Final Report

μAV Linked Vehicles

2022-2023 Academic School Year

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Table of Contents

1. Overview

Introduction

This document serves as a technical user manual intended to provide an outline of the device that has been designed to fulfill the requirements as provided by Micro-AV. This device is to serve as a coupling mechanism which automatically links stationary or non-stationary mini-vehicles such as electric tricycles or vehicles similar to the ELF vehicle. It is important to note that the vehicle for which the system will be adapted to has not been finalized, and so instead of finalizing a design for a mode mounting between the vehicle and the linking system, a standardized coupling is to be set instead. Figure 1 provides the general appearance of the entire assembly.

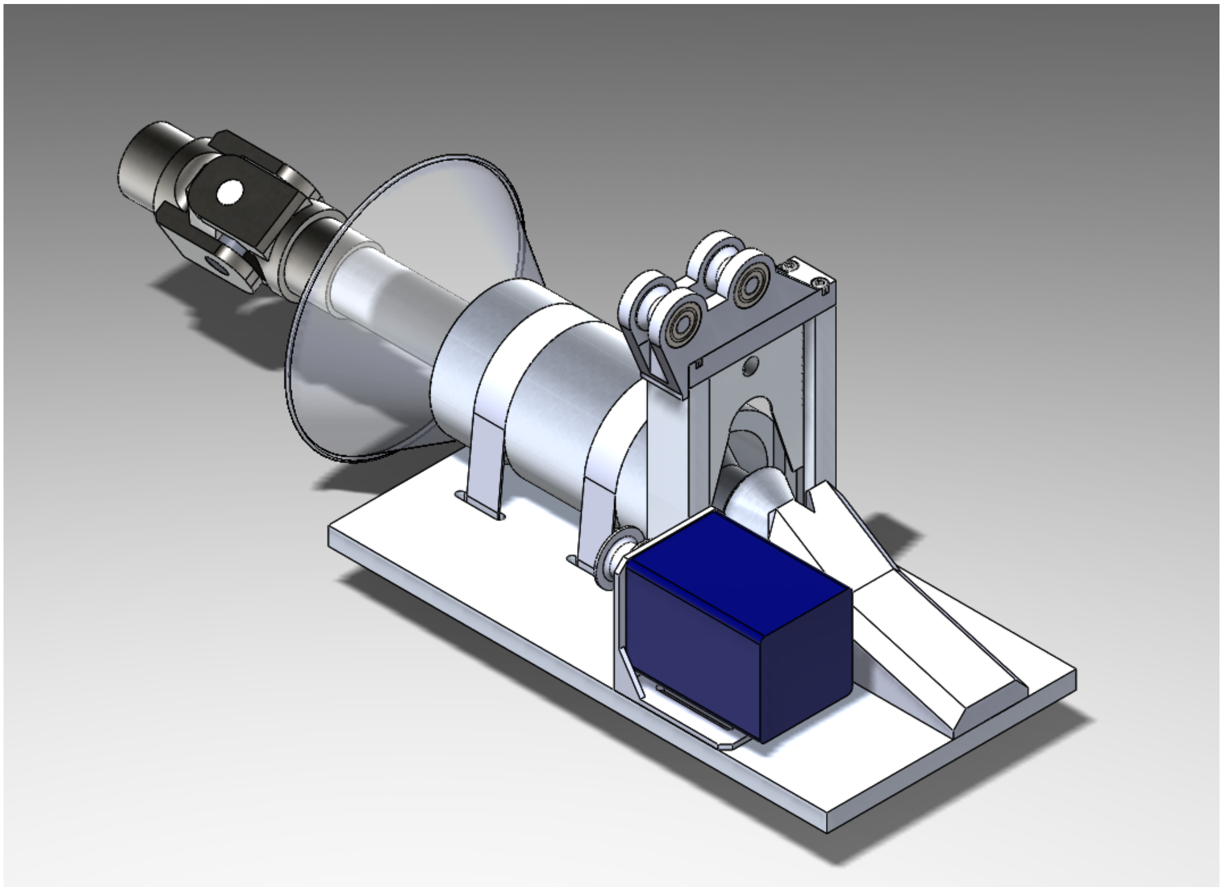


Figure 1. General Appearance of Assembly

Project Initial State

The system in its initial state was conceptual. The existing physical systems consisted of two separate trike systems that were not fully motorized with some electrical systems. As for the coupling system, due to the fact that the system was yet to be designed, there were no physical components or materials readily available on hand or to be ordered.

The project existed primarily as a set of requirements that needed to be fulfilled. The system was to be able to link two vehicles to one another by utilizing a bumper system without requiring direct human intervention when either coupling or decoupling. The system was to be mounted to be compatible with both ELF vehicles and electric trikes. Due to the fact that the trikes were already on hand, the system was to be designed according to the trikes. The requirements and constraints are to be further detailed below.

Constraints

The following system has been designed to meet the following specifications:

- Coupling is purely automatic
- Decoupling does not require human interaction
- All components within system are capable of withstanding forces due to collisions with a 5 mile per hour differential
- Supports vehicle weights of 40 lbs

*A lifetime of approximately 30,000 couples – untested

The processes in which these specifications have been designed to be tested for will be detailed in section 7.

Key Features and Functionality

There are four primary components that interact in the system, the male assembly, the female assembly, the locking mechanism assembly, and the dampening assembly.

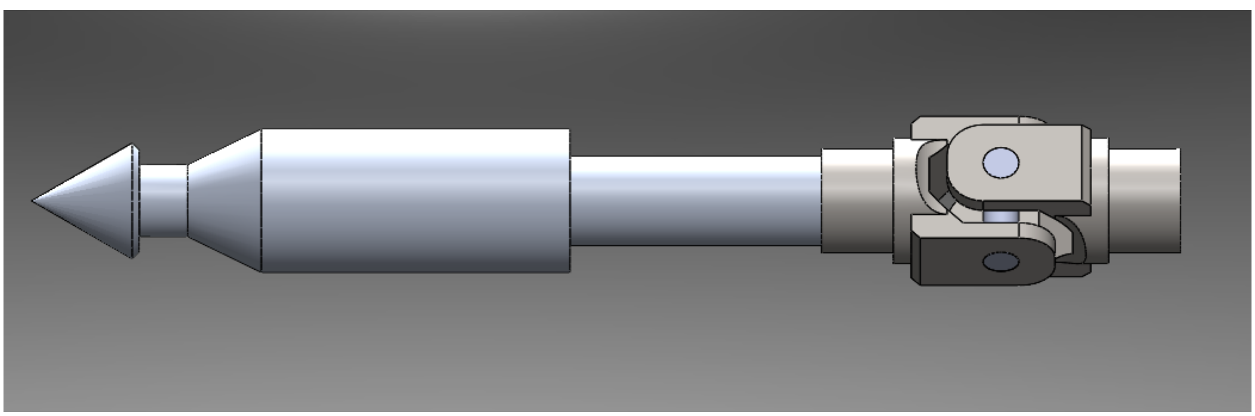


Figure 2. Male Assembly

The male assembly consists of a shaft which is connected to a universal joint. The end of the shaft is tapered to allow for a smoother coupling process when entering the female and locking mechanism assemblies. The universal joint allows for multiple degrees of freedom during the operation of the trike when it is coupled. The male assembly is to be mounted to the front of a vehicle.

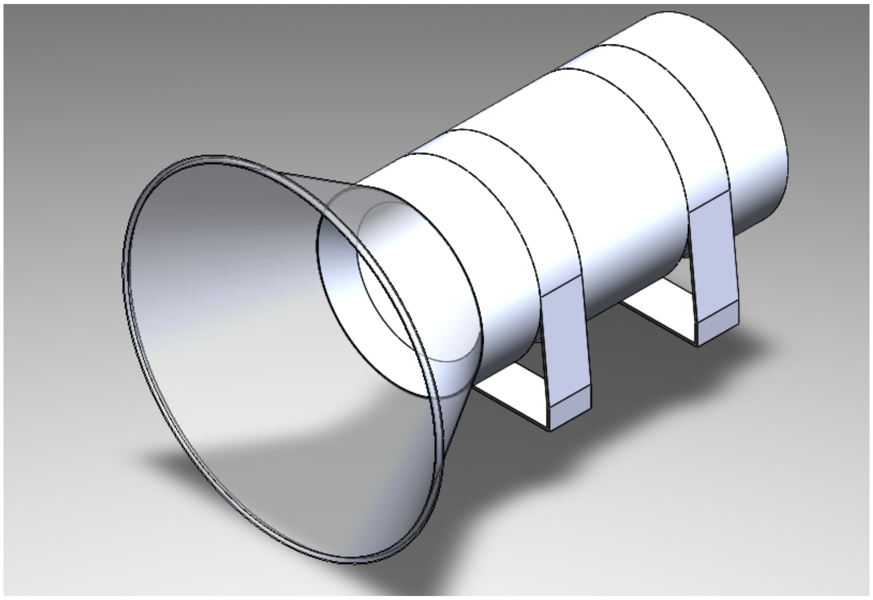
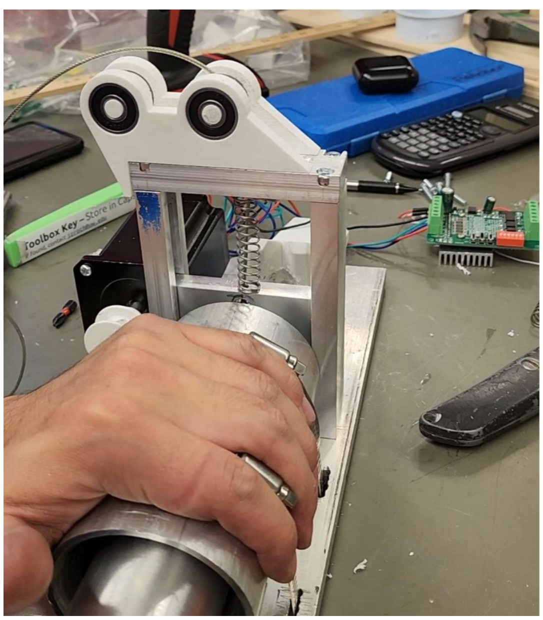


Figure 3. Female Assembly

The female assembly consists of a hollow shaft which has a funnel attached to one end of it. The funnel provides additional mechanical forgiveness provided that the angle of coupling is not perfectly aligned. The pipe clamps secure the female assembly onto the locking mechanism.



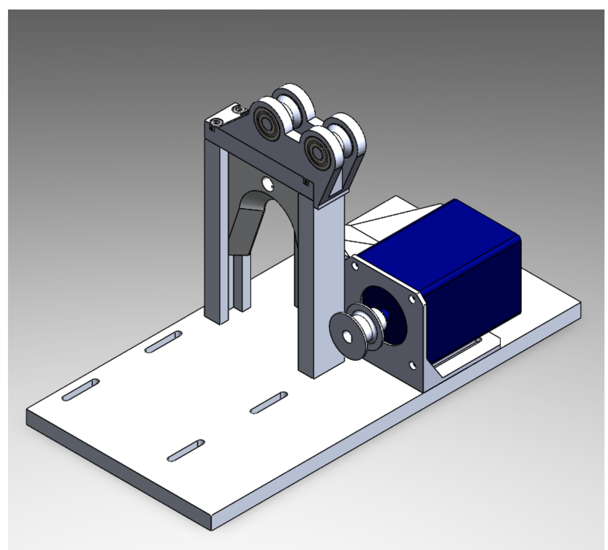


Figure 4, 5. Locking Mechanism Assembly

The locking mechanism assembly consists of multiple mechanisms. The locking gate is the primary function that locks the male shaft into place after traveling through the female assembly. The face of the locking gate is chamfered such that it is concave facing the male assembly, allowing for it to be pushed easier. As the maximum diameter of the male head exceeds that of the gate, the male is automatically locked in once it passes through the gate. A rubber spring bumper will be mounted to the end of the base plate after the male shaft passes through the gate, which will prevent it from over-traveling.

To decouple, a stepper motor applies torque to a pulley and cable which pulls the locking gate up. Return springs apply a downward resistive force such that tension remains on the cable, preventing it from becoming unraveled, and pushes the locking gate down to resting position, where it is making contact with the base plate.

2. Parts List

TOP LEVEL

ITEM NO	DESCRIPTION
1.0	MALE ASSEMBLY
2.0	FEMALE ASSEMBLY
3.0	LOCKING MECHANISM ASSEMBLY
4.0	DAMPING ASSEMBLY
5.0	TEST ASSEMBLY

1. MALE ASSEMBLY

ITEM NO.	ITEM	DESCRIPTION
1.1	MALE SHAFT	Universal Joint Assemblies (Standard Series): 1 1/4” x 1 1/4” I.D.(Inner Diameter), 1000 RPM, 800 Lbs, 5" Overall Length, 1/4” Keyway, 133020
1.2	U-JOINT	Universal Joint Assemblies (Standard Series): 1 1/4” x 1 1/4” I.D.(Inner Diameter), 1000 RPM, 800 Lbs, 5" Overall Length, 1/4” Keyway, 133020
1.3	MALE SHAFT SET SCREW	3/8-16 x 1/2" Hex Head Screw Bolt, 10Pcs 18-8 (304) Stainless Steel, Fully Threaded, Plain Finish, by SG TZH

2. FEMALE ASSEMBLY

ITEM NO.	ITEM	DESCRIPTION
2.1	FUNNEL	24 FL oz Tin Funnel
2.2	PIPE CLAMP	VIVOSUN Stainless Steel Air Ducting Clamps, 4/6/8/12 Inch Adjustable Hose Clamps with Worm Drive for Ducting, Heating, Cooling, Exhaust, and Ventilation (Pack of 2) (12 inch size)
2.3	FEMALE SHAFT	Multipurpose 6061 Aluminum Round Tube, 3/8" Wall Thickness, 3" OD, 2ft length

3. LOCKING MECHANISM ASSEMBLY

ITEM NO.	ITEM	DESCRIPTION
3.1	BASE PLATE	Multipurpose 6061 Aluminum, 7/16" Thick, 6" x 12"
3.2	LOCKING GATE	Multipurpose 6061 Aluminum, 7/16" Thick, 6" x 12"
3.3	RAIL GUIDE	Multipurpose 6061 Aluminum Sheets and Bars 1/2" Thick 1" Extruded 2ft Length
3.4	RETURN SPRING	Corrosion-Resistant Precision Compression Springs 2" Long, 0.42" OD, 0.336" ID, 302 Stainless Steel
3.4*	RETURN SPRING (ALT)	Corrosion-Resistant Precision Compression Springs 2" Long, 0.42" OD, 0.31" ID, 302 Stainless Steel
3.5	RUBBER SPRING ASSY	Ultra-High-Load Fastener-Mount Compression Spring, 1" Long
3.6	ARDUINO UNO BOARD	Arduino Uno REV3

3.7	MOTOR	STEPPERONLINE Nema 23 Stepper Motor 2.4Nm(339.79oz.in) 4.0A 8mm Shaft 57x57x82mm 4 Wires
3.8	MOTOR MOUNT	weideer 2Pcs 57mm Stepper Motor Mounting Bracket Alloy Steel L-Shape Fixed Seat for NEMA23 Stepper Motor with Screws and Nuts K-029-57
3.9	BRAIDED CABLE	18-8 Stainless Steel Lanyard - Not for Lifting, Ball with Shank/Plain-End, 3/64" Rope Diameter, 24" Long, Nylon
3.10	DRIVER BOARD	HiLetgo TB6560 3A CNC Router Single 1 Axis Controller Stepper Motor Driver Board
3.11	PULLEY HOLDER	3D PRINTED PLA PULLEY HOLDER
3.12	PULLEY	3D PRINTED PLA PULLEY
3.13	SCREW	Zn-Plated Alloy Steel Socket Head Screw, 8-32 Thread, 3/4" Long

4. DAMPING ASSEMBLY

ITEM NO.	ITEM	DESCRIPTION
4.1	AIR SHOCK	DNM Damping 3 System Mountain Bike Air Rear Shock Rebound/Lock Out/Air Pressure Adjustable AL 7005 Shark/AL 6061 Shock Body 165mm (6.5") x 35mm 190mm (7.48") x 50mm 200mm (7.87") x 55mm
4.2	AIR SHOCK MOUNT	3D PRINTED

5. TEST ASSEMBLY

ITEM NO.	ITEM	DESCRIPTION
5.1	DOLLY	NA

Cost Estimate

ITEM NO.	ITEM	PRICE	QTY	NOTES	SOURCE
1.1	MALE SHAFT	$ 45.64	1		Link
1.2	U-JOINT	$ 66.70	1		Link
1.3	MALE SHAFT SET SCREW	$ 8.13	1	Purchased in Set of 10	Link
2.1	FUNNEL	$7.79	1		Link
2.2	PIPE CLAMP	$12.99	1		Link
2.3	FEMALE SHAFT	$126.05	1		Link
3.1	BASE PLATE	$31.17	1		Link
3.2	BASEPLATE/LOCKING GATE	NA	1	Using same stock metal as Item 3.1	Link
3.3	RAIL GUIDE	$26.14	2		Link
3.4	RETURN SPRING	$7.33	1		Link
3.4*	RETURN SPRING (ALT)	$8.14	1		Link
3.5	RUBBER SPRING	$11.43	1		Link
3.6	ARDUINO UNO BOARD	$29.95	1		Link
3.7	MOTOR	$25.99	1		Link
3.8	MOTOR MOUNT	$10.99	1		Link
3.9	BRAIDED CABLE	$3.07	1		Link
3.10	DRIVER BOARD	$11.39	1		Link
3.11	PULLEY HOLDER	NA	NA	3D PRINTED	NA
3.12	PULLEY	NA	NA	3D PRINTED	NA
3.13	SCREWS	8.03	1	Purchased in Pack of 50	Link
4.1	AIR SHOCK	$119.98	1		Link
4.2	AIR SHOCK MOUNT	NA	1		Link
	COST OF PARTS	$ 552.88			
	COST OF MACHINING	$ 326.87			
	TOTAL COST	$ 879.75			

3. Machining Drawings and Documentation

Male Shaft

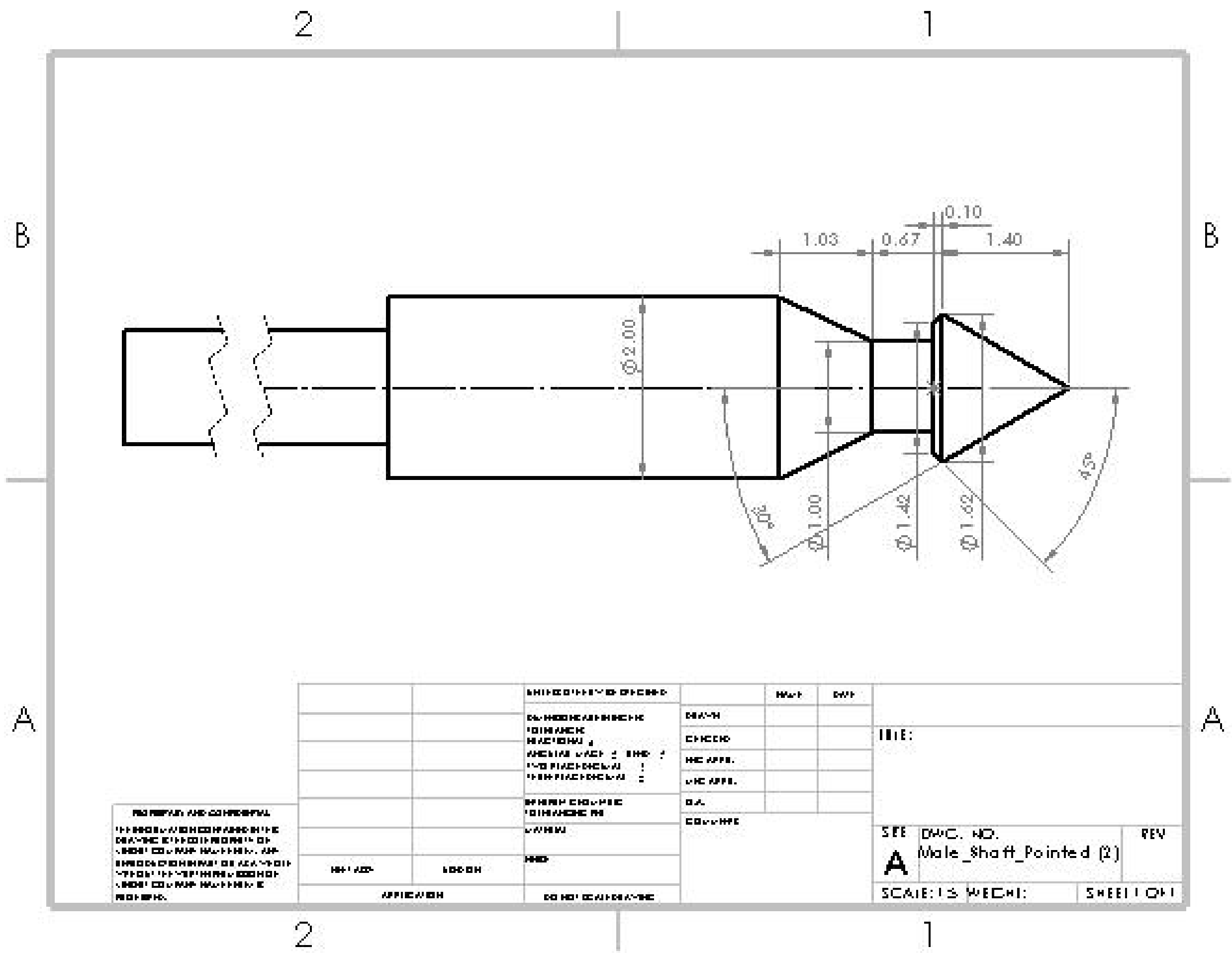


Figure 6. Male Shaft Machining Schematic

The male shaft was arguably the most complex machined item made in the entire assembly. The male shaft was made from Item No. 1.1. Item No. 1.1 was cut down the middle on the vertical band saw to create 2 roughly 12" long pieces. Each 12" piece of stock was loaded into the lathe with the 4 jaw independent chuck in addition to the live center mounted in the tail stock in order to ensure adequate contact before machining on the lathe. The first step of machining the male shaft was to cut the taper on the tip of the male shaft. This was done by setting the compound slide to the required angle and utilizing the left handed turning tool. After the taper was completed the interior shoulder and taper towards the base of the shaft were cut simultaneously with the same left handed turning tool. The dial gauge was utilized for this application to ensure accurate dimensions. The chamfer on the tip of the male shaft was completed also with the compound slide. A shoulder was turned down on the end of the shaft to fit into the universal joint. For weight savings the center of the shaft was core drilled with a large diameter drill bit roughly 5-6" into the shaft. If a longer drill bit was available, the shaft would have been drilled further to reduce weight even more. Weight can also be reduced in the future by bringing the interior diameter (fitting the universal joint) further up the shaft therefore extending that shoulder to reduce even more material.

Female Shaft

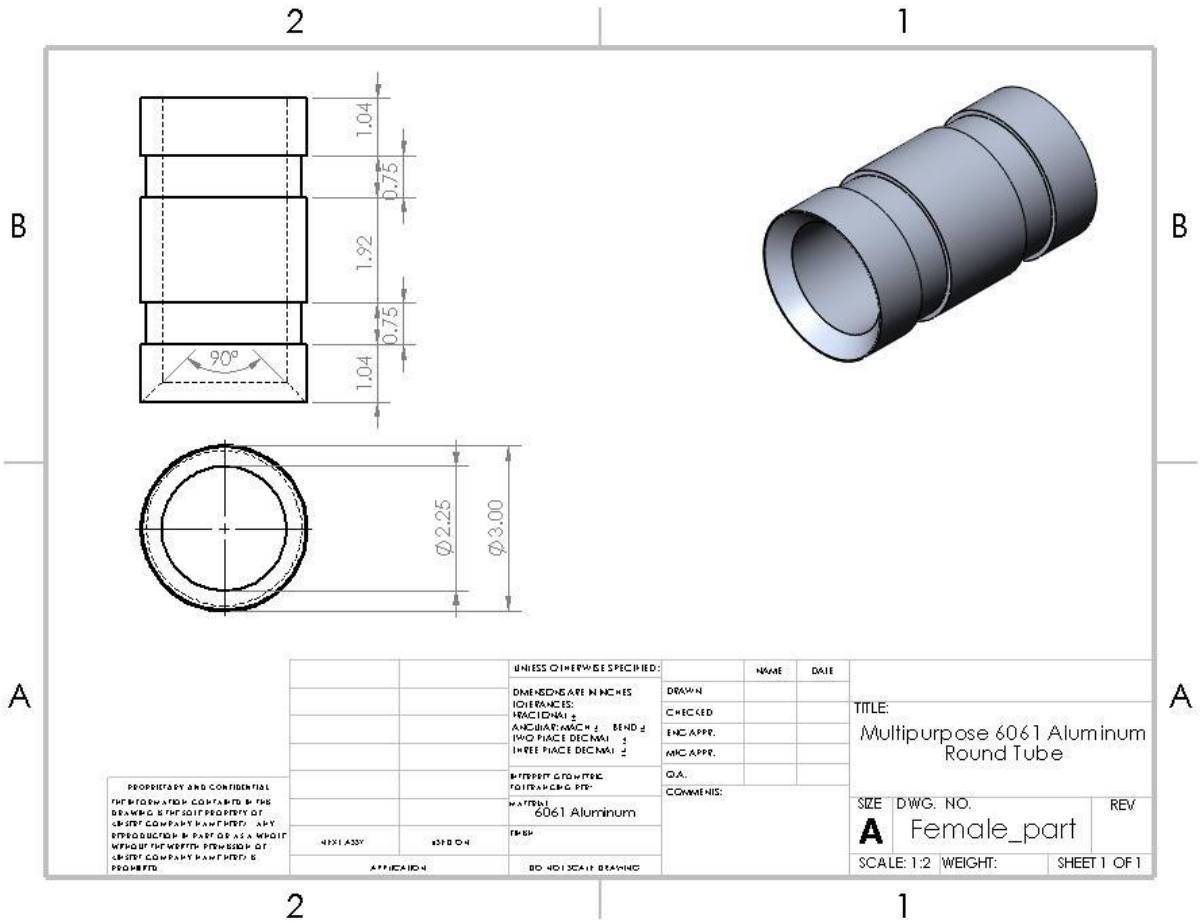


Figure 7. Female Shaft Machining Schematic

Female shaft was made from Item No. 2.3. Two (roughly) 5.5" lengths were cut from each end of the bar stock on the vertical bandsaw. After each length was cut to size the interior 45 degree chamfer was done with a right hand turning tool on the lathe. The two indented bands for the pipe clamps were also done with a right hand turning tool and pre-planned and measured according to the drawing above. These bands were not made exactly to spec as they can be within a very rough tolerance for our application. To reduce weight in the future the female shaft could be shorter and made from aluminum stock with thinner walls that will still accommodate the forces of the system.

Rails

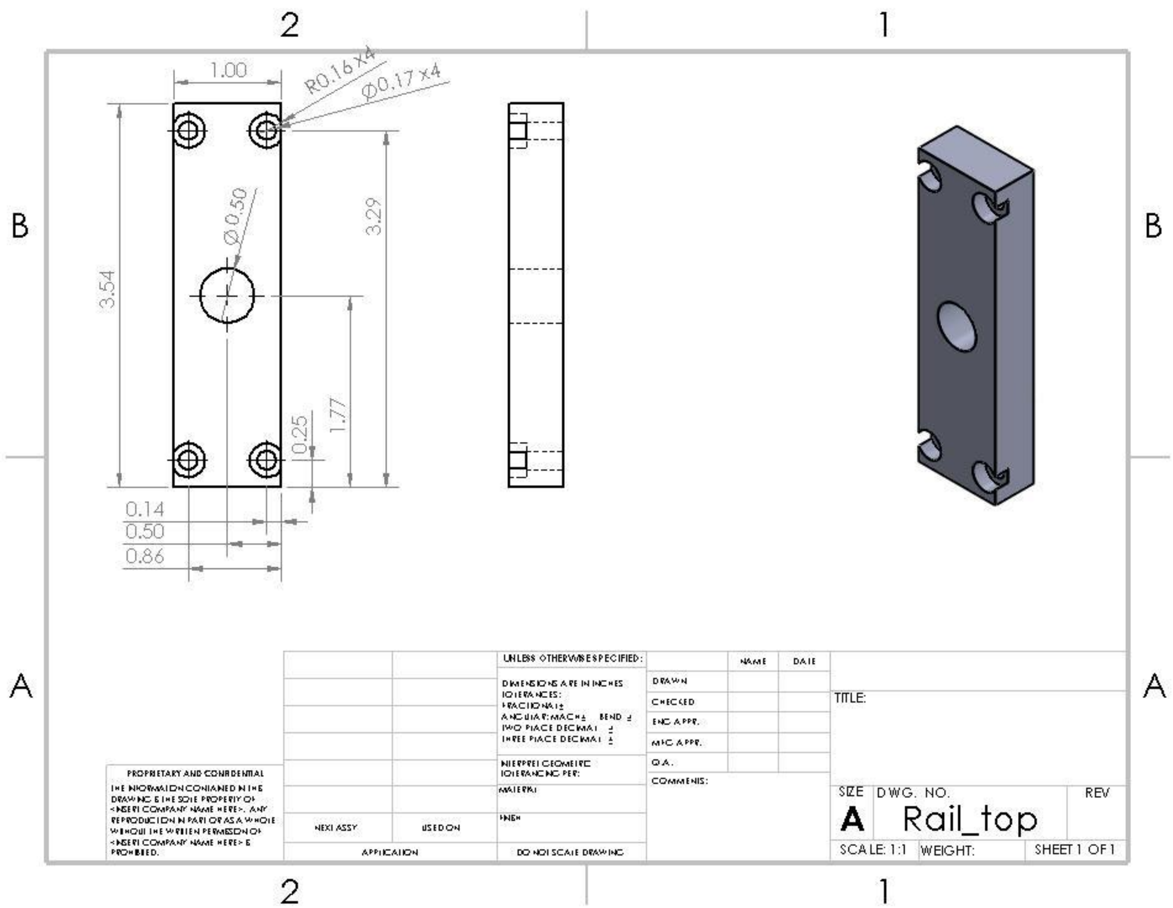


Figure 8. Rail Top Machining Schematic

The top portion of the rail was made of Item No. 3.3. The rail was cut to (roughly) 3.29" on the vertical band saw. After the rail was cut to size it was then scribed and center punched according to the dimensions listed above. The 5 holes were then center drilled and each hole was drilled to size as specified above. The 4 corner holes were counterbored with a larger drill bit size as the UWB shop does not have any counterboring bits.

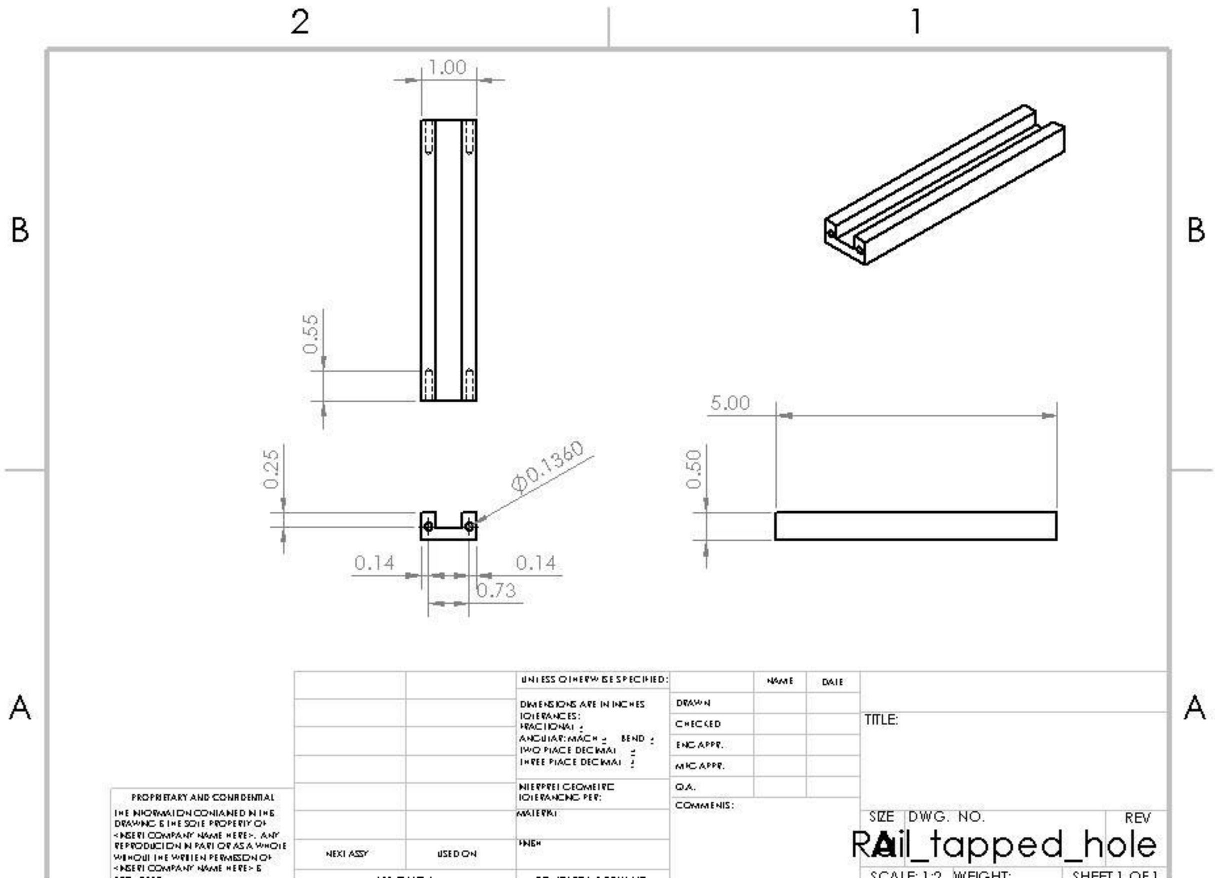


Figure 9. Rail Side Machining Schematic

The two side components of the rail are also made from Item No. 3.3. Two 5” pieces were cut from the stock with the vertical bandsaw with a rough 0.20” overhang to account for facing on the Manual Mill. After the pieces were cut roughly to size all 6 sides were then faced on the Manual Mill to ensure a smooth surface. After the pieces were faced they were individually channeled to create the interior channel to accommodate the locking gate. A ⅜” milling bit was used in accordance with the manual feed to take off roughly 20 thou of material at a time and create the channel. Once the channel was created it was then extended by a specified amount on each side of the pre-existing channel to create a total channel width of roughly half an inch.

Baseplate

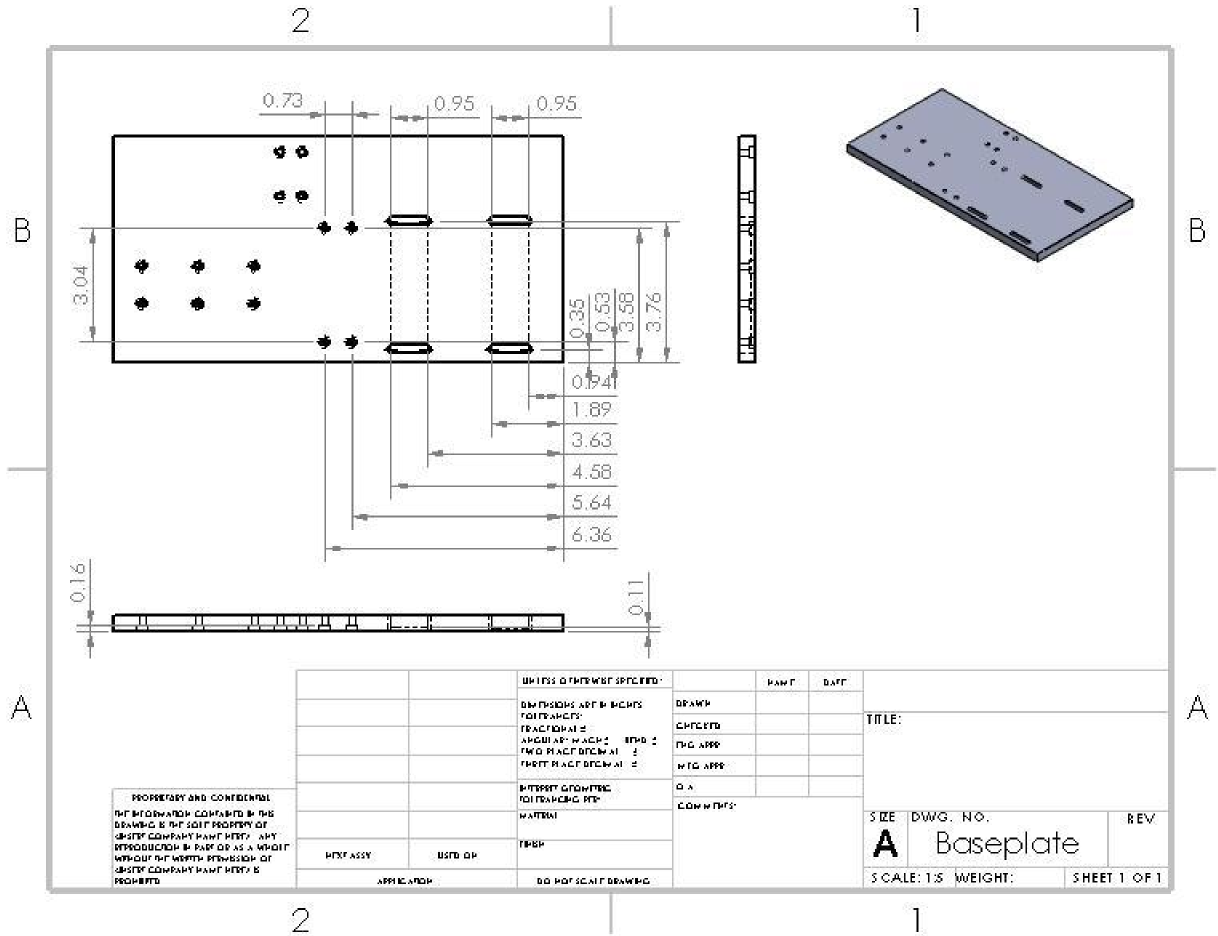


Figure 10. Base Plate Machining Schematic

The baseplate was made from Item No. 3.2. Two of the 7/16" edges were faced in order to create a perpendicular angle in order to accurately pre plan and dimension the holes on the base plate. All holes were center drilled and then drilled to size with the corresponding drill bit on the drill press. Some holes were counterbored with a larger drill bit size according to the drawing above. The slots for the pipe clamps were drilled out with a smaller drill bit and then were smoothed out with the use of a Dremel. In the future the baseplate can be modified to accommodate greater weight savings by cutting out parts of the plate not utilized by other components in the assembly. There will also be additional holes drilled into the baseplate in order to mount the assembly for testing.

Locking Gate

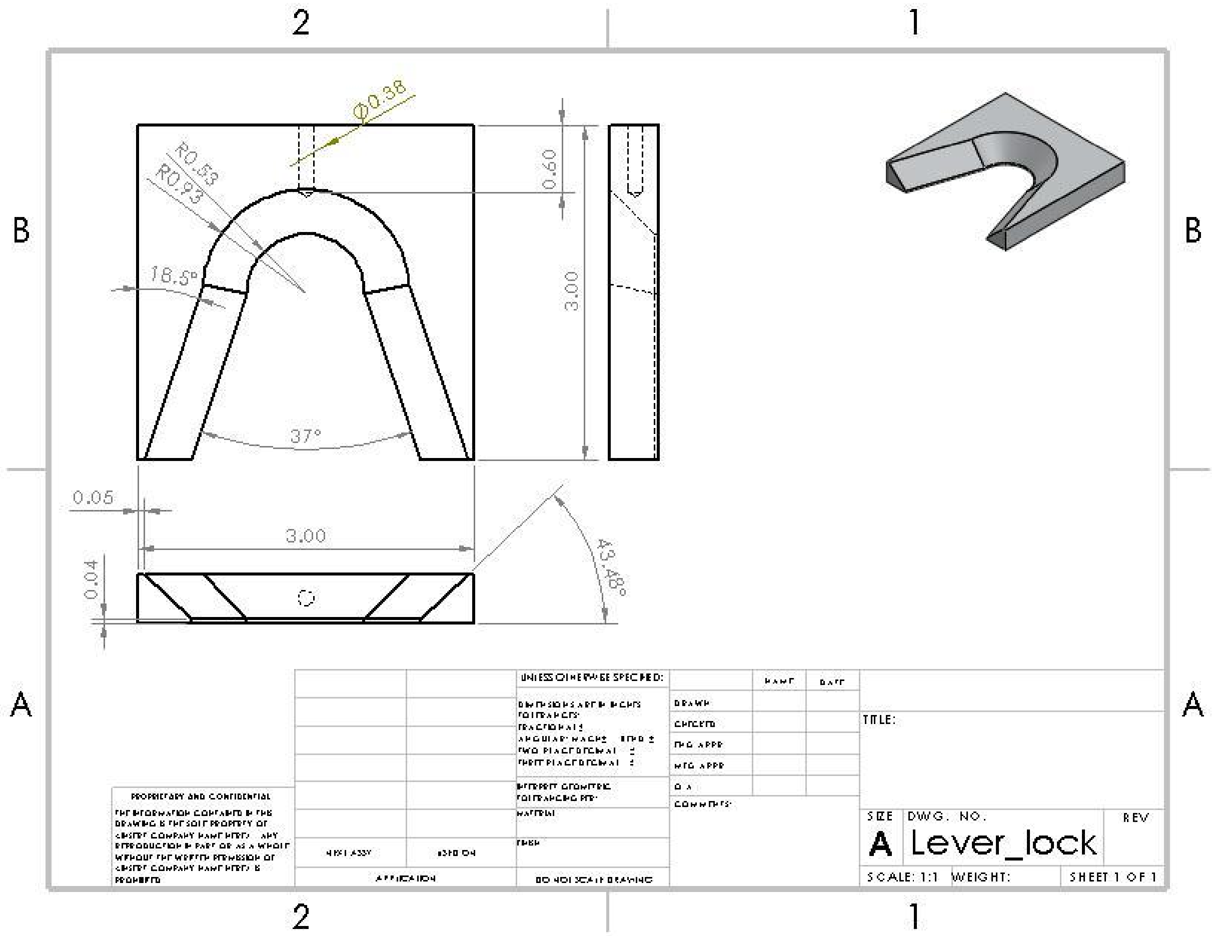


Figure 11. Locking Gate Machining Schematic

The locking gate was made from Item No. 3.2 and was cut to a 3.5”x3.5” square on the vertical band saw to allow room for cutting down to true size. This part needed to be within a tighter tolerance than the other machined piece such as the male and female shaft in order to properly interact with the machined rails. After the piece was cut to the 3.5” square, it was faced on all 6 sides on the manual mill and then loaded into the (Tormach 3 Axis) CNC. The CNC was utilized first to cut down the piece to an exact 3” square. Once the locking gate was cut to true size it was then loaded into the CNC again to have the interior portion removed according to the drawing above. This process was a bit of a trial and error as the G-CODE necessary for cutting the part had a few problems. The G-CODE was extracted through SolidWorks CAM after initializing the system according to the CNC specifications and toolcrib.

Additional Items

All additional items in the assembly were either 3D printed in house or purchased as is.

3D Printed:

- Pulley
- Dampening block
- Bearing Rail Mount for Cable

Purchased:

- Universal Joint
- Universal Adjustable Pipe Clamps
- Stepper Motor
- Stepper Motor Mount
- Funnel

*The funnel was purchased and modified to fit the assembly. Modified and cut to size with metal shears.

Machining Time and Feasibility

Overall the machining of all components took roughly 30-40 work hours split between two people. There were many hardships associated with machining this project as the UWB machine shop was constantly in use and it was difficult to utilize the machines needed. There were also a limited number of hours available for shop use due to the requirement of supervision while running machinery.

If this project were to be outsourced to a machine shop it would take no more than half the time as a rough estimate. Outsourcing machining can cost anywhere between $40-150 per hour depending on the shop and what machines need to be utilized. This cost is not including the raw cost of the (stock) material itself which is roughly $300. On average I would estimate that outsourcing a second set to a machine shop to manufacture would be about $1500.

4. Electrical Schematics

Motor Wiring

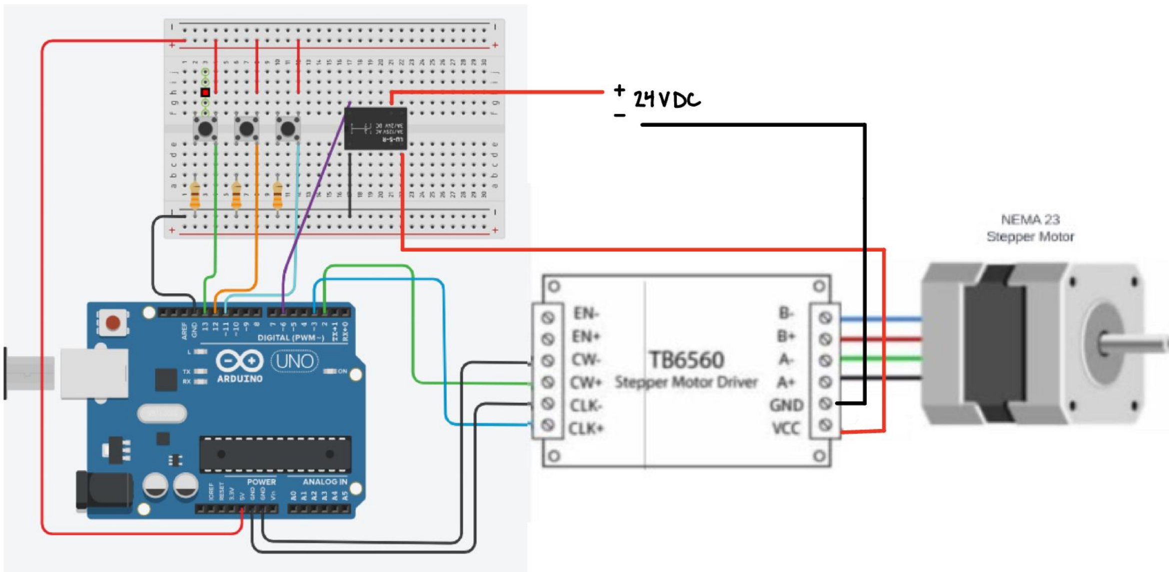
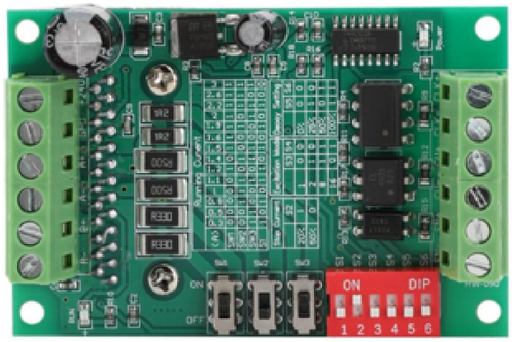


Figure 12. Motor Wiring Diagram

The CW+ connection of the motor driver is connected to pin 2 on the Arduino, which controls the direction of the motor. The CLK+ connection of the motor driver is connection to pin 3 on the Arduino, which controls the stepping. Additionally, there are three buttons, connected to pin 13, 12, and 11 of the Arduino through the breadboard. The button connected to pin 13 will cause the motor to raise the gate to decoupling height. The button connected to pin 12 will switch the relay and therefore cut power to the motor, dropping the gate. The button connected to pin 11 will single step the motor in the upward directions. The GND and VCC connections are to a 24V DC power supply through a relay controlled by the 5V signal from pin 6 on the Arduino.



SW1	SW2	SW3	S1	S2	S3	S4	S5	S6
ON	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF

Figure 13. Motor Driver Switch Settings

The TB6560 is an analog motor driver board, which allows for control over the speed and stepping of the motor without making modifications to the code.. The interface for changing these parameters are the series of 9 switches on the bottom right corner of the board, as pictured above. The settings are shown in the figure above, and the switch configuration tables can be found in the Appendix section.

5. Code

```
#define dirPin 2        // defines the pin connected to CW+
#define stepPin 3       // defines the pin connected to CLK+
int steps = 100;
int buttonUpPin = 13;   // defines the pin connected to the button
int buttonDownPin = 12;
int buttonSingleStep = 11;
int relayPin = 6;



void setup() {
Serial.begin(9600);
pinMode(stepPin, OUTPUT);
pinMode(dirPin, OUTPUT);
pinMode(buttonUpPin, INPUT);
pinMode(buttonDownPin, INPUT);
pinMode(buttonSingleStep, INPUT);
pinMode(relayPin, OUTPUT);
}

void loop() {
int buttonUp = digitalRead(buttonUpPin);  // reading input from button
int buttonSingle = digitalRead(buttonSingleStep);
int buttonDown = digitalRead(buttonDownPin);
if(buttonUp == HIGH){
  digitalWrite(relayPin, HIGH);
  digitalWrite(dirPin, LOW);           // set the direction of the motor
    for (int i = 0; i < steps; i++){      // iterate for set number of steps
    digitalWrite(stepPin, HIGH);        // initiate stepping
    delayMicroseconds(2000);
    digitalWrite(stepPin, LOW);         // stop stepping
    delayMicroseconds(2000);
}
```

```
    }
    delay(500);
    }

    else if (buttonDown == HIGH){
      digitalWrite(relayPin, LOW);
      digitalRead(relayPin);
      delay(50);
    }

    else if (buttonSingle == HIGH){
      digitalWrite(relayPin, HIGH);
      digitalWrite(dirPin, LOW);           // set the direction of the motor
        for (int i = 0; i < 1; i++){       // iterate for set number of steps
          digitalWrite(stepPin, HIGH);        // initiate stepping
          delayMicroseconds(2000);
          digitalWrite(stepPin, LOW);         // stop stepping
          delayMicroseconds(2000);
    }
    delay(100);
    }

    }

```

6. Assembly Instructions

Male Assembly

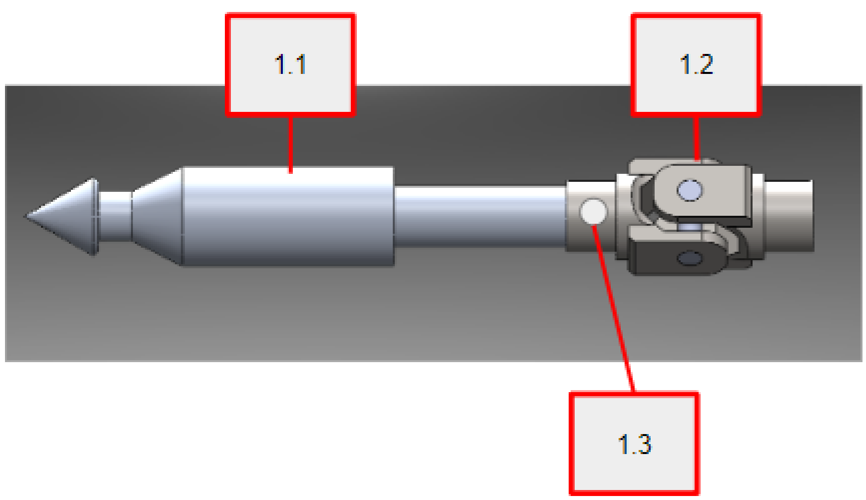


Figure 14. Male Assembly

1. Using Item 1.3 (Male Shaft Set Screw), fix Item 1.2 (Universal Joint) onto Item 1.1 (Male Shaft)

Female Assembly

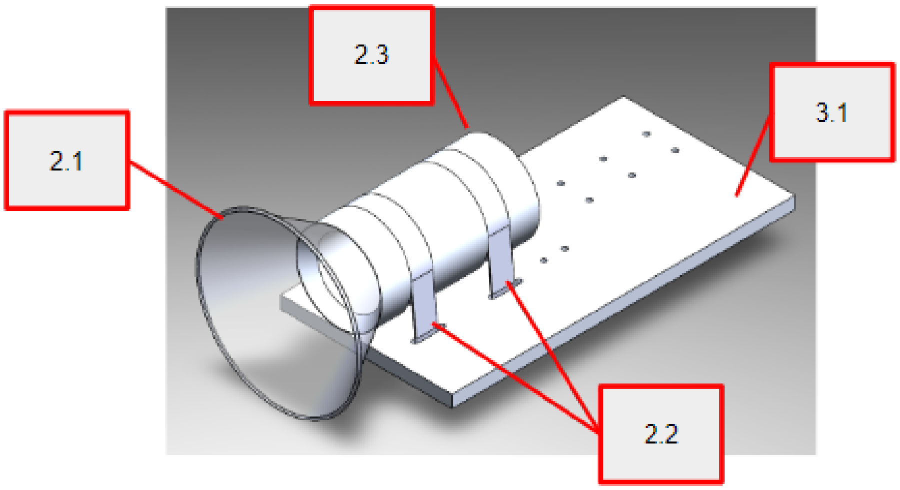
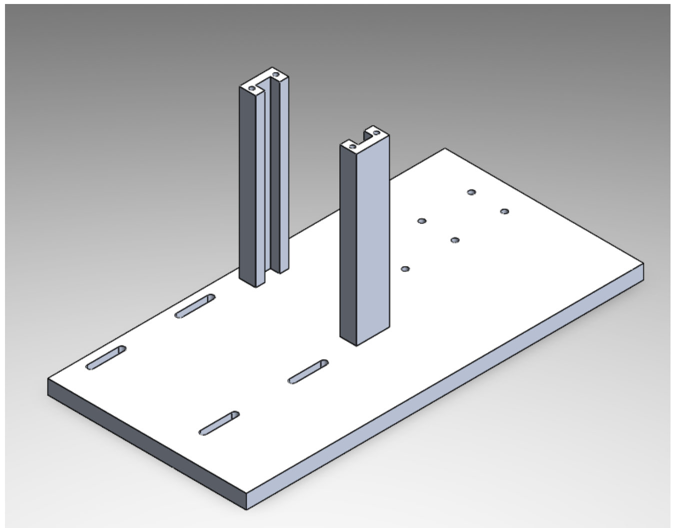


Figure 15. Female Assembly

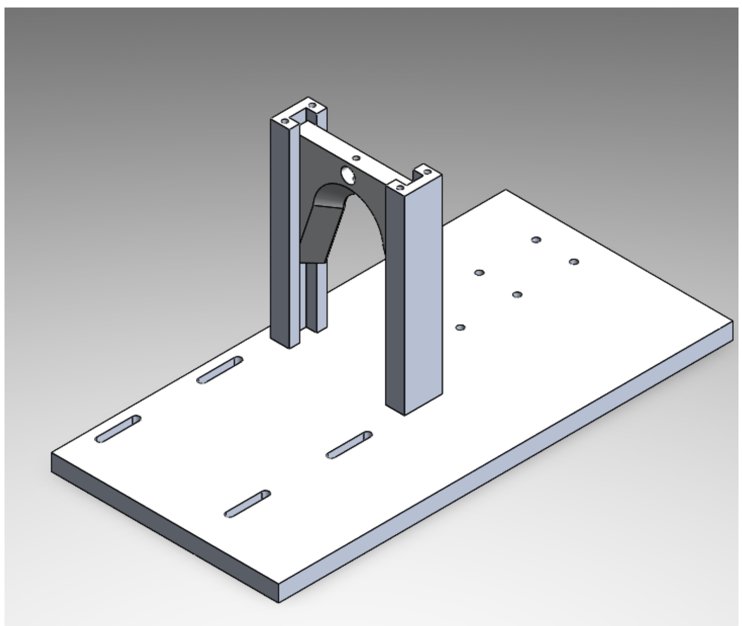
1. Slide Item 2.1 (Funnel) over Item 2.3 (Female Shaft). Secure with metal zip ties.
2. Place the combined items 2.1 (Funnel) and 2.3 (Female Shaft) on Item 3.1 (Base Plate).
3. Route both counts of Item 2.2 (Pipe Clamp) through the four slots in Item 3.1 (Base Plate). Secure with screwdriver.

Damping Assembly

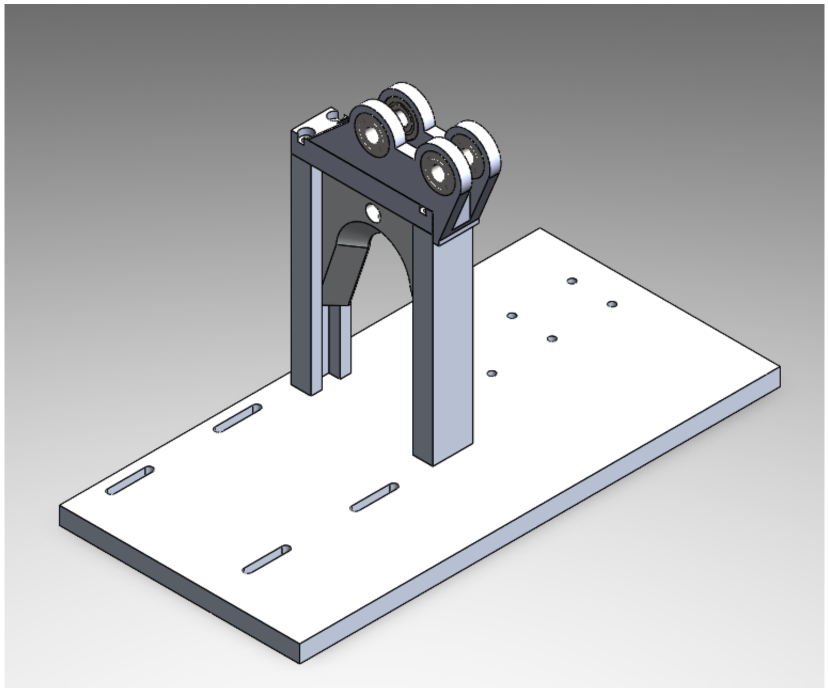
1. Construct Item 3.3 (Rail Guide), screwing them onto Item 3.1 (Base Plate) into the tapped holes as shown below using Item 3.13 (Screws).



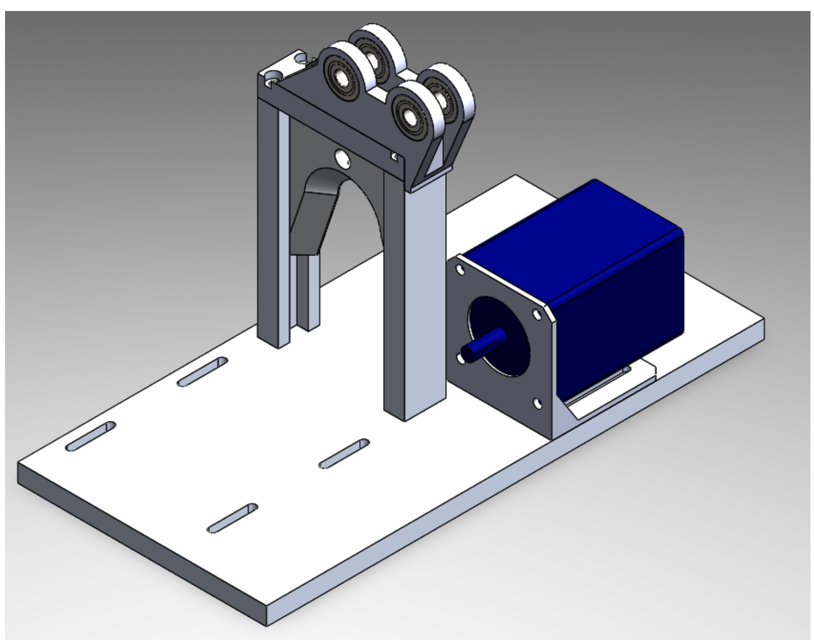
2. Place Item 3.2 (Locking Gate) into rails created by Item 3.3 (Rail Guide).



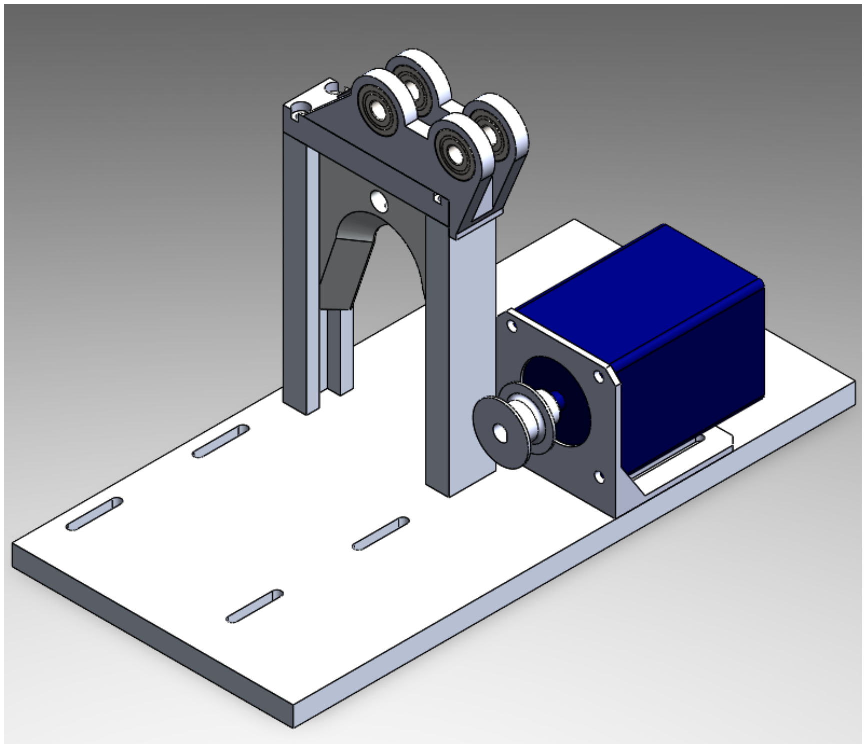
3. Route Item 3.9 (Braided Cable) through the slot in Item 3.2 (Locking Gate), then through Item 3.4 (Return Spring).
4. Install the top bar of Item 3.3 (Rail Guide) on top of the first two rail support structures. Screw in to secure with Item 3.13 (Screws). Secure Item 3.11 (Pulley Holder) on top of the top bar.



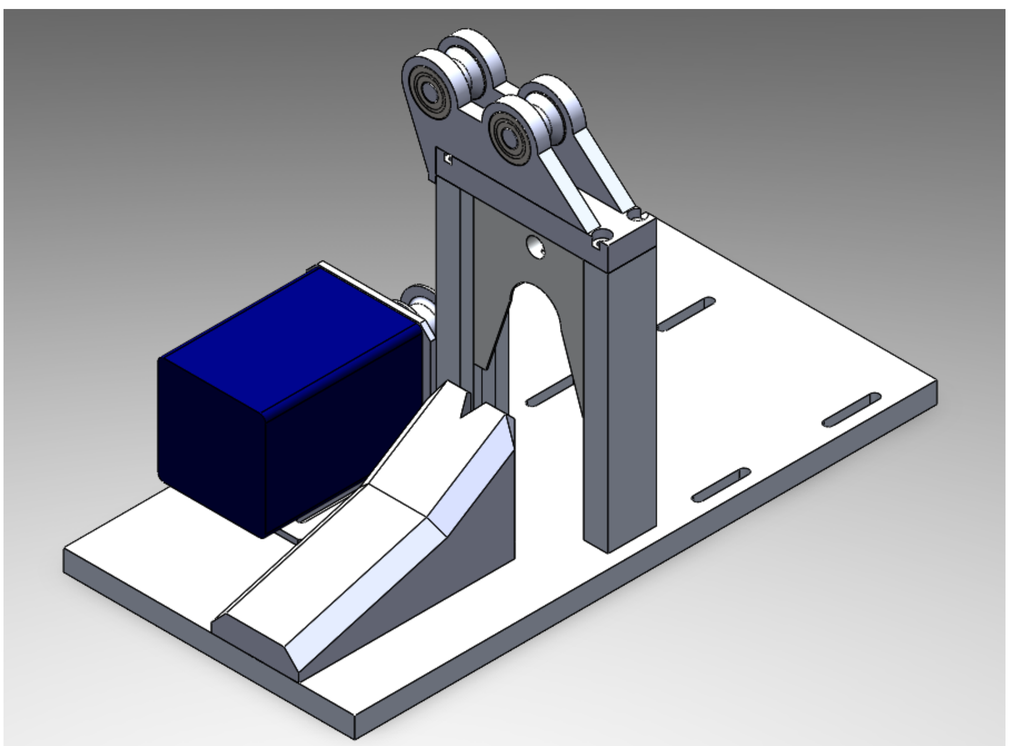
5. Secure Item 3.8 (Motor Mount) onto Item 3.1 (Base Plate) next to the rail guide system. Install Item 3.7 (Motor) onto Item 3.8 (Motor Mount). Secure with screws. *Once Locking Mechanism assembly has been completed, establish electrical connections as detailed in prior defined electrical schematics.



6. Route Item 3.9 (Braided Cable) through Item 3.11 (Pulley Holder) and into Item 3.12 (Pulley). Press-fit Item 3.12 (Pulley) onto the motor shaft of Item 3.7 (Motor).



7. Secure Item 3.5 (Rubber Spring Assy) onto the Item 3.1 (Base Plate) as shown. Secure with screws.



7. Testing & Verification

Procedures

In order to verify that the above design and process yields a system which meets specified requirements, a test procedure was drafted. There are three main functions which the system must satisfy, yielding three tests, which verify that

1. The system couples when the respective male and female assemblies collide at the specified speed differential (Coupling)
2. The system can allow for decoupling between male and female assemblies when programmed to do so (Decoupling)
3. The system allows for continuous linking between vehicles while traveling (Linking)

Test 1 – Coupling

1. Mount the respective male and female assemblies onto the test dollies. Allow a minimum of 10 feet between the dollies.
2. Leaving the dolly with the female assembly mounted stationary, push the dolly with the male assembly mounted towards the female assembly, aligning a path of collision.
3. Verify that the male shaft goes through the female assembly and pushes up the locking gate and passes through it, allowing the gate to close down on the shaft.

Test 2 – Decoupling

1. Mount the respective male and female assemblies onto the test dollies.
2. Couple the male and female assemblies by pushing the dollies towards each other.
3. Verify that power is being supplied to both the Arduino (5V) and the stepper motor (24V-36V).
4. Operate the switch button to verify that the motor
    a. moves in the correct direction

b. exerts the requisite torque to lift the locking gate while the system is coupled
c. exerts the requisite holding torque to maintain the gate at a height which allows the male shaft to decouple
d. releases the held torque to allow the locking gate to clamp down after a sufficient amount of time has elapsed.

Test 3 – Linking

1. Mount the respective male and female assemblies onto the test dollies.
2. Tie a rope around the dolly with the female assembly mounted.
3. Pull the dolly through various terrain conditions and verify that the coupler does not degrade in any fashion.

Test Reports

Since the tests performed were visual, there is no raw data and therefore a video is provided in the QR code below to show the current working state of the system. The video shows the coupling and decoupling test is demonstrated.

1. During coupling, the system performed as expected, with a reasonable amount of force required to lift the gate and secure the male shaft. This test was performed stationary and in alignment, as shown, and served to prove the success of the locking mechanism itself.
2. During decoupling, the motor was able to pull the gate up and hold it high enough for the male shaft to fully retreat and the return springs forced the gate back to the “ready” position. The test was deemed successful, however there may be room for improvement. A few observations during this test were that the springs were not strongly secured to the assembly relative to the amount of energy they stored, and the motor did not move smoothly or return to the exact same “ready” position each time. This caused some failed decoupling attempts, but these cases lessened as the motor code and assembly were tuned during the testing phase.

8. Future Work and Recommendations

To Be Completed:

I. Electrical Connection

A. Quick connect system near connection between male and female counterparts
B. All in one system (all on the same baseplate)
C. Acts as an interface for power and information to be shared between trikes

II. Integrated Shock/Dampening System

A. Male shaft machined in a way to make it “telescope” so dampening system can operate inside the shaft and be contained
B. Secondary/additional mounting for the dampening system in between the system and trikes consisting of an adjustable air shock to accommodate different weights/loads on the trikes
C. Upgrade the rubber hardstop (air shock, oil shock, spring)
    1. Change the spring factor for coupling comfort based on cargo/passengers/etc.
D. Upgrade/improve the rubber hardstop’s mount to the baseboard
    1. Make the position variable in the x,y,z
    2. Upgrade material from PLA to more durable material that can sustain constant cyclic loading

III. Mounting

Currently the system is mounted to testing dollies for the sake of the current project scope. A concise mounting assembly will need to be manufactured and installed onto the trikes in order to incorporate the system into the Micro-AV physically linked vehicles.

Both the male and female counterparts can be mounted to either the front or back of the trikes. It is important to note that mounting the male shaft to the front of the trike may pose some safety concerns. As a recommendation, It would also be easier to mount the female assembly to the back of the trikes given the current mounting surfaces, such as the rear bike rack frame. New mounting surfaces may also need to be manufactured for the trikes if the current mounting surfaces are not strong enough to accommodate the loads of the system. These mounting surfaces would need to be securely welded or bolted onto the chassis of the trikes. The mounting of the system will largely depend on further testing done once the trikes are fully operational.

IV. Improved Machining/Weight Reduction

A. Baseplate
   1. Consider another material (wood or composites)
      would recommend altering materials of other components before the baseplate due to it being the primary support structure and taking the majority of the load of the system
   2. Chamfer all edges for safety and usability
   3. Improve design to reduce the overall unutilized sections
      a) Run (SolidWorks) simulations to see where the baseplate is holding the most load/stress and shave the rest down
      b) Trim with mill and bandsaw
   4. Add small depressions/channels to the baseplate (utilizing the manual mill) that match up with the ribbed bands on the female part to keep it from sliding within the assembly

B. Rails
   1. Run more testing for lifetime fatigue due to impacts because the rails take the majority of the impact and dynamic loading during coupling
   2. If yielding or shear starts to develop increase the thickness to accommodate a third 8-32 screw or 2 larger screws
   3. Make sure that both walls of the rail channel are down milled at a slow feed speed to get the smoothest finish (resulting in the lowest coefficient of friction)

C. Lever Lock
   1. Run tests or simulations to find the best angle of the leverlock sweep
   2. 7/16" flat aluminum stock is inexpensive, it is not difficult to manufacture multiple different iterations of the Lever Lock using the CNC machine
   3. Potentially reduce the height of the lever lock to reduce the height of the rails (make the overall assembly shorter in the Z axis)
   4. Change the lever lock material to one with a higher hardness (6061 Aluminum is too soft for the male shaft to repeatedly hit long term, experience failure due to similar metals consistently colliding with another)

D. Top Connecting Rail
   1. Reduce overall thickness (stresses are not high at the top of the rail assembly)
   2. Clean up or redo the current one (done with minimal time and can be improved)

E. Female Shaft
   1. Improve method of mounting to base plate (noted above)
   2. Reduce thickness (and diameter) of tube stock for weight savings

3. Material change

F. Male Shaft
1. Reduce weight by coring the shaft or turn the outside of the shaft (from the second slope back) down to a smaller diameter and make a 3D printed sleeve that would save weight
2. Test different tip shapes for optimal coupling comfort
3. Test different tip shapes for optimal lever lock travel distance and engagement
4. Reduce overall length

G. Pulley System
1. Motor
    a) Reduced motor size if friction and loads allow
    b) Change to a geared setup for easier adjustments and increased engagement (complicated)
    c) Print/manufacture housing to protect the current electronics and motor (motor and breadboard/wires exposed in current prototype)
    d) Create a feedback loop to maintain set top and bottom positions
    e) Remove the button press required to reset to the motor after decoupling (either have a sensor or a set time control)
2. Pulley
    a) Manufacture out of metal to withstand long term stress (optional depending on further testing and results)
    b) Change the radius if higher torque is required in the system
3. Pulley mount assembly
    a) Reprint so skateboard bearings fit securely with a tighter tolerance
    b) Reduce size (simulations needed for stresses to determine size)
    c) Change material from PLA (PLA is not corrosion or weather resistant to long term exposure). Recommend Nylon X, PETG, or ABS.
4. Return springs
    a) Attach to rails more securely

V. Second Set

A second set of both a male and female counterpart will need to be machined in order to allow for interchangeable coupling between two trikes. This second set will allow for each trike to have a corresponding set to be able to couple front to back and back to front. This is necessary for further implementation and testing of the physical platooning ideal that Micro-AV proposes for future use.

This second set can either be manufactured in house at UWB or it can be outsourced to a machine shop. Manufacturing in house would be more cost effective however it would be much more time consuming and results would not be up to par with those of outsourcing to a shop.

VI. Recommendations for Future Capstone Groups

As the current system and assembly is a rough prototype it would be beneficial for future groups to use this system as a starting point for future additions and improvements. As listed above, the system can be further modified through machining for weight reduction and increased efficiency. Given that the materials ordered to manufacture the system in house are inexpensive, it would be advantageous for future teams to experiment with creating their own male and female counterparts and the corresponding geometry. With continued prototyping the system will become increasingly more efficient.

One recommendation for future teams will be to further explore a solution that can accommodate yaw and pitch forces in the trikes when physically coupled. The current solution involves utilizing a universal joint connected to the male shaft to accommodate these forces. However, it is not feasible for use in transit as the universal joint does not have tight enough tolerances within the bearings and internal assembly to be able to support the weight of the male shaft when not connected to the rest of the system.

Overall, the main focus in future teams will revolve more heavily around the electrical side of the project as this year's scope was focused mostly on the mechanical components. There will be mechanical changes that can be implemented and made as the electrical system and connections are further developed between the trikes and the assembly.

9. Appendix

References

[1] Shenzen Global Technology Co., LTD (Shenzen City, China). *TB6560*. Accessed: April 24, 2023. [Online]. Available: https://www.makerguides.com/wp-content/uploads/2019/08/TB6560-Manual.pdf

[2] "TB6560 Stepper Motor Driver with Arduino Tutorial." MakerGuides. https://www.makerguides.com/tb6560-stepper-motor-driver-arduino-tutorial/ (retrieved April 24, 2023).

Additional Tables

(A)	SW1	SW2	SW3	S1
0.3	OFF	OFF	ON	ON
0.5	OFF	OFF	ON	OFF
0.8	OFF	ON	OFF	ON
1	OFF	ON	OFF	OFF
1.1	OFF	ON	ON	ON
1.2	ON	OFF	OFF	ON
1.4	OFF	ON	ON	OFF
1.5	ON	OFF	ON	ON
1.6	ON	OFF	OFF	OFF
1.9	ON	ON	OFF	ON
2	ON	OFF	ON	OFF
2.2	ON	ON	ON	ON
2.6	ON	ON	OFF	OFF
39	ON	ON	ON	OFF

Figure A1. Current Table

The current going through the motor is adjusted by setting the switches SW1, SW2, SW3, and S1 on or off.

Stop current	S2
20 %	ON
50 %	OFF

Figure A2. Stop Current Table

The stop current is the current used to hold the motor at a stopped position, and can be adjusted by turning S2 on or off. A higher stop current value will result in increased holding torque.

S3	S4	Microstep resolution
OFF	OFF	Full step
ON	OFF	1/2 step
ON	ON	1/8 step
OFF	ON	1/16 step

Figure A3. Microstep Table

The microstepping can be adjusted by turning switches S3 and S4 on or off. A smaller microstep resolution will result in smoother movement.

	S5	S6
0 % Normal	OFF	OFF
25 %	ON	OFF
50 %	OFF	ON
100 % Fast mode	ON	ON

Figure A4. Decay Setting Table

The decay setting determines how the driver chip deals with back EMF from the motor, and can be adjusted using switches S5 and S6.