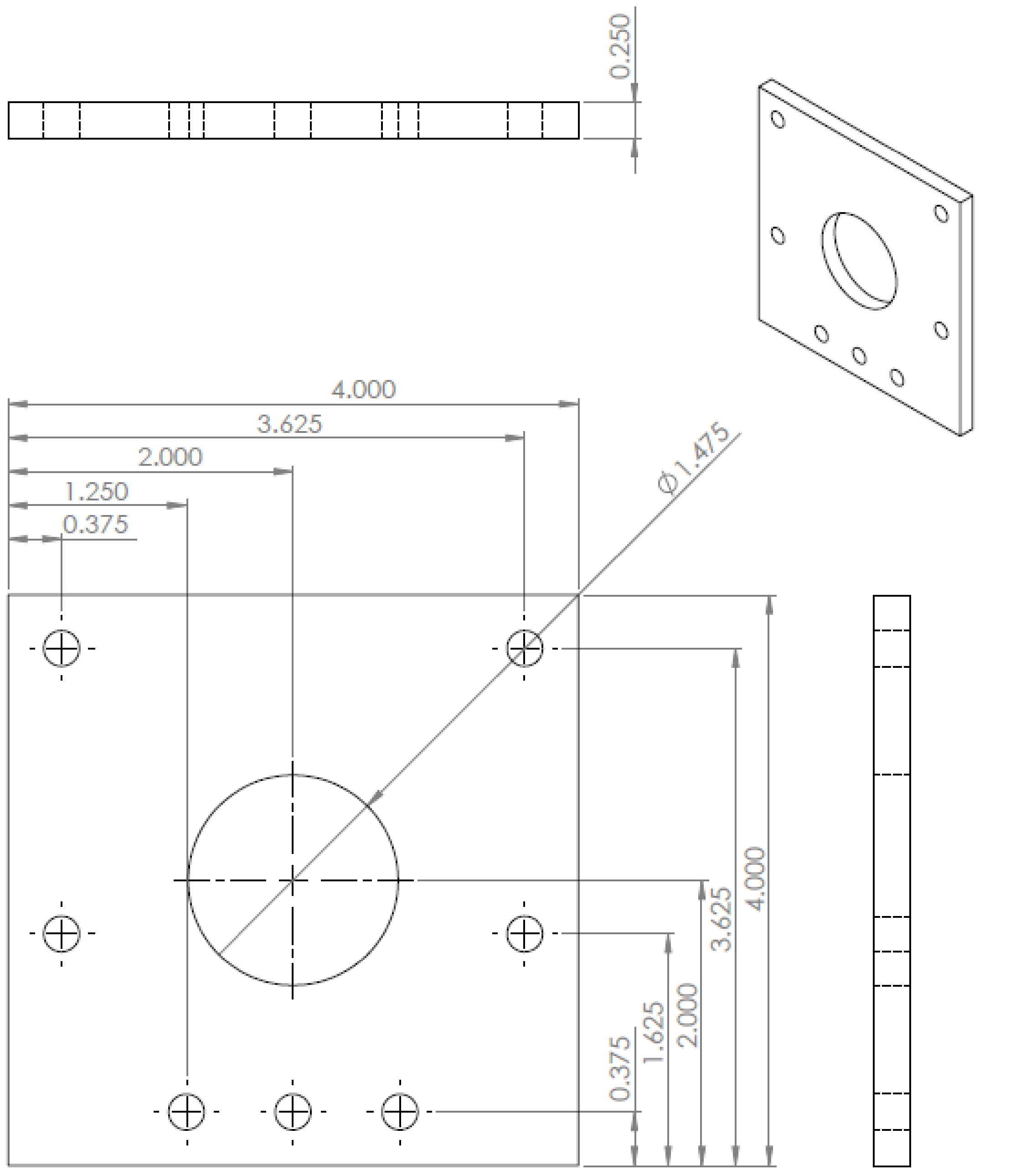
Steering Mount

- Provides structure for steering motor and potentiometer with flexible coupling
- Flexible coupling allows potentiometer to be fixed while the turning fork axis of rotation moves
- 100% scrap lab materials

Appendix B: Supplementary Material

This appendix contains technical drawings for replicating all of the parts produced for this project.





ALL HOLES 0.25" DIAMETER UNLESS OTHERWISE STATED

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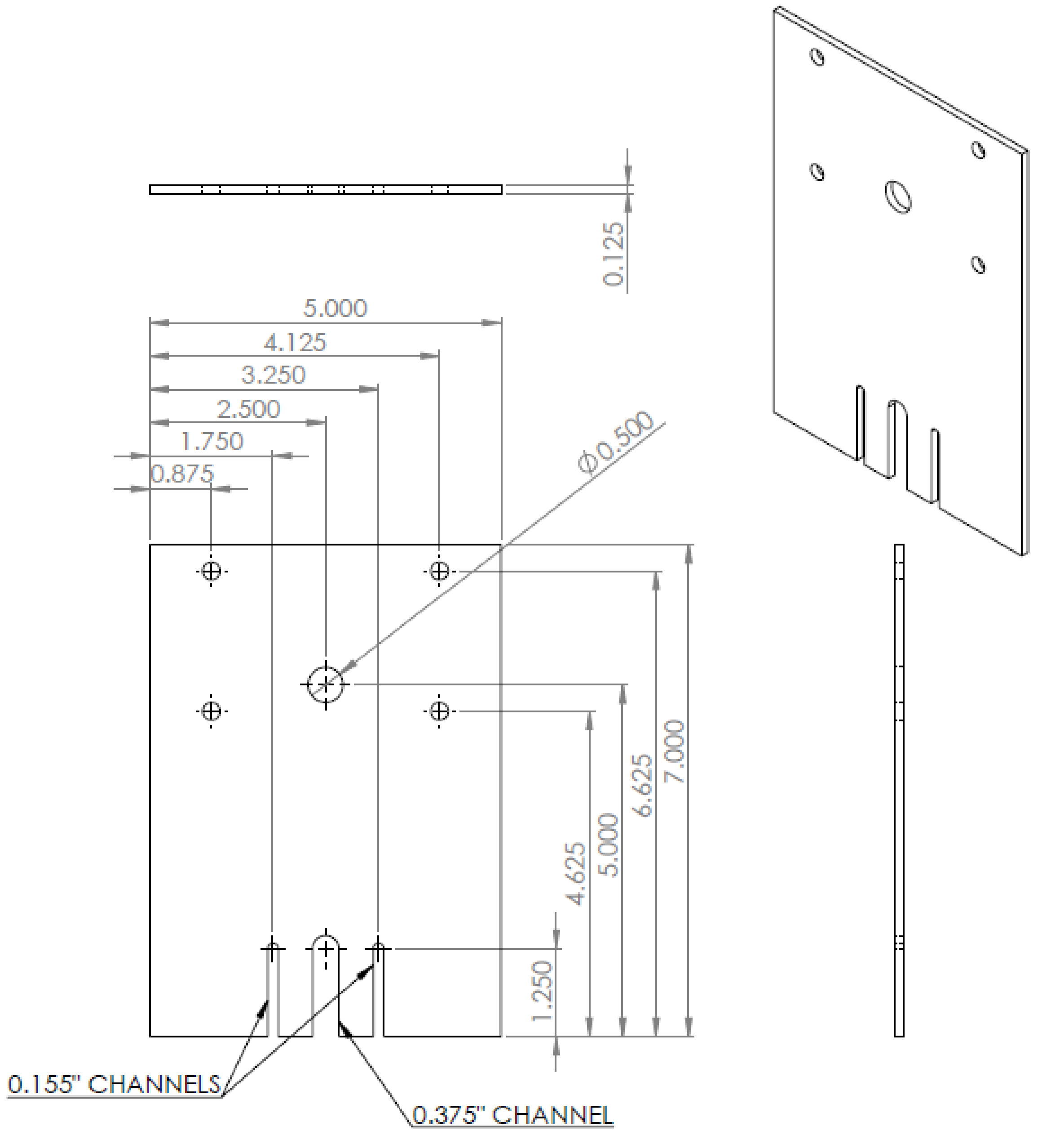
	NAME	SIGNATURE	DATE	TITLE:	
DRAWN	F. KOENNECKE		5/20/14	Bottom Plate	
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL: AL 6061-T0	DWG NO. 1 — A4
				WEIGHT:	SCALE:1:1 — SHEET 1 OF 1



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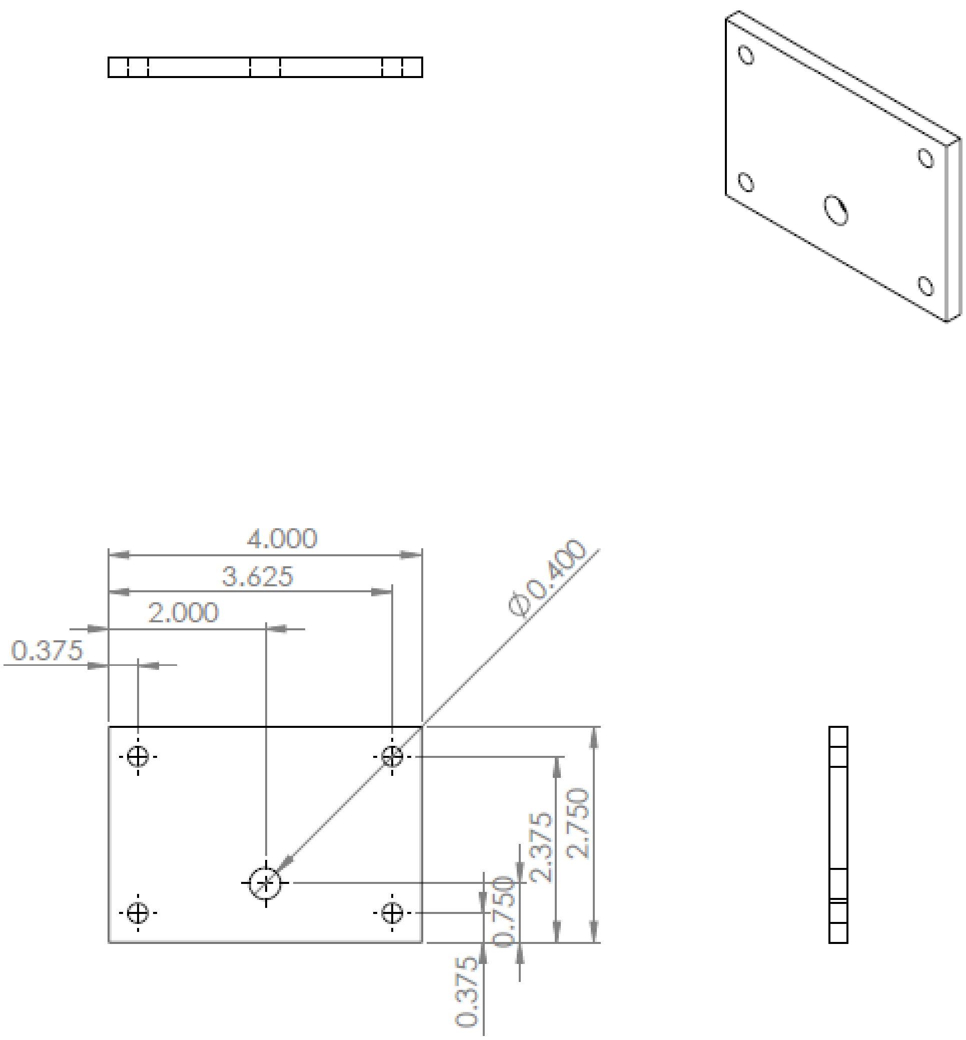
DRAWN	F. KOENNECKE		5/20/14			
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: AL 6061-T0	DWG NO. 1	A4
				WEIGHT:	SCALE:1:2	SHEET 1 OF 1



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UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES	FINISH: NONE		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE	TITLE: Top Plate	
DRAWN	F. KOENNECKE		5/20/14		
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL: AL 6061-T0	DWG NO. 1 — A4
				WEIGHT:	SCALE:1:2 — SHEET 1 OF 1