Final Report:
Robotic Vehicle Sensor Placement System For Air Force Research Labs

Senior Design II

Nathan Phipps, Anthony Stehr, Erich Wanzek, Ariel Lafuente(Team Lead), John Milner, Phi Nguyen, Dat Nguyen, Jacob Zahorik, Semere Filmon

Advisors: Dr. Daniel Jensen
Sponsors: Air Force Research Labs
AFRL Mentors; Mr. Mickey Wright, Mr. Mike Lazalier

Team Member Information:

Semere Filmon	303-669-7763	Semere.filmon@ucdenver.edu
Ariel Lafuente	210-473-6011	Ariel.lafuente@ucdenver.edu
John Milner	906-373-6072	John.milner@ucdenver.edu
Dat Nguyen	720-431-3993	Dat.nguyen@ucdenver.edu
Phi Nguyen	720-335-7658	Phi.2.nguyen@ucdenver.edu
Nathan Phipps	303-902-3816	Nathan.phipps@ucdenver.edu
Anthony Stehr	303-995-1336	Anthony.stehr@ucdenver.edu
Erich Wanzek	701-361-5855	Erich.wanzek@ucdenver.edu
Jacob Zahorik	720-495-0920	Jakezahorik@gmail.com

Table of Contents

Abstract

Special Operations Force (SOF) requires an automated insertion suite for situational awareness sensors. A two-semester effort has been taken inside a Capstone project to plan, prototype, and design a method to achieve the needs of a particular stakeholder group. This group of stakeholders includes military personnel, police, and field service personnel for covert unmanned placement of sensors at elevated locations. Research, a detailed design process, prototyping and analysis has been conducted to optimize a multitude of subsystems within our insertion suite. The subsystems include delivery/deployment of sensors, adhesive sticking of sensors following deployment, drone system vertical ascension for variable height during deployment of sensors, rover support for docking with drone systems, and communications / signal processing across systems.

Through techniques of design innovation, our prototypes were downselected to reflect a full system composed of these subsystems, in order to achieve the placement of a sensor package at a desired location. This text sets out to describe our research, selection and design processes throughout the course of our work.

Problem Overview

Special Operations Force (SOF) requires an automated insertion suite for situational awareness sensors. The Air Force Research Labs (AFRL) have decided to conduct a University Design Challenge, which calls for a device that can covertly place a sensor up to a height of 100 feet. In this report we will be conducting a thorough overview and analysis of the mechanisms we plan to develop. Under the guidance of Dr. Dan Jensen we will be using the Design Innovation method.

The Design Innovation method consists of four phases named Discover, Define, Develop, and Deliver. Throughout the report we will be providing specific insight of all the different methods and techniques used within each phase. Inside the Discover phase, activities such as the identification of stakeholders, interviews, Scenarios generation, and Affinity Analysis are conducted to allow our team to identify and understand the needs of stakeholders. The goal of this phase is to understand the problem at hand, and to alleviate any knowledge discrepancies inside the team. Once insights have been made from the Discover phase, groups of specific design functionalities are created. Entering the Define phase, the goal is to reframe the perceived problem at hand, here this will allow us to explore different ideas and potential points of views that may not be visible in first observations. Activities within this phase are Function Decomposition and the Journey Map. Following the Define phase is the Develop phase where the goal of the team is to ideate and model concepts based on identified insights and point of views developed from the first two phases. Inside this phase we work with Mind Maps, Design by Analogy, and 6-3-5 sketches to brainstorm potential ideas. We then use the Real Win Worth Analysis and decision matrix to down select to our best solutions.

Finally we progress through the Develope phases where the purpose is to iteratively prototype and test down selected concepts. In this phase the team broke down into five different subgroups which are the Main Vehicle Device Design, Vertical Ascension, Sensor Attachment, Sensor Deployment, and Data Communications team. Throughout this phase we are in constant contact with advisors, technical experts, and faculty to help revise the team's progress and analysis.

Customer Needs & Affinity Analysis

First Phase of the 4-D Design Innovation Process-Discover Phase:

The Discover phase was an opportunity for understanding the problem at hand. The purpose of this phase is to help reduce any knowledge deficits that the team may have. Here we break this phase into two sections where Customer Needs are identified, and Affinity Analysis is used to group specific customer needs into design functionalities.

Customer Needs:

The customer needs consists of requirements that are catered towards law enforcement, hunters, rescue teams, firemen, United States Army, United States Department of Defense's United States Special Operations Command, Air Force Research Labs, and government entities like the Federal Bureau of Investigations or the Central Intelligence Agency. Our team thought of a variety of general needs that focused on interaction with people, navigation, maneuverability, interaction with environment, defense countermeasures, and materials.

Interaction with people consisted of ideas that revolved around a vehicle design that involved on site personal for a variety of situations. Implementing a direct line of communication by means of video feed for personal or object recognition and audio feed with a microphone for a two-way communication system.

Navigating the vehicle requires control systems that would allow a vehicle to maneuver from one location to another. The team thought of global position systems that would rely on coordinate systems to map out the vehicle's traversal. Thermal and infrared systems were proposed to overcome weather or visibility complications.

Maneuverability revolved around accessing difficult locations or handling materials. Some of the difficult locations have been listed as terrain such as muddy landscapes, buildings with limited access, and elevated locations without a ground path to access the target. Handling materials whether dangerous or heavy, were considered for the safety of the personnel involved with a mission/operation.

The vehicle's ability to withstand environmental obstacles was important for the versatile nature of the vehicle. Size of the vehicle was considered for overcoming smaller environments such as entrances to a building that are restricted from fallen debris or damage. Harsh weather conditions like rain or snow, everything between daylight and night attributed to ideas of resilient materials to water or dust, along with a self-illuminating system for darker environments.

Defense countermeasures such as software preventing unauthorized access to the vehicle's controls systems would ensure the designated personnel would always operate the vehicle. Another countermeasure was a self-destruct mode in case a mission was compromised.

Materials consisting of advanced battery technology, resistance to external damage, weatherproof enclosure, and appropriate colors for stealth. All of these ideas were addressed with a main goal of allowing the vehicle to be deployed in any real-world situation.

The customer needs were aimed at determining the core requirements of our stakeholders. Law enforcement, military, civilian, and rescue teams were the main stakeholders when developing the customer needs.

Affinity Analysis:

The Affinity Analysis is a method used for analyzing co-occurrences between activities performed by specific groups of individuals. Our team thought of a variety of scenarios that would be conducted by military organizations, Rescue, reconnaissance, hostage situations, drone attacks, bomb defusal/disposal operations, radioactive material operations, sensitive equipment/information recovery, and landing zone identification. These scenarios were based on typical operations that armed forces would conduct.

Rescue missions, such as locating stranded individual(s) in an isolated or barren location. A video feed on a vehicle could be used to locate/recognize a person(s) of interest while traveling through an environment with limited visibility. Advanced battery technology would allow for longer deployments and for a stable connection to the operators.

Hostage scenarios would use robust systems that could withstand extensive physical damage while deployed in a hostile environment. Using a two way audio system for hostage negotiation, also an audio filtering system for detecting the location of hostages. Arming a vehicle with non-lethal weapons to disarm or stun human threats. Implementing an array of mechanical contraptions to open doors or access difficult spots.

Drone attacks conducted by military personnel to identify enemy locations and attacking an area of interest. A versatile waterproof drone with state of the art navigation, infrared and thermal cameras for overcoming lighting conditions for targeting systems, an integrated weapon system would be used for initiating an attack, and an efficient power supply system for long deployment sessions.

Reconnaissance missions for surveying locations for topographic data. A stealth orientated color scheme would allow for an undetectable vehicle that would carry an integrated shield enclosure to prevent unauthorized access or control of the vehicle. Data could be gathered by using a microphone with a long range condenser for detecting movement or assailants.

Improvised Explosive Devices (I.E.D.s) could be defused or set off with an autonomous vehicle. A driver could remotely access an area with possible I.E.D.s and use sonar sensors for detecting buried or out of sight explosives. A robot with mechanical arms could be used for defusing or removing an I.E.D. and the robot's material would be able to withstand use or an accidental detonation for reuse. Depending upon the situation, cheaper robots could be used for setting off I.E.D.s.

First responders or nuclear facility personnel could use a robot to handle radioactive materials. A navigation system would consist of an advanced tracking system, video feed, and thermal feed to the operator for detecting radioactive materials. The robot would be designed to withstand radioactive exposure, temperature variances, and condensation. Sensors for detecting radioactive material so that the dangerous materials could be moved with mechanical arms.

An aircraft goes down, carrying sensitive information, and a recovery team is required to access a crash site. Topographic data could be gathered with a drone to survey where the aircraft has landed and if there are survivors near the crash site. Similar to reconnaissance, providing a rescue team with information would allow for swift execution of a rescue operation.

Identifying a safe landing zone for a helicopter, could utilize an autonomous vehicle to determine if the desired location is safe. Pilots and Special Forces Operators could survey an area remotely, by using a vehicle such as a drone or an on the ground robot to place a marker for determining whether a landing zone is acceptable or not.

In conclusion the affinity analysis is useful for creating situations that were catered towards military personnel. By creating a list of ideas and our team categorizing them based on keywords has proven to aid the creation process. Documents created throughout the Discovery Phase can be seen in **Appendix A-1**.

Design Methods

Second Phase of the 4-D Design Innovation Process-Define Phase:

The Define Phase was an opportunity for reframing our given challenge and gaining perspective through divergent styles of thinking to explore as many possibilities to encourage maximum numbers of ideas and points of view. Here we used two tools to accomplish this: Functional Decomposition and Journey Mapping.

Journey Map:

The purpose of the Journey Map is to create an activity diagram that a user would perform to interact with our device to accomplish their mission. By doing this we can find opportunities to automate, innovate, get rid of unnecessary steps, combine functions, and discover possible failures.

The insights we gathered were:

We must make the device lightweight for human transportation. What are the methods of loading and housing sensors? Can we make this device modular? Can we have different modes or combinations of transportation? What are the different methods of retrieving a sensor? Can we make device self-test damage sensing? If the device breaks, how are we going to fix it? Spare parts?

The following is a detailed description of that process:

The Journey Map process started with a discussion of the story that our device will follow. We tried to put ourselves in the shoes of the operator and begin the story as soon as the device is being chosen for operation. Beginning here allowed us to start developing ideas of the possible options the device could consist of and the actions that would be required to prepare the device for transportation. Possible options for the device were things like multiple modes of transportation, different batteries, sensors and more.

After the user had gathered all necessary parts they would transport the device to a location for deployment. Here was our first encounter for an insight and it was to make the device and components as lightweight as possible for human transport. The possibilities for the mission requirement led to another insight; try to make the sensors and other parts modular for ease of preparation. Along with this came the idea to maybe make a combination of all the modes of transportation (wheel, tracks, limbs) to make a robust movement method.

Operating the device follows several pretty simple looped actions. Move to sensor placement location, place the sensor, monitor sensor, repeat. While going through this loop there are several branch off points but some of the insights we gathered were; design for sensor retrieval, or self-destruct. The final insights came from a maintenance stand-point; Can the device check for damage to itself or the sensors, and can we make spare parts for easy fixing. Our first iteration of Journey Mapping gave us a majority of these insights, however when restructuring the map and checking for possible alternative routes, we discovered and were able to clearly see the rest.

The Journey Map activity can be seen in **Appendix A-2**.

Functional Decomposition:

The functional decomposition was an opportunity to ask the right questions for what our device does. For this we can describe the functions that our device must perform in order to complete its goal as well as describe some of the qualities of the functions.

In short, we spent a lot of time trying to organize the functions of our device. Due to the project's broadscope it was hard to define functions for our device without already defining the device itself. However, we were able to narrow our breakdown into two major functions: Function of the sensors and the device that deploys the sensors. Each major function has several minor functional parts.

For the sensor they are as follows: Mobility (specified weight, dimensions), Deployment (covert, versatile, consistent, in varied conditions), Communication (relaying information, remote locations, visual i.e. camera), Retrieval (location, line of visibility, sonar techniques), and Environmental Resilience (shielding, strong components, redundant systems).

For the deployment device(s) they are as follows: Mobility (avoid hazards, transverse variable terrain, carry specific weight, vertical ascension) Deployment (covert, versatile, consistent, in varied conditions, quickly), Navigation (know current location, sensor location, transport sensors, tracking), Communication (monitor device systems, relaying information, remote locations), Retrieval (location, extract sensor, rehouse sensor), Environmental Resilience (shielding, strong components, redundant systems

Both the Functional Decomposition and Journey Mapping had at least one revision. This allowed us to better define the project and set us up to optimally generate ideas in the following weeks.

The Functional Decomposition activity can be seen in **Appendix A-3**.

Ideation (Concept Generation)

Third Phase of the 4-D Design Innovation Process- Develop Phase:

The Develop phase serves the purpose of brainstorming multiple ideas, while taking into consideration the previous two phases(Discover & Define). Once a lot of ideas are generated, we then go into a down selection process where we choose the best ideas. Here we will review Design by Analogy, 6-3-5 Sketches, and the group down selection process.

Design By Analogy:

In the Design by analogy phase of our work we examined the use of word maps and an online biological database to help further draw information regarding the development and planning of a vehicle insertion suite. Specifically we used the website WordVis, in order to draw inspiration and creative thinking surrounding important words within the description of the desired functions for the vehicle insertion suite. The results from this portion of the design by analogy phase included a visual/textual breakdown of 14 words into hundreds of similar terms. Among the initial words broken down, in multiple instances we went one step further, ideating word maps of words generated by WordVis in a previous word map iteration. Some of the terms/words examined included retrieval, delivery, recovery, covert, deployment, navigation and so forth. Here retrieval was a keyword where the functional description would be: “Retrieval of a sensor at an elevation of 10 feet or greater.”

Using some of our original terms, in addition to the new terms generated in our word maps, we were able to acquire research and data used to creatively examine biological functions similar to our key functions. The online biological database utilized was AskNature. From the research this database provided we were able to see how nature emulated similar functions to the ones required by our vehicle’s insertion suite. Examples of insights included the concept of moth’s using their wings to shield themselves from sonar, thus displaying the function of being covert. An additional example of function modeling from biological analogy included the concept of jumping spiders having multiple eyes. Here the term multiple eyes was drawn, by our group, to emulate the function of full view or 360 degree in the xy, and possibly z domain, with regards to the visuals from a camera system. Again the sentiment of full vision was echoed in a similar biological analogy, this time referencing chameleons in their abilities to achieve 360 degrees of vision.

The Design by Analogy activity can be seen in **Appendix A-4**.

6-3-5 Sketches:

The purpose of this exercise was to come up with creative solutions involving our overall project and expanding on them with the input of others from the group. Each member drew and annotated three concept systems for the chosen opportunity statement. With the mind-map and analogies as inspirations, a base structure of creative solutions were drawn by each member. The next step was editing and adding onto other group members' ideas. This allowed for each idea to be developed with the combined effort and ideas of multiple group members that fostered a diverse solution development that may not come to light on its own outside of this exercise.

This exercise generated 150 drawings between the 10 group members. Solutions ranged from sensor placement, vehicle design, hardware/software implementation and more. Not all ideas here were implemented into further iterations, but this exercise did spawn ideas that were critical to moving forward in our product development. The idea that sparked the basis of our prototype moving forward was the amalgamation of a quadcopter and a ground vehicle. This design had the best of both worlds which was high reach given by the drone and load bearing capacity of the ground rover. Further edits to this design strengthened the idea of the use of a tether that doubled as a powerline, allowing for the load bearing ground vehicle to carry larger batteries and reduce the weight on the drone allowing for longer flight times. The tether implementation was also furthered later in an interview with police officer Phibbs. Another promising idea that came from this exercise was the wall climbing caterpillar drone. The base idea started as a six legged robot with moving pistons between each section allowing two sections to be clamped to the wall while one section contracts or extends to move the robot up and down. Further edits here involved the use of electro-magnets, adhesives, or suctioning devices on the feet of the robot. Other ideas came from this exercise that were also furthered in the prototyping phase.

Group Down Selection Process:

After the Ideation (Concept Generation) process, we had more than 30 different ideas. So, the request was downselection the ideas and at the end we will be able to choose the best idea for the next step (prototype process). To do the request, we used the Real-Win-Worth method.

What is the Real-Win-Worth method?

Real-Win-Worth is a strategy to manage risk and reward. It provides a way to rapidly assess the marketability of and innovation. First of all, “Real” is technological feasibility, to answer the question: is this idea real? We need to answer the question: do we have technology to do this idea? If the answer is yes which means we have enough technology to build and test this idea, then the idea is Real. Second, “Win” is the user’s need. The idea is “Win” if it meets all or most of the user’s requirements. To define the idea “Win” effectively, we need to completely understand the user’s requirements which are determined through the interviews with Stakeholders. Finally, “Worth” is business viability. To determine the idea is “Worth”, we need to compare the cost needed to make the product from the idea. We will not know exactly the cost because we have not made the product yet, however, we can be able to estimate the cost by determining what kind of material, what technology will be used and how long it takes to build? By combining the Real, Win, and Worth, we defined the good ideas and down selected the ideas from 30+ to 7 ideas. However, 7 ideas are too many and we wanted to keep down selecting the ideas. Therefore, we used a second method which is Matrix comparison.

Matrix comparison is a method to compare one idea to other ideas, and through the comparison, we define which idea is better than others. So, we built a matrix which is shown below in **Figure 1**.

	x	1	1	1	1	1	1
	0	X	1	1	1	1	0
	0	0	x	1	0	0	0
	0	0	0	x	0	0	0
	0	0	1	1	x	0	0
	0	0	1	1	1	x	1
	0	1	1	1	1	0	x
	0	2	5	6	4	2	2

The ideas were disposed in 7 rows and 7 columns. Then we compared the idea with others one at a time. The idea is better = number 1 in the matrix, and 0 = not better. After the matrix is full filled with 1 or 0 (the comparison is finished). We sum the total evaluation for each design.
→ The one with highest point is the best design.

Figure 1: Matrix Comparison Method for Idea Down Selection.

After matrix comparison activity, we determined the spider robot is the best design with the score of 6. The second design is the drone with an arm and attachment sensor device which the score is 5, and the third design is the boom arm. The scores between those three designs are very close to each other. Therefore, we decided to keep all three designs for the next step (initial prototype process) instead of choosing only one design, and we are going to pick one of those designs for the final design after the initial prototype process.

Fourth Phase of the 4-D Design Innovation Process: Deliver Phase

Design Requirements

In this section the design requirements that were synthesized from the analysis of customer needs and the analysis of performance and failure modes will be discussed. **The first function of high importance, is navigating to the approximate location for the sensor placement.** This function will be implemented by a main robotic rover vehicle, which would navigate to the approximate spot carrying a payload that consists of the vertical ascension device and sensor(s). **The second function of high importance was to move the sensor to the exact location it is supposed to be placed.** The placement requirement includes placement in three dimensional space including up to 100 ft high. The height requirement could be representative of trees, light poles, buildings and other natural or man-made objects. The important function of vertical ascension will be implemented via drone. **The third function of high importance is to stick and secure the sensor at the desired location.** This will be implemented by the use of proper adhesives and attachment mechanisms. **The fourth function of high importance is data communication and data gathering.** The data that needs to be gathered and transmitted will consist of a multitude of sensor and video feed data that will enviable successful navigation and operation of the robotic device. Recorded data from the situational awareness sensors will either be transmitted in real time or stored temporarily in a micro memory device such as an SD card. These critical functions of data transfer and storage will be implemented by the use of appropriately chosen off the shelf communication modules that can function with open source hardware such as arduino and raspberry pi. These four design functions of high importance described above represent the most important and fundamental requirements to achieve an overall successful design of a robotic device that will place and retrieve sensors from vertical heights. Thus because of the importance of these four first functional categories, our initial prototyping was focused on ideas and problems surrounding each of these functions of high performance.

In addition to these four main functions of high importance, there is another tier of functions of high importance that will lead to overall design success. The first of these functions is focusing the sensor in the correct and desired direction once the sensor unit is properly attached to the designated attachment point. This will be implemented by the use of a mechanism with adjustable degrees of freedom for all three spatial axesses or angular access such as a servo motor controlled gimbal joint. The next of these additional functions of high importance consists of loading the data for processing in the case of the data being stored in memory on the device. (This would be the case in environments of operation where live time transmission of large amounts of data is not feasible or practical. Off loading of the data will be implemented by a close proximity data link being established to the sensor by a rover vehicle close in range that would have high memory storage and more powerful communication equipment due to its larger size. Another way that this function could be implemented would be a retrieval of the sensor, or a mechanism ascension/descension mechanism to retrieve and replace the sensor. The next additional function of high importance is data processing. The data that is collected from the sensors need to be collected, transmitted, reloaded, and processed to be displayed to the mission operators. This will be implemented by the use of code on embedded systems such as Raspberry Pi. In conjunction with this function, another function of high importance is displaying the data to provide quality and useful information to the operator(s). which displays video feed from the robotics devices and the deployed situational sensors, along with control inputs interfaces to send commands to the devices. This all could be implemented on off the shelf embedded system components such as Raspberry Pi.

For the first semester, the team decided to focus our time on the exploration of the first four main functions of high importance because of how crucial these functions are in scope of the design requirements. The additional functions of high importance will be explored at the start of next semester through prototyping.

Initial Prototyping Results

(A) Spider Climber

The spider robot was the first designed model (**Figure 2**). The spider was intended to be a piston actuated, modular body that could scale up corners of buildings and attach a sensor at the desired location. We found that the spider could haul a relatively heavy load but was only effective on corners and cylindrical poles that had rough surfaces.

Figure 2: Spider Prototyping

(B) Boom Arm

The second experiment that we conducted was using a boom (**Figure 3**). We found that using a boom to extend our reach causes excessive torque applied to the transportation vehicle. In addition, a large amount of stress was applied to the boom causing plastic deformation. Required cross-sectional area was calculated but yielded an unreasonable diameter to achieve targeted height of 100 ft. Thoughts of adding motorized wheels to the end of boom and utilizing the wall to minimize strain was explored but assuming that there would be a wall at the desired location could hinder versatility of sensor deployment in different environments. This also did not overcome challenges of reaching the targeted height. After learning that these two ideas may have flaws that could not overcome the challenges of reaching one hundred feet. We decided to move onto a drone.

Figure 3: Boom Arm Prototyping

(C) Drone

We first experimented with using an adhesive to attach a mount for a sensor (**Figure 4**). We found that the drone could not apply enough steady pressure that was long enough for the adhesive to attach to the wall. The team discovered an alternative solution. We built a device attached to the top of a drone that could launch a dart-like device. This method would only work for softer materials like wood or drywall.

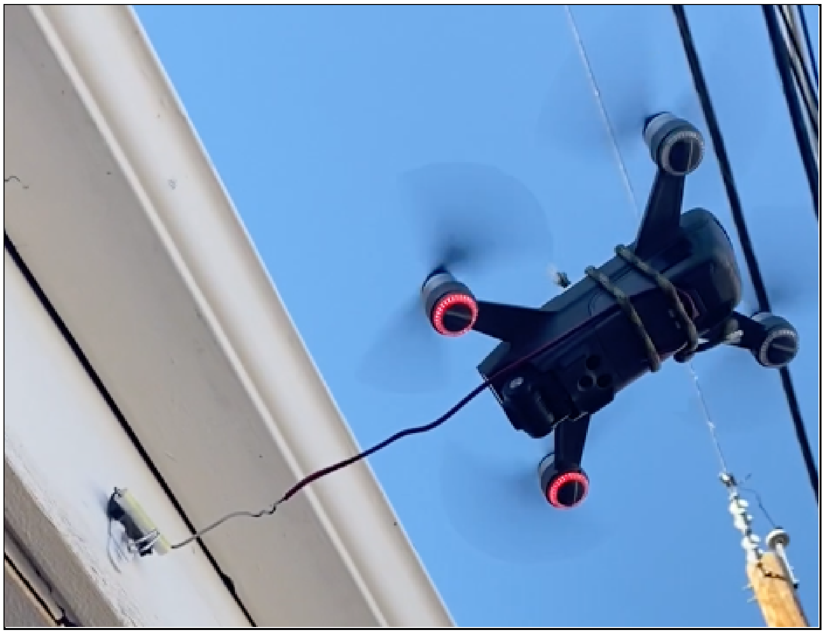


Figure 4: Drone Arm Prototyping

Other than the three main designs, other critical systems were needed to be prototyped and tested.

(D) Data Communication:

Our testing trials consisted of two NRF24L01 transceiver modules sending unique arduino data packets to one another to test accurate data transfer. One transceiver was connected to arduino and the serially connected to a laptop for data display and keeping track of missed packets, see **Figure 5**.

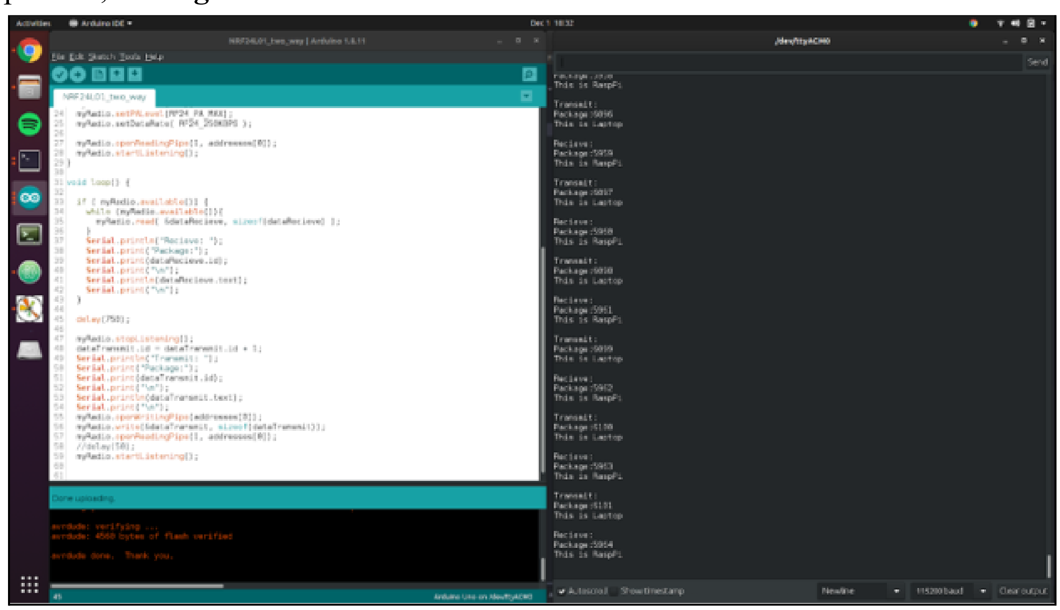


Figure 5: Data Com Test

The second was attached to an arduino and powered via 12V battery. The devices have three different power modes they can operate at and data transfer rates. For all tests the power mode and data transfer rate were set to max. However, data packets were only sent every quarter second and a total of ten seconds was used to measure the percentage of missed packets.

The first test was to make sure there was a good connection, <1 meter. This test was an easy success and no problems arised. The second, real, test was to place household objects in between the devices. Using a flat screen living room tv which allowed for a large flat "barrier" where there would be no line of sight. The test was a success and all data had been transferred correctly. Next was the wall test. The devices were placed into different rooms and separated by mainly drywall. Initially, we encountered a failed test (>50% missed packets), because the antennas are directional and we mistakenly placed the antenna the wrong way however after adjusting towards the direction of the other device there was a minimal (<5% missed packet) error for transferred data. Final indoor test was between the thicker brick wall between an apartment and hallway. Here the test failed (>50% missed packets). Even though some packets did get through, looking back, it might have been going through the door which was not directly in front of the device, but close by.

Outdoor testing was the next step to test the range of the devices. The laptop station was placed on an apartment balcony which is located on the third floor of it's building. The second mobile device was moved to the furthest line-of-sight distance possible from the other. Missed packets were communicated via phone between people at each device. Using google maps to calculate straight line distance (See **Figure 6 & 7**), the separation was approximately 800 ft. or 243 m.

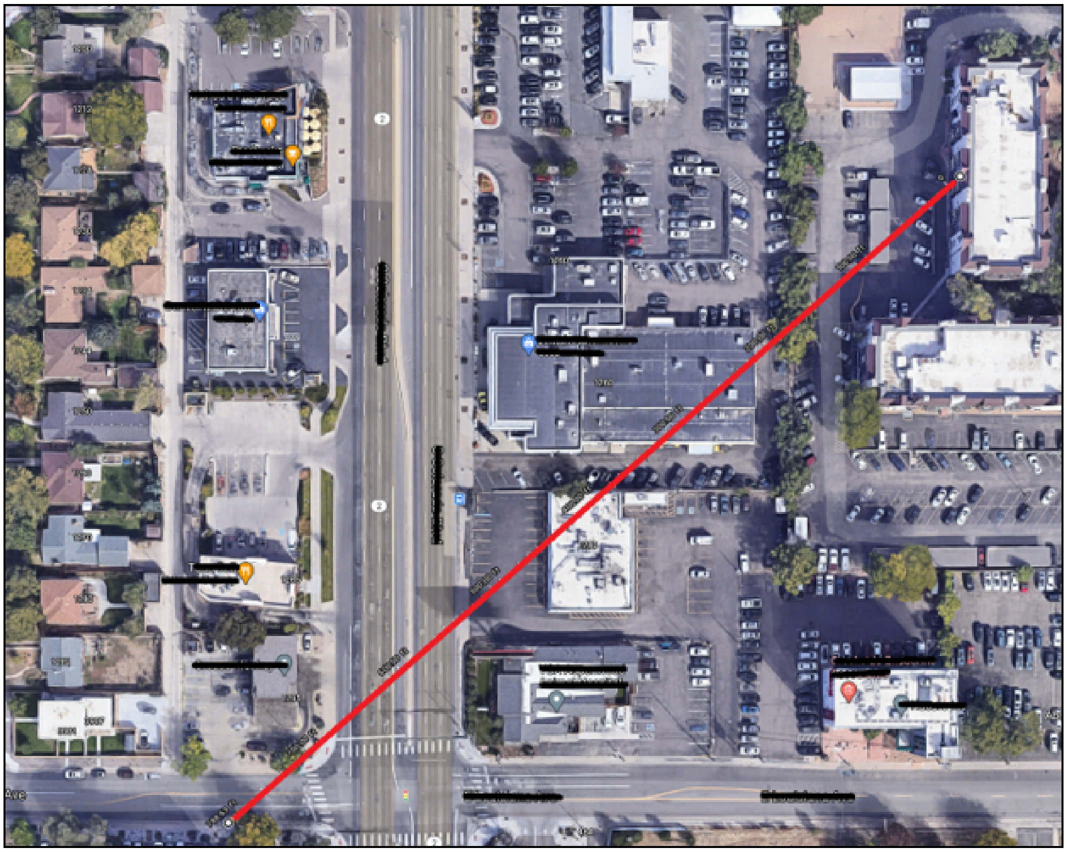


Figure 6: Data Com Test

Figure 7: Data Com Test

Next was to test non line-of-sight transfer. The mobile device was then moved to a further distance where the view was obstructed by multiple houses, taller buildings, and trees. At approximately 1700 ft or 512 m, the device was still communicating fairly well (<5% missed packets) so testing stopped here.

The conclusion for these tests is that this device scheme should work great for our system, and will allow us to send signals to our different hardware. The fact that they can be connected with arduinos and raspberry pi (also was tested) makes it a great solution for wireless communication. If better devices are discovered in the near future, we aren't hard set on these as long as we can easily swap over.

(E) Prototype Results : Wireless Video Transmission:

Because of the light weight of the camera, it was able to stay attached to the adhesive for more than 1 hour and we had to remove it ourselves because the battery that was powering the camera ran out of charge. The video quality was good because the distance between the receiver and the camera was much lower than the maximum range of the transmitter which can go up to 2.4 km depending on the receiver and the antenna used. The total weight of the camera and the battery used for powering it was about 7 grams. From the above results, our test was successful when tested on a wall at a height of 10 meters.

(F) Adhesive Selection:

Adhesive trials were conducted between several different adhesives. Upon the suggestion of Dr. Dan Jensen, we examined a pressure sensitive adhesive (rat trap glue) in its ability to form adhesive bonds. The pressure sensitive adhesive appeared to be very effective in regards to the limiting factors that we were testing. The desirable factors that we were testing for included low force exertion, low force exertion time (i.e. how long a force was applied to a surface with the with regards to the object being glued/bonded to it), and high weight tolerance (i.e. can the bonded surface support weights of 0.5 lbs to 2 lbs). Additional tests were conducted to examine what surfaces provided reasonable adhesive bonding; an example includes the wet surface test, whereby rat trap glue was not successful in achieving reasonable bonding.

The conclusion from these trials was that the Terro brand glue trap, and glue traps in general, could uphold the desired qualifications necessary to achieve the desired sticking parameters we were seeking. For in-depth analysis of these trials please consult **Appendix A-5 Tables 1 - 10.**

Design for Functions of High Importance

______After the initial stage of prototyping the team compiled and examined enough information to determine methods that contain the highest probability of success. Our final design is as follows (Shown in **Figure 8**):

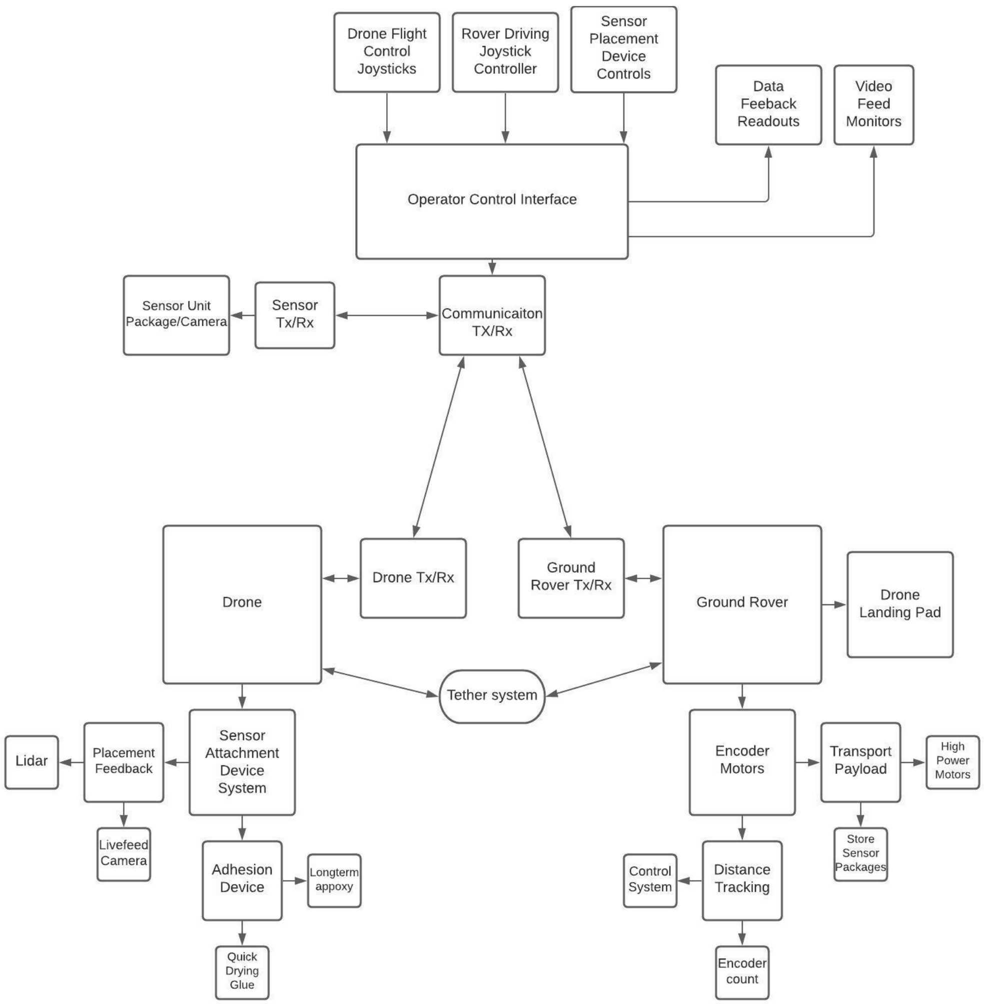


Figure 8: Final Product System Breakdown

The four main subsystems consist of a ground vehicle (rover), a drone, a sensor attachment device carried by the drone, and a base station which all combine to make the entire system and perform the functions of high importance. The rover, which houses the drone on top of its frame is connected to the rover with a tether. Then it navigates to a location in close proximity to the desired location of where the sensor needs to be placed. Next the drone, which has the sensor attachment mechanism, then ascends to the required vertical height of the desired sensor placement location. The sensor package, which has an adhesive covered front-face and a rear mounted FPV camera, is then shot from the mechanism to the surface of the desired location.

Final Product Design/Solution

(A) Drone:

I. Safety Protocol:

Safety for our team, equipment, materials, and other miscellaneous hardware was considered throughout the entire process of testing and assembly of all done components. The team's safety was considered first and foremost at all times. Facial protection was utilized when working with hazardous tools/materials. Team members were kept at a safe minimum distance of 15 feet away from the drone and rover, while testing the various implementations. This was enforced among ourselves and kindful reminders were enforced as needed. The equipment was carefully transported among all of the group members, between meet up sessions and were carefully organized for easy access to parts, tools, and hardware throughout the testing/assembly process. Materials were treated similarly as the equipment, but if there were hazardous materials involved, protective gear was worn by each group member while handling hazardous materials. Whenever, potentially hazardous tools were used, gloves, eye/ear protection were utilized by the team member operating the hazardous tools.

Specifically for the drone work, we created a safety protocol sheet that was approved by a drone expert on the faculty at the University of Colorado - Denver. The protocol can be seen in **Appendix B.**

II. Quad-Copter:

For the Quad-Copter, we used the frame F450 with Pixhawk flight controller, 30A ESC, a GPS device and four 1400kV motors. (**Figure 9**)

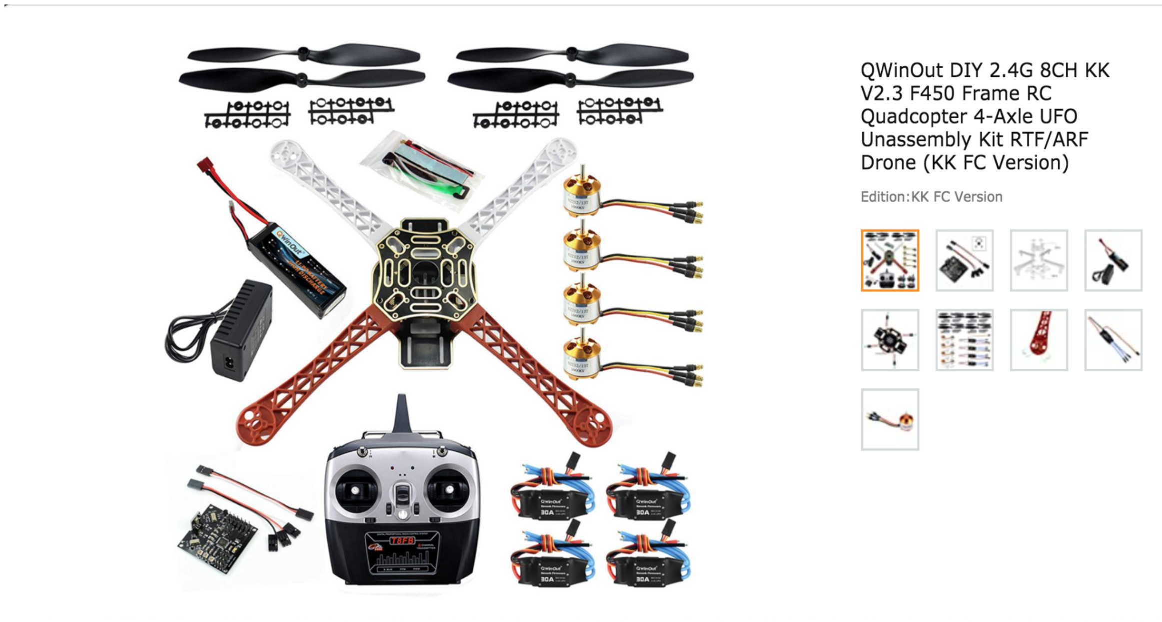


Figure 9: Quad-Copter

This drone has enough power to lift up a singular launching mechanism system but not enough power to fly up to 100 ft as the project's request. Due to this limitation the team decided to upgrade the stock 1400kw motors to 2200kV motors. Now the drone had the capability reaching an altitude of 100ft, however the drone unstable and frequently lost the balance when the launching mechanism was loaded on top of the drone. It is also important to note that the team only used the Quad-Copter to test the small (single shooting mechanism) since it was cheaper for the initial prototyping phase.

III. Hex-Copter:

For the Hex-Copter, we initially used a QWinOut Unassembled ARF (No Battery) DIY 2.4G 6Ch KK Multicopter Flight Control F550 AirFrame RC Hexacopter DIY Multicopter Drone Combo Set (**Figure 10**).

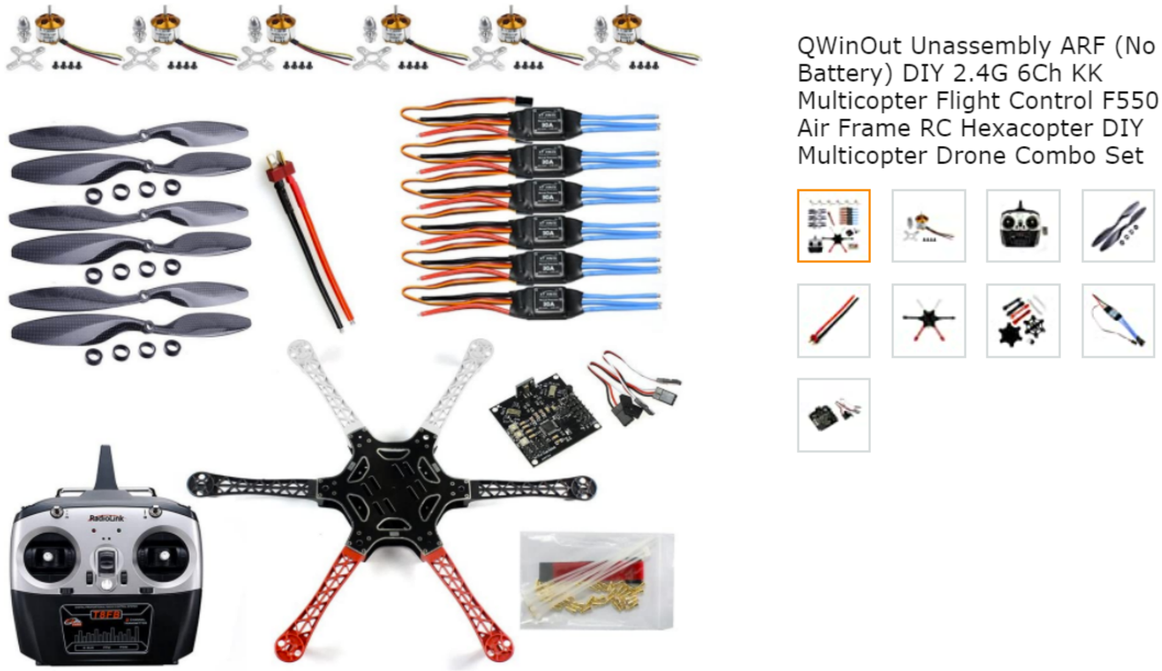


Figure 10: Hex-Copter

For the final product we used a QWinOut ARF/PNP Full Set Hexacopter DIY Drone Kit Tarot 690mm Frame with 750KV Motor GPS PIX 2.4.8 32 Bit Flight Controller (ARF)(**Figure 11**). The drone has enough power to lift up the launching mechanism system. We discovered that more motors would provide additional vertical thrust, therefore higher power motors were no longer essential. When testing the shooting mechanism with the mechanism above the drone. It was discovered that the launching mechanism may sag and make contact with the propellers. To resolve this issue, we relocated the mechanism to the underside of the drone.

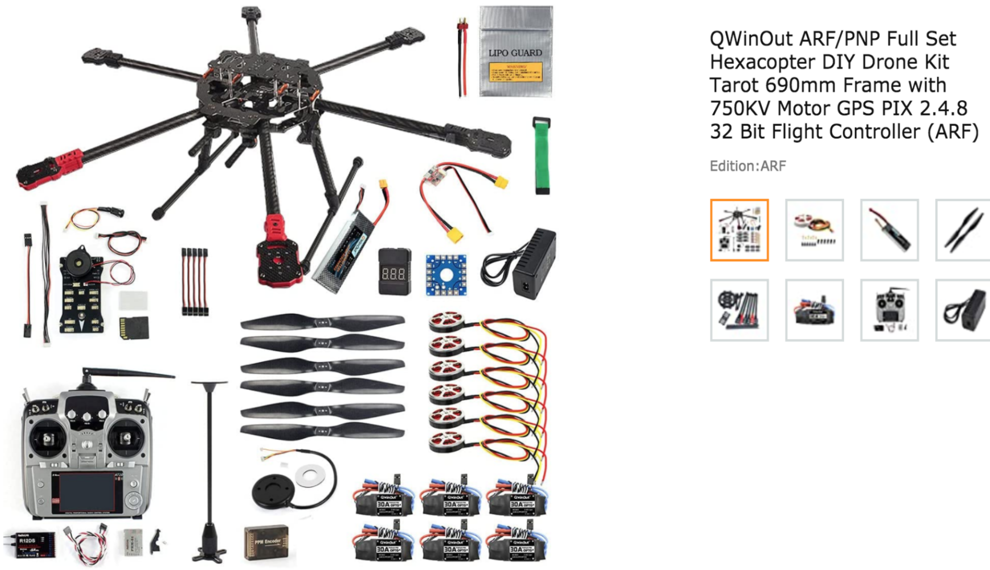


Figure 11: Hex-Copter Final

(B) Sensor Package:

I. Basic Sensor Package:

The basic sensor package consists of a single FPV camera/transmitter module and a 200 mAh 3.7V lipo battery. Here, the camera had a built in transmitter and antenna. To receive video feed from this package we used a Sky Droid 5.8 GHz OTG dual antenna receiver connected with a laptop. Since the Sky Droid was made for implementation on devices with Android operating systems, we used an Android operating system emulator to run the video camera application in order to receive the video feed on any devices not operating on Android Operating Software(OS). With the current model of FPV camera and Sky Droid receiver, we are able to achieve a successful transmission distance of over 100 meters. Using the 200 mAh lipo battery, the system can be powered for up to an hour. This basic sensor package provided a light-weight solution for sensor package deployment, and served to display a light-weight solution to sensor deployment in terms of the sensor system itself.

With this setup, there are certain limitations when keeping the design minimal. The first difficulty we dealt with was achieving a transmission distance over 100 meters with obstructions. To extend this distance, a clover antenna was implemented in later iterations. This antenna configuration allows for a better transmission that extends the distance as well as transmitting with obstructions. Another difficulty was dealing with overheating of the FPV camera. Due to variances in production of these cameras, amounts of overheating varied between individual devices, so initial tests were conducted to determine which individual cameras performed with minimal overheating. Small fans were tested as an addition to the system, but did not reduce heat well enough to be worth the power use. Dealing with shock absorption was another hurdle for this design. When launching the sensor package at the wall or when a package doesn't successfully adhere to the target location, a strong enough shock to the system can damage the sensitive FPV camera. Shock to the system can also cause the lipo battery to send a large charge through the device which has a high potential of damaging the FPV camera. Lipo batteries are also sensitive to force, so as to not damage the camera or battery, shock absorption was a worthwhile add to the sensor package. The final difficulty we faced was extending the battery life of the system. We worked with a larger 2000 mAh 3.7V lipo battery that would greatly extend battery life, but due to size constraints, we proceeded with the smaller 200 mAh battery.

(E) Launching Mechanism:

I. Pressure Mechanism:

The pressure release mechanism is composed of a two part CO2 pressure chamber that is connected to a 12V electric solenoid valve that will use a circuit to trigger the valve. The first chamber consists of a CO2 canister and metal container, and the second chamber consists of a 3D printed CAD design. The CAD design can be seen in the Engineering Documents & Calculation section under the Computer Aided Design and Schematics. The electric solenoid valve is connected to a circuit which is made up of an Arduino Nano, two TIP31C transistors acting as switches, and a transceiver to receive commands wirelessly. On the controller side, an Arduino Nano utilizing push buttons is used to send command signals to the triggering circuit through the use of NRF24 transceivers. Each push button is assigned to trigger one solenoid valve. When the trigger is activated, compressed CO2 from the first chamber will exit through the electric solenoid valve into the second chamber. Within this second chamber the compressed gas will enact a force onto the sensor package. This force will then cause the sensor package to accelerate for a short period of time while the sensor package is within the 2nd pressure chamber. Once the sensor package has fully exited the 2nd pressure chamber, the sensor package will have an initial horizontal velocity. Calculations to determine the initial velocity of the sensor package can be seen in the Engineering Documents & Calculation section under 2-D Kinematics. The schematic of the valve connections, the Arduino Uno, and pressure chambers diagram are shown in the Engineering Documents & Calculations section under Computer Aided Design and Schematics.

II. Spring Mechanism:

The spring release mechanism consists of a 3D printed CAD design, remote control rack and pinion trigger system, and compression spring. This mechanism functions by storing energy into a spring and translating the stored energy into kinetic energy. Calculations to determine the initial velocity of the sensor package can be seen in the Engineering Documents & Calculation section under 2-D Kinematics.

III. Selection of Launching Mechanism:

For the final launching mechanism design, there were major issues regarding the alignment of the deployment of the sensor package for both the spring and pressure system. After 100+ design iterations, the pressure mechanism was chosen for final design implementation. The alignment issues were corrected when the 2nd pressure chamber was extended to be closer to the desired location of sensor placement. Since the travel distance of the projectile was shortened, this prevented the “airtime” in which the package could become misaligned.

(F) Rover:

I. Chassis:

The decision to purchase a pre-built robotic vehicle chassis was made when we were able to locate a company that custom builds robot chassis that could fit our needs. The criteria we were looking to fill are: size, weight, motor power, and payload. The main purpose of the rover vehicle is to transport the drone to and from its deployment location along with carrying additional hardware for the mission (on-board computer, tether system, batteries, gps)(**Figure 12**). To assure the rover is able to carry all additional hardware, the largest available size of 20 x 26 inches for the frame was chosen. These rover specifications allowed us to carry the largest drone we planned to use as well as carry an additional 40 pounds.

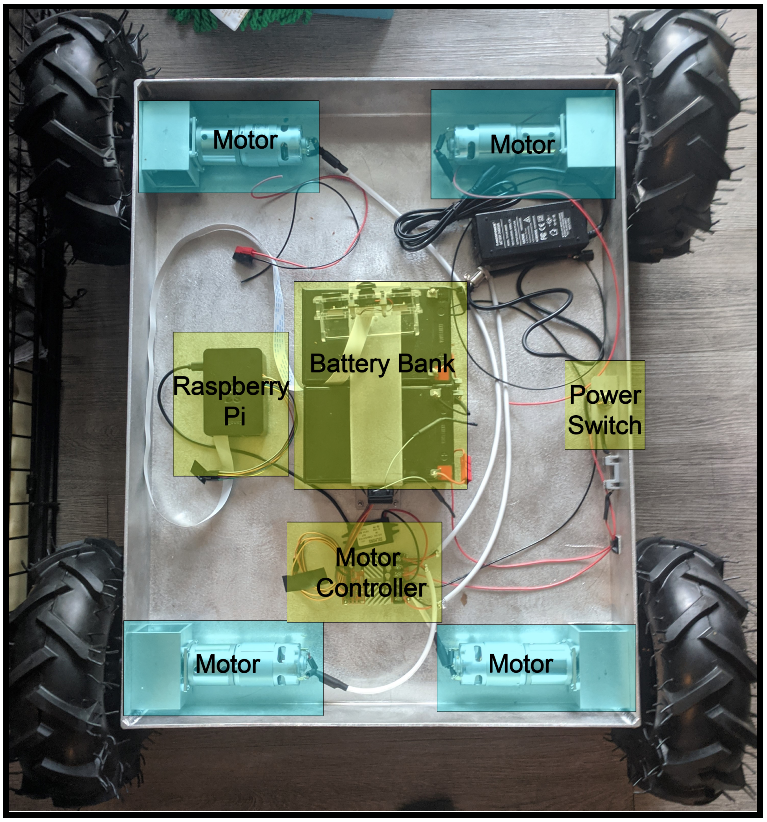


Figure 12: Assembling of Rover

II. Electronic Components:

The motor controller allows for 30 amps to each set of motors continuously and a peak of up to 60 amps. Since some components of the system provided by the rover manufacturer are limited to 15 amps. We have capped the motor controller current draw to 12 amps. This still allows for enough power to the motors to climb over obstacles and operate as intended.

Each 12v battery has 12 Ampere hours of charge and at idle the Raspberry Pi draws on average 1 amp and max current draw is 15 amps. This gives us a range of roughly 1.5-12 hours of operating time.

Purchasing this rover allowed us to utilize more of our time programming the controls for the motors as well as implement the wireless communications. The main controller hardware is the Raspberry Pi, a low-cost, versatile computer which made data handling more efficient and effective due to its GPIO ports. These allow for easy integration of our NRF24L01 Transceivers and BN-880 GPS module. All information compiled through the Raspberry Pi can then be sent wirelessly to the Base Station if needed.

To drive and operate the rover, a separate controller was designed using an Arduino Nano, NRF24 transceiver, and a simple analog joystick. This device allows for separate, independent control and can also act as a receiver for the ground station. Controls can also be offloaded to the base station computer if necessary.

III. Tether:

The robotic system was designed to have the drone be tethered to the rover vehicle. This serves the purpose of having a direct mechanical attachment to the drone in the case of a system failure or for recovery capability after a drone failure (tether system seen on **Figure 13**). The tether system also serves as a proof of concept for possible future iterations involving a tether system consisting of a power transmission line and data transmission line to the drone allowing for enhanced capabilities such as extended flight time and a robust communication link to the drone. In order for the tether system to function properly and to have the tether not be present in the maneuvering space of the drone, the amount of tether slack needs to be dynamically controlled so that the tether is given the right amount of slack as dictated by the vertical height and vertical ascension rate rate at any given moment. Dynamical control of the tether requires a control system. A complete autonomous tether system was designed and prototyped to control a tether attached to the drone. This tether spool system had to be capable of controlling the tether so that it could unspool or spool up the tether cable to accommodate whatever current height and vertical ascension rate the drone is operating at. The autonomous tether system and mechanism designed and prototyped to accomplish the requirements consists of a motor controlled spool and a tension sensor. The tension sensor continuously reads the tension in the tether cable to determine if the spool should let out more tether or pull more tether in. By setting a desired constant tension, the system will always adjust the amount of tether deployed so that there is a constant tension between the drone and the rover at all given time. The system as described represents a closed loop control system where the plant is the tether and the tether spool and motor, and the feedback loop is the tension sensor (**Figure 14**). The control error is the difference in the measured tension and desired tension value. The tension sensor consists of a simple pulley system, referred to as a pulley dancer, consisting of two fixed pulleys and one free moving pulley on a liner track which is connected directly to a potentiometer and a tension spring. The dancer pulley moves to a position which is proportional to the tension in the tether system. The sliding dancer pulley will move to the position at which the force exerted by the tension spring and the tension force exerted by the tether line on the dancer pulley are equal. This equilibrium position is measured by a sliding potentiometer and the analog signal from the potentiometer is sampled by the ADC on an Arduino microcontroller.

A proportional, derivative, integral (PID) controller is implemented in C code on the arduino microcontroller. The embedded PID controller continuously reads the tension value and sends a command signal to the tether spool motor to readjust the tension.This control system allows for the correct amount of tether to be deployed at the correct rate as the drone maneuvers to the desired location for sensor placement. The spool motor is controlled by a LN298 H-Bridge motor controller. A more detailed discussion of the tether control system embedded system code can be found in Programs & Coding section late on.

Figure 13: Rover & Tether Integration

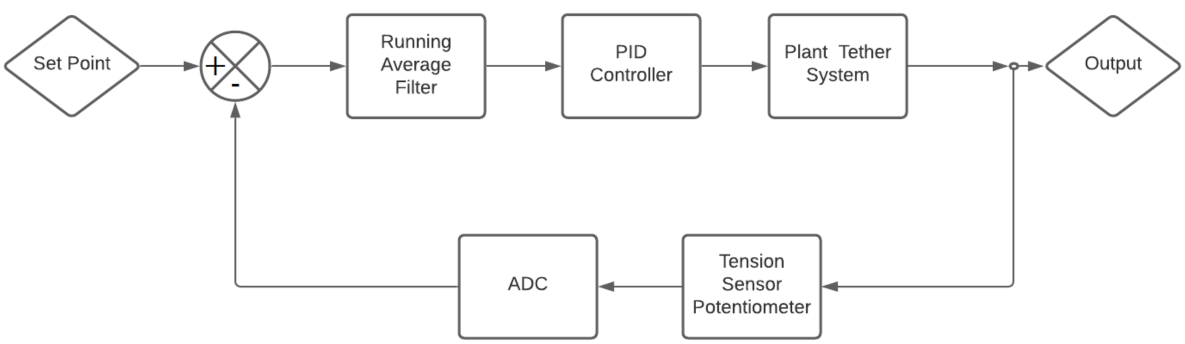


Figure 14: Tether System Control Loop

(E) Full System Testing:

I. Multi-sensor Package Placement Testing:

Full system testing consisted of integrating each sub system into the testing phase. Systems were integrated both one by one and sometimes in parallel until full system testing was achieved. To reiterate previous text, system integration involved subsystems such as the rover system, the drone system, the sensor package system, data communications systems, the sensor deployment system, adhesive bonding, as a system, and the tether system. Finally, after each system demonstrated reasonable success on its own or in combination with other systems full integration was carried out. This process started with developing the launching system, drone system rover subsystems, adhesive system and sensor package on their own. Next we integrated the sensor package launching mechanism with our chosen adhesive selection based on adhesive testing results, whereby pressure sensitive adhesives were selected as our main adhesive material. From there we added our pressurized launching mechanism to various drones, while optimizing our drone motors, blades, and batteries. Next we implemented a tether system with our drone systems for testing. Once we demonstrated reasonable success in achieving flight and stability with the drone and tether systems integrated, we implemented our full system together for testing.

This full system testing influenced additional decisions for the optimization of multiple systems while also impacting group workflow decisions. Specific decisions for improving workflow consisted of making conscious decisions to improve meetup efficiency with regards to tasks at hand for the project. One instance of workflow improving methods being utilized involved ensuring to charge multiple drone batteries in advance of group meetup since battery power largely determined whether a full system test could be implemented. Another workflow improving incite uncovered during full system testing involved the purchasing of additional sensor cameras, more 200 mAh lipo batteries and more lipo battery chargers for sensor package systems, for the sensor package system. In this particular instance the sensor package lipo batteries, as well as cameras seemed to undergo immense wear and tear during testing, as pressurized launching of the sensor package didn't always result in adhesive bonding of the sensor package at the desired location. Ordering extra parts allowed for more effective time usage as we had spare parts interchangeable when other parts weren't charged or became defective.

Our first iterations of full system tests uncovered several of the aforementioned workflow bottlenecks, but, as testing continued, the amount of issues occuring from trial to trial reduced, until reasonable success in full system testing was achieved. Finally, multiple strings of trials began to demonstrate success with regards to many of the main functional goals required in this sensor deployment project. We began to experience trials where we would observe success in travelling across a ground terrain, achieving a designated vertical height via flight, deploying a projectile sensor while the sensor package would display sticking to a targeted area, proper transmission and reception of control systems (including video feed, rover control and drone control), and stable drone tether operation during flight. Consistency and reduced error in navigating our “staple” functional goals further demonstrated our impending system finalizations for competition submission.

Our final full system tests reflected success in rover operations, success in drone operations with regards to tasks of vertical ascension, success in stability of flight with a fully operational tether system, success with regards to data communications across multiple systems (including drone, rover, launching mechanism and video feed support), success in launching multiple sensor package systems, success in adhesive bonding of the sensor package system against a targeted destination, and success in landing the drone on the rover safely.

Engineering Documents & Calculations

(A) 2-D Kinematics:

I. Energy:

To determine the initial speed of the sensor package with the spring loaded mechanism, assuming friction is negligible, **Equation 1** is transformed into **Equation 2**.

$$\frac{1}{2}mv^2 = \frac{1}{2}k\Delta x^2 \qquad \textbf{(1)}$$

$$v_i = \sqrt{\frac{k\Delta x^2}{m}} \qquad \textbf{(2)}$$

II. Horizontal Projectile Motion:

To determine the initial speed of the sensor package using the pressure system, a simple calculation was done using projectile motion. A fixed height *H* of the projectile was set, the sensor package was launched, and the horizontal distance *X* in which the packaged traveled was recorded. **Figure 15** shows this schematic.

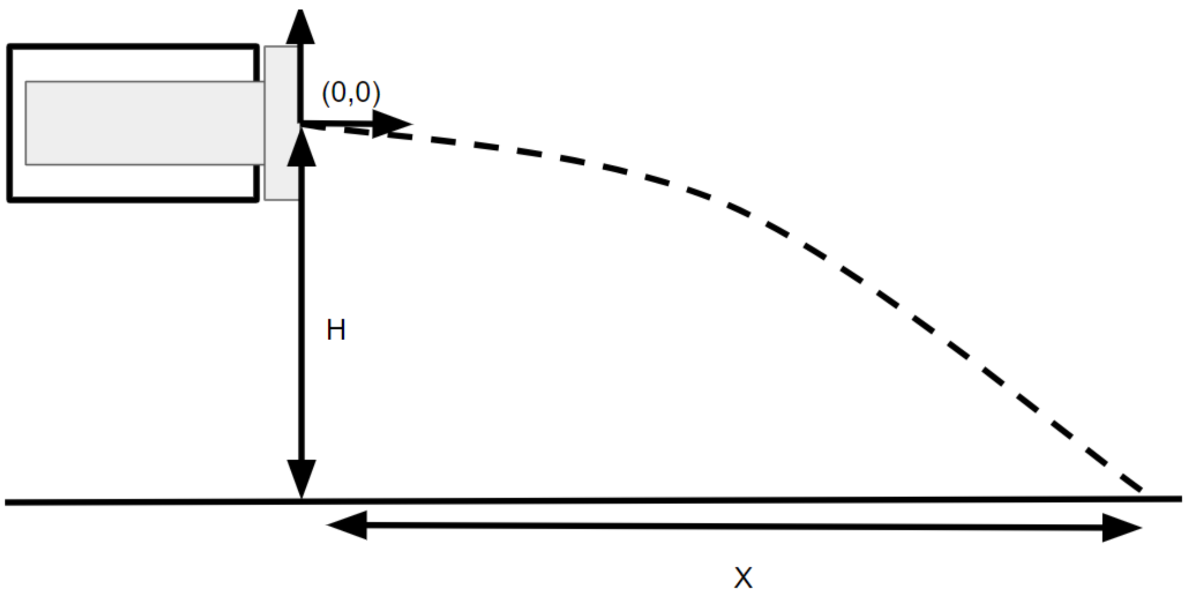


Figure 15: Projectile schematic for determining initial velocity of sensor package using the pressure system.

First, to determine the initial speed of the pressure launching mechanism, it is important to notice the initial velocity will be only in the horizontal direction since the sensor package is initially fixed in the vertical direction. Using **Equation 3** to solve for time *t*, imputing the fixed height *H* for *Y*, and acceleration due to gravity g, **Equation 4** is created.

$$Y = \frac{-1}{2} g t^2 \quad \textbf{(3)}$$

$$t = \sqrt{\frac{2H}{g}} \quad \textbf{(4)}$$

Equation 4 now provides the time in which it takes for the sensor package to drop the fixed distance *H*. Plugging **Equation 4** into **Equation 5**, the initial velocity of the sensor package can be calculated by solving for v_i. After solving for time for a fixed height of 3 ft, and conducting multiple launches, the sensor package traveled at an average horizontal distance of 6.75 ft. After calculations were performed, the initial speed of the pressure launched was calculated to be about 15.6 feet per second.

$$X = v_i t \quad \textbf{(5)}$$

Once the initial velocity of the sensor package is calculated, these values can be put into a lumped mass model which can be used to model the sensor package attaching to the wall. The lump mass model can be seen in the section below titled Lumped Mass Model.

(B) Material Optimization:

For our 3D printed components our team used PLA (Polymer Lactic Acid) because of the availability and value. The following section will have more details about the specific properties of PLA were involved in selecting the material for 3D printing. As for other materials selected, our team ended up utilizing PVC pipes (Polyvinyl Chloride) for the sensor housing in designs. This allowed for the projectile of the sensor package to remain in attachment alignment towards the wall.

(C) Computer Aided Design and Schematics:

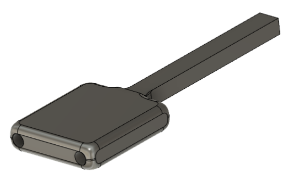


Figure 16: Extended Drone Arm. Designed to attach directly onto the frame for added stability extending the reach by 8.5 inches.

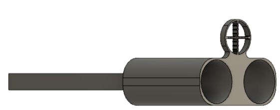


Figure 17: Extended Two Barrel Shooter. Fitted to attach onto the end of the extended Drone Arm. Increases reach by another 8 inches.

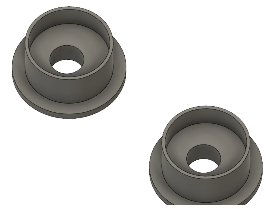


Figure 18: End caps to sensor package. Designed to fit FPV cameras into slots with +- .01 inch tolerance to ensure no movement on impact.

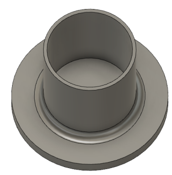


Figure 19: Tops of package sensor. Tops of the package were given a 0.4 inch larger diameter for increased surface area.

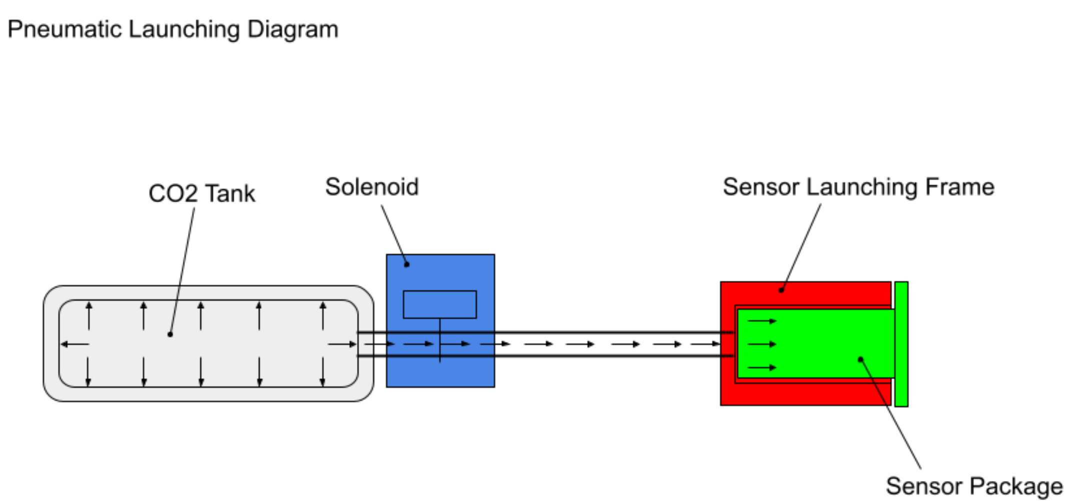


Figure 20: Pneumatic Launching schematic, basic overview.

(D) Circuit Diagrams:

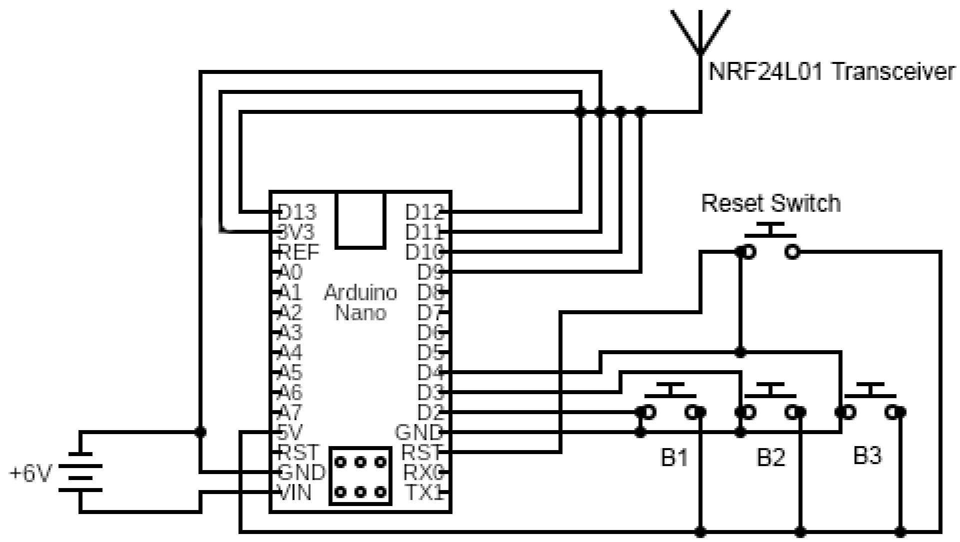


Figure 21: Launcher Trigger Transmitter Circuit

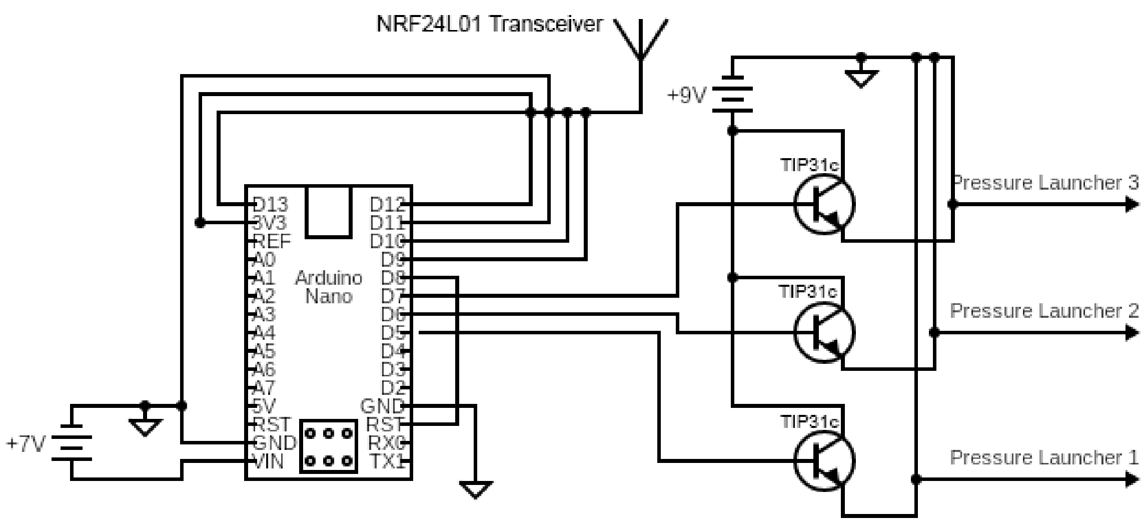


Figure 22: Launcher Trigger Receiver Circuit

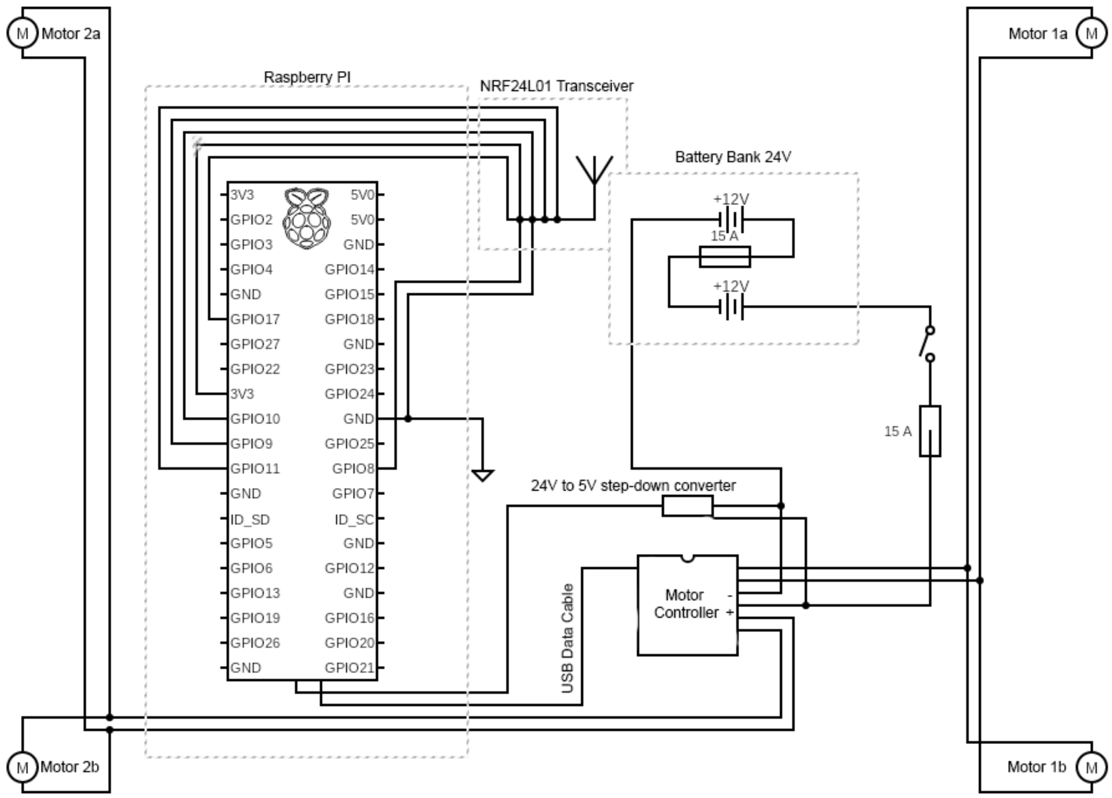


Figure 23: Rover Wire Circuit

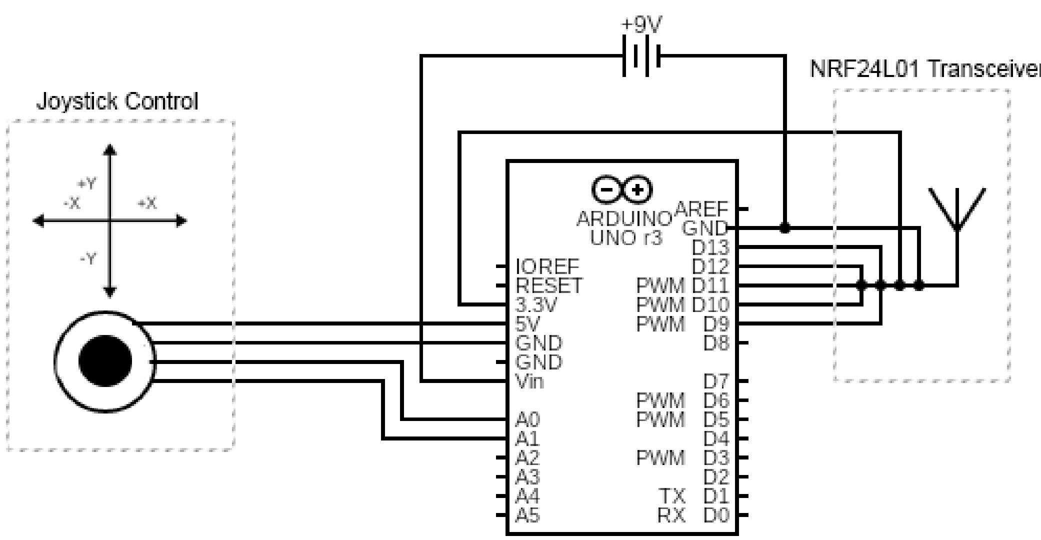


Figure 24: Rover Driving Control Circuit

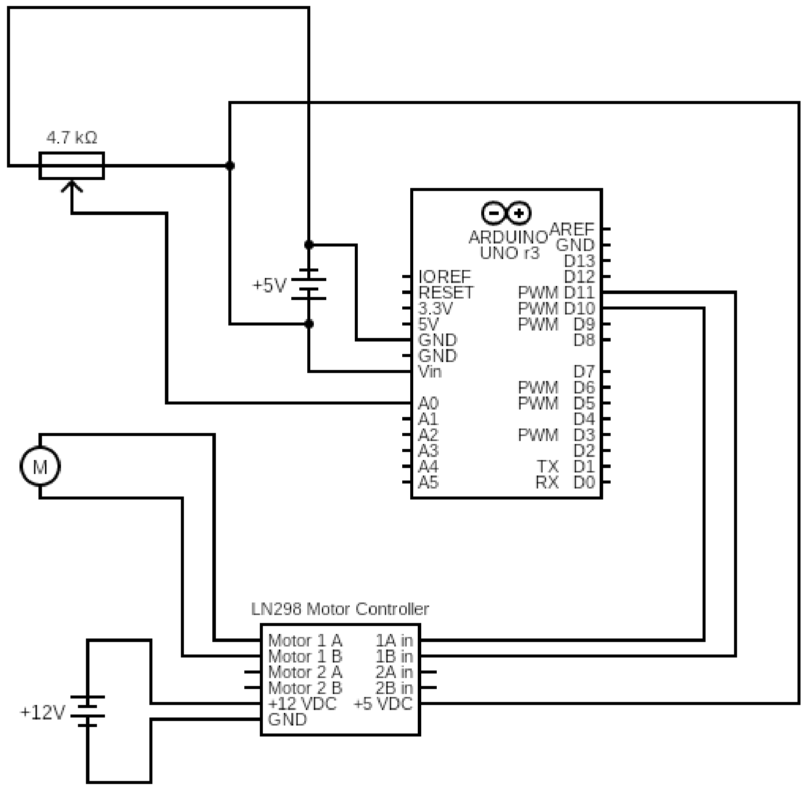


Figure 25: Tether Control System Circuit

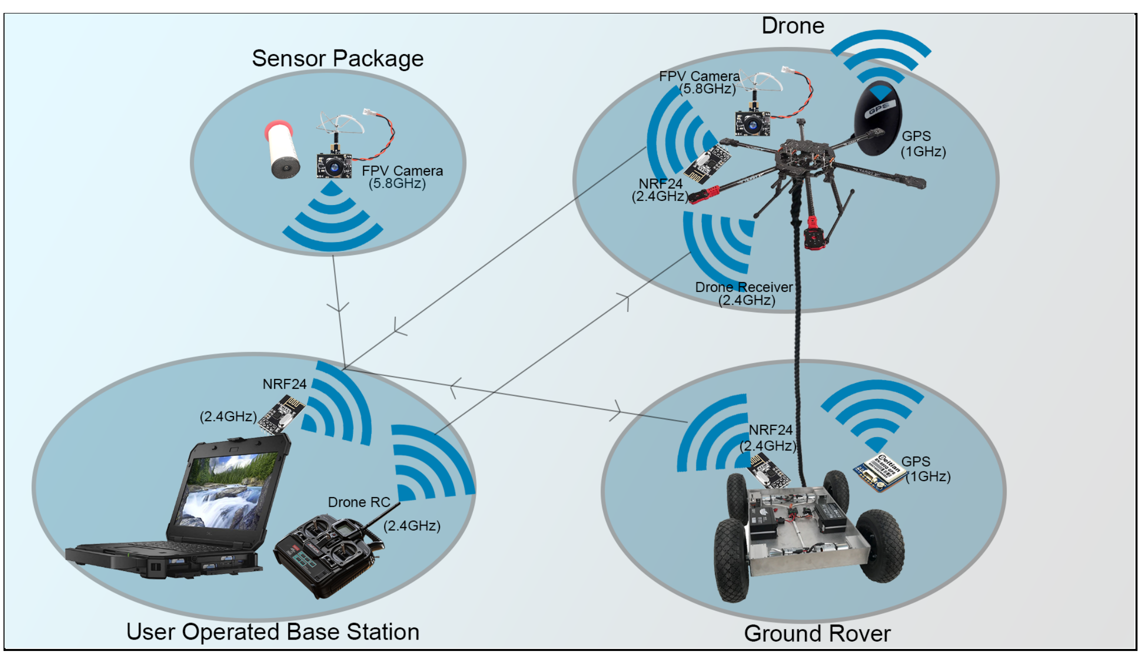


Figure 26: Wireless Communication Diagram

(E) Programs & Coding:

For implementing all hardware and communication devices, a combination of Arduino C++ and Python scripts are used to operate all sub-system programs. The base station laptop uses a python script for accessing camera feeds, and one python script for accessing communications with the rover and the trigger mechanism on the drone. GPS information is sent to the base station and can be observed in Google Earth (**Figure 27**). On the Rover side, one python script handles rover motor controls and GPS data traffic.

All coding is optimized for max speed especially for wireless communications while allowing for individual process runtime completion and exception handling. This is crucial for fluid rover motor controls and the pressure launcher trigger timing.

The python motor controller library is provided by the manufacturers of the motor controller (roboclaw), so implementation is straight-forward using prebuilt functions.

The PID control algorithm for the tether system was implemented in C++ code in an Arduino embedded system using the ATmega328P microcontroller. The PID control source code was provided from the PID control library provided by the PID_v2 library developed by Brett Beauregard. The proportional, integral and derivative coefficients for the PID algorithm were determined from a procedure of iterative tuning in which the parameters were adjusted and the response of the tether system device subsequently characterized. This tuning process was performed until a desired response of the tether system was observed.

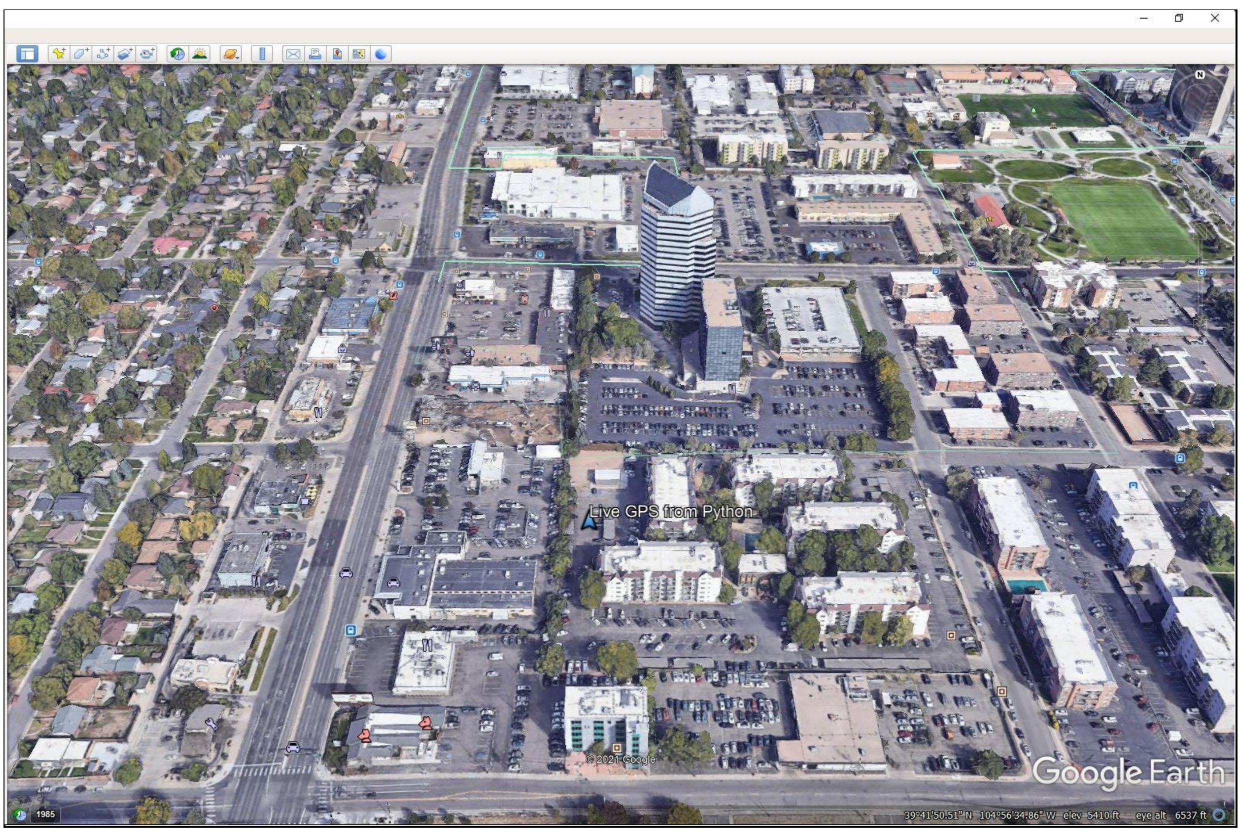


Figure 27: GPS Location displayed in Google Earth

Future Optimizations:

(A) Drone:

Due to the complexities and uncertainties of building and implementing DIY drones, our system would greatly be improved by a high-end pre-built drone such as DJI. This would allow for a simpler more streamlined deployment of the sensor package. With the current limitations of the flight controllers and GPS we are currently not able to use “Position Hold” which can eliminate sway in the drone and allows for a steady way to ascend the drone to its target height for sensor deployment.

(B) Coding and Programming:

For a more streamlined user interface a GUI is half developed but not fully functional for our system. This is due to the most recent implementations and code. However this is something that would stream relevant information and all camera feeds to one window.

(C) Pan and Tilt Gimbal Sensor Package:

Initial prototyping processes lead us to develop basic pan and tilt gimbals to provide users greater control with regards to the sensor package. Pan and tilt systems were developed using two servo motors with 180 degree sweeping motions to sweep both the vertical and horizontal directions. Upon development and integration with the sensor deployment team, however, these prototypes seemed less feasible for integration purposes based on size constraints with the supported casing/housing size in which the launching mechanism would support. Specifically the inner diameter of the cylindrical sensor housing provided difficulties with the expanding size of the sensor package necessary to furnish two sweeping servo motors. Additionally, battery life dwindled since the two additional servo motors ate up more battery power. Still, optimization and iteration of this prototype continued, whereby a bigger battery was integrated into the design however, size did not conform to the housing/casing specifications required by the launching mechanism.

Two codes were developed for the gimbal. The first code swept horizontally 180 degrees (pan), then lowered itself vertically 90 degrees (tilt). Next the servo rotated 180 degrees horizontally in the opposite direction and increased its vertical position (tilt) back up 90 degrees to its starting position, where these sweeping motions would continuously loop. The second code we developed for the pan and tilt systems involved using two potentiometers to control the servo motors. One potentiometer or knob controlled the horizontal direction of the camera and servos, while the other potentiometer controlled the vertical direction. In this second code, both knobs allowed for 180 degree control with respect to their viewing plane (i.e. vertical or horizontal). See **Appendix C Tables 1 - 2** for a more in-depth analysis.

Due to sensor casing/housing diameter issues and time constraints with regards to the competition due dates for the project we pushed focus away from further development of this particular system. However, future developments of this system could potentially include this system. This system, itself, if achievable with regards to the size of our sensor housing limits, present additional desirable features for greater viewing depth of a camera or for greater control in regards to aiming the direction of any potential sensor package.

(D) Lumped Mass Model for Sensor Package

Using a two degree of freedom lumped mass model(**Figure 28**). The values of the forces exerted between the sensor package can be calculated using ODE 45 in MATLAB if the technology inside the sensor package is susceptible to damage.

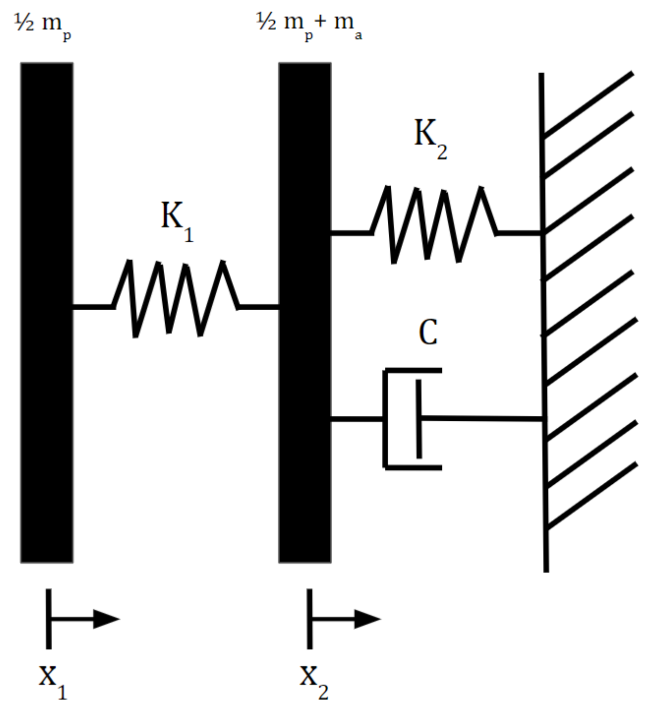


Figure 28: Lumped Mass Model for Sensor package Attaching to the Wall.

(E) Transceiver Implemented Sensor Package:

In addition to previous sensor package systems and assets, we assembled a compact and light-weight microcontroller based sensor package with a built in transceiver. Due to time constraints regarding the competition we were unable to further ideate and develop prototypes based off of this particular iteration of the sensor package system. None the less we were still able to build the bones of the structure, by mindfully soldering an Nrf24l01 transceiver and an Arduino Micro to a PCB board to display that a data transmitting or data receiving system can be built to fit inside of a small sensor housing capsule with inner diameter of 30mm or bigger. Here the Nrf24l01 transceiver has the abilities to both send and receive data, depending on the user's needs. Additionally, this system was powered by a 200 maH lipo battery. This capability of transmitting and receiving data could bear great importance for future sensor package systems.

Future iterations of this prototype could include users sending servo signals from their computers or data systems to the sensor package itself to operate small gimbals, if implemented into a reasonable package size. This displays the packages ability to receive signals. Meanwhile, on the data sending side of the sensor package, the package can send acquired data, received from the microcontroller or various other sensors, back to a computer or data receiving system/transceiver. One future implementation of this "data sending ability" that we considered but couldn't implement, due to competition time constraints, consisted of attaching a temperature sensor to generate temperature data in case of overheating. This generated data could then shut off the system in the case of system overheating.

Meanwhile, in the case of "system shut-off" the user on the data receiving end would receive an alert that the sensor package system had overheated, hence the "system shut-off." Thus less confusion would arise if a video feed disappeared or failed to populate in the video feed viewer. The reason we considered reducing system failure in regards to issues of overheating stemmed from multiple trials of using our FPV camera system, and cloverleaf antenna camera systems; whereby our cameras would sometimes get so hot that they could undergo permanent damage if not monitored and used properly. One particular instance of this issue was observed when we placed this camera near foam and in a short period of time the foam started to melt, while smoke was produced.

Overall, the structure of this system could provide much greater depth in sensor package capabilities depending on user needs as they relate to sending and receiving data across a sensor package system.

Budget:

Over the course of nine months, we have spent $6341.12 for research and development of our system. Each resource was from the following:

Mechanical Engineering Department	$1342.43
Electrical Engineering Department	$1215.44
AFRL Funds	$3783.25
Total	$6341.12

Full itemized list can be found in **Appendix D**

Appendix A-1: Discover Phase Documents

Stakeholder Engagement Plan

Robotic Sensor Placement – AFRL Design Challenge

Members: Anthony Stehr, Dat Ngyuen, Erich Warzek, John Milner, Nathan Phipps, Semere Filmon, Courtney Kunkleman, Ariel Lafuente, Jacob Zahorik, Phi, Nguyen

Stakeholder Groups Identified:

Main: Military (SOF) - Mickey Wright.

Others: Law Enforcement, Search and Rescue, Hunters, Natural Resource Departments.

Method of contact/interview:

Primary: Email to Zoom/Web Call. **Secondary:** Email.

Schedule:

Date/Deadline:	Task:	To be completed by:
Sept 2.	Complete SEP and Submit	John Milner
Sept 3.	Contact Mickey Wright Verify other stakeholders. Review, reassess, refine interview Questions	Ariel Lafuente All All
Sept 3-7.	Members conduct selected interview. (More info sept 3.)	All-individually
Sept 8.	Collect/Conclude Stakeholder Interviews. Gather information on miro-board.	All All
Sept 10.	Analyze data to create "Personas" and "Scenarios"	All

Discover Phase: Scenario Assignment

Robotic Sensor Placement – AFRL Design Challenge

Members: Anthony Stehr, Dat Ngyuen, Erich Warzek, John Milner, Nathan Phipps, Semere Filmon, Courtney Kunkleman, Ariel Lafuente, Jacob Zahorik, Phi, Nguyen

Due to focus on SOF community our we decided to exclude Personas.

Scenarios for Automated Insertion Suite for Situational Awareness Sensors.

All scenarios would implement our Automated Insertion Suite to help resolve issues.

1. Rescue/Tracking Missions

Scenario:

A search and rescue team is trying to locate a stranded individual who is in hostile wilderness in eastern Europe during a snowstorm.

Personas: Stranded persons, SF Operators, Rescue worker, local residents, relatives of lost person, lost person, other (site managers or operators in jurisdiction where mishap occurred).

2. Hostage Situation

Scenario:

Innocent bystanders are being held hostage inside of a location Bank. Unknown number of hostile and innocent people are inside and there are no discreet methods of acquiring video footage to have a visual update on the wellbeing of these people.

Personas: Law Enforcement SF Operators, Hostages.

3. Drone Attack

Scenario:

Military Advisors need positive surveillance identification of terrorist target before conducting drone strike on location in remote Iraq.

Personas: SF Operators, Non-target individuals, Other related military personnel.

4. Reconnaissance

Scenario:

Reconnaissance mission requiring stealth. Needs to observe conversations and be able to move into position enabling them to gather intelligence while remaining concealed in area with little concealment opportunities (Desert plain).

Personas: SF Operators, Scout Teams.

5. Bomb Identification and Disposal/Route Planning

Scenario:

Military convoy gets information of IED placement along convoy route that contains dirt roads. Exact deployment locations are not known until route is overlooked.

Personas: SF Operators, Explosive Ordnance Disposal (EOD), Other related military personnel.

6. Radioactive Material Handling, Retrieval, and Safety.

Scenario:

Nuclear facility experience a catastrophic problem and it is necessary to locate, isolate, contain the affected area as well as identify and navigate at risk personnel to safety.

Personas: Nuclear Facility Security, First Responders, CBRN personnel.

7. SI (Sensitive Equipment/Information) Recovery Missions

Scenario:

Expensive Aircraft breaks down, recovery team must locate, as well as retrieve pilot and parts in a mountainous area. There is no information be provided of the location, and the team is going in blind.

Personas: Pilots, Task force engaged in tracking and recovering Pilot and Aircraft. Any site managers responsible for interactions in jurisdiction of crash site.

All scenarios can be found on MiroBoard: https://miro.com/app/board/o9J_kmLBVFI=/

Customer Needs in Order of Importance

	Interaction with People	Navigation	Maneuverability	Interaction with Environment	Defense/Countermeasures	Materials
General Needs	• Establishment of Communication • Video Feed Link • Object recognition • Speaker to relay instructions to at risk personal • Operator to drive and defuse/detonate bomb with robot • Non-threatening design to aid de-escalation	• GPS navigation • Radar/Lidar • Reliable remote control • Reliable coordinates (GPS) to keep track of locations • Detailed information about surrounding areas (trees/ lakes/ village) • thermal camera • Need Infrared sensors to find target behind object	• Ability to access difficult to reach places in rough terrain, ex: works in mud, and rocky areas • Unmanned Mobility, Access to difficult to reach Areas • Robotic Arm to handle objects and materials • Ability to carry heavy objects • Easily maneuver in buildings	• ability to move in different environment • Weather resilient, ex: rain proof, snow proof, weatherproof components • Robotic Arm to handle objects and materials • Illuminate hard to see places • Computer Vision to distinguish people or objects • Able to maintain connection in remote locations where signal is less optimal • Compact	• resistant to being moved by "enemies" • Need a software to protect the drone not to be hacked • Self-Destruct system if mission compromised by enemy • Attack accurately. need high tech direction system for weapon.	• Long lasting battery • Resistant to damage • Waterproof • Stealth and/or Camouflage
Specific Situational Needs	• Object recognition, recognize person as stranded individual • Need less people to control the drone • Recognizable as a rescue vehicle by stranded individual, ex: not camouflage, easy to see depending on if mission is non-covert		• Robot able to Deliver water, food, medical supplies if people not yet able to reach them • extending arm for opening doors	• durability for radioactivity and temperature fluctuations • Radiation sensors • Ground penetrating Radar to detects buried bombs	• If caught by enemy, needs to auto delete memory. destroy top secret tech • Smart camera that could detect movement in an area that is restricted • potential for arming with non-lethal	• durability for radioactivity and temperature fluctuations • Automated robots that are cheap that sets off explosive • Heavy duty material for

Appendix A-2: Journey Mapping Activity

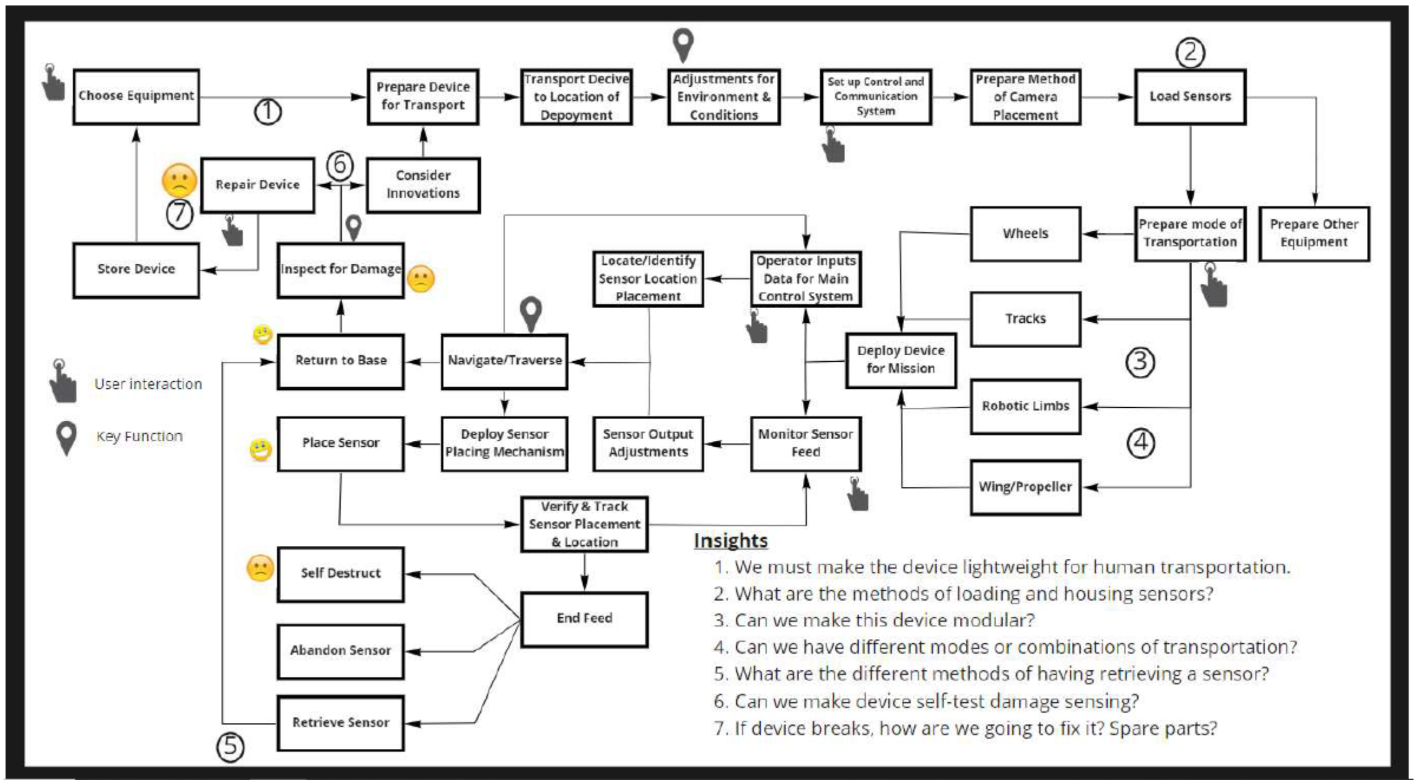
Journey Mapping Assignment

Robotic Sensor Placement – AFRL Design Challenge

Senior Design

September 22, 2020

Members: Anthony Stehr, Dat Ngyuen, Erich Warzek, John Milner, Nathan Phipps, Semere Filmon, Courtney Kunkleman, Ariel Lafuente, Jacob Zahorik, Phi, Nguyen



Appendix A-3: Functional Decomposition Activity

Functional Decomposition Assignment

Robotic Sensor Placement – AFRL Design Challenge

Senior Design

September 09, 2020

Members: Anthony Stehr, Dat Ngyuen, Erich Warzek, John Milner, Nathan Phipps, Semere Filmon, Courtney Kunkleman, Ariel Lafuente, Jacob Zahorik, Phi, Nguyen

Functional Decomposition: Sensors

Mobility (specified weight, dimensions)
Deployment (covert, versatile, consistent, in varied conditions)
Communication (relaying information, remote locations, visual i.e. camera)
Retrieval (location, line of visibility, sonar techniques)
Environmental Resilience (shielding, strong components, redundant systems)

Functional Decomposition: Device that Deploys

Mobility (avoid hazards, transverse variable terrain, carry specified weight, vertical ascension)
Deployment (covert, versatile, consistent, in varied conditions, quickly)
Navigation (know current location, sensor location, transport sensors, tracking)
Communication (monitor device systems, relaying information, remote locations)
Retrieval (location, extract sensor, rehouse sensor)
Environmental Resilience (shielding, strong components, redundant systems

Aappendix A-4: Design By Analogy Activity

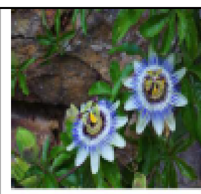
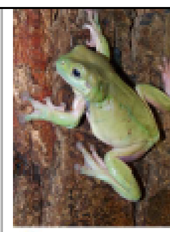
Design by Analogy Assignment

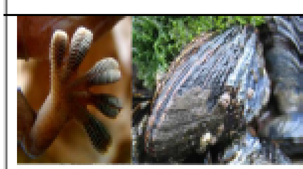
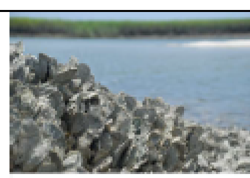
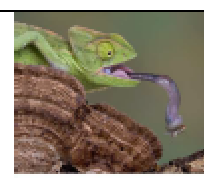
Robotic Sensor Placement – AFRL Design Challenge

Senior Design

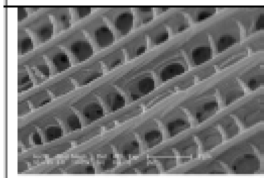
October 13th, 2020

Members: Anthony Stehr, Dat Ngyuen, Erich Warzek, John Milner, Nathan Phipps, Semere Filmon, Courtney Kunkleman, Ariel Lafuente, Jacob Zahorik, Phi, Nguyen

<table>
<tr><th colspan="5">Vertical Ascension</th></tr>
<tr>
<td>
asknature.org
Tendrils stick to various surfaces : Virginia Creeper - AskNature</td>
<td>
asknature.org
Tendrils enable upward climb : Flagroot - AskNature</td>
<td>
asknature.org
Tendrils enable climbing up smooth surfaces : - AskNature</td>
<td>
asknature.org
Toe pads adhere and clean themselves : Australian Green Treefrog - AskNature</td>
<td>
asknature.org
Screw-and-nut leg joint assists climbing : Trigonopterus - AskNature</td>
</tr>
<tr><td colspan="5">Looking at ways for equipment to gain supportive attachment to wall, tree, lamp post, etc. Leg joints offer alternative to axle style attachment for limbs or other external support that aid in vertical movement.</td></tr>
</table>

<table>
<tr><th colspan="4">Delivery</th></tr>
<tr>
<td>
asknature.org
Geckel nano-adhesive - AskNature</td>
<td>
asknature.org
Adhesive is both strong and flexible : Eastern Oyster - AskNature</td>
<td>Bioinspired adhesive tape</td>
<td>
asknature.org
Tongue moves fast : Chameleon - AskNature</td>
</tr>
<tr><td colspan="3">Adhesive applications for securing camera attachment. Some studies in robotic applications have published results that have allowed robotic wheels to attach and move along steep inclines and surfaces.</td><td>Research the mechanism to catapult our sensor towards the desired location</td></tr>
</table>

Camouflage

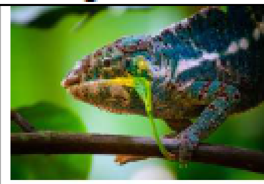


asknature.org

Wing scales help camouflage from sonar : Butterflies and moths - AskNature

asknature.org

Adaptive camouflage helps blend into the environment : Cuttlefish - AskNature



asknature.org

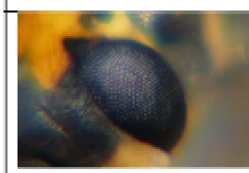
Skin changes color : Short-horned Chameleon - AskNature

asknature.org

Optical metamaterials - AskNature

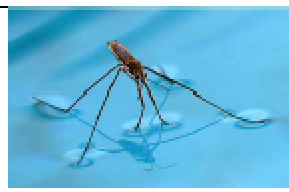
Adapting the structures of moths wings can help avoid detection from sonar. Other animals have adaptive tissues that help them blend in, while the velvet belly lantern shark uses light to illuminate other organisms that will then light up and create a distraction. Finding a way to keep our structures from being easily detected would be beneficial.

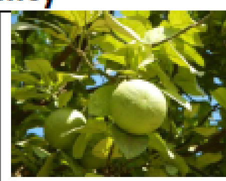
Durability



asknature.org

Hydrophobic de-icing - AskNature





asknature.org

Pressurized struts dissipate impact : - AskNature

asknature.org

Leaves resist bending : Plants - AskNature

Creating ways to Increase durability and adaptability to extreme environments inspired from material or geometry found in nature.

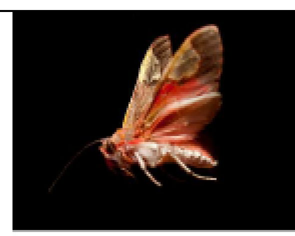
Durability

asknature.org

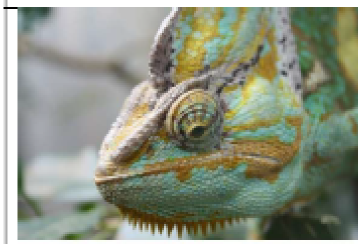
Bumps and grooves protect surface : Sahara Scorpion - AskNature

We can apply this to our sensor if we believe that the senor will be subjected to harsh conditions such as hail.

Camera Adjustment		
 asknature.org Scale shape enables limbless movement : Boa Constrictor - AskNature	Threads Transfer Movement: Jumping Bean Moth	Hydro skeleton Changes Shape
Different approaches to gimble or other standard camera movement designs that can be lightweight and adaptive in form. Finding a way to build upon the "snake light" idea but also incorporate a wider size array by controlled collapse and expansion.		

Covertness	
 asknature.org Wing feathers enable near-silent flight : Owls - AskNature	 asknature.org Clicking noises interfere with predators' sonar : Grote's Bertholdia Moth - AskNature
Being covert in the sense that it remains undetected from sonar applications by producing signal interferences.	

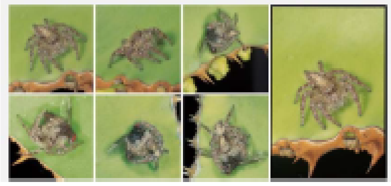
Field of View



asknature.org

Eyes give 360° vision : Chameleon - AskNature

The eight eyes of a jumping spider provide it with excellent vision via two principal eyes used for stereoscopic vision and the other six for a panoramic view around the spider.

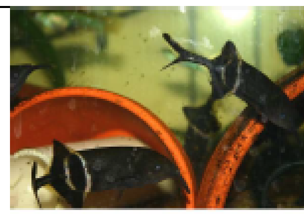


360 vision and different points of view- Finding ways to have a broad or a maneuverable vision while navigate device.

Data Communication

asknature.org

Receptor organs filter background noise : - AskNature



asknature.org

Electricity helps communications : Brienomyrus brachyistius - AskNature

asknature.org

Optical hydrophone - AskNature

Using natural methods of communication may provide us some innovating ideas when needing to create a feedback loop between the sensors.

Data Communication

Locomotion in Caterpillars

asknature.org

Change increases aerodynamic performance : Common Swifts - AskNature

Using nature to inspire idea's for mechanical movement. By using mechanical movement concepts from animals, to apply to our design.

Appendix A-5

Table 1: Dry Time, Liquid Nails, Vinyl Composition Adhesive on Brick and Wood Surfaces

Brick Post		Adhesive Dry Time	
	Type of Adhesive	5 minutes	10 Minutes
	Liquid Nails	Did not form bond	Bonded for 1 minute and 30 seconds before box fell off brick
	Vinyl Composition Tile Adhesive	Did not form bond	Did not form bond
Wooden Post		Adhesive Dry Time	
	Type of Adhesive	5 minutes	10 Minutes
	Liquid Nails	Did not form bond	30+ minutes of bonding. Time measurements were not taken after 30 + minutes
	Vinyl Composition Tile Adhesive	Did not form bond	Did not form bond

Table 2: Wet Surface Test, Terro Brand Glue Trap:

Brick Post		Stick Time:
	Terro Glue Trap	Instant Failure, no weight applied
Wooden Post		Stick Time:
	Terro Glue Trap	4 Minutes, 30 seconds, no weight applied

Table 3: Wet Surface Test, Victor Brand Glue Trap:

Brick Post		Stick Time:
	Victor Glue Trap	Instant Failure, no weight applied
Wooden Post		Stick Time:
	Victor Glue Trap	Instant Failure, no weight applied

Table 4: Using a Scale to Measure Force, Terro Brand Glue Trap:

Brick Post		Stick Time:	Force Applied:
	Terro Glue Trap	2+ Hours	15 lbs
Wooden Post		Stick Time:	Force Applied:
	Terro Glue Trap	2+ Hours	4 lbs

Table 5: Using a Scale to Measure Force: Victor Brand Glue Trap:
No figure necessary, trial not performed due to group discussion and plan revision.

Table 6: Low Force, Quick Slap Trials, With Instant 1 lbs Weight Added, Terro:

Brick Post		Stick Time:
	Terro Glue Trap	instant failure
Wooden Post		Stick Time:
	Terro Glue Trap	40 seconds

Table 7: Low Force, Quick Slap Trials, With Instant 1 lbs Weight Added, Victor:

Brick Post		Stick Time:
	Victor Glue Trap	Instant Failure
Wooden Post		Stick Time:
	Victor Glue Trap	Instant Failure

Table 8: Low Force, Quick Slap Trials, With 5 Minute Wait Before 1 lbs Weight Added, Terro:

Brick Post		Stick Time:
	Terro Glue Trap	45 Minutes
Wooden Post		Stick Time:
	Terro Glue Trap	2+ Hours

Table 9: Low Force, Quick Slap Trials, With 5 Minute Wait Before 1 lbs Weight Added, Victor:

Brick Post		Stick Time:
	Victor Glue Trap	5 minutes
Wooden Post		Stick Time:
	Victor Glue Trap	Fell Before Weight Was Applied

Appendix B

Drone Flight Safety Procedure

Robotic Sensor Placement – AFRL Design Challenge

Senior Design

March 04, 2021

Members: Anthony Stehr, Dat Ngyuen, Erich Warzek, John Milner, Nathan Phipps, Semere Filmon, Ariel Lafuente, Jacob Zahorik, Phi, Nguyen

This document serves the purpose of containing the step-by-step procedures that must be executed before, during, and after the done flight takeoff.

1. Drone flight must be inside.

2. Tether must be established with drone; in addition, the line must be shorter than the closest distance from any individual or physical obstacle.

3. Everyone is wearing protective eye wear such as goggles.

4. Turn on Transmitter.

5. Commence start up procedure.

    a. Check if Remote Control is transmitting signal.

    b. Check if Drone is Receiving Remote Control Signal.

    c. Check if Distance Sensors are Fitted.

    d. Check if Distance Sensors are Functioning.

    e. Check Propellors are properly fitted to motor.

    f. Check Propellors not damaged.

    g. Check Propellor guards are not damaged.

    h. Check to see if Kill Switch is installed and functioning(light).

    i. Check that everyone is clear from Drone is 15 ft away from drone before takeoff.

    j. Assure necessary flight modes on Remote Control are selected.

6. Before drone is turned on, everyone in the room verbally states, “DRONE ON”.

7. Drone is Turned on by pilot.

8. Pilot moves 15 feet away from drone.

9. Before drone begins flight, everyone in the room verbally states, “DRONE IN FLIGHT”.

10. Drone directed by pilot to lift off.

11. Drone Pilot will verbally state each action that will be done with drone.

12. No one comes closer to the drone than the length of the tether when drone blades are moving.

13. Once drone flight is complete, everyone in the room verbally states, “CLEAR AREA”.

14. Commence shut down procedure.

    a. Land Drone at the minimum of 15 feet from the closest individual

    b. Wait 5 seconds after propellers are brought to a complete stop.

    c. Turn off Transmitter.

    d. Pilot will turn off and put Remote Control on a flat surface.

    e. Pilot will Approach Drone.

    f. Pilot will disconnect power source from drone.

15. Once shut down procedure is complete, the pilot will state, “DRONE OFF”.

Appendix C

Table 1: Constant Sweeping Code, Pan (180 degrees) and Tilt (90 degrees):

```
#include <Servo.h>
Servo myservo;
Servo myservo1;
int pos0 = 0;
int dTime = 20;

void setup() {
  myservo.attach(9);
  myservo1.attach(8);
}

void loop() {

  for (pos0 = 0; pos0 <= 180; pos0 += 1) {
    myservo.write(pos0);
    delay(dTime);
  }
  for (pos0 = 90; pos0 <= 180; pos0 += 1) {
    myservo1.write(pos0);
    delay(dTime);
  }
  for (pos0 = 180; pos0 >= 0; pos0 -= 1) {
    myservo.write(pos0);
    delay(dTime);
  }
    for (pos0 = 180; pos0 >= 90; pos0 -= 1) {
    myservo1.write(pos0);
    delay(dTime);
  }
}
```

Table2: Two Potentiometer / Knob Controlled, Pan (180 degrees) and Tilt (180 degrees):

```
#include <Servo.h>

Servo myservo0;
Servo myservo1;

int potpin0 = A0;
int potpin1 = A1;
int val0;
int val1;

void setup() {
  myservo0.attach(10);
  myservo1.attach(9);
}

void loop() {
  val0 = analogRead(potpin0);
  val1 = analogRead(potpin1);
  val0 = map(val0, 0, 1023, 0, 180);
  val1 = map(val1, 0, 1023, 0, 180);
  myservo0.write(val0);
  myservo1.write(val1);
  delay(15);
}
```

TETHERBOY

```
#include <PID_v2.h>
#define PIN_INPUT 0
#define PIN_OUTPUT 3

//Define motor comntrol pins
int motor1pin1 = 10;
int motor1pin2 = 11;

//Define Variables
double setpoint, Input, Output, readin, readin_map;

//Specify PID tuning parameters
double Kp = 1.25, Ki = 3.1, Kd=0.05;

//Instantiate PID controller
PID myPID(&Input, &Output, &setpoint, Kp, Ki, Kd, DIRECT);

//Define Parameters for running Average
#define WINDOW_SIZE 8
int INDEX = 0;
int VALUE = 0;
int SUM = 0;
int READINGS[WINDOW_SIZE];
int AVERAGED = 0;
//////////////////////////////////////////////////////////////////////////////////////////////
//////////////////////////////////////////////////////////////////////////////////////////////
void setup() {
  pinMode(motor1pin1, OUTPUT);
  pinMode(motor1pin2, OUTPUT);
  Serial.begin(9600);

  //initialize the variables we're linked to
  readin = analogRead(PIN_INPUT);
  //Mapping function 1 converst logritmic input to linear inpute (0-100)
  Input = (1 / 2006.002) * exp((1 / 86.5) * float(readin));
  setpoint = 955.00;
  myPID.SetOutputLimits(-255, 255);
  //turn the PID on
  myPID.SetMode(AUTOMATIC);
```

```
void loop()
{
  readin = analogRead(PIN_INPUT);

  SUM = SUM - READINGS[INDEX];       // Remove the oldest entry from the sum
  VALUE = readin;         // Read the next sensor value
  READINGS[INDEX] = VALUE;           // Add the newest reading to the window
  SUM = SUM + VALUE;                 // Add the newest reading to the sum
  INDEX = (INDEX + 1) % WINDOW_SIZE; // Increment the index, and wrap to 0 if it exceeds the window size

  AVERAGED = SUM / WINDOW_SIZE;      // Divide the sum of the window by the window size for the result

  //Serial.println(double(readin));
  //Serial.print(",");
  //Serial.print(AVERAGED);
  //Serial.print(",");
  Input=AVERAGED;

  Serial.println(double(800));
  Serial.print(",");
  Serial.print(Input);
  Serial.print(",");
  Serial.print(double(1024));
  Serial.print(",");
  Serial.print(setpoint);
  Serial.print(",");

  myPID.Compute();
  analogWrite(PIN_OUTPUT, Output);
  //Serial.println(Output);

  if (Output < 0) {
    analogWrite(motor1pin2, -Output);
    analogWrite(motor1pin1, 0);
  } else {
    analogWrite(motor1pin2, 0);
    analogWrite(motor1pin1, Output);
  }
}
```

Appendix D

ID	Item name and description:	Quantity	Vendor:	Expected cost	Subtotals	w/ Shipping	NOTES
15	Configurable - IG42-SB4-T, Custom Size 4WD All Terrain Robot	1	https://www.superdroidrobots.com	1049.3	1049.3	1155.1	
16	4pcs Emax Mt2213 935kv Brushless Motor 2CW 2CCW with Orignal 1045 Propller fo	1	Amazon	66.99	66.99	66.99	
18	FPV Extended range	5	amazon	89.95	80		
19	3D filament	4	amazon	194	194	274	
20	FishDrop baitcasting reel	1	Amazon	32.99	32.99		
21	Valve Solenoid	1	Amazon	38.51	38.7		
23	Potentiometer	1	Amazon	6.66	5.99		
24	Deegoo-FPV NEW 12pcs NRF24L01+ 2.4GHz Arduino Wireless RF Transceiver Mod	1	Amazon	13.99	13.99		
25	Readytosky Bidirectional 40A Brushless ESC 2-6S UBEC 3A 5V for Remote Control S	1	amazon	16.99	16.99		
26	Diamond grip cord	1	amazon	22.95	22.95		
27	Fitting-Reducer-Adapter	1	amazon	9.57	9.16		
29	MacCan Pneumatic PT1/4-N1 Male Branch Tee 1/4" Tube OD x 1/8" NPT Thread Ai	1	Amazon	10.06	10.06	148.19	
28	Adapter fitting	1	amazon	6.64	6.59	6.59	
30	ARCELI 5PCS PS2 Joystick Game Controller XY Dual-axis Joystick Breakout Module	1	amazon	8.99	8.99		
31	WayinTop 2Set Wireless Transceiver Receiver with Tutorial, NRF24L01+PA+LNA R	2	amazon	37.98	37.98		
32	Abuff Wall/Ceiling Mount Single Pulleys in Zinc, 1-1/2 inch Pulleys for Lifting, 6 P	1	amazon	33.99	33.99		
34	12 Inch Traffic Training Cones, Plastic Safety Parking Cones, Agility Field Marker C	1	amazon	23.99	23.99		
35	1pc Linear Motion High Precision Sliding Rail Guide Bloc Rod Linear Shaft Rail Rod	1	amazon	11.59	11.19		
36	WMYCONGCONG 10 PCS B103 10K Ohm Slide Potentiometer Double Linear 10K El	1	amazon	12.99	12.99		
37	2PCS L298N Motor Driver Controller Board Module Stepper Motor DC Dual H-Brid	1	amazon	11.99	11.99		
38	Encoder Metal Gearmotor 12V DC High Speed 600RPM Gear Motor with Encoder f	1	amazon	14.99	14.99		
39	QWinOut F550 Airframe RC Hexacopter Drone Kit DIY PNF Unassembly Combo Se	1	amazon	153.88	153.88	325.32	
40	QWinOut Platinum Pro 2-6S 30A Speed Controller ESC OPTO for DIY Hex Multi Rot	1	amazon	89.99	89.9		
41	QWinOut 5010 350KV/750KV Brushless Motor High Torque for DIY RC Drone Kit M	1	amazon	115.45	99.89	219.79	
42	QWinOut ARF/PNP Full Set Hexacopter DIY Drone Kit Tarot 690mm Frame with 75	1	Amazon	644.99	644.35	644.35	
43	Official Creality Ender 3 V2 Upgraded 3D Printer Integrated Structure Designe wit	1	amazon	279	279	300.86	Priority was requested
44	Gems Sensors A2011-C203 303 Stainless Steel General Purpose Solenoid Valve, 10	2	amazon	76.9	38.45		
45	1/4 Inch OD Air Push to Connect Fittings Pneumatic Fittings Kit, Air Union Quick D	1	amazon	9.99	9.99		
46	12V 1800mAh Ni-MH 10 Cell Rechargeable Replacement Battery Pack for RC Car, E	1	amazon	24.99	24.99		
47	3/8 NPT Air Lines Fittings 1/4 OD Tubing Push Connect Air Fittings Quick Connect	1	amazon	13.99	12.99		
49	CPROSP CO2 Cartridge Adapter 12g Quick Change Black Instead of 88g or 90g CO2	1	amazon	19.79	19.79	144.66	
48	Metalwork Push to Connect Inline Manifold Union Tubing Fitting, 6mm 1/4" Tube	1	amazon	8.99	8.99	48.47	Priority Added
50	10 Pack Push to Connect Tube Fitting, Air Tool Fittings Straight Push Quick Releas	1	amazon	7.5	7.5		
51	AUSTOR 132 Pieces Sanding Drum Set with Free Box Including 120 Pieces Drum Sa	1	amazon	7.99	7.99	21.48	
52	Super Mondo Spiky & Soft 2 in 1 Stretch Ball - Flip it back and forth from spiky to s	1	amazon	12.99	12.86		
53	REXQualis 120pcs Breadboard Jumper Wires 20cm Length Dupont Wire Kit 40pin M	3	amazon	19.47	18.57		
54	Karcy Plastic Test Tubes with Caps 30ml Clear Tube for Science,Sample,Party,Can	1	amazon	13.99	13.98		
55	Accessbuy Spring Assortment Set Zinc Plated Compression and Extension Springs	1	amazon	10.99	10.99		
56	Encoder Metal Gearmotor 12V DC High Speed 600RPM Gear Motor with Encoder f	1	amazon	14.99	14.99		
57	60-Pack Acoustic Panel Polyurethane Foam Sound Proof Acoustic Treatment Roo	1	amazon	49.99	49.99		
58	FPV Receiver 5.8G 150CH OTG Receiver UVC Video VTX 5dBi SMA Female Plastic f	3	amazon	82.77	82.77		
59	UMLIFE Micro SD Card Module, 6PCS Storage Board Memory Shield Expansion Mo	1	amazon	6.99	6.99		
60	Yootop 10Pcs 1W 8Ohm Round Internal Magnet Mini Loudspeaker MP3 MP4 Playe	1	amazon	6.99	6.99		
61	Micro Center 32GB Class 10 Micro SDHC Flash Memory Card with Adapter (2 Pack)	1	amazon	9.39	9.39		
62	150mah 1s 3.7v 25c Lipo Battery (5 Port Charger)	3	amazon	35.97	32.97		
63	Feetech FS90R 360 Degree Continuous Rotation Micro Servo Motor + RC Tire Whe	1	amazon	14.89	14.89		
64	Adafruit Feather M0 Basic Proto - ATSAMD21 Cortex M0 [ADA2772]	1	amazon	22.22	22.46		
66	for Arduino, kuman Expansion Board ATmega328P + Acrylic Transparent Base Plat	3	amazon	29.61	29.61		
67	CPROSP CO2 Cartridge Adapter 12g Quick Change Black Instead of 88g or 90g CO2	1	amazon	19.79	19.79		
68	Anderson Metals - 06120-0602 06120 Brass Pipe Fitting, Reducer Adapter, 1/8" NP	1	amazon	9.16	9.16		
69	Gems Sensors A2011-C203 303 Stainless Steel General Purpose Solenoid Valve, 10	1	amazon	38.1	38.1		
70	Evike Airsoft - 12-Gram CO2 Cartridge for Airsoft and Air Gun	1	amazon	32.95	32.95	427.45	
				3599.81	**3528.98**	**3783.25**	

Electrical Engineering Department			
QWinOut 450mm Airframe	1	amazon	286.52
NRF24L01 Wireless Transceiver	1		9.39
MicroSDXC	1		18.99
SKYDROID FPV Receiver	2		40.99
GPS Module Built-in Compass	1		23.99
Gimbal for FPV	3		8.89
FPV	3		17.99
3pcs Pro Micro	2		18.99
LiPo Battery	6		5.99
Port Charger	1		5.99
Lidar	1		129.99
FAN BLOWER	3		15.25
Pixhawk	1		99.99
Prop Guards	1		15.99
Propellers	2		10.99
Digital Servo 360	1		17.99
400mAh 2S 30C LiPo	1		16.78
5500mAh 3S 11.1V 50C Lipo Battery	1		59.99
Male and Female Connector	1		7.99
7500RPM Coreless Micro	1		7.98
Pixhawk Power Module	1		12.99
7pcs 260mAh HV 1S LiPo	1		19.99
Micro FPV AIO 600TVL Camera	4		16.82
Paint marker	1		56.38
600mW FPV Transmitter	1		27.99
FPV Antenna 5.8GHz	1		9.99
Alkaline Batteries	1		9.03
Double Sided Tape Heavy Duty	1		5.94
Total			979.8

Mech Department			
Filament	1		149.99
Mini Solderless Prototype Breadboard	2		6.98
Mini Breadboard	3		6.99
100pcs Double Sided PCB Board Kit	1		13.99
Arduino Microcontroller	1		20.7
Kitchen Scale	1		10.99
Propeller	1		11.98
QWinOut F450-V2 Drone Frame	1		22.98
Soldering Iron	1		16.99
Module Development Board	1		22.69
Air Push to Connect Fittings	1		11.99
Carbon Fiber Propeller	1		13.5
Cartridges Holder Capsule Adapter	1		23.99
Stranded Wire Electric Wire 6	1		10.82
Digital Servo 360	2		17.99
Fan	3		22.87
Laser Head Laser Tube	1		8.49
Pneumatic Air Line 1/4	1		15.99
Push to Connect Fittings	1		13.99
Electric Solenoid Air Valve	1		9.35
Prop Guards	1		15.99
Performance Propellers	1		13.99
2200KV Brushless Outrunner Moto	1		27.88
Speed Torque Metal Gear Servo	1		32.99
Lithium ion Polymer Battery 2000mAh	1		20.99
CMOS Camera Module	1		8.99
Thermal Conductive Glue	1		7.75
PWM MOTR	1		8.99
Raspberry Pi Camera Module	1		32.99
CanaKit Raspberry Pi 4	1		149.99
Micro Electrical Male	1		7.99
FPV Drone Quadcopter 4-axle	1		477.37
GPS Module w/Flash HMC5883 Compass	1		18.57
Total			1257.74
Mech Department			1257.74
Electrical Department			979.8
AFRL funds			3783.25
Total			6020.79