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

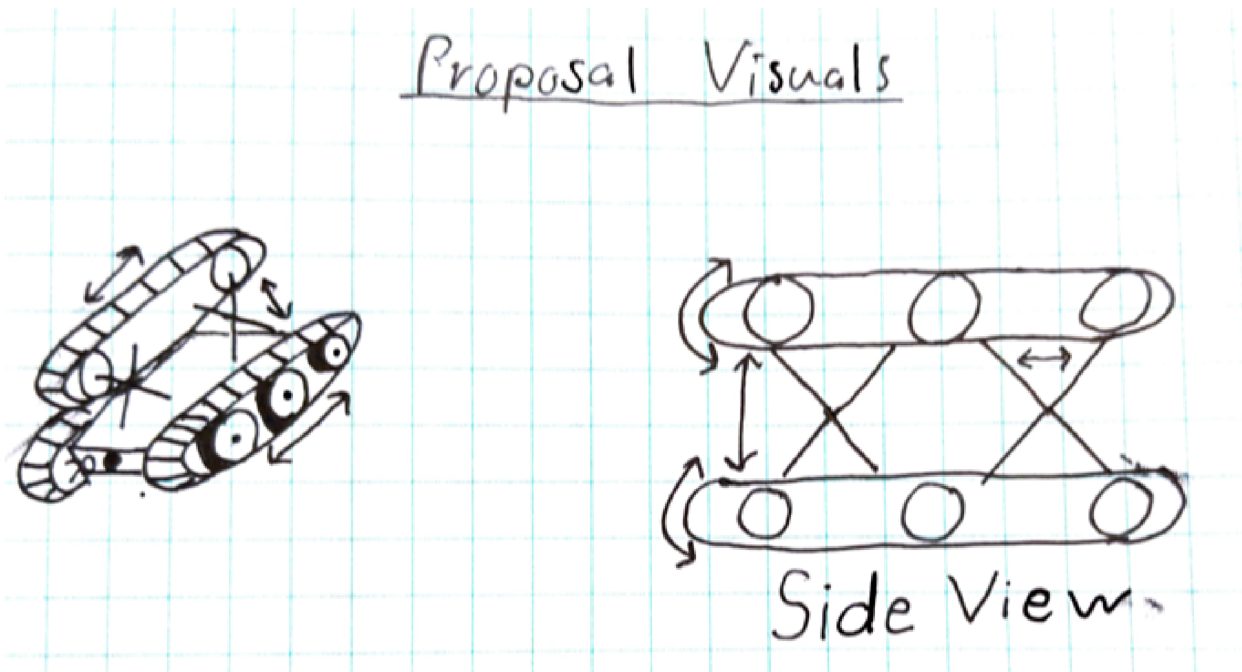
For about the past decade, drones have become more available and more widely used in many commercial, industrial, and domestic applications. These drones have allowed us to see and examine situations that a human could not with unprecedented freedom. Specifically, we can now use drones to scope out crawl 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" [2] 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

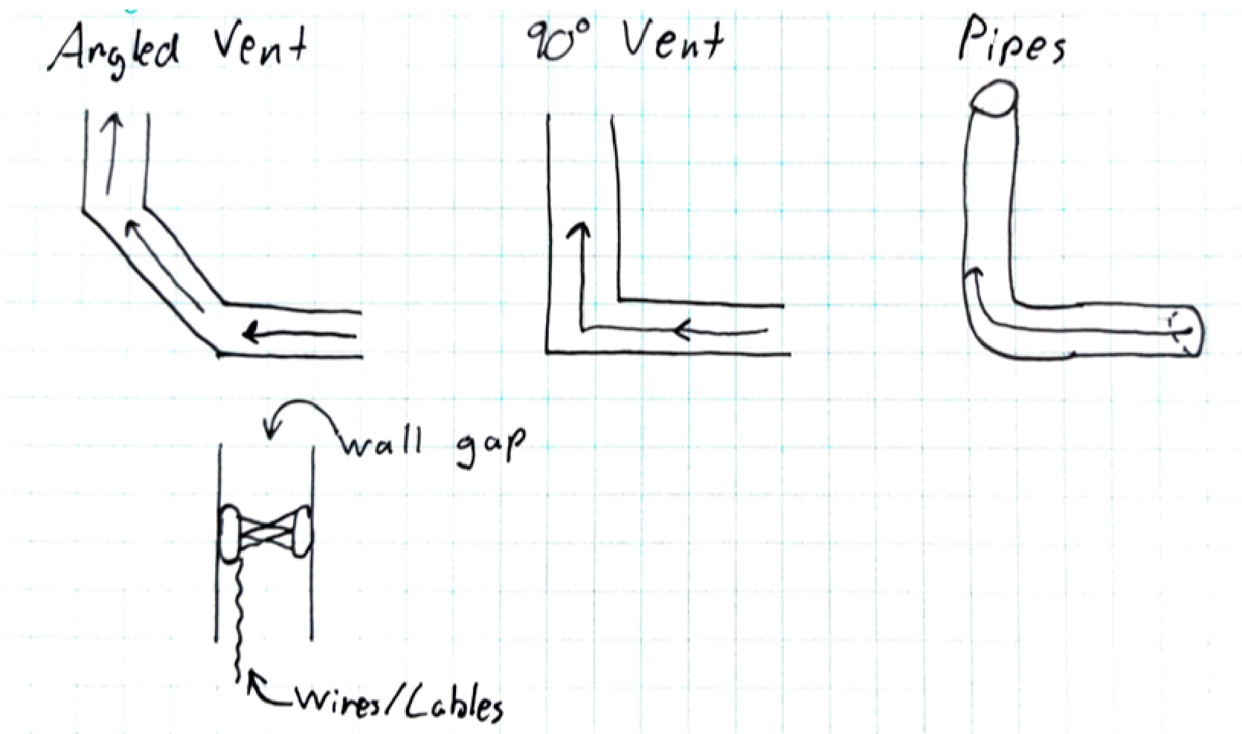
Our solution aims to change this. We propose a similar foundation, as in a wheeled or tracked drone, to explore tight spaces, but we would like to add a third method of traversal to allow our drone to climb vertically, providing new and convenient access to a full length of ventilation, plumbing, etc. 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



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



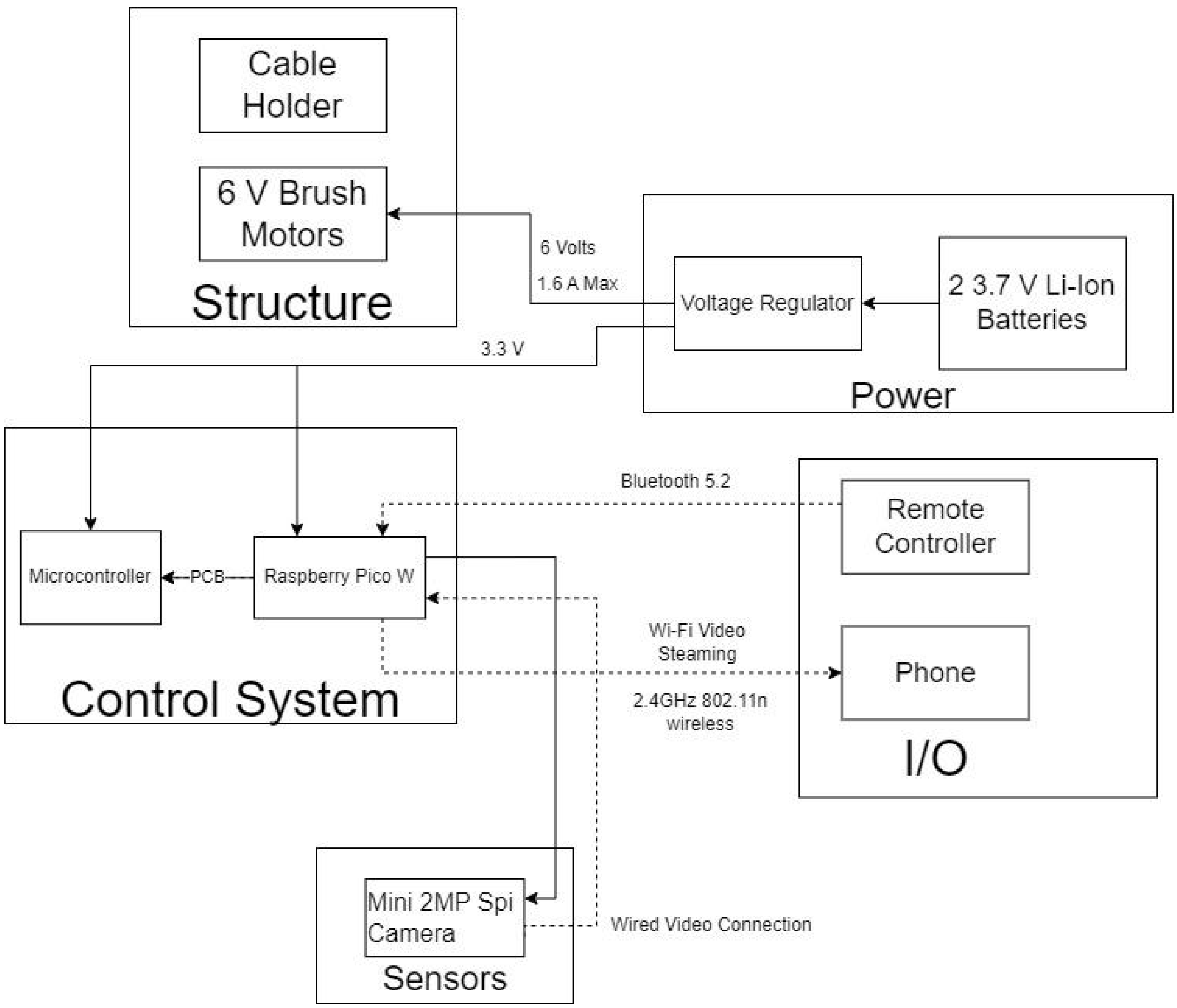
-A number of scenarios that we plan for our drone to operate in. Bottom picture depicts the drone threading wires/cables through a wall.

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.
- 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 remote-controlled and stream video back to the user.
- The drone should be able to drag and feed a wire behind it while traversing a space.
- The drone should have the ability to climb at a 90 degree angle to the ground in tight vertical spaces.
- The drone should be able to operate on motors that take no more than 6 V and stall out at 1.6 A of current while being able to perform the above tasks.

2 Design

2.1 Block Diagram



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 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.

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.

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.

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 Pico from the camera, then from the Pico to the user's phone, which will see the live camera feed. The remote control will be paired to our Pico via Bluetooth, and the Pico will then feed inputs to the microcontroller.

2.2.5 Control System

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

2.3 Subsystem Requirements

The requirements needed for each subsystem:

2.3.1 Mechanical/ Physical

1. The motors must be able to propel the drone through any incline up to 90 degrees.
2. The motor that powers the expansion mechanism must be able to push the top track with sufficient force to keep the drone's traction with both sides of the environment.
3. The cable holding apparatus must be able to secure cables and wires up to a ½ inch.

2.3.2 Sensors

1. The camera must be able to provide live color video back to the Raspberry Pico, which transmits to the user's device.

2.3.3 Power

1. The power subsystem must provide 6 volts and a range between 150mA and 1.5 A to the motors in the mechanical subsystem.
2. The power subsystem should also be able to provide 3.3 volts and 150mA as needed to our microcontroller and Raspberry Pico.

2.3.4 I/O

1. The remote control should be able to pair with the Raspberry Pico in order to send control inputs to the board.
2. The user's device should be able to receive incoming video signals from the drone's camera, providing a live feed.

2.3.5 Control System

1. The Raspberry Pi Pico will use Bluetooth 5.2 and 2.4GHz wireless signals to communicate with the remote controller and user's streaming device, respectively.
2. The microcontroller will receive signals from the Pico and appropriately interpret them to send signals to the motors corresponding to what the desired movement is from the user.

2.4 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.

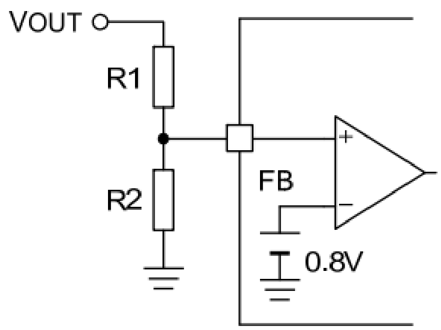


Figure 74. Feedback Resistor Circuit

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

※ 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.

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 $\pm$0.1% variant, so if we run all four possible cases:

+0.1% (10kOhm) R2 and +0.1% (65kOhm) R1

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

+0.1% (10kOhm) R2 and -0.1% (65kOhm) R1

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

-0.1% (10kOhm) R2 and +0.1% (65kOhm) R1

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

-0.1% (10kOhm) R2 and -0.1% (65kOhm) R1

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

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 Ethics and Safety

In terms of ethics, our group followed IEEE Code of Ethics adopted by the IEEE Board of Directors through June 2020 [1]. 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 [1]

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 [1]

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 [1]

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

[2] 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.

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