Low-Cost Autonomous UAV

Proposal

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Part 1. Project Description

A. Background

The sponsor of this project, Booz-Allen-Hamilton, is an American contractor that specializes in providing consulting, analysis, and engineering services to its clients. With over 32,600 employees and 80 different locations around the world, Booz-Allen-Hamilton's largest clients are the American government and military.

Recently, as highlighted in the Russian-Ukrainian War, Unmanned Aerial Vehicles (UAVs) have quickly cemented themselves as the next-generation of intelligent platforms for diverse military and commercial applications. However, the current selections of UAV platforms on the market lack the capabilities for modularity and autonomy. On the other hand, aftermarket support for UAV adaptation often comes with high development costs and long lead time. Overall, the current UAV options that are available to both commercial and military customers are either generalist drones that lack the specialization for individual tasks or custom-orders that come at a high price.

The main goal of this project is to fill the vacancy in the market by developing a drone that is capable of modularity. Additionally, as Artificial Intelligence and Image Processing technology become a major part of futureproofing, the drone is expected to operate with a certain amount of autonomy that can lead to the decrease of overall maintenance and operational need. The specification of the drone positioning are listed below:

- Modularity for use case adaptation
- GPS positioning
- On-board imaging and sensing
- Inter and intra-network communication
- Sufficient operating lifespan
- Autonomous capabilities

B. Scope of Work

The overarching goal of this project is to produce an operational prototype quadcopter with a small degree of autonomous decision-making. This drone is intended to serve as a foundation for future projects commissioned by the sponsor. The primary use case of the UAV is its function as a security/perimeter surveillance device. If our quadcopter does not achieve the expected level of autonomy, then its low cost and modularity will be its only main distinguishing factors compared to current offerings.

Additionally, our primary role in this co-engineered project is to build the physical drone and write the software necessary to manually and autonomously operate it. Our partner team is ECE Team 7, and their primary role is to create a data framework for use by multiple drones.

The scope of our project encompasses several things. First, the design and assembly of drone hardware to meet the capabilities of physical flight and surveillance. This encompasses the selection of physical components, the design of their configuration, and the actual assembly of the drone unit. Second, the creation of a modular payload system as a central feature of the drone. This payload system should be modifiable for different use cases, and support a small-medium amount of additional weight, making the drone more beneficial and convenient to the user's desires. Third, the design and writing of programs related to physical flight and image processing. We intend to synthesize available code for both quadcopter flight control and computer vision to make the best use of our time and resources. We anticipate that we will first need to achieve manually-controlled flight before executing autonomous, CV-driven flight. Lastly, the drone's primary use case and function is its "sentry mode" for surveillance applications. As such, we will design for functions related to this use case.

Some out-of-scope goals further help direct our time and resources towards our project goal. First, the drone will not require high altitude capabilities. Since this is to be a functional surveillance prototype, our maximum altitude need not exceed 200 feet. Second, our drone will not need to carry heavy payloads. A delivery or transportation use case has not been included in scope, and as such we need not design for it. Third, our project team will not be primarily responsible for selecting sensors or other peripherals. Team 7 is responsible for selecting sensors and cameras for the drone based on their data collection needs. We will consult and approve their decisions, but ultimately take our direction from them. Finally, we will not be writing the communication layers, data APIs, or data processing programs necessary to mesh multiple drones into one network, as these tasks fall within Team 7's objectives

C. User and System Requirements, and System Specifications

User Requirements

1. The drone should support a 6 minute minimum flight time
    a. Combined power consumption of the drone over 6 minutes must be less than our battery capacity. The largest contributors to power consumption will be motors and computing on-board the Jetson Nano.
2. The drone shall measure ~500mm x ~500mm in size, and support its flight payload and a small sensor payload.
3. The drone shall cost less than $500 when fully assembled, without the cost of the Pixhawk or Jetson Nano.
4. The drone shall be capable of basic autonomous flight.
5. The drone shall be capable of performing on-unit object tracking and recognition.

System Requirements

1. The drone shall have the battery capacity necessary to sustain 6 minutes of power consumption
    The largest amount of power shall be allocated for the motors and on-unit Jetson Nano.
2. The drone must have a minimum thrust ratio of 1.5.
    The motors shall be selected using the expected weight of the drone.
3. The drone shall be constructed from low-cost and readily available materials.
4. The drone shall have positional tracking capabilities and the user shall be able to set the coordinates of the drone as well as the hovering altitude.
5. The Jetson Nano will be configured and programmed with computer vision functions and routines.
    The drone shall have a high-quality camera for capturing live images at a set refresh rate and resolution
    The data collected from the camera and processed by the Nano shall be used to generate the flight instructions.
6. Requirements for wireless protocol /data transfer speed/reliability

System Specifications

1. Overall power consumption over 6 minutes must be less than battery capacity.
2. Thrust generated by motors must be at least 1.5 times the weight of the drone.
3. The drone components should be readily available from online retailers.
4. The drone will have a GPS to determine its position, and a Lidar range finder to determine its altitude.
5. The drone will utilize a Jetson Nano compatible camera to capture images, which will then be input into an OpenCV object recognition library onboard the Jetson Nano.

D. Constraints

Our project must meet a wide range of specifications within different constraints. These include specific performance and cost constraints provided by our sponsor, regulatory and legal constraints from local and national bodies, as well as other environmental, manufacturability, maintainability, and interoperability constraints. Specific constraints and our plan to address these are given below. If a constraint was better translated into requirements, then those requirements are found in the previous section.

- **Performance Constraints**
  - Intended Purpose: Personal Property Surveillance
  - See Part 1.C: Requirements
- **Budget/Cost Constraints**
  - This project has a $500 total development/acquisition budget constraint. This value doesn't include the cost of the Pixhawk 6C flight controller, NVIDIA Jetson Nano, or lithium-ion battery.
- **Regulatory Compliance**
  - All flight testing for this project must <u>not</u> be done in a Davidson County park (unless within the confines of a designated flying area) in accordance with Metro Government of Nashville and Davidson County Ordinance 13.24.400. Under this ordinance, it is a Class C misdemeanor to "voluntarily bring, land, or cause to descend or alight with or upon any park any apparatus for aviation [including drones]." [1]
  - If the final drone exceeds 0.55 lbs in weight after takeoff, it must be registered with the FAA. The drone operator must complete a TRUST test and register with the FAA. [2]
  - Although the intended use case of the drone is surveillance, it is a Class C misdemeanor under Tennessee Senate Bill SB 1892 to use an unmanned aircraft system (UAS) for unlawful surveillance of persons or property. It's considered a criminal act to possess, distribute, or use captured images for any purpose without consent (the latter is a Class B misdemeanor). [3]
  - Under Tennessee Code 39-13-902 "Lawful capture of images - Use for lawful purposes," it is legal to capture an image using a UAS in the state for 1) "purposes of professional or scholarly research and development by a person acting on behalf of an institution of higher education." [4]
- **Environmental Constraints**
  - The drone should be operable under ideal-moderate weather conditions (<10 mph wind gusts, 70% humidity, 40-85 degrees F, no rain).
- **Testing and Validation**
  - See Part 2.C: Testing
- **Manufacturability and Availability**
  - All components should be readily available from drone hobby shops, online retailers, or be available for individual construction (e.g. frame)
  - All components should have availability for construction of multiple drones.
- **Maintenance and Repair**
  - Hardware components must be replaceable with a basic level of hardware knowledge and without damage to the core components of the drone.

E. Work Breakdown

For the remainder of our project execution, we will be following the schedule phases in the GANNT chart, given in Fig. 2 in the following section. The primary phases of the project are research, design, prototyping, programming, and testing. There is minimal overlap between the phases so that each team member can contribute to the phase's subtasks, as well as the aspects of the project that will move at the same pace.

The research phase encompasses the background research and exploration of different areas of the project, as well as the project space as a whole. This phase is essential to deciding what steps to take and what aspects are important to our project. The entire team worked on this task, each member focusing slightly on their area of expertise. In the design phase, the tasks include the selection of power and peripheral components, the design of the frame, and the design of software drivers. This phase also includes designing the integration of machine learning into the system, but this task will occur later in the project. During this phase, Oscar, Walker and Jerry worked to investigate and design our power and peripheral needs. Trenton was initially responsible for the exploring and creating frame design options;, however, since we were direct to purchase the frame rather than 3D-print or machine it, he pivoted to helping Arianna and Walker investigate the software and algorithm frameworks and design.

The prototyping phase has been streamlined to just the task of assembling the drone by the entire team. Oscar and Jerry are the primary leads of this hardware-heavy phase. Overlapping with this phase is the programming phase. Arianna will take charge of writing the embedded flight programs, while Walker will be handling object detection and network communications. He will also be directing the autonomous flight programming, which will require the contributions of the entire team. In the final testing phase, the entire group will work on software and flight calibration testing, and work to meet the test cases and scenarios created by Jerry.

Our team already meets every week, and we meet with our sponsors on a weekly basis. For the network diagram given in Fig. 1, our critical path is shown by the red path along the different tasks. In this diagram, the early start, early finish, late start, and late finish are all included in each task.

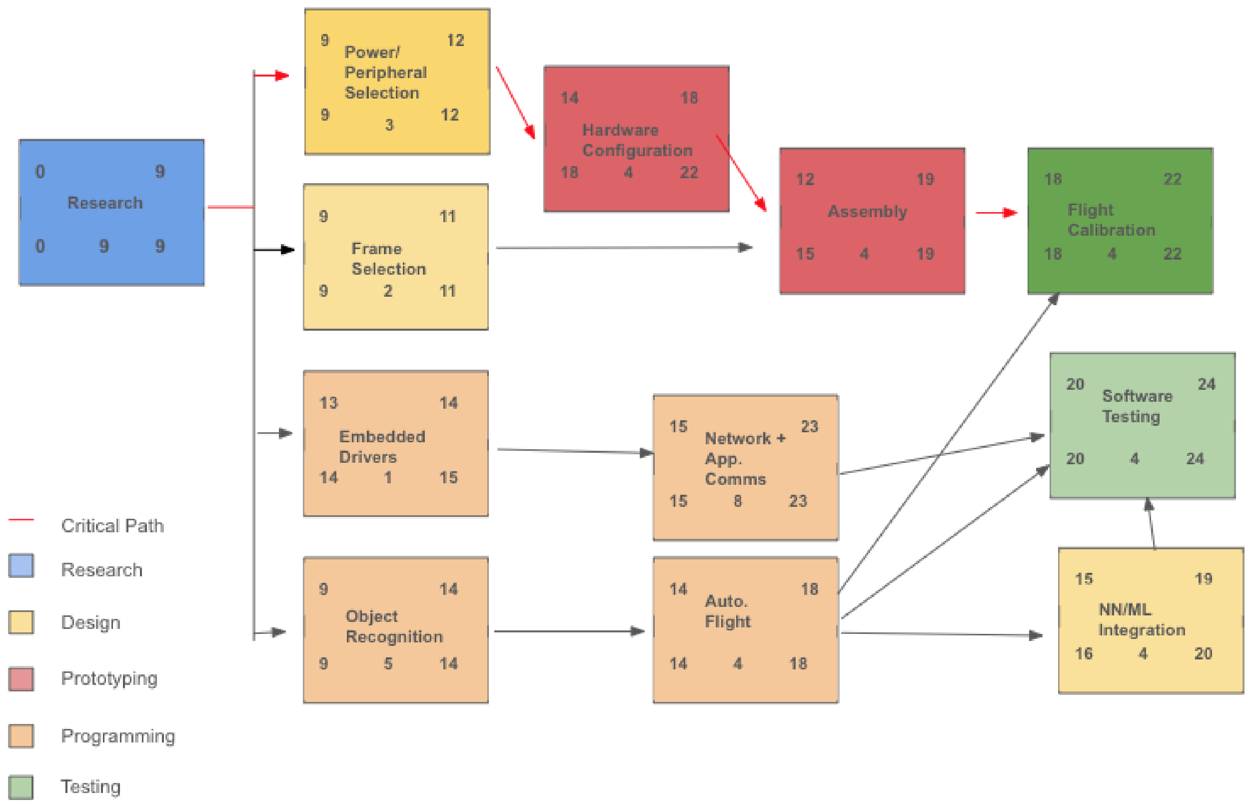

Figure 1. Project Network Diagram

F. Project Schedule

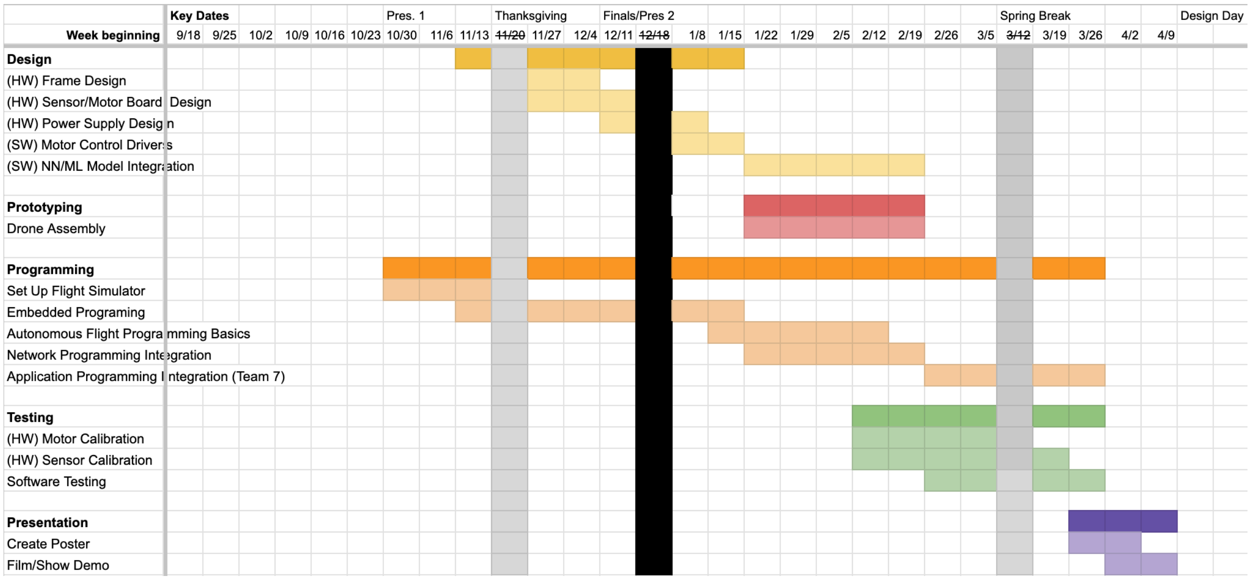

Figure 2. Project GANTT Chart

<u>**Major Project Phases:**</u>

Research Phase: (9 weeks total)

- Includes coordinating sponsor meetings, exploring hardware and software frameworks and platforms, and ramping up technologies and languages.

Design Phase: (6 weeks total)

- Includes designing and selecting options for frame, motors, power, and software components.
- Machine learning system design will happen later once the basic flight deliverable has been achieved.

Prototyping Phase: (9 weeks total)

- We are no longer prototyping the frame in-house
- We will still need to physically assemble the drone, but less iteration is necessary

Programming Phase: (17 weeks total, most of the project)

- First tasks:
  - Setting up a flight simulator to test physical requirements
  - Beginning to write motor and flight drivers/programs
  - Beginning computer vision programs on Jetson
- Later and longer/more-involved tasks:
  - Writing and testing autonomous flight algorithms, integrating sensor communications, integrating image processing and computer vision data with flight instructions
- Final/stretch tasks:
  - Integrating with Team 7 for network communications and API to talk to central computer

Testing Phase: (6 weeks total)

- Testing different use case scenarios and calibrating motors/sensors for our chosen scenarios

- Testing lag and reliability of software under different environmental conditions
- Testing data framework integration alongside Team 7

G. Summary Budget

For our budget, the goal given to us by our sponsors has been $500, which includes the budget from the other UAV team. This, however, is a deceiving statistic considering the components our sponsor has already given us.

The components that have already been given to us are as follows: the sensor, the battery, the flight controller, and the Jetson Nano. The sensor we will be using is the Runcam Night Eagle 3, which costs $70. We have another optional camera that is more expensive but will help us with tracking and recognition. It's called the Oak D Lite, and its value is $150. The battery, flight controller, and the Jetson are retailed at $40, $291, and $129 respectively. All of these combined with the Runcam Night Eagle 3 will come for $530. However, these were given to us by our sponsors and will not count toward our purchasing budget.

Moving forward to our purchasing budget, the frame of our drone will be $38, and it is from the vendor Aliexpress. Our battery charger, called the Hiyiton V6 Balance Charger, is worth $40. For the connectors, we plan to use a wide variety of them from many different suppliers. In total the cost will be $38 for 10 units. For our BECs, we will use the SoloGoods RC BEC, and for 2 units it costs $13. Our ESCs will be of the QWinOut series, and its retail price is $38 for 4 units. Our motors are priced at $80 for 4 units, and our propellers are priced at $12 for 4 units. For all of the components we will need to purchase, the total cost will be $259, which is way below our budget of $500.

Because we are way under budget, our consideration of getting a more expensive sensor could come to fruition. If we were to buy the brand-new sensor and include it in our purchasing cost, the total purchasing cost would be $409. We may look into making this addition in the future, but that depends on whether we foresee any other costs coming out of the project as well as how the budget looks for the other UAV team.

The total cost if we were to take into account the components that have been given to us by our sponsor, then the overall costs would be $789. An easily accessible data table is available below.

Frame	1 unit	$38
Charger	1 unit	$40
Connectors	10 units	$38
BECs	2 units	$13
Motors	4 units	$80
Propellers	4 units	$12
ESCs	4 units	$38
Total Purchasing Cost		$259

Table 1. Breakdown of Selected Component Cost

Components Already Available		
Sensor	1 Unit	$70
Battery	1 Unit	$40
Flight Controller	1 Unit	$291
Jetson Nano	1 Unit	$129
Total Additional Costs		$530
Total Unit Cost		$789
(Optional) Depth Camera		$150

Table 2. Breakdown of Provided Component Cost

H. Sponsor Interaction

Our group has scheduled weekly meetings with our sponsor in which we present our progress and address any concerns or questions either party has. Thus far, our weekly meetings have been extremely productive in providing us with guidance through the project and ensuring that both the team and sponsor understand the scope of the project. Any major in-class reports and presentations have also been submitted to our sponsors to keep them up to date with all of our progress. Additionally, we have submitted our component list to our sponsors taking into consideration all of the recommendations and requirements presented to us. Communication with our sponsors has not been an issue, while there have been some concerns that both sides have presented, these have all been resolved.

Through our weekly meetings we are able to keep a constant feedback loop and ensure that the project progresses as smoothly as possible. One example of this is when the requirements of the size and flight time were changed after we presented various frame and battery options to our sponsors. They picked a larger frame and were able to provide us with a battery that fit that size and resulting power requirement. This could have been a larger issue had there not been constant communication between the team and the sponsor. Overall, sponsor communication has been one of the key contributing factors to the progression of the project.

Part 2. Technical

A. Proposed Technical Approach

In order for the drone to hover and accelerate the motors would need to provide a thrust to weight ratio of around 1 and 1.5 respectively. As can be seen in Table x, motors can function at different throttles which produce more thrust at the cost of power efficiency. Further, we have to ensure that our selected battery would be able to supply enough current to all the motors and peripheral devices like the Pixhawk 6C Flight Controller and Jetson Nano. Our objective is to find a balance between how much current the motors consume, a higher current drains the battery quicker and can overheat the motors, and overall flight performance of the drone. The concepts we utilized in order to achieve our objective for the design are mainly electrical with some mechanical principles.

With our total drone weight of 1709g that means that our optimal thrust per motor is roughly 854 for a thrust to weight ratio of 2,however, this is not completely necessary as a ratio of 1.5 and above should suffice, but the closer to 2 the better. We will assume that when accelerating our motors are operating at roughly 65-70% throttle producing a thrust of 770g and drawing around 7.5 A each. Below are some of our calculations for expected thrust to weight ratio, draw current, and battery lifetime.

AIR2216II-Test Report

Type	Propeller	Throttle	Voltage (V)	Thrust (g)	Torque (N*m)	Current (A)	RPM	Power (W)	Efficiency (g/W)	Operating Temperature (°C)
AIR2216II-KV920	T1045II	30%	16	210	0.03	1.44	4042	23	9.12	80°C
		35%	16	259	0.04	1.87	4469	30	8.67	
		40%	16	309	0.05	2.29	4855	37	8.45	
		45%	16	373	0.05	2.86	5301	46	8.15	
		50%	16	447	0.06	3.60	5780	58	7.76	
		55%	16	536	0.08	4.53	6298	72	7.39	
		60%	16	628	0.09	5.61	6800	90	7.01	
		65%	16	729	0.10	6.78	7281	108	6.73	
		70%	16	814	0.11	7.92	7679	126	6.44	
		75%	16	906	0.12	9.20	8096	147	6.18	
		80%	16	993	0.14	10.59	8468	169	5.88	
		85%	16	1087	0.15	12.11	8867	193	5.65	
		90%	16	1191	0.16	13.81	9257	219	5.43	
		95%	16	1289	0.18	15.68	9675	249	5.18	
		100%	16	1332	0.18	16.37	9857	260	5.13	

Note: Motor temperature is motor surface temperature @100% throttle running 10mins.
(Date above based on benchtest are for reference only, comparion with that of other motor types is not recommended.)

Table 3. Motor Specification Sheet for 2216 920KV [5]

*Note: This test sheet operates at 16 V as opposed to the 14.8 input voltage we will be working with. However, the performance should be really similar with a minor downgrade in performance.

$$Thrust_{Tot} = 4(750\ g) = 3000g$$

Equation 1. Expected Thrust of Drone

$$Thrust_{Tot}/Weight_{Tot} = \frac{3000g}{1709g} = 1.76$$

Equation 2. Expected Thrust to Weight Ratio for Nominal Operation

A 2:1 ratio is the ideal ratio for best maneuverability in a drone, while our nominal designed operation does not meet the ideal ratio, when necessary our design can meet the 2:1 ratio by operating at around 75% throttle and drawing 9.5 A to generate 888g of thrust per motor. This means a total thrust of 3552g and we obtain a thrust to weight ratio of 2.08. Additionally, our selected battery is rated at 5000 mAh and 20C which means that it can provide up to 100A as shown in Equation 3 below. Equations 4-5 show the total current ranges depending on the motor throttle and equations 6-7 show the expected lifetime at these currents. Our proposed design should operate for at least 7 minutes and should be able to fly for upwards of 9 to 10 minutes.

$$I_{Max} = C \times Ah = 20 \times 5 = 100\,A$$

Equation 3. Maximum Current Provided by Selected Battery

$$I_{Drone} = I_{FC} + I_{JN} + 4I_{NominalMotor} + I_{Cam} = 1.5 + 1.5 + 30 + 0.1 = 33.1\,A$$

Equation 4. Total Current of Drone at Nominal Operation

$$I_{Drone} = I_{FC} + I_{JN} + 4I_{HighMotor} + I_{Cam} = 1.5 + 1.5 + 38 + 0.1 = 41.1\,A$$

Equation 5. Total Current of Drone at a Higher Motor Throttle for Thrust to Weight Ratio

$$T_{Flight} = \frac{Ah}{I_{Drone}}60 = \frac{5000}{33100}60 = 9.06\,min$$

Equation 6.. Expected Lifetime at Nominal Operation[6]

$$T_{Flight} = \frac{Ah}{I_{Drone}}60 = \frac{5000}{41100}60 = 7.3\,min$$

Equation 7. Expected Lifetime at High Throttle[6]

B. Results / Progress to Date

We began our project by researching previously constructed quadcopter drones of the dimensions specified by our sponsor. We investigated different frame options and sensor configurations, and familiarized ourselves with the Ardupilot platform and the documentation provided on the company's website. We learned about the different measurements and characteristics of the motors, connectors, propellors, and other components that we would need to request for purchase from our sponsor, and set up our initial flight simulator and development environments. We also took time to [re-] familiarize ourselves with programming languages we would be using throughout the project.

A month or so into the project, we began meeting with our sponsor on a weekly basis. These meetings are our primary touchpoints with the sponsor, and create a feedback loop that ensures the team and sponsor agree on the expectations of the project and of our current activities. This process has already resulted in a pivot of requirements, and in turn a change in components,

Originally, we had hoped to have at least assembled our drone by the end of this semester. This delay in progress was the result of a shift in requirements by our sponsor: originally, our drone was to be approximately 250mm x 250mm in size, and to support little-to-no additional payload beyond its sensor array. After selecting our components and presenting some options for carbon frames, we were instructed to use the 500mm x 500m frame, to adjust our motors, battery, and propeller selections accordingly, and to re-submit our purchase justification and requests.

Below is our selected component list as presented to our sponsors. Here, we list the components we believe are best for our drone, provide a small justification for the selection of each item, and give a link to where the item could be purchased.
Furthermore, a complete component list is provided in Appendix A in which we include all components such as the battery, flight controller, and Jetson Nano which were already selected and provided for us.

Motors:
- 4pcs 2216-920KV brushless motors. **$80**
  This motor is the most cost-efficient option. Although it has to operate at around 60-75% throttle in order to maintain effective acceleration. For the 10-15 minute lifetime, this should be sufficient.

Battery Charger:
- 1pcs Hiyiton Balanced Charger **$40**
  We need to be able to charge the LiPo battery. This station is relatively low-cost compared to others.

Frame:
- 1pc S500 Quadcopter Frame Kit. **$38**

This frame has ample room for each component and already has a power distribution board. The size does warrant larger propellers and more thrust, but for the price and utility, this is our best option.

Connectors:

- 3pcs, 2pc XT60 Parallel Battery Connectors. **$27**
  These parallel connectors allow us to have an organized set of parallel connections from the battery to the ESCs and other components. Additionally, they are rated for 60A which our design should never really reach or exceed.

- 2 pcs, Male and Female XT60 pairs **$4**
  These connectors are needed in order to connect the battery to the distribution board of the frame.

- 2pcs XT-60 Female to HXT 4MM Male Bullet Connector Adapter Cable **$7**
  This connector allows us to connect the battery to the distribution board.

ESCs:

- 4pc QWinOut 2-4S 30A RC Brushless. **$38**
  While our motors should never go near 30A, these ESCs give an extra cushion in terms of pulling more amperage given the design's weight. Further, these ESCs come at a decent price.

BECs:

- 1pc SoloGood 2Pcs RC BEC UBEC 5V 5A. **$13**
  These BECs are for the Pixhawk 6C flight controller and the Jetson Nano 5V. Since the flight controller and the nano have the same input voltage this bundle is the best option since we don't have to look into other BECs.

Propellers:

- 4pcs T1045, 10''x4.5 propellers. **$12**
  These propellers are directly used in the motor spec sheet. By using these propellers, we best replicate the conditions of our preliminary calculations in order to ensure our motors are pulling the thrust we need.

Total of Component List: $259 (Shipping Not Included)

Total Cost of Unit: $789 (including battery, Pixhawk 6C, and Jetson Nano)

Total Weight (Including battery, flight controller, and Jetson Nano): 1709g

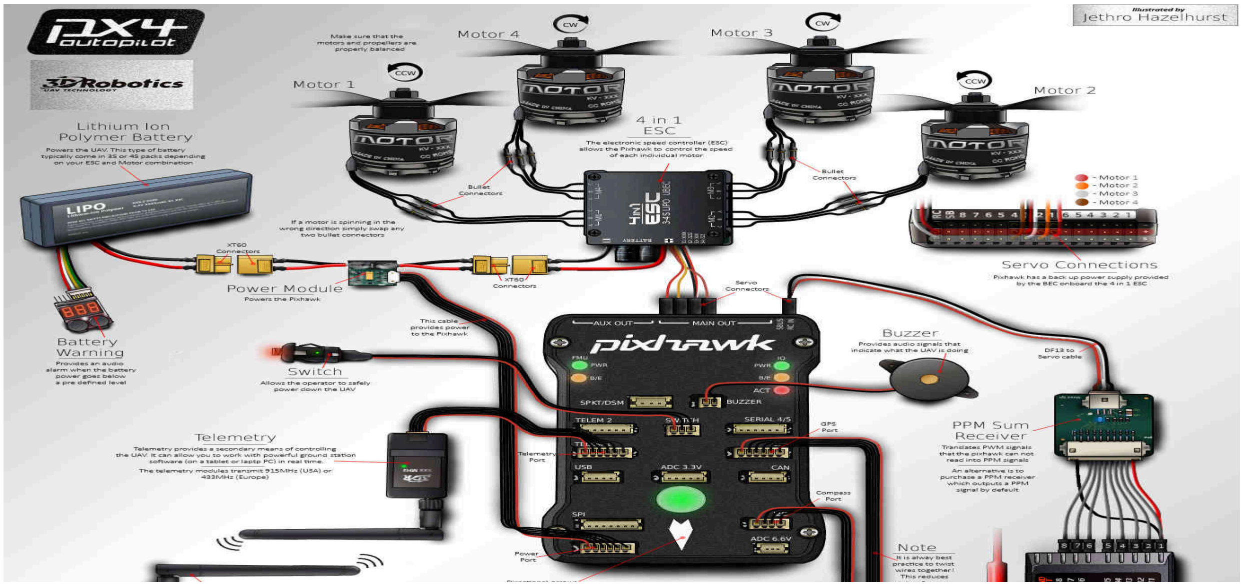

Figure 3. Wiring Diagram of Drone [7]

**Note: This is not exactly how our drone is designed. The battery, motor, and flight controller integration is how our drone is going to be wired.*

Further, we have begun the process of working on our code for drone flight and object recognition. Below are some excerpts

```
// rtl_init - initialise rtl controller
bool ModeRTL::init(bool ignore_checks)
{
    if (!ignore_checks) {
        if (!AP::ahrs().home_is_set()) {
            return false;
        }
    }
    // initialise waypoint and spline controller
    wp_nav->wp_and_spline_init();
    _state = RTL_Starting;
    _state_complete = true; // see run() method below
    terrain_following_allowed = !copter.failsafe.terrain;
    return true;
}
```

Figure 4. Sample Code of Return to Launch Test in ArduPilot

```
import tensorflow as tf
import cv2
import numpy as np

# Load the pre-trained model
```

```
model = tf.saved_model.load('path/to/your/model')  # Replace with the path to saved
model

# Load the label map
category_index = {1: {'id': 1, 'name': 'person'},  # Replace with label map
                  2: {'id': 2, 'name': 'car'}}

# Initialize the video capture
cap = cv2.VideoCapture(0)  # 0 corresponds to the default camera, adjust if needed

while True:
    # Read a frame from the camera
    ret, frame = cap.read()

    # Prepare the image for inference
    input_tensor = tf.convert_to_tensor([frame])
    detections = model(input_tensor)

    # Process the detections and draw bounding boxes
    for i in range(detections['detection_boxes'].shape[1]):
        class_id = int(detections['detection_classes'][0, i])
        score = float(detections['detection_scores'][0, i])
        bbox = [float(coord) for coord in detections['detection_boxes'][0, i]]

        if score > 0.5:  # Adjust the threshold as needed
            h, w, _ = frame.shape
            ymin, xmin, ymax, xmax = [int(coord * h) for coord in bbox]
            class_name = category_index[class_id]['name']

            cv2.rectangle(frame, (xmin, ymin), (xmax, ymax), (0, 255, 0), 2)
            cv2.putText(frame, f"{class_name} {score:.2f}", (xmin, ymin - 10),
cv2.FONT_HERSHEY_SIMPLEX, 0.5, (0, 255, 0), 2)

    # Display the resulting frame
    cv2.imshow('Object Detection', frame)

    # Break the loop on 'q' key press
    if cv2.waitKey(1) & 0xFF == ord('q'):
        break
```

```
# Release the video capture and close the OpenCV window
cap.release()
cv2.destroyAllWindows()
```

Figure 5. Sample Object Recognition Code on Jetson Nano

C. Proposed Method(s) for Design Validation

Due to the interdisciplinary nature of this project, the design validation process needs to be split into two sections with each section targeting a specific part of the project: hardware and software.

I. Hardware
   1. In the scope of this project, hardware refers to the motor, frame, power system, and peripherals. The main purpose of the hardware validation is to make sure all hardware components are functional and the foundational flight capability of the drone.
   2. Sensor/Peripheral Testing
      (1) The main components of this test can be done independent of the drone's completion. Connected directly to the computer, the input and output of the peripheral and sensor can be controlled and monitored for necessary adjustments.
   3. Motor/Power/Frame Testing
      (1) Since these components are the integral part of the drone function, it is impossible to test them independently. The main goal of the testing will be to ensure proper flight function through the integration of the Pixhawk 6c flight controller. The validation will be performed post drone constructions and expected to be one of the more challenging validation steps

II. Software
   1. In the scope of this project, software consists of the autonomous decision making program and the image processing functions of the drone. The main goal of the software validation is to achieve the targeted amount of autonomy with low margin of error to ensure proper usability.
   2. Flight Testing
      (1) Our drone flight code will be programmed using ArduPilot, which utilizes a built-in unit test suite based on Google's GTest framework to decrease debugging time and ensure our code operates as intended.
   3. Object Recognition Testing
      (1) Our computer vision code will first be verified off of the drone by utilizing both white and black-box testing to ensure our code is free of bugs. The code will then be run using the Jetson Nano and different objects will be captured by the camera to ensure the system recognizes them correctly.

Part 4. Acknowledgments

Team 8 would like to express our sincere gratitude to all those who have contributed to the progress of this project

Supervisor and Mentors:

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Rojae Johnson - Staff Electronic Engineer at Booz-Allen-Hamilton
Roshawn Treadwell - Booz-Allen-Hamilton Representative

Faculty Members:

Dr. Walter Collett - Professor of the Practice of Electrical and Computer Engineering

Associated Team:

Team 7 - Vanderbilt University ECE Senior Design Project Group

Part 5. References

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Part 6. Appendices

Appendix A