ECE 445

Senior Design Laboratory

Project Proposal

Vertical Climbing Drone

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1 Introduction

In this section we aim to provide context to the problem and how our project provides a solution.

1.1 Problem

For about the past decade, drones have become more available and more widely used in many commercial, industrial, and domestic applications. These drones have allowed us to see and examine situations that a human could not with unprecedented freedom. Specifically, we can now use drones to scope out crawl spaces, vents, pipes, and other tight environments where it would require much more work to put a human inspector. The commercial and industrial sectors have already adopted this new capability, where we can see that "pipe climbing robots have multiple usages such as inspection in chemical industries or for public sewers" [1] among other, more domestic uses. That being said, these drones are nearly all of a similar build: wheels or tracks to crawl along the floor. However, in vents and pipes, we put bends in them to change elevation. A tracked or wheeled drone that rides along the floor will be unable to move any further, as it would get stuck on the upward bend or be lost if it went downward through a vertical shaft.

1.2 Solution

Our solution aims to change this. We propose a similar foundation, as in a wheeled or tracked drone, to explore tight spaces, but we would like to add a third method of traversal to allow our drone to climb vertically, providing new and convenient access to a full length of ventilation, plumbing, etc. A top mounted track or wheel structure that can extend out to fill the length from floor to ceiling of a small space would allow the drone to drive itself up or down a vertical shaft. That is, it can climb walls so long as there are two surfaces on the top and bottom to wedge itself between. The additional freedom that comes from a new plane of traversal would have many applications.

As mentioned before, this would be a prime traversal tool to scout ventilation ducts and pipes for blockages, damages, and other conditions that would otherwise be problematic to the operation of these systems. Furthermore, we can easily fabricate a holder to attach wire or cable that would allow our drone to be the perfect candidate to run cabling and wires in the space between floors, the gap in the walls, or the tight areas in the ceiling. The utility this provides, and convenience, should be apparent to see. The fields that would use this drone currently have tools that attempt to accomplish what our idea is ideal for to a limited degree. We have special snaking tools to carry wires and cables, but they have limited range and cannot take a vertical bend very well. There are already drones as mentioned earlier to traverse small spaces, but they are forced to ride on the ground and also fail to traverse any vertical dimension. Our proposal would be the ideal tool for any job that requires tight spaces.

1.3 Visual Aid

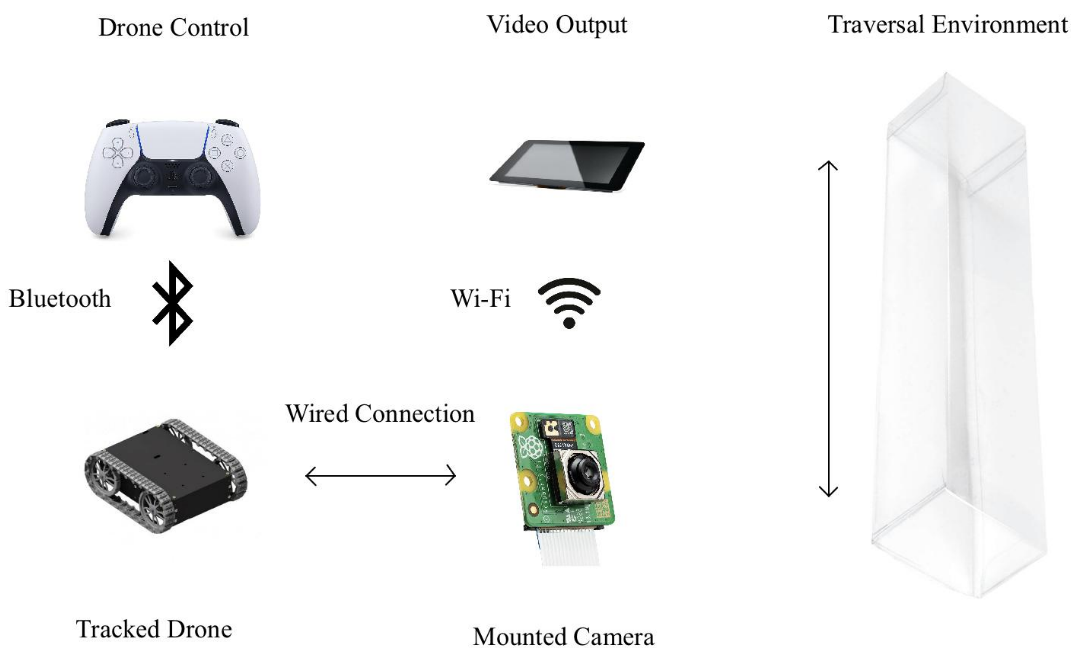


Figure 1: Visual Overview of Project

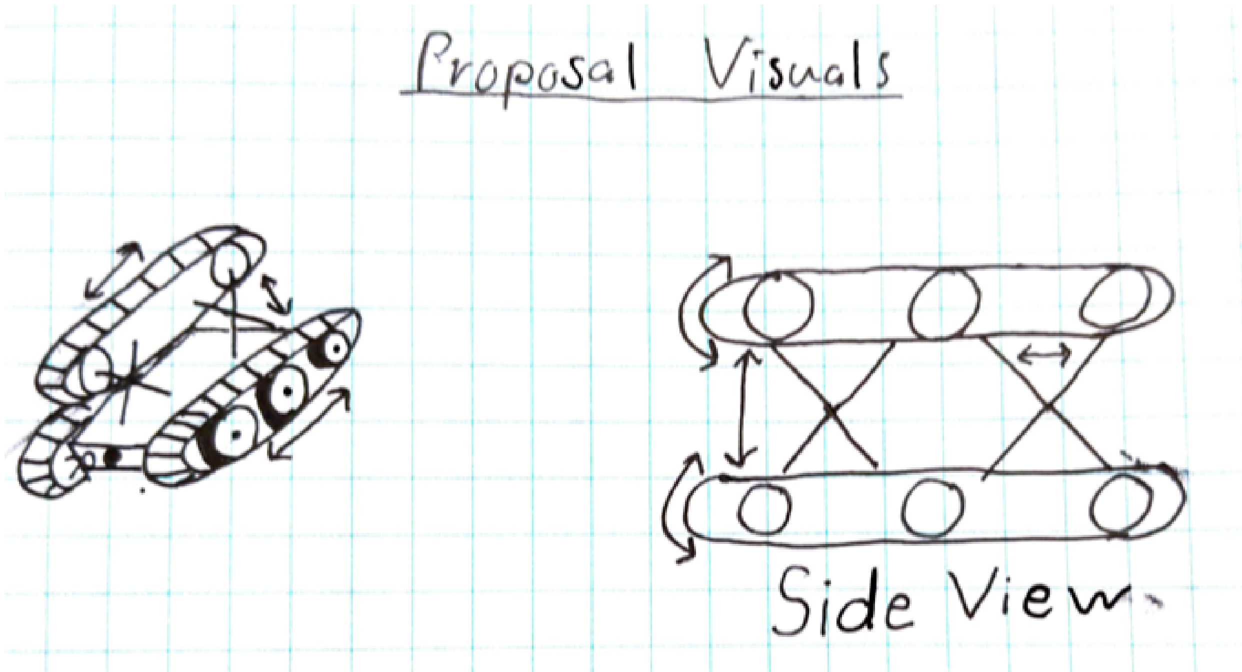


Figure 2: Initial Sketch of Proposal

-An initial sketch of our drone, including an angle view to get a full idea and a side view of the track layout.

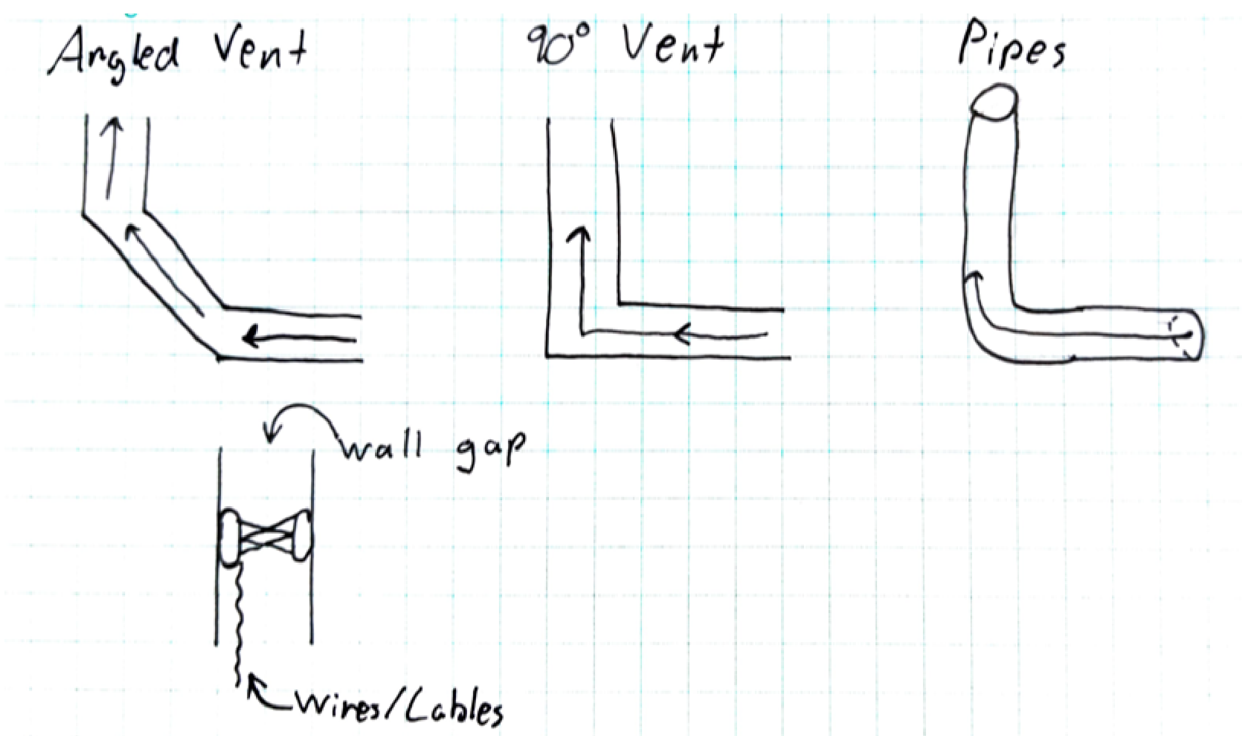


Figure 3: Sketches of Use Cases for Drone

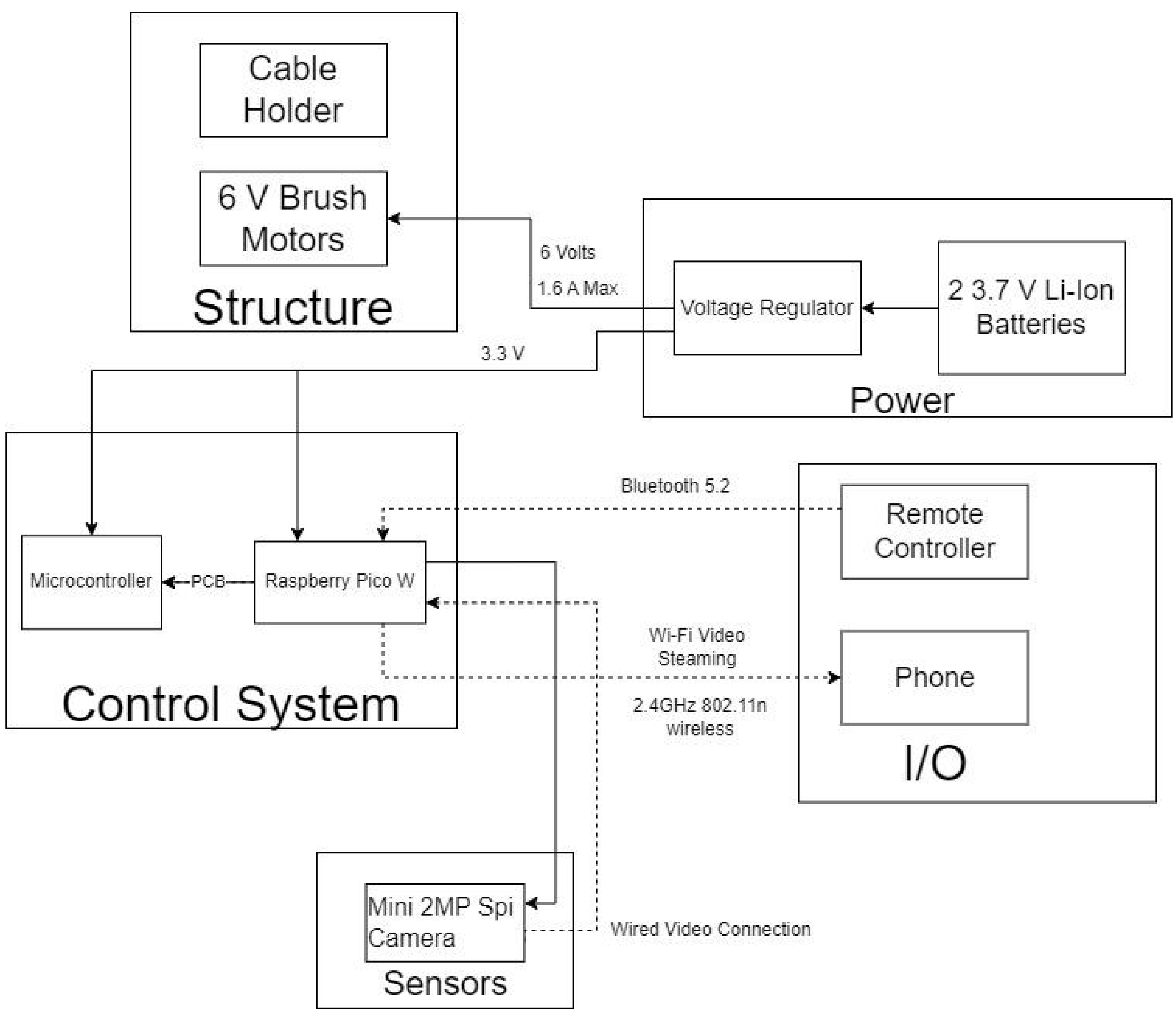
-A number of scenarios that we plan for our drone to operate in. Bottom picture depicts the drone threading wires/cables through a wall.

1.4 High Level Requirements

- The drone should be able to complete an in-place 360 degree spin in addition to driving forward and backward as well as being able to climb at a 90 degree angle relative to the ground in tight vertical spaces.
- The top track should be able to expand at least 4 additional inches to fit the diameter of the space to apply additional traction.
- The drone should be able to drag and feed a wire up to 0.5 inches in diameter behind it while traversing a space.

2 Design

2.1 Block Diagram (Figure 4)



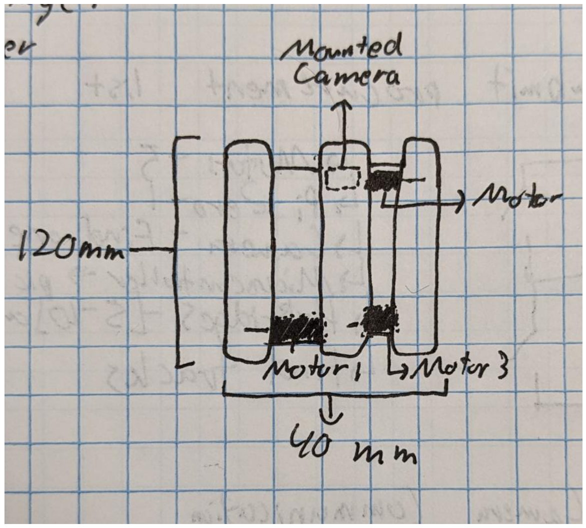


Figure 5: Top-Down View of Drone

In this top-down view of our drone, we've highlighted the length and width of the drone. The three black boxes represent 3 out of our 4 total motors, where the top motor drives the right track, motor 1 drives the left track, and motor 3 drives the middle, top track.

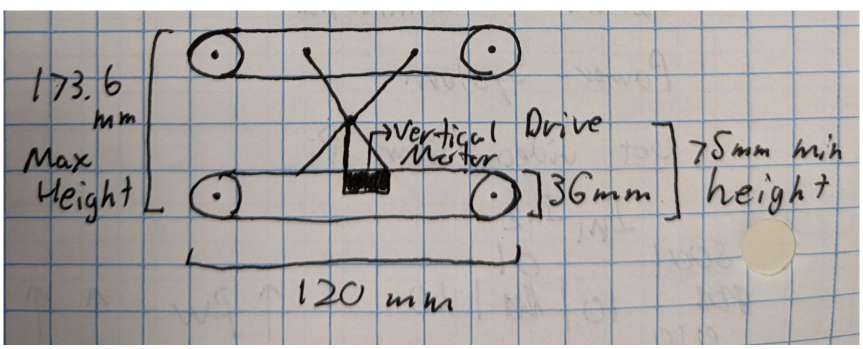


Figure 6: Side-On View of Drone

In the side-on view of the drone, we've shown the scissor lift mechanism used to expand the distance between the chassis and the top track. We're aiming for about 173.6 mm of total height while expanded and around 75 mm or less in height when folded up. The drive wheels are 35 mm in diameter, and the track that is wound around them should be around 1 mm thick, so we've got a total of 36 mm of height for the lower part of the chassis.

2.2 Subsystem Overview

Our system is divided into 4 different subsystems, which take advantage of both hardware and software.

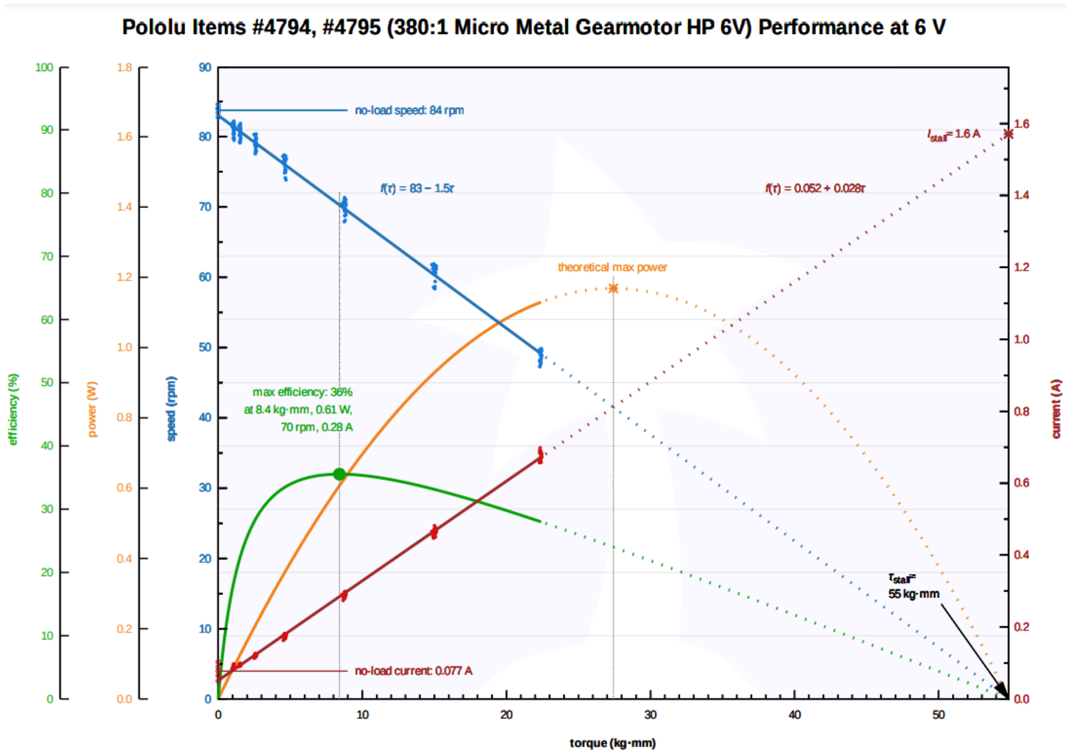
2.2.1 Structure

The structural subsystem will consist of the mechanical parts, such as the motors, chassis, and our wire holder. The motors are fairly straightforward, they will drive our tracks and expansion mechanism. We'll be using 6 V brushed motors for their ease of use and reduced cost compared to their brushless counterparts. We have no real need for the advantages that the brushless versions offer. The chassis will be lightweight plastic, with a great deal of 3-D printed parts and spots for our motors to sit as well as our PCB. The wire holder is also simple: a small circle to thread a wire through and then a screw to secure it in place. The motors will run off of 6V as mentioned previously, with stall current of 1.6 A and a no-load current of 100 mA. Our chassis will also feature a scissor lift mechanism that can expand 4 inches to increase the height of our drone, making it fit within a variety of spaces.

Requirements:	**Verifications:**
Motors will operate off of 6V and have current range from 100 mA (no-load) to 1.6 A (stall current).	• Attach motors to power system • Use a multimeter to measure both voltage and current when no load is attached. • Slowly add a load until the motor has stalled, being careful not to keep the motor stalled for too long. • We should see 6 V in both cases, 150 mA in the no load case, and then an increase in current draw while we add load until we maximize current at 1.6 A.
Expansion mechanism should add at least 4 inches.	• Measure height while at minimum expansion • Attach expansion motor to power system

	• Draw out the expansion mechanism to its furthest position • Measure height and difference from minimum position while fully expanded
Wire holder can hold wires up to ½ inch diameter.	• Measure the diameter of our holder • Feed various cables of diameter up to ½ inch and secure them • Ensure the wires remain secured in normal operation

Figure 7 - Torque vs Current, RPM, Power, and Efficiency Graph [2]



2.2.2 Sensors

The sensor included in our project will be our 2MP camera. We really only need visual data to feed back to the operator, and the 2MP camera will certainly provide sufficient visual fidelity for efficient operation. This camera displays in color, as opposed to the other variants that would display in black and white. If the drone is sent in for inspection purposes - say for example to check if certain wires are compromised - the operator would find a lack of color especially detrimental, so we opted for a color camera.

Requirements:	**Verifications:**
Mounted camera should transmit color video back to Pi via the wire harness meant for connection between the two, at which point the Pi passes the video onto the user's viewing device.	• Turn the drone on and connect the viewing device to the Pi over Wi-Fi • Once connection is established, we should have access to the live feed in color and without unmanageable latency

2.2.3 Power

The power subsystem will consist of 2, 3.7 V lithium ion batteries wired in series to provide a total of 7.4 volts. Our motors present the highest voltage requirement at 6 V, so 7.4 is more than enough to supply them. We'll follow up our batteries with a voltage regulator like the BD9E302EFJ-E2 buck switching regulator so that we can guarantee constant voltages for our motors and microcontroller.

Requirements:	**Verifications:**
Power subsystem should be supplying our H-bridges with enough voltage for them to output 6V and 1.5 A maximum.	• Using a multimeter, check the incoming voltage for the Vin pin on each H-bridge • This verification step goes hand in hand with motor verification in structure
Subsystem should simultaneously be providing at least 3.3 V and up to 500 mA to the Pi, microcontroller, and logic elements of our circuit.	• Use a multimeter to ensure that we get at least 3.3 V, up to 5 V, and that 500 mA is being properly drawn from the batteries.

2.2.4 I/O

The I/O will simply be a remote controller and the operator's phone. We plan on using Wi-Fi as the transmission medium for video, fed to our Raspberry Pi Zero from the camera, then from the Zero to the user's phone, which will see the live camera feed. The remote control will be paired to our Zero via Bluetooth, and the Zero will then feed inputs to the microcontroller.

Requirements:	**Verifications:**
The Pi Zero should transmit video to a viewing device over Wi-Fi.	• The user should attempt to connect with the Pi Zero over Wi-Fi • A live video stream should be viewable on the chosen viewing device.
The Pi Zero should receive commands via Bluetooth from a controller	• The drone should respond to commands given by the remote control in a way that accurately and quickly reflects the input given over a Bluetooth connection.

2.2.5 Control System

The control system will be composed of two components, the Zero and the microcontroller. The Zero will be handling most of the more advanced data, specifically it captures the remote control signals via Bluetooth and outputs the video streaming via Wi-Fi. From there, the Zero will feed our remote control signals to the microcontroller to coordinate our motors with the intended result of each input.

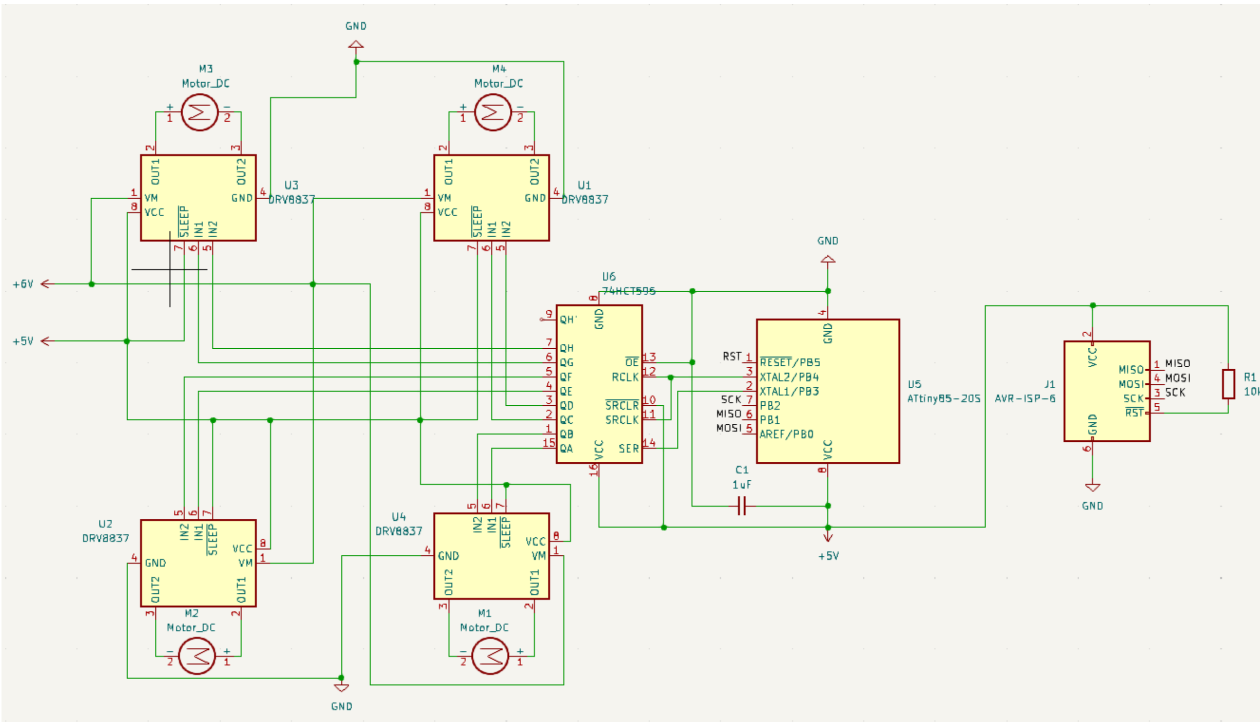
The microcontroller will be an Attiny85, and will be outputting serial data into a 8 bit shift register. This 8 bit shift register will shift 8 times to store the serial data, and the outputs of the shift register will feed into the H-bridges. The Attiny85 will poll the Zero in set intervals to give the H-bridge time to execute instructions.

Requirements:	**Verifications:**
The Attiny85 will receive a code from the Pi that specifies a motion type to carry out and will send the appropriate bits to the H-bridges	• Based on our truth table below, we should be able to measure the IN1 and IN2 pins on each H-bridge to make sure they align with what we expect to see based on the input we give.

Figure 8 - Movement Input Truth Table:

	Left Motor (IN1, IN2)	Right Motor (IN1, IN2)	Top Motor (IN1, IN2)
Coasting	00	00	00
Forward	10	10	01
Rotate Left	10	01	xx
Rotate Right	01	10	xx
Backward	01	10	01
Brake	11	11	11

Figure 9 - Control System Schematic



2.3 Tolerance Analysis

Since we're using the voltage regulator mentioned above to control the input to the motors, it's a critical component to the whole design. The datasheet [3] contains some warnings and suggestions that talk about our choice of resistances for our output. Specifically, we need to hit a target feedback ratio if we want to ensure the proper V_{out} value of 6 V.

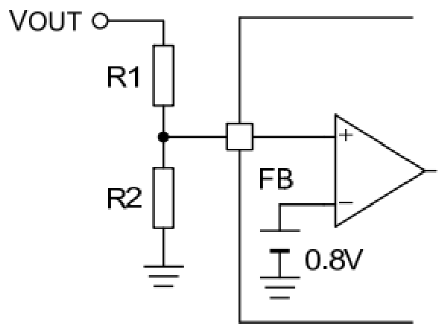


Figure 74. Feedback Resistor Circuit

$$V_{OUT} = \frac{R_1 + R_2}{R_2} \times 0.8 \text{ [V]}$$

※ Minimum pulse range that can be produced at the output stably through all the load area is 200nsec for BD9E302EFJ.
Use input/output condition which satisfies the following method.

$$200(nsec) \leq \frac{V_{OUT}}{V_{IN} \times F_{OSC}}$$

Please set feedback resistor R1 + R2 below 700 kΩ . In addition, since power efficiency is reduced with a small R1 + R2, please set the current flowing through the feedback resistor to be small as possible than the output current I_O.

Figure 10: Circuit Diagram for use of linear regulator

Here, we know we need to have a combination of R1 + R2 that does not exceed 700 kOhms, but we also need to find a valid combination that is large enough to make sure our power efficiency is not affected. The math would be as follows:

$V_{out} = 6$ V

6 = (R1 + R2)/ R2 * 0.8
7.5 = (R1 + R2)/R2
7.5(R2) = R1 + R2

From here, we actually get to decide what we think is a valid solution for R1 and R2, so we can put in a value for R2 and see what R1 would need to be. After some guess and check, we found that we can use the 10 kOhm ERJ-PB3B1002V with a 65kOhm ERA-3AEB6492V resistor. Both of these can be found in a ±0.1% variant, so if we run all four possible cases:

<u>+0.1% (10kOhm) R2 and +0.1% (65kOhm) R1</u>

$$(10,010 + 65,065)/(10,010) * 0.8 = 6\,V$$

<u>+0.1% (10kOhm) R2 and -0.1% (65kOhm) R1</u>

$$(10,010 + 64,935)/(10,010) * 0.8 = 5.9896\,V$$

<u>-0.1% (10kOhm) R2 and +0.1% (65kOhm) R1</u>

$$(9,990 + 65,065)/(9,990) * 0.8 = 6.0104V$$

<u>-0.1% (10kOhm) R2 and -0.1% (65kOhm) R1</u>

$$(9,990 + 64,935)/(9,990) * 0.8 = 6\,V$$

As we can see above, we have very small deviations in voltage that fall within the range of acceptable voltage values for our motors, so there won't be any disruption of performance from the motors. This falls well within tolerances with easily obtainable parts.

3 Cost and Schedule

3.1 Cost Analysis

Item	**Quantity**	**Price**	**Total**
2 MP Camera	1	$24.99	$24.99
Raspberry Pi Zero W	1	$14.99	$14.99
Tread Tracks	1	$14.95	$14.95
Polulu Motors	4	$22.99	$91.96
H-Bridge Driver	4	$0.89	$0.89
Cable Clip	1	$0.89	$0.89
LithIO Batteries	1	$18	$18
Item Subtotal			$166.67

Machine Shop		$200	$200
Labor	(10 Hours/week * 3 * 11 weeks)	$48.50/ hour	$16,005
Total			**$16,368.67**

3.2 Schedule

Week	Task	People
10/2 - 10/8	● Finish PCB design ● Refine PCB design according to feedback ● Order parts ● Submit design plans to machine shop	● All ● All ● Jacob ● Jacob
10/9 - 10/15	● Send in PCB design ● Begin testing components on a breadboard	● Jacob ● All
10/16-10/22	● Continue breadboarding and taking measurements ● Solder and begin testing PCB ○ Make changes and resubmit if necessary ● Begin writing code for Pi Zero and microcontroller	● All ● Josh ● Josh + Jacob ● Jeffrey + Josh

10/23-10/29	• Have the power requirements met for both the motors and controllers • Last PCB design revision (if necessary) • H-bridge and motors meet specified behavior • Check in on machine shop and make further physical design decisions as necessary	• Jeffrey • Josh + Jacob • Jacob • Jacob
10/30-11/5	• Have remote control and camera streaming functioning • Power systems are worked out • Begin mounting on chassis • Attempt to integrate all systems • Final PCB design should work ○ If not, submit one last version	• Josh + Jeffrey • All • All • All • All
11/6-11/12	• Further integration moving towards completion • Refinement of operation for the completed drone	• All • All
11/13-11/19	• Using feedback from mock demo to make last minute alterations	• All
11/20-11/26	Fall Break	
11/27-12/3	Final Demos	• All

4 Ethics and Safety

In terms of ethics, our group followed IEEE Code of Ethics adopted by the IEEE Board of Directors through June 2020 [4]. We recognize that technologies have the ability to affect one's life thus we hold ourselves to the highest ethical standard when working professionally in a team including but not limited to:

> **1. Seeking and providing truthful reviews and feedback of our technical work [4]**
>
> Within our group, we will follow course guidelines for timely feedback and confirmation with Teaching Assistant and Professors. We have already met with our Teaching Assistant once and plan on doing so, every week, for the remainder of the semester
>
> **2. Constantly learning and acquiring new skills throughout the training and design process [4]**
>
> We will also ensure to consult expertise (Professors, Teaching Assistants, Machine Shop Technicians) if questions or uncertainties arise during this project. This group consists of members with different areas of expertise, including power, programming, raspberry pi programming, PCB design, motors etc. By working together, we will be able to constantly learn from one another and ensure we all are successful.
>
> **3. Treating all people with respect and kindness and ensuring these codes are properly followed [4]**
>
> To ensure good teamwork and efficient communication, our team established a Discord server. With a shared Google Drive storage space, we made sure that all documentation is accessible for all team members. GitHub is used for software and schematic version control along with storage. This system not

only keeps track of all technical details but also confirms that all members are on the same page.

As far as ethical concerns go for our project specifically, we've addressed them as follows:

1. All of our electrical components will be "stowed" so that they are not exposed and dangerous to the operator nor will they cause unintended damage to the small spaces that we plan on having our drone operate in.

2. We'll ensure to use the existing standard for Bluetooth and Wi-Fi connections for security. The connection will only be between operator and drone, with the transmitted data being used for no other purpose than meaningful guidance of said drone.

3. The motors and treads used in the design will be designed as safe as possible so our project won't cause unintended harm to an operator's fingers or other small objects. The motors should not spin excessively quickly or be pushed well beyond their safe limits.

References

[1] O. Inbar and D. Zarrouk, "Analysis of climbing in circular and rectangular pipes with a reconfigurable sprawling robot," *Mechanism and Machine Theory*, vol. 173, p. 104832, Jul. 2022, doi: https://doi.org/10.1016/j.mechmachtheory.2022.104832.

[2] Pololu Robotics and Electronics, "Pololu Micro Metal Gearmotors," Pololu Corporation. [Online].

https://www.pololu.com/file/0J1487/pololu-micro-metal-gearmotors_rev-5-1.pdf (visited on 10/3/2023)

[3] *"7.0V〜28V Input, 3A Integrated MOSFET Single Synchronous Buck DC/DC Converter* ", BD9E302EFJ, Regulator, Sep 18, 2023

[4] IEEE. ""IEEE Code of Ethics"." (2020), [Online]. Available: https://www.ieee.org/ about/corporate/governance/p7-8.html (visited on 9/14/2023).