SONOMA STATE UNIVERSITY
Department of Engineering Science
Electrical Engineering

Senior Design Project Progress Report
EE 492 Senior Design Project Planning

Autonomous Recharging of Unmanned Aerial Vehicle (ARAV)

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Project Website: https://mcginnisa.github.io/ssuuav/

Acknowledgments

We would like to thank and acknowledge our faculty advisor, Dr. Wu, as well as the rest of the Sonoma State University Electrical Engineering Department faculty, for their extremely valuable support and guidance during our college careers.

Abstract

Unmanned Aerial Vehicles (UAV) are gaining popularity due to their agility and ease of manufacture. However, due to battery life limitations, longer autonomous flight patterns are not feasible for most of these vehicles. There is an imminent need among researchers and industry engineers alike to develop UAV systems capable of supporting autonomous recharging routines for a variety of applications. Our proposed solution to this problem is the creation of an autonomous system involving a lightweight UAV paired with an intelligent landing platform. The landing platform will be equipped with an on-board camera and single board computer (SBC) capable of accomplishing image recognition of the UAV. Combined with an onboard wireless charging pad, these key elements of the landing platform will support the autonomous landing and recharging of the UAV. The landing platform will further be designed as portable subsystem capable of being deployed on a variety of surfaces, thus allowing for further developments in autonomous vehicle applications.

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1. Problem Statement

Completely autonomous unmanned aerial vehicle (UAV) systems have immense potential to solve modern problems in novel ways. Industry professionals and public institutions alike are actively researching the potential of these vehicle systems to perform a variety of automated tasks, such as: field surveillance, search-and-rescue operations, and parcel delivery. The types of UAV systems being developed by engineers and scientists exhibit significant variability with regard to overall system cost and functionality. Smaller and lower-cost UAV systems often suffer from limited support of vehicle-mounted sensors and/or real-time processing of navigational data from the UAV itself. This presents a significant challenge to UAV system developers working with more accessible vehicle platforms, as some of the most difficult and dangerous parts of any aircraft's utilization are its take-off and landing routines. Additionally, battery life limitations among more budget-friendly aerial vehicle options typically make longer autonomous flight routines impractical or unfeasible.

A solution is therefore needed to accomplish the autonomous landing and recharging for such an economical UAV system. A system which supports these autonomous behaviors would therefore allow developers of UAV applications to overcome some of the limitations imposed by the use of affordable, lightweight aerial vehicles. The solution proposed by this project seeks to tackle a key challenge of autonomous and unmanned aircraft missions in an accessible and generalizable way.

2. Introduction

Unmanned aerial vehicles are capable of nimble and autonomous flight, and there are numerous UAV applications – including the ones previously described – which would benefit greatly from the availability of automated battery recharging systems. These systems would support remotely recharging UAVs actively engaged in programmed flight routines and without the aid of a human operator. The development of UAV applications is being performed by individuals and institutions with varying levels of material resources, and smaller organizations and labs must often work with low-cost, feature-constrained vehicular systems. Therefore, the limitations on the features supported by a budget-friendly UAV system effectively become limitations on the range of UAV applications that may be successfully developed by smaller institutions.

Our goal is to develop a system that involves an unmanned aerial vehicle functioning in tandem with an intelligent and portable Landing Platform (LP). The UAV will perform an automated flight routine and alert the LP when a particular low-battery threshold is reached. When alerted, the system will initiate an automated landing sequence. The landing sequence will align the UAV through the use of the LP's onboard sensors, and send commands for mid-flight position adjustments over a radio module. This synchronized landing routine will allow the UAV to touch down on the landing pad, which will integrate a wireless charging deck capable of recharging the UAV's on-board battery without the need for a physical port connection. The LP's onboard control computer will be accessible over a local network.

The automated landing sequence is anticipated to successfully coordinate the precise positioning of both the LP and UAV such that the UAV can land directly on a wireless charging platform as needed while performing a variety of potential flight missions. The system will function on flat ground, in natural scenarios that will demonstrate its viability for real world applications. We expect this landing-and-recharging routine to be a significant contribution to further developments in the world of autonomous UAV flights, especially as it pertains to budget-friendly devices.

3. Literature Review & Previous Works

Commercial use of battery-powered unmanned aerial vehicles (UAV) for various observation tasks has become popular with the increasing availability and affordability of instruments such as heat sensors, LIDAR, and cameras [1]. While the viability of UAV use has vastly increased, these vehicles generally have limited flight time [2]. Longer UAV flight routines could be made possible by the development of systems whereby the UAV operates in tandem with an unmanned ground vehicle (UGV) designed to function as both a landing pad and battery recharging station for the UAV. Such UAV-UGV systems are not commercially available, but they have been revealed to be in development by companies such as UPS [3]. Due to increased demand on shipping companies as online shopping services have risen in popularity [4], a system that can be used to autonomously recharge a UAV (or, in certain cases, an entire fleet of UAVs) is desirable for research institutions, commercial entities, and government agencies.

In an ambitious project from Wenzel et al., a UAV-UGV pair system was developed for testing techniques to land a quadcopter on a moving platform. This project is highly relevant to the ARAV project due to its heavy reliance on affordable machine vision hardware to determine the position and orientation of the moving platform, as well as the use of micro-quadcopters [5]. This system leverages a Wii Remote infrared constellation sensor to track the position of the landing pad. This is an elegant solution because the Wii Remote removes the machine vision processing burden from the main flight microcontroller, leaving precious resources for the proportional-integral-derivative control loop. The microcontroller aboard the UAV is free to run a control loop at an update frequency of 50 Hz [5]. Critically, the tracking system is also very light, at under 10 grams, which allows for a much longer flight time than a bulky camera. The modularity of the system also allowed different aerial vehicles to be tested with the UGV location system. An Atmel ATmega 644P microcontroller was used as the main flight controller, and a ZigBee local area network was established between a ground station and the UAV for control, much like our system. The entire infrared tracking system consumes 1.8 W of power, and the four motors aboard consume a maximum of 222 W [5]. The camera from the Wii Remote was removed and stripped of its Bluetooth module, so that the camera could be run at three times the refresh rate, as well as allow for a reduction in power consumption and size. The Wii Remote camera was fitted on a servo mounted to the UAV, so that the constellation could be tracked in its narrow 45 degree vision cone without needing to pitch the aircraft. The infrared constellation on the UGV consisted of a three-dimensional four-beacon configuration, which provided orthogonal axes between the beacons for tracking from any azimuth or elevation. There was a design tradeoff in the distance between the beacons. If the beacons were too far apart, the constellation wouldn't fit in the vision cone of the Wii Remote camera, however if the beacon constellation was too small the camera wouldn't be able to resolve the distinct points at a distance. This system is highly similar to the proposed ARAV system, and several features of this system can inform ARAV design choices. The system still maintains the camera aboard the UAV, burdening the UAV with image recognition power consumption and an extra camera payload. The ARAV system will relieve the UAV of this responsibility [5].

Another dual system developed by Jae-Keun Lee et al. supported the continuous and autonomous tracking of a UGV's position by a UAV equipped with a downward-facing camera, much like the ARAV project. [6] Images captured by this camera were wirelessly transmitted to a remote PC which in turn recognized the position and orientation of a unique monochromatic symbol on the upper face of the UGV's landing landing platform. The interpolated position of the UGV within the UAV's image frame was then issued to issue controls to the UAV from the remote PC, thus ensuring that the UAV maintained a stable hovering position over the UGV at all times. The use of a simple visual pattern to determine all necessary UAV controls in this case is comparable to our unique control scheme, however this system does not implement autonomous UAV flight commands besides those necessary to maintain a fixed position relative to the UGV, nor does it take into consideration any battery recharging needs that would arise for longer flights. In contrast to the proposed ARAV system, mounting a camera on the UAV rather than the UGV precludes the use of smaller and more affordable aerial vehicles for broader research into related applications. This project informed our investigation into April Tag detection techniques.

As dual systems are being implemented more frequently, common problems are arising from the limited computational power of the aerial vehicle, which is a shortcoming the ARAV system aims to address. As noted by Yingxin Wei, UAV sends telemetry via wireless signals which are susceptible to distortion and transmission delay [7]. This project is relevant to the system being developed as it describes optimizations for UAV-UGV pairs with the primary processing core available on the drone. This primary processing core handles image processing as well as flight for the drone which causes a large battery draw for the drone. The processing is done by a Raspberry Pi which is a fairly low-power Linux machine which is capable of communicating over IEEE 802.11 with the UGV. The transmission consists of PWM signals which enable the movement of the UGV toward the UAV. The system developed by Yingxin Wei was used as a testbed for low-power algorithms that would produce similar performance in the detection and direction of the UGV. The tests performed were to simulating a real-world scenario in that the UGV would follow the UAV through various obstacles, in this case a series of light beacons revealing a path for the UAV to locate and use to direct the UGV. This UAV-UGV pair was directed by an algorithm that optimized the UGV's route towards the UAV-identified light beacon. While this algorithm was effective, Yingxin Wei notes that it is prohibitively expensive due to the computational complexity [7]. Despite the proposed approximation which showed promise in the aforementioned simulations done, the applicability of the research was deemed to be largely confined to systems involving larger and more expensive aerial vehicles than those most appropriate for the scope of this project.

4. Methodology

Given the existing limitations on autonomous landing and battery recharging behaviors by affordable, lightweight UAVs, our team proposes a paired system comprised of a small UAV and portable landing platform. The proposed system incorporates some of the techniques used in prior research, as well as some novel control mechanisms of our own design. These major design decisions were informed by some of the most relevant research available on the topic of UAV-UGV control systems, as described above. Additionally, the decision to implement the landing surface as a portable platform – as opposed to a complete UGV subsystem – was based on the desire for our system to be compatible with a variety of different mountable surfaces and locations. This would broaden the range of applications for which our autonomous system could be deployed.

The UAV is expected to have adequate agility for making targeted landings, and thus the accurate positioning of the UAV over a recharging station would entail the transmission of flight control commands from a single board computer to the UAV over a radio module. The control commands themselves would be calculated by an algorithm that interprets information about the UAV's altitude and position. The altitude of the UAV is queried from an onboard range sensor, and positional data is extrapolated from an image of the UAV as seen from an upward-facing camera module to be mounted on the landing platform. The location and orientation of the UAV, relative to the landing pad, would be determined by an image recognition scheme involving the use of RGB color detection. By loading as much of the necessary computational features as possible on the landing platform, the power supplied to the UAV could be prioritized for accomplishing extended flights or other task completion behaviors.

Due to the great difficulty in performing an extremely precise autonomous landing, the means of recharging the UAV upon touchdown would be through an inductive charging interface using a widely-available wireless charging standard. This would eliminate the need to maneuver the UAV toward an even smaller range of acceptable landing positions, as would be the case if direct contact of physical power ports were necessary to recharge the UAV battery. While the UAV will be powered by the inductive charge provided by the landing pad's wireless charging deck, the complete landing platform subsystem (including the camera and radio modules, single board computer, and wireless charger) will be powered by a large, mounted battery pack.

5. Challenges & Risks

A principal source of challenges in accomplishing our proposed solution is the need for our system to reliably make rapid and accurate vehicular control decisions for the UAV. Crucially, the generation of necessary control commands requires a predictable and reliable determination the UAV's position from the image information sent by the camera module to the single board computer. The resolution of the camera and the processing capabilities of the computer must be leveraged against the overall power consumption of the system. It must also take into account the inherent latency between the issuance of a flight control command by the computer and the physical movement of the UAV in response to these commands. A major risk in accomplishing this robust control scheme is inadequate consideration of various physical factors, such as: the aerial vehicle "ground effect," the altitude ambiguity due to a non-uniform landing pad surface, and uncertainty in proper interpretation of the UAV's orientation within the image frame of the camera. The ground effect is problematic turbulence which results from the aircraft getting too close to the ground. The mitigation of these project risks entails meticulous planning and testing of multiple versions of the control algorithm used in the landing routine.

Other significant challenges of this project from the standpoint of resource-heavy deliverables include the creation of numerous custom-made printed circuit boards (PCBs) to ensure a compact and reliable implementation of critical UAV and landing platform hardware, the development of multi-layered 3D modeling for the landing platform, and the tidy management a plethora of software packages and tools as needed for discrete computational tasks and communication functionality. These particular project challenges can be minimized by an appropriate allocation of design tasks among project team members, as based on individual skill sets, and through the adoption of an overarching approach of simplicity to the hardware and software design choices. A potential challenge in the long-term operation of this system is the build-up of dust on the upward facing camera lens that will cause reflections and obstructions of the incoming light. As this factor might require complicated automated systems to regulate, the instructions for care and operation of the system will include a preliminary inspection of the lens and cleaning if necessary.

6. Project Requirements

6.1. Marketing Requirements (MR)

MR-1. A complete system will consist of a Crazyflie Quadcopter (UAV) and a Landing Platform providing for wireless flight control of the UAV without human input.

MR-2. The system will be able to land the UAV on a designated point on the Landing Platform on UAV low battery signal.

MR-3. The Landing Platform must be able to fully recharge the UAV in a reasonable time frame.

MR-4. The Landing Platform should be able to provide a reasonable amount of recharges for the UAV.

MR-5. The UAV should have a reasonable flight time.

MR-6. The Landing Platform will use an upward facing camera to provide necessary feedback for landing the UAV.

MR-7. The system must have the ability to operate indoors under normal lighting conditions.

MR-8. The system must be portable.

MR-9. A personal computer must be able to connect wirelessly to the Landing Platform to query or reconfigure the control software.

MR-10. The UAV must include safety line mounting points.

6.2. Engineering Requirements (ER)

ER-1. The UAV will successfully respond to 95% of commands issued remotely by the Landing Platform at a distance of 3 meters (MR-1).

ER-2. UAV will be able to land within 5 cm of target point (MR-2).

ER-3. Wireless communication between the Landing Platform and the UAV will have a latency under 100 ms at 3 meters (MR-2).

ER-4. The Landing Platform will be able to charge the UAV within 1 hour (MR-3).

ER-5. The Landing Platform battery will be able to provide 25 W over 4 hours (MR-4).

ER-6. The UAV will be able to fly for at least 5 minutes, with the landing sequence taking no more than 3 minutes (MR-5).

ER-7. Landing platform is able to detect an overhead UAV within a height of 2 meters in an indoor environment lit by T8 fluorescent light bulbs (MR-6, MR-7).

ER-8. The complete system will fit within a footprint of less than 0.25 m^2 (MR-8).

ER-9. The landing platform control system will support remote connection via SSH (MR-9).

ER-10. Anchor point can suspend double the weight of the UAV when attached with 5 lb rated fishing line (MR-10).

7. Implementation

A system will be created that will involve an unmanned aerial vehicle functioning in tandem with a remote Landing Platform (LP) equipped with a centralized control computer, upward-facing camera, and wireless charging pad. The UAV will fly an automated path and alert the LP when a battery threshold is crossed. When a low-battery threshold is crossed, a landing sequence will be initiated for the UAV. The landing sequence will consist of aligning the UAV through the use of the LP's onboard camera and sending commands for on-the-fly position adjustments through the use of a radio module. The LP will allow a remote user to access to receive status updates. The Landing Pad will be portable, such that it can easily be mounted to an existing platform, indoor structure, or separate vehicle system entirely.

7.1. System Architecture

The system comprises an autonomous UAV and a portable landing platform. Shown in Fig. 1 is a high level block diagram for the entire system. In Fig. 2 the block diagram for the LP is shown. In Fig. 3 the software routine for autonomous landing is shown.

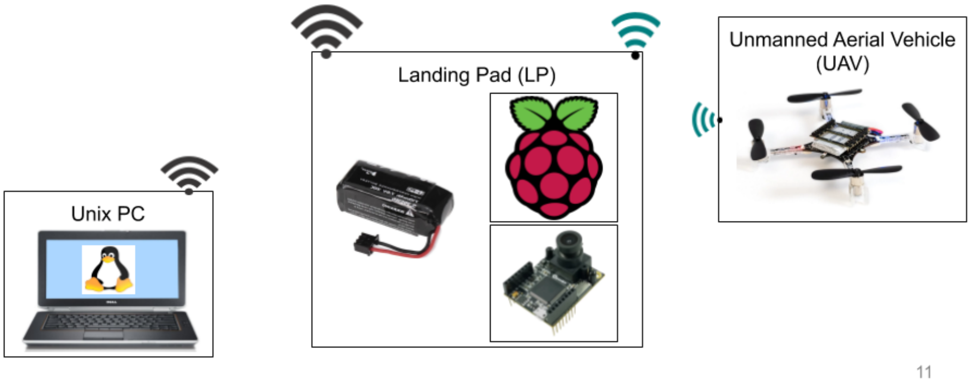


Fig. 1 - High Level Block Diagram

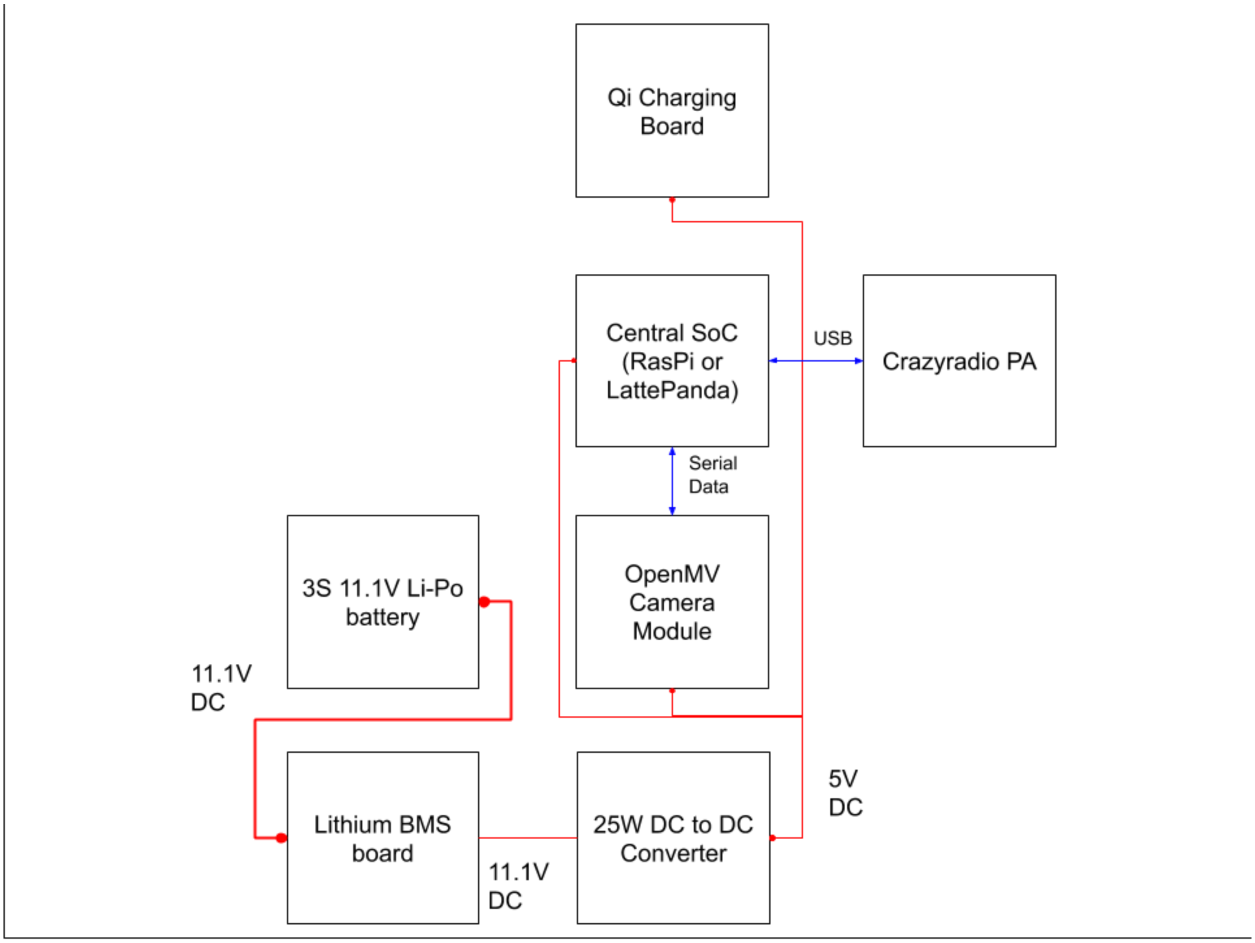


Fig. 2 - Block Diagram of Landing Platform

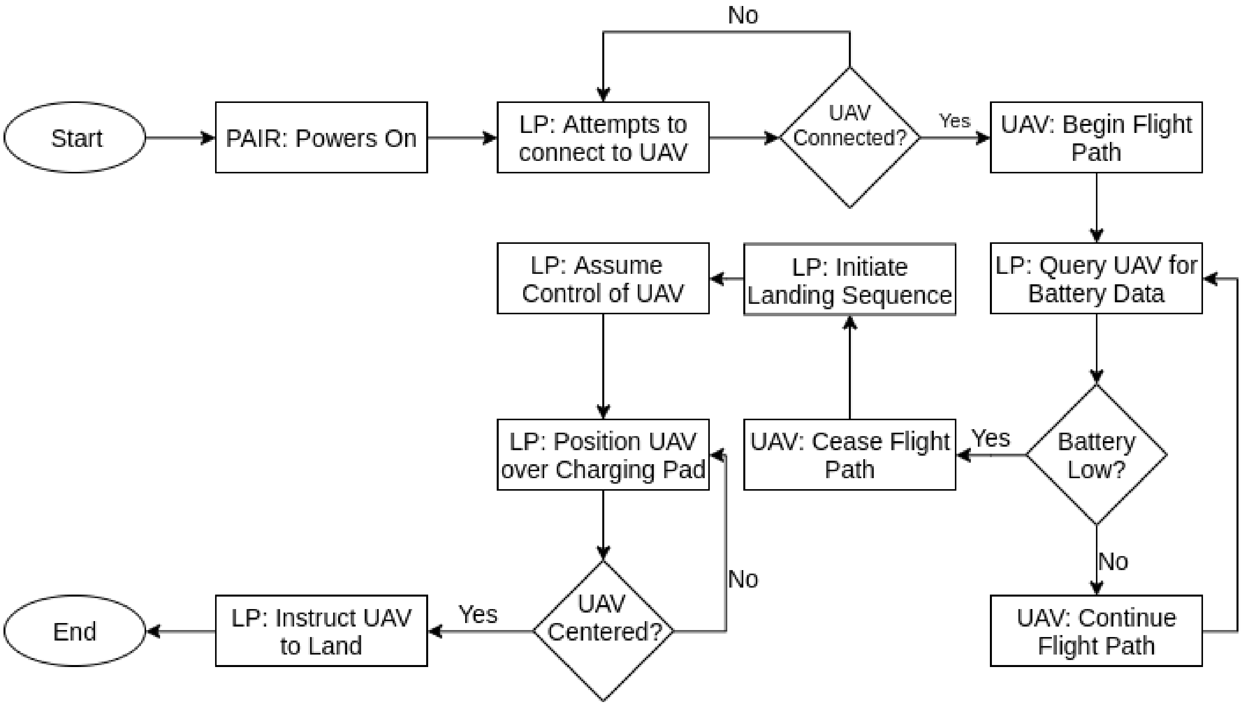


Fig. 3 - Landing Routine Software Flowchart

7.2. Budget/Parts List

Minimizing costs and making efficient use of grant funds is a core consideration of this project. Cost was taken into account at every step of the component selection process. Several premium parts – such as a LattePanda single board computer and higher resolution cameras – were considered, however the low cost solutions shown below were chosen after their capabilities were determined to be sufficient for meeting our Engineering Requirements. A summary of the necessary parts and corresponding project budget is shown in Table 3 below. In Table 1 and Table 2, design matrices are shown for the component selection process. The design matrix takes into account several important criteria for the component being selected. The score was based on our evaluations of the product.

Table 1 - Single Board Computer Design Matrix

	Cost	Size	Complexity	Power	Documentation/ Support	
Raspberry Pi 3B+	10	7	8	5	10	40
LattePanda	3	5	5	9	9	31
ASUS Tinker Board S	4	5	2	8	3	22
Raspberry Pi 4	9	5	4	6	5	29

Scoring: 10 is most important /10 is best compared to other options

Description: The 3B+ was chosen because the documentation and support is excellent, as well as the cost. It’s performance and ARM limitation should not be a problem for this application. The design matrix is shown above in Table 1.

Conclusion: We plan to use Raspberry Pi 3B+.

Table 2 - Camera Design Matrix

	Cost	Size	Complexity	Power	Documentation/ Support	
OpenMV H7	3	4	10	5	10	32
RasPi Camera	10	7	2	3	3	25
JeVois	3	7	6	7	7	30

Scoring: 10 is most important /10 is best compared to other options

Description: The OpenMV was selected because the documentation and software libraries available were far superior to the openCV and RasPi machine vision libraries. The RasPi camera does not have the same libraries available. The JeVois did not have as much support as desired. The design matrix is shown above in Table 2.

Conclusion: We plan to use the OpenMV H7.

Table 3 - Qi Charger Design Matrix

	Cost	Charging Area	Charging Maximum Distance	Shape	
ZealSound 5 coil charging pad	3	10	4	5	22
CHOETECH Dual Fast Wireless Charger	5	5	5	5	20
Anker Wireless Charger	7	2	5	1	15

Scoring: 10 is most important /10 is best compared to other options

Description: Our most important design criteria for the Qi charger was maximizing charging area. The charging speed was not as important in this consideration, as the Qi receiver on the UAV can only supply 10W maximum. For this reason, designs with five coils or greater are most desirable. Of the available five coil options, the ZealSound model was chosen because it has the largest charging area.

Conclusion: ZealSound 5 coil charging pad will be used.

Table 4 - Summary of major parts required and project budget

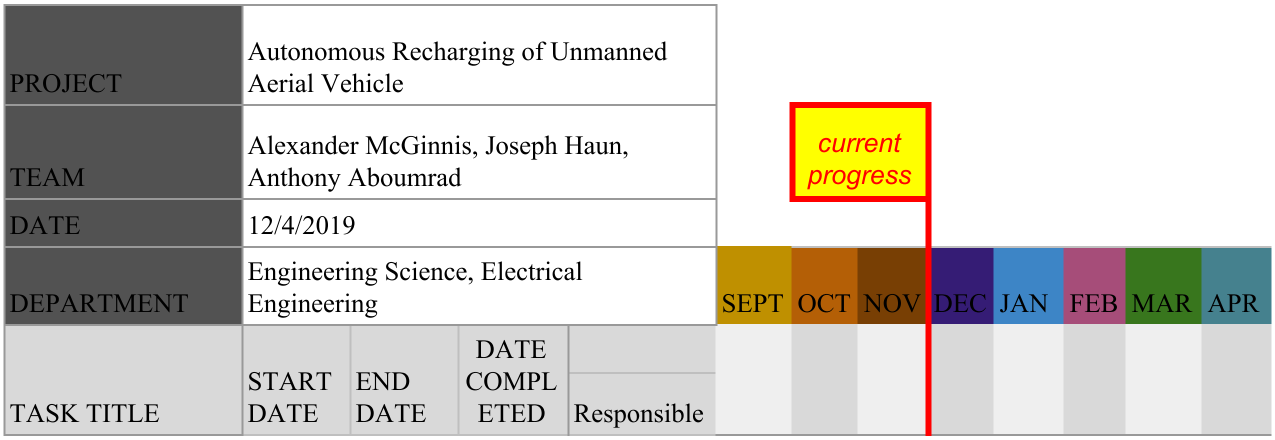
Part/ Quantity	Description	Number	Price (USD)
Camera Module	OpenMV Cam H7 a small, low power microcontroller board with onboard camera capable of image processing	1	65.00
Radio Module	CrazyRadio PA 2.4 GHz USB radio dongle compatible with CrazyFlie software	1	30.00
Wireless Charging Deck	Qi 1.2 charging deck natively compatible with CrazyFlie	1	30.00

Battery Pack	A 5200 mAh 50C 11.1 V	1	33.99
Single-Board Computer	Raspberry Pi 3B+	1	40
Micro UAV platform	Crazyflie 2.0	1	195.00
Shipping	shipping and handling costs	NA	40
Total Cost			433.99

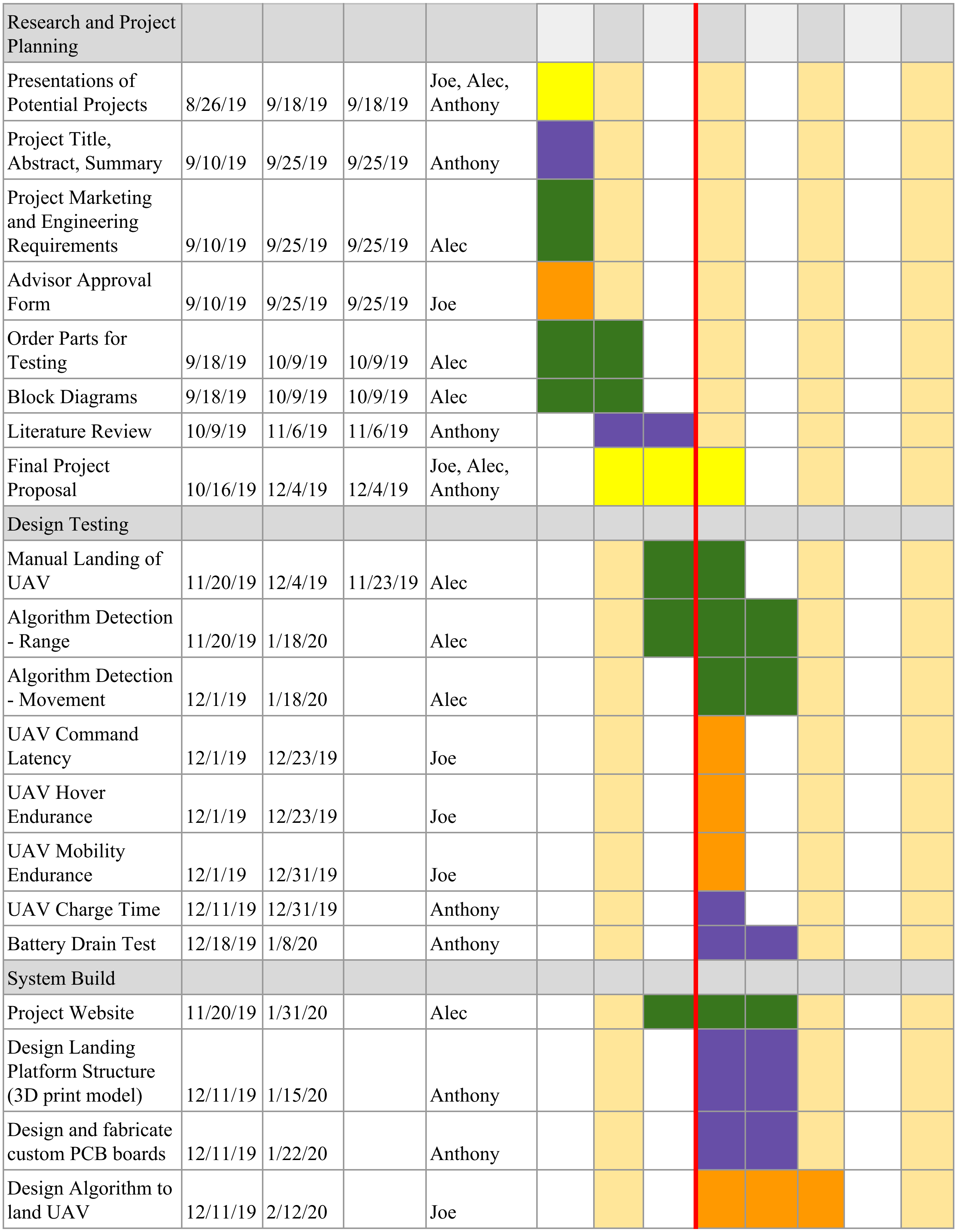
7.3. Project Schedule

The team is currently becoming familiar with the OpenMV H7 camera module, CrazyFlie 2.0 Micro-drone, and Python software packages that will be used to implement the system. We anticipate continuing to experiment with potential hardware and software configurations until the middle of December. Over the Winter break, the landing routine will be completed and further testing will continue. Additionally, all necessary hardware components – including the 3D-printed landing platform base and various PCBs – will be drafted and fabricated for use in the complete system assembly. Once individual device testing is completed and hardware components made available, the overall system testing will commence with each subsystem implemented either aboard the landing platform or the UAV itself. The power subsystem will also be tested under full load, and verification of subsystem communication to the central control board will be performed to ensure overall control system integrity. The complete project schedule is summarized in Table 4.

Table 5 - Gantt chart for project schedule



PROJECT	Autonomous Recharging of Unmanned Aerial Vehicle											
TEAM	Alexander McGinnis, Joseph Haun, Anthony Aboumrad											
DATE	12/4/2019											
DEPARTMENT	Engineering Science, Electrical Engineering				SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR
TASK TITLE	START DATE	END DATE	DATE COMPLETED	Responsible								



Research and Project Planning												
Presentations of Potential Projects	8/26/19	9/18/19	9/18/19	Joe, Alec, Anthony	🟨							
Project Title, Abstract, Summary	9/10/19	9/25/19	9/25/19	Anthony	🟪							
Project Marketing and Engineering Requirements	9/10/19	9/25/19	9/25/19	Alec	🟩							
Advisor Approval Form	9/10/19	9/25/19	9/25/19	Joe	🟧							
Order Parts for Testing	9/18/19	10/9/19	10/9/19	Alec	🟩	🟩						
Block Diagrams	9/18/19	10/9/19	10/9/19	Alec	🟩	🟩						
Literature Review	10/9/19	11/6/19	11/6/19	Anthony		🟪	🟪					
Final Project Proposal	10/16/19	12/4/19	12/4/19	Joe, Alec, Anthony		🟨	🟨	🟨				
Design Testing												
Manual Landing of UAV	11/20/19	12/4/19	11/23/19	Alec			🟩	🟩				
Algorithm Detection - Range	11/20/19	1/18/20		Alec			🟩	🟩	🟩			
Algorithm Detection - Movement	12/1/19	1/18/20		Alec				🟩	🟩			
UAV Command Latency	12/1/19	12/23/19		Joe				🟧				
UAV Hover Endurance	12/1/19	12/23/19		Joe				🟧				
UAV Mobility Endurance	12/1/19	12/31/19		Joe				🟧				
UAV Charge Time	12/11/19	12/31/19		Anthony				🟪				
Battery Drain Test	12/18/19	1/8/20		Anthony				🟪	🟪			
System Build												
Project Website	11/20/19	1/31/20		Alec			🟩	🟩	🟩			
Design Landing Platform Structure (3D print model)	12/11/19	1/15/20		Anthony				🟪	🟪			
Design and fabricate custom PCB boards	12/11/19	1/22/20		Anthony				🟪	🟪			
Design Algorithm to land UAV	12/11/19	2/12/20		Joe				🟧	🟧	🟧		

Fabricate & Assemble Landing Platform	12/23/19	2/12/20		Anthony		▨		🟪	🟪	🟪		▨
Implement power switching, sensor module, interface PCBs	12/23/19	2/12/20		Alec		▨		🟩	🟩	🟩		▨
Final Project Presentation	1/29/20	3/4/20		Joe, Alec, Anthony		▨		▨	🟨	🟨	🟨	▨
Performance Testing												
Network Access Test	11/26/19	12/4/19	11/16/19	Joe		▨	🟧	▨		▨		▨
UAV Query Test	12/18/19	1/8/20		Joe		▨		🟧	🟧	▨		▨
Single Board Computer Power Consumption	1/8/20	2/5/20		Anthony		▨		▨	🟪	🟪		▨
Camera Power Consumption	1/8/20	2/5/20		Alec		▨		▨	🟩	🟩		▨
Qi Charger Power Consumption	1/8/20	2/5/20		Anthony		▨		▨	🟪	🟪		▨
Software Landing of UAV	1/22/20	2/29/20		Joe		▨		▨	🟧	🟧		▨
Landing Routine Duration Test	1/22/20	2/29/20		Joe		▨		▨	🟧	🟧		▨
Dimension Measurement	1/29/20	2/5/20		Anthony		▨		▨	🟪	🟪		▨
Anchor point weight test	1/29/20	2/12/20		Alec		▨		▨	🟩	🟩		▨
Anchor point thrust test	1/29/20	2/12/20		Alec		▨		▨	🟩	🟩		▨

8. List of Tests

8.1. Summary of Tests

A variety of Functional Tests (FT) and System Verification Tests (ST) were performed on the UAV-LP pair in order to confirm the satisfaction of the project’s Marketing and Engineering Requirements. Below is a summary of the tests conducted, followed by a more detailed description of the test procedures and outcomes.

Table 6 - Summary of tests

Test Num.	Summary	Mktg. Req #	Eng. Req #	Results	Pass / Fail
FT.1.1.1	UAV Command Reliability	MR-1	ER-1	Scheduled	Unknown
FT.2.2.1	Manual Landing of UAV	MR-2	ER-2	5 cm precision achieved	Pass
FT.2.2.2	Software Landing of UAV	MR-2	ER-2	Scheduled	Unknown
FT.2.3.1	UAV Command Latency	MR-2	ER-3	In Progress	Unknown
FT.3.4.1	UAV Charge Time	MR-3	ER-4	Scheduled	Unknown
FT.4.5.1	Camera Power Consumption	MR-4	ER-5	AVG 0.8 W	Pass
FT.4.5.2	Qi Charger Power Consumption	MR-4	ER-5	Scheduled	Unknown
FT.4.5.3	Single Board Computer Power Consumption	MR-4	ER-5	TBD	Unknown
ST.4.5.1	System Battery Life	MR-4	ER-5	TBD	Unknown
FT.5.6.1	UAV Hover Endurance	MR-5	ER-6	In Progress	Unknown
FT.5.6.2	UAV Mobility Endurance	MR-5	ER-6	Scheduled	Unknown
FT.5.6.3	Landing Routine Duration Test	MR-5	ER-6	Scheduled	Unknown
FT.6.7.1	Algorithm Detection Range	MR-6, MR-7	ER-7	3m	Pass
ST.8.8.1	Dimension Measurement	MR-8	ER-8	Scheduled	Unknown

FT.9.9.1	Network Access Test	MR-9	ER-9	RPi accessible	Pass
ST.10.10.1	Anchor point weight test	MR-10	ER-10	Scheduled	Unknown
FT.1.1.1	UAV Query Test	MR-1	ER-1	Scheduled	Unknown

8.2. Description of Tests

FT.1.1.1 - UAV Command Reliability: Confirm reliability of wireless communication between Landing Platform and UAV. (MR-1, ER-1)

- Setup: The UAV will be connected to the Landing Platform's Single Board Computer via CrazyRadio PA module. The Single Board Computer will run a Python script that queries the battery voltage on the UAV. This script will be run at increasing distances between the Single Board Computer and the UAV.
- Expected Outcome: The UAV will successfully respond to commands sent by the Single Board Computer at least 95% of the time, up to a distance of 3 m.
- Actual Results: TBD
- Conclusion: TBD

FT.2.2.1 - Manual Landing of UAV: Perform controlled landings of the aerial vehicle by human operator in order to ensure adequate maneuverability for precise landings. (MR-2, ER-2)

- Setup: A personal computer was equipped with the Crazyradio PA module, a PlayStation 3 controller, and the Crazyflie client (a GUI control application for the Crazyflie quadcopter, distributed by the Bitcraze AB development team). We performed manual control of the Crazyflie using the PlayStation 3 controller and made multiple attempts at a precise landing on a target setpoint on smooth surface in an indoor setting.
- Expected Outcome: Based on prior observations of indoor Crazyflie operation, the attempts were expected to demonstrate successful landings to within 5 cm of target.
- Actual Results: Manual landings were consistently within 5 cm of the target.
- Conclusion: The Crazyflie quadcopter was shown to be capable of an adequate degree of control precision for its intended purpose.

FT.2.2.2 - Software Landing of UAV: Perform controlled landings of the aerial vehicle by means of software-automated flight control commands in order to ensure adequate precision of landings upon a target set point. (MR-2, ER-2)

- Setup: A Raspberry Pi 3B+ computer will be equipped with the Crazyradio PA module and a basic Python script capable of performing autonomous control of the Crazyflie quadcopter. The computer will be connected to the OpenMV camera module, which runs an image recognition algorithm in order to generate control commands for the quadcopter. These commands will be determined by a combination of the aerial vehicle's height and its in-frame position. We will make multiple attempts at a precise landing on a target setpoint on smooth surface in an indoor setting.
- Expected Outcome: Attempts are expected to demonstrate successful landings to within 5 cm of target, thus demonstrating that software landing can achieve ideal placement upon a wireless charging pad
- Actual Results: TBD
- Conclusion: TBD

FT.2.3.1 - UAV Command Latency: Determine total command latency from the issuance of a single flight control command by the Single Board Computer to a corresponding response by the UAV motors. (MR-2, ER-3)

- Setup: From a simple oscilloscope configured to display time-domain signals, one probe will be connected across the USB data pins on the Crazyradio PA module (connected to the single board computer) and another probe will be connected to one of the UAV's motor control lines while the motors are themselves disconnects to ensure stable mtest conditions. A simple thrust command will be issued by the single board computer and transmitted to the UAV over the radio module. A measurement will be made of the delay between the occurrence of a signal level change on the USB data pin and the motor control line. The latency between the control command and the UAV motor response will be profiled for various distances between the radio module and the UAV.
- Expected Outcome: Latency under 100 ms for adequate control timing.[8]
- Actual Results: TBD
- Conclusion: TBD

FT.3.4.1 - UAV Charge Time: Determine the total time required to charge the UAV battery using the Qi wireless charging pad. (MR-3, ER-4).

- Setup: The UAV will perform flight operations until its battery is depleted to the point of being unable to maintain flight. The UAV will then be placed on the Qi charger pad and timed until it reports a full battery status. Multiple iterations of this test will be performed for the various compatible battery capacities (250 mAH, 380 mAH, and 750 mAH).
- Expected Outcome: The UAV battery will be fully charged within 1 hour.
- Actual Results: TBD
- Conclusion: TBD

FT.4.5.1 - Camera Power Consumption**:** Test the power consumed by the camera when our chosen image-recognition algorithm is running. (MR-4, ER-5)

- Setup: The camera module ran a specific image-recognition algorithm. The power consumption over a 25 minute period was determined via USB power monitor. The test was performed once while a detectable object was the frame and once without any detectable object in frame.
- Expected Outcome: The Camera module will consume no more than 5 W, regardless of whether or not a detectable object is in frame.
- Actual Results: The camera module consumed, on average, less than 1 W for both scenarios.
- Conclusion: The camera module meets the specified power requirements.

FT.4.5.2 - Qi Charger Power Consumption**:** Test power consumption of Qi charger while actively recharging UAV battery. (MR-4, ER-5)

- Setup: Using a multimeter, we will measure the peak product of the voltage and current flowing to the transmitting Qi charger while the UAV battery is charging.
- Expected Outcome: Qi charger should consume no more than 10 W.
- Actual Results: TBD
- Conclusion: TBD

FT.4.5.3 - Single Board Computer Power Consumption**:** Test power consumption of single board computer in Landing Platform. (MR-4, ER-5)

- Setup: A USB power consumption monitor will be placed inline with the single board computer and a suitable power supply. The single board computer will be allowed to idle for 25 minutes while a idle-state power consumption measurements are taken. The single board computer's power consumption will then be measured while running a stress test program which will utilize > 75% CPU capacity for 25 minutes. For both test iterations, the power consumption measurements will be averaged over the recorded test period.
- Expected Outcome: Single board computer will consume no more than 15 W during either test iteration.
- Actual Results: TBD
- Conclusion: TBD

ST.4.5.1 - System Battery Life**:** Confirm that the Landing Platform's battery supports system operation over the specified time period. (MR-4, ER-5)

- Setup: The Landing Platform will be powered by a fully-charged 11.1 V battery pack, as specified by the system design. All components of the landing platform - camera, single board computer, and Qi charger - will be switched on to maximize the system's power consumption. The system's total operation time until failure of at least one component will be measured.
- Expected Outcome: The system will maintain operation for at least 4 hours.
- Actual Results: TBD
- Conclusion: TBD

FT.5.6.1 - UAV Hover Endurance: Determine the total amount of time the UAV is able to hover for various battery capacities (250 mAH, 380 mAH, and 750 mAH). (MR-5, ER-6)

- Setup: Begin timing UAV once it lifts off and commences a software-defined hover routine at a fixed height from the ground. Continue timing until the UAV is unable to maintain the hover height.
- Expected Outcome: UAV hovers for at least 5 minutes with each battery.
- Actual Results: On average, the UAV was able to hover for 6 minutes with a 250 mAH battery and 8 minutes with a 380 mAH battery. The 750 mAH battery will be tested upon receipt from vendor.
- Conclusion: Any of the previously-identified compatible batteries will adequately meet the minimum hover time of five minutes.

FT.5.6.2 - UAV Mobility Endurance: Determine the total amount of time the UAV is able to fly a given autonomous flight pattern. This pattern could either be in the horizontal or vertical planes. (MR-5, ER-6)

- Setup: Two autonomous flight routines will be performed by a UAV equipped with a fully-charged onboard battery. The first routine will be a horizontal figure-eight pattern and the second will be a vertical figure-eight pattern. The UAV will be timed from initial take-off until flight failure due to inadequate battery power. The tests will be performed for the various compatible battery capacities (250 mAH, 380 mAH, and 750 mAH).
- Expected Outcome: UAV will be able to maintain either autonomous flight routine for at least five minutes.
- Actual Results: TBD
- Conclusion: TBD

FT.5.6.3 - Landing Routine Duration Test: Determine the total amount of time required to autonomously land the UAV. (MR-5, ER-6)

- Setup: An in-flight UAV will be positioned at the edge of the Landing Platform's detectable range (at the maximum specified height) and the completion of the autonomous landing sequence will be timed. Only successful landings will be considered valid data points. The tests will be performed for the various compatible battery capacities (250 mAH, 380 mAH, and 750 mAH).
- Expected Outcome: The time trials should indicate that successful landings can be made within three minutes for all specified batteries.
- Actual Results: TBD
- Conclusion: TBD

FT.6.7.1 - Algorithm Detection - Range**:** Determine the range of reliable UAV detection by various image-detection algorithms. (MR-6, MR-7, ER-7)

- Setup: The camera module was configured for a desired image-recognition mode. The UAV was manually brought into frame and raised to various height intervals to determine the limits of reliably detecting the UAV with a given image-recognition algorithm (RBG detection, Frame Difference, and April Tag detection). This range determination was made for each of the various image-recognition modes
- Expected Outcome: The camera module should consistently detect the UAV up to 2 m.
- Actual Results: The camera module reliably detected the UAV up to 2.9 m, 1.8 m, and 1.5 m for the RGB, Frame Difference, and April Tag detection algorithms, respectively.
- Conclusion: The RGB detection algorithm will be used to determine the position of the UAV as it performs favorably to the other methods and provides the adequate range.

ST.8.8.1 - Dimension Measurement: Confirm that the complete system is constrained to a size which supports portability. (MR-8, ER-8)

- Setup: The Landing Platform's physical dimensions will be measured with a ruler and its footprint will be determined.
- Expected Outcome: The Landing Platform will have a footprint under 0.25 m^2.
- Actual Results: TBD
- Conclusion: TBD

FT.9.9.1 - Network Access Test: Confirm that Landing Platform's single board computer can be accessed via SSH (MR-9, ER-9)

- Setup: A remote user PC was used to make numerous SSH connection attempts to the single board computer in order to determine reliable access.
- Expected Outcome: The single board computer should be able to make a successful connection to 95% of the time.
- Actual Results: Consistently-successful SSH connections were made between multiple user PCs and the Landing Platform's single board computer.
- Conclusion: The system adequately supports remote machine access via SSH.

FT.10.10.1 - Anchor Point Weight Test: Confirm that the UAV anchor points will support twice the weight of the UAV on an anchor line. (MR-10, ER-10)

- Setup: A 5 lb fishing line will be affixed to the UAV's anchor point, with its loose end secured to a weight equivalent to twice the weight of the UAV. The UAV will be securely mounted to a fixed structure while the anchor point's durability is tested with the freely-hanging weight.
- Expected Outcome: The anchor point will not fail, and support the specified weight without compromising its structural integrity.
- Actual Results: TBD
- Conclusion: TBD

8.3. Preliminary Results

As of December 2019, there are two main efforts which are working towards a common goal of controlling the UAV with input from the OpenMV camera. These efforts are developing tracking software in the OpenMV, and controlling the UAV via command line on a Raspberry Pi. So far, we have implemented a combination frame differencing algorithm and edge detection algorithm, which accurately tracks the UAV with no identifying markers necessary. The downside of this technique is that small perturbations in the background can cause errors, and the location of the UAV blob centroid is subject to high frequency noise. We have also realized an April Tag detection script which accurately and rapidly tracks the location of a bottom mounted April Tag on the UAV. The drawbacks of this technique are the frame must be digitally cropped because of limited RAM, which greatly decreases the vision cone. Another tracking technique has also been implemented on the OpenMV, a color tracking script. This system works quite well when the drone is close to the lens, but the large amount of color information incurs other limitations in the script, such as lower frame rate. The final form of our tracking software will likely include a hybrid of these methods, using statistical analysis on the different locations returned by these tracking techniques.

With regard to the remote operation of the UAV, we first tested the basic functionality of the Crazyradio PA module by running an update of the CrazyFlie firmware, as well as perform manual control of the UAV via PlayStation 3 controller. Upon demonstrating the successful use of this means of control, we further implemented UAV flight control by means of Python script running on a Linux-based machine. Similarly to manual operation with the handheld controller, the Python script made use of the Crazyradio PA libraries to connect to the device and send commands via a serial port to the module. The module then relayed the commands to the UAV, thus demonstrating that scripted commands (including those necessary for autonomous flight) were achievable with a system that closely approximates the Raspberry Pi control system outlined in our current project design.

9. Customer Survey

In order to evaluate customer attitudes, expectations, and need for the product, several interviews were conducted with individuals interested in the system. To begin the customer survey process, preliminary questions were determined to engage the customer and begin an open dialogue where they might share their experience. By asking open ended questions, the potential customers are encouraged to disclose insights which might answer questions our team might never have thought of. Some examples of questions that were asked during the interview were

- What are you or your organization going to use this system for?
- Under what conditions do you want this system to be capable of operating in?
- What performance do you expect out of this system?

Some more specific questions were asked as well

- How long should the landing routine take?
- How much of the battery should the landing routine take?
- What safety precautions should be in place?
- What failure rate should this system have?
- What flight-time should the UAV have?

Two potential customers were interviewed. This first is a postgraduate student, specializing in robotics, who is researching and teaching at the University of Southern California in Los Angeles. The second is a mechanical engineer that is currently working at Lawrence-Berkeley National Laboratories.

For the specific questions asked in the interviews, the customers did not always have specific answers. The common themes between the two customers were given the most weight for consideration, which included that the landing should be highly reliable and require little human intervention, and that the landing should consume a small amount of battery power, as the drones will already be low on power. It is important to note that several desires expressed by the customers were deemed to be too ambitious for the first step, and left to future work outside of the scope of this senior design project. The marketing requirements listed above represent an aggregate of the desires expressed by the potential customers interviewed.

10. Regulation Compliance of Our Project

In the Safety and Health Information Bulletin Preventing Fire and/or Explosion Injury from Small and Wearable Lithium Battery Powered Devices (SHIB 06-20-2019) from the Occupational Safety and Health Administration (OSHA) several guidelines for how to safely handle lithium batteries are enumerated. These guidelines include proper prevention procedures and employee training procedures. The bulletin states that employees should be trained on how to properly identify defective, damaged, or otherwise failing lithium powered devices and batteries. Additionally, employees should be trained to immediately remove defective devices and batteries from the workplace. Employees should also be trained to quickly remove lithium devices which are worn on the body, if the device feels hot or is leaking, releasing gas, hissing, bulging, cracking, or on fire [11]. When lithium batteries become damaged, they present a fire and explosion hazard. They can be damaged by improper charging, short-circuit, or physical damage. For this reason, lithium battery users must be vigilant to avoid hazards related to these devices. These hazards include physical impacts which damage lithium batteries through crushing, dropping or puncturing and charging the devices with unsuitable chargers [11].

As the system will be designed for indoor use, many of the Federal Aviation Administration's (FAA) guidelines do not apply to the system being created. So long as it is flown indoors, which is not FAA controlled airspace, the operators of the system will not be required to receive any certification through the FAA [12]. However, if the system were to be taken outdoors, any operator of the system would be required to qualify for an Airman Certification through the FAA that will legally allow the operation of the UAV within controlled airspace under Part 107 of the FAA regulations [12]. If the UAV were to be substituted for another the operator making the substitution will be required to review FAA Part 107 to determine if their UAV requires registration prior to flight outdoors [12]. As this system contains a UAV that is lighter than 0.55 lb, it does not require registration with the FAA. If this system were to be taken overseas, the operator of the system would be required to comply with their current location's equivalent to the FAA as well as receiving any specific certification required by the local FAA equivalent [12].

Given the safety and regulatory considerations described above, we must also be prepared to provide sufficient guidance to our intended customer as to the employer training requirements covered by the OSHA Training Standards Policy Statement (Memorandum

04-28-2019). [13] Per OSHA training standards, these guidelines listed must be provided in a clear, readable manner to the intended operator. To this effect, both written and verbal training will be prepared so that any operator of the system may be instructed by designers as well as reference a comprehensive document that details the safe operation and safe operating environments of the system per given regulations. If the system is to be operated outside these specified environments, the operator will be instructed to review and consult with relevant authorities to ensure that they are operating the system in a safe and legal manner for their desired environment. The instructions must also provide the safety regulations detailing the proper handling of all components of the system including the lithium polymer batteries in the landing platform, lithium polymer batteries in the UAV, and any other electronics present within the system in both operation and disposal.

11. Ethics of the Engineering Profession and Our Project

The IEEE code of ethics is what we, as aspiring electrical engineers, will use to determine our behavior and choices throughout this project. The first point of this code is that we will “hold paramount the safety, health, and welfare, to the public” [9] as we are detailing a system that potentially would injure someone in the case of malfunction we will ensure that all pieces of the system are fully tested and will operate within specification and intent. We will “strive to comply with ethical design and sustainable development practices” [9] by providing reputable sources for all components used within this product as well as sources for any idea that was used to help create this system that is not within our control. As a large part of this design process we will “seek, accept, and offer honest criticism of technical work” [9] from both our mentors as well as our peers. We will do this by scheduling appointments and engaging in frank discussions about the progress we are making and steps that need to be taken to create the best product available while still following our own ethical guidelines as well as that of the university. As a product that will be available for the public, we will avoid “pandering to lurid curiosity” [10] and “undertake technological tasks for others only if qualified by training or experience” [9] and if necessary we will “maintain and improve our technical competence” [9] through research and consultations with more experienced members of our chosen profession. We will also “assist colleagues and co-workers in their professional development” [9] by helping to create an environment that is welcoming of criticism and allows for open dialogue regardless of relative situations.

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