

Multiple UAV Coordination

Project Proposal

By:

Ethan Hoerr, Dakota Mahan, and Alex Vallejo



Department of Electrical and Computer Engineering

Advisor:

Dr. Joseph Driscoll

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Executive Summary

The goal of this project is to create an overhead image map of the Bradley University Alumni Quad using multiple autonomous unmanned aerial vehicles (UAVs). As evidenced by patents, research, and prior work in this field, it is clear that global attention has been placed on the use of such UAVs or drones for accomplishing military, commercial, and research tasks. This emerging technology offers gains in efficiency to these sectors that were previously unavailable. The following proposal identifies constraints and design considerations, considers economic feasibility, societal impacts, provides a timeline for project completion, and makes a case in support of the financial support of this project.

The purpose of this proposal is to assure the managers and financial backers of the project's worthiness of financial support. The project proposed will fulfill the specified task of mapping the Bradley Alumni Quad. However, this proposal also makes a case that the business potential of the project can be expanded by adapting the project for and marketing it to other organizations and companies based on their needs. Such potential services derived from this project that could be sold include aiding the efforts of mapping, search and rescue, security, professional photography, military, and more. A key benefit of using multiple autonomous UAVs in these applications is a potential increase in efficiency and safety.

The project goals will be fulfilled by implementing design options that have been adopted at a high level from existing patents, research, and prior work [1]-[4]. Such goals include accomplishing the task using multiple UAVs; giving the UAVs autonomy; maintaining formation of the UAVs; ensuring group obstacle avoidance; and implementing a leader-follower configuration for task management. The leader-follower configuration will be realized with a Parrot AR Drone 2.0 serving as the lead UAV, and Skywalker quadcopters acting as the follower or slave UAVs. The lead UAV will guide the slave UAVs through the air above the specified land region, while the slave UAVs are responsible for capturing digital photographs of the terrain. Using a flocking algorithm, the slave UAVs will stay in formation for the duration of the mission. Finally, the entire system will operate autonomously, as the lead drone will be given GPS waypoints to navigate the region with, while guiding the slave UAVs along the way.

Given the task of mapping the Bradley Alumni Quad, and the existing resources for developing this project, the total project cost is approximately \$305. This includes the cost of purchasing aerial vehicles, infrared emitter LEDs and receivers, discrete electronic components for circuit design, the cost of PCB design, plus digital cameras and storage for aerial photography. Existing resources made available to this project, and thus excluded from the projected cost, include a Parrot AR Drone 2.0 quadcopter and one Skywalker quadcopter. In the event that this project is marketed as a standalone package and sold to clients as such, the cost of these existing items must be considered, and a price of about \$678 will be placed on future iterations.

In terms of project performance, it is expected that this project will be able to successfully complete the task of mapping the Bradley Alumni Quad in a timely manner such that battery life is not exhausted before completion. Also, key objectives such as collision avoidance will be fulfilled using the leader drone as the primary source of environment sensing.

Abstract

The goal of this paper is to propose a project that utilizes multiple unmanned aerial vehicles to autonomously generate an image map of the Bradley University Alumni Quad. The proposal shows that by switching to an autonomous, multiple-UAV system, the replacement of processes already benefiting from the use of UAVs will result in increased safety and efficiency. Current processes may put people in danger in the military; may use slower data acquisition methods and gain less information with existing drones; or, may be cost-prohibitive by using more expensive aircraft. By using a combination of a single higher- cost drone – equipped with GPS guidance for navigation and image processing techniques for obstacle avoidance – with lower-cost drones set to follow the leader and maintain a flocking formation amongst each other, this project can cheaply accomplish such aerial tasks as surveying a specified region of land, among other potential areas of development. Furthermore, current research indicates that the coordination of multiple slave drones with the implementation of a flocking algorithm is possible. Impacts of this project include increased data on the health of crops, increased safety for first responders, military, and police, and quicker problem solving for fire fighters and first responders.

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Introduction

Recent global attention has been fixed on the use of drones or unmanned aerial vehicles (UAVs), particularly in military, security, research, and hobbyist purposes. An operator can complete a risky target removal mission safely and discretely across the world. However, beyond military purposes, drones can also be used for research and commercial purposes. The Bradley Electrical Engineering senior project described in this document seeks to use multiple UAVs to accomplish the task of generating an overhead image map of the Bradley Alumni Quad. Using autonomous control methods, the task will virtually complete itself with little user interaction.

The problem this project seeks to solve is the creation of an overhead image map of the Bradley Alumni Quad. There are several sub-issues that will also need to be addressed before achieving the main objective. One of these issues is the autonomous coordination and control of multiple UAVs. As will be seen in upcoming sections on background research, there are benefits and challenges to using multiple UAVs to accomplish a task; the primary benefit is increased efficiency, while the problem of coordinating multiple UAVs introduces added difficulties. Other objectives included in this project include the aerial image-capturing process, and post-flight image data collection and merging to produce the desired output image.

Multiple UAV coordination can be achieved in many ways, and should be decided upon in a manner that is appropriate for the task in mind. This project will focus on one such coordination scheme, known as “swarming” or “flocking”. Although the use of such a scheme will be specific to the requirements of the project, valuable insight will be uncovered into the capabilities of such a coordination scheme that can be used and further refined by future projects.

The project is bound to some constraints that will need to be observed, some of which are inherent limitations in the equipment being used. For example, the battery life of the AR Drone is 18 minutes of flight time. The AR Drone is controlled by connecting to its onboard WiFi hotspot, which, through testing, was found to have a steady connection until a distance of 60.96 meters, at which point communication was halted. The follower Skywalker drones have a maximum flight time of 7 minutes. Through testing in lab, it was found that the Skywalker drones can carry an additional 15 grams of payload and still maintain flight. Finally, as defined with the project advisor, the task of taking aerial photographs needs to take place at least 3 meters above ground level to avoid collision with a human. In compliance with FAA Advisory Circular 91-57, the UAVs must never exceed an operating height of 121.92 meters.

In order to be deemed successful, there are functional requirements that must be satisfied by the project. The system must navigate and create a map of the Bradley Alumni Quad. To qualify as a swarming group of UAVs, at least 3 drone UAVs must be implemented; these drones must maintain a group formation, and also must follow the leader AR Drone. In addition, all UAVs must avoid collision, and must be equipped with manual override control. Finally, the aerial images taken during flight must be merged into one final, composite image.

Summarized in Tables I-III, found in Appendix G, specifications have been established for the various subsystems in this project. The AR Drone’s front-facing camera, used for object detection, may detect objects at distances between 1 and 10 meters. The AR Drone, as well as the Skywalker quadcopters, will execute a takeoff and landing sequence between 0-3 meters above ground level. The maximum distance the Skywalker drones may detect other drones in any direction is 2 meters. Each of the Skywalker drones will be equipped with an Atmel ATmega328P microcontroller. The ATmega328P’s analog-to-digital (ADC) converter, which digitizes voltage from the infrared receivers, will convert voltages to integers at a rate of at least 100 Hz. 4 ADC channels will be used for each ATmega328P

found on each Skywalker quadcopter, to digitize voltages from its 4 infrared receivers. The reference voltage of this ADC is 5V, and its resolution is 10-bits. Finally, the target surface area of the Bradley Alumni Quad, as determined with an online tool [7], is 6096.56 square meters. A screenshot of this computed area can be seen in Appendix F.

The use of UAVs can be beneficial to military and commercial efforts which already make use of manned aircraft to achieve outcomes such as mapping, search and rescue, security, and professional photography. This project proposes that the efficiency of such efforts may be increased using multiple, autonomous UAVs. By using unmanned drones, operating costs and risks of injury or loss may be reduced significantly.

Background Info

Prior research exists and has been used to inspire the design process of this project. In [1], an overview is given for the basis of a “swarming” or “flocking” coordination algorithm. In [2], a leader-follower configuration is utilized for controlling multiple UAVs to complete a task. In [3], the advantages of using multiple UAVs parallel the scale of the task to be completed.

In the patent [1], some key objectives for a “swarming” or “flocking” formation scheme are given. This includes a method for maintaining multiple UAVs in formation, as well as a system for group obstacle avoidance. The elegance with flocking is that high-level results can be achieved using a relatively low-level control system. Adding additional units to the flock or swarm is also relatively simple, as the group dynamics are not defined by a master controller, but rather by the sum of the actions of each individual unit.

In the research [2], the effectiveness of a leader-follower configuration in the use of multiple UAVs is shown. The task to be completed is the aerial visual tracking of a moving ground target. In the project described in this proposal, this leader-follower configuration is used in conjunction with the “swarming” configuration described in the preceding paragraph. This goes to show that not one coordination scheme is necessarily superior to another, but that choosing the right scheme requires a broad view of the task at hand.

In [3], the benefits of using multiple UAVs to accomplish a task are shown. In this particular assignment, multiple fixed-wing drones navigate a region of airspace, measuring vertical wind speed of discretized regions of air space. Using the data captured during the mission, drones can reroute to take advantage of upward drafts that will prolong flight time without expending onboard power. The immediate benefit of using multiple drones for this task is that more air space can be measured simultaneously. An additional benefit from using more than one drone is that the group as a whole can benefit from one another’s data, which can then increase the chances of a successful mission.

As can be seen in [1]-[3], the efficiency and reliability of tasks can be greatly improved by introducing additional UAVs into the equation. While the topics discussed in [2]-[3] suggest different forms of added efficiency from the use of UAVs, the underlying theme is that, if implemented properly, the use of multiple autonomous UAVs will offer some advantage in accomplishing tasks.

Related Work

A similar project under the title “Flock 1” has been developed by Planet Labs, a firm located in San Francisco, California. Flock 1 is an array of “Earth-imaging satellites, comprised of 28 Dove satellites.” A Dove is a single satellite built with a radio antenna, optic sensors for imaging, and solar panel for converting sunlight into energy. While similar to this project in terms of desired outcome, the aims of Flock 1 are much larger in scope: these satellites orbit the earth 16 times a day, creating an image of the surface of the earth each pass.

As indicated by the company's website, their target customers include agriculture, energy, forestry, infrastructure, mapping, and natural resources industries, for the purposes of change detection, custom maps, persistent monitoring, as well as planning and logistics [4]. The project outlined in this proposal is smaller in scope in terms of potential surface area to be covered, as well as operating altitude and presumably cost. However, it may be likely that if such a demand for imaging is being fulfilled by Planet Labs on a larger scale, this project can successfully and competitively meet similar demands on a lower scale.

Clearly, patents, research, and work similar to the project described in this proposal already exist. Most of the design options considered in this project have been adopted from existing ideas at a high level: accomplishing a task using multiple UAVs; giving the UAVs autonomy; maintaining formation of the UAVs; group obstacle avoidance; and leader-follower configuration.

Constraints

- Follower drone battery life: 7 minutes flight time
- Leader AR Drone battery life: 18 minutes flight time
- Skywalker drone payload: 15 grams
- AR Drone wireless communication cutoff distance: 60.96 meters
- \$1000 Budget
- Execution of aerial photography task must be at a distance above ground level greater than 3 meters to avoid human height, but less than 121.92 meters (latter requirement as per FAA Advisory Circular 91-57)

Requirements

- Project must make use of at least 3 drone UAVs to be considered a swarm
- Project must navigate and create map of the Bradley Alumni Quad
- Project must avoid collision
- Drones must be equipped with manual override control
- Skywalker drones must maintain group formation
- Skywalker drones, as a group, must follow AR Drone
- Aerial images from flight must be merged into one composite image

Specifications

- AR Drone front-facing camera can detect objects between 1-10 meters
- Takeoff and landing sequence will occur between 0 and 3 meters from ground level
- Skywalker drones can detect one another from a distance of 2 meters
- Must be able to contain enough pictures to cover a 6096.56 square meter area

Design Method

As mentioned in the Introduction section, the goal of this project is to complete the task of creating an overhead image map of Bradley University's Alumni Quad by using multiple autonomous UAVs. The proposed solution is inspired by advice from the project advisor, Dr. Joseph Driscoll, as well as from existing work found while researching. For example, the concept of using a leader-follower configuration for managing the flight of the entire group, as well as utilizing a flocking configuration for controlling the follower UAVs, were ideas adapted from existing work presented in the Background Info section. Specifically, the leader UAV will guide the flocking follower UAVs through the air, while the followers will be taking photos of the terrain below. The leader and follower UAVs will be equipped with infrared emitters to act as visual beacons, and the follower UAVs will be equipped with infrared receivers to detect the proximity of these beacons. They will then use this information to determine which direction to move based on how well each UAV conforms to the flocking algorithm set in place.

Before arriving at the selected design, multiple design alternatives that met key constraints and objectives were considered. Such objectives included efficiency, flocking, safety, and autonomy. Table V, shown in Appendix G, gives a set of metrics for measuring how well these objectives are met. Table VI, shown in Appendix H, compares some alternatives that were considered and ranks how well each alternative met the given objectives. As a result of this process, the chosen design utilizes: a leader ("Mothership") UAV; follower UAVs with cages; an infrared detection system; the use of an inertial measurement unit for aerial navigation; and optical (visual) collision detection, which is delegated to the leader UAV. Key components of the design which are critical for the success of the project include: the Parrot AR Drone, designated as leader drone; Skywalker quadcopters, which will be used for the follower drones; infrared emitters and detectors, used for the beacon detection system; and standalone cameras to be mounted to the follower drones for taking photos of the terrain below.

Research and development will take place at Bradley University, in various locations on campus. Primarily, most of the lab work and development will take place in the Robotics Lab in Jobst Hall. Once the system reaches a point in the development phase where GPS-based flight tests will be conducted, experimentation may take place outdoors at the Alumni Quad, and/or inside the Markin Recreation Facility, which has an indoor soccer field equipped with safety glass and overhead nets. Comparing and testing various infrared emitters and detectors will take place at the beginning of the project development phase. The quadcopters will also be tested for design constraints such as flight time, battery life, and payload; if necessary, alternative units will be considered if the proposed components do not suffice.

Bradley University's Alumni Quad will serve as the final proving ground for this project, as this is the target destination for creating a composite overhead image map. The task will be considered successfully completed if each of the following conditions is met. The leader drone must guide the flight of the follower drones, ensure system obstacle avoidance, and navigate the Alumni Quad using GPS

Table IV. – Project Budget.

Part	Quantity	Price	Total Price	After First iteration			
Skywalker Quadcopters	3	\$ 34.50	\$ 103.50	Skywalker Quadcopters	3	\$ 34.50	\$ 103.50
AR Drone	1	\$ 299.99	\$ 299.99	AR Drone	1	\$ 299.99	\$ 299.99
Reciever	12	\$ 2.44	\$ 29.28	Transciever	12	\$ 2.44	\$ 29.28
Emitters	16	\$ 8.51	\$ 136.16	Emitters	16	\$ 8.51	\$ 136.16
ATMega328P	4	\$ 4.30	\$ 17.20	ATMega328P	4	\$ 4.30	\$ 17.20
Voltage Regulator -3.3V	4	\$ 1.95	\$ 7.80	Voltage Regulator -3.3V	4	\$ 1.95	\$ 7.80
PCB	4	\$ 4.00	\$ 16.00	PCB	4	\$ 4.00	\$ 16.00
470 Ohm Resistors	96	\$ 0.15	\$ 14.40	470 Ohm Resistors	96	\$ 0.15	\$ 14.40
SD Cards(8 Gb)	4	\$ 7.00	\$ 28.00	SD Cards(8 Gb)	4	\$ 7.00	\$ 28.00
Putty	1	\$0.00	\$0.00	808 Pinhole Camera	3	\$ 8.79	\$ 26.37
Atmel Studio	1	\$0.00	\$0.00	Total Price Overall			\$ 678.70
AVR Dragon	1	\$ 49.00	\$ 49.00	Sale Margin			47.34%
808 Pinhole Camera	3	\$ 8.79	\$ 26.37	Consumer Price			\$ 999.99
Total Price Overall			\$ 727.70				
				For Research Only	\$	304.81	

waypoints. Also, the follower drones must capture images of the entire Alumni Quad; these images must then be retrieved from the drones and merged with software to create the final composite image of the Alumni Quad.

Economic Analysis

As a market standpoint the Multiple UAV coordination project has some amount of risk. For instance, there is a major cost that weighs on decisions, the difficulty of the project, and the time constraint given. There is a risk in unmanned vehicles in general with the FAA regulations in place at the moment, and the changing rules constantly can make a product un-useable. Along with this risk, trying to take a jump in innovation is a risk in itself. As for the time constraint and difficulty it has been addressed the similar components of our project have been conducted. Furthermore, the time constraint has been touched on with a series of preliminary research that allows for increased confidence in the project ahead.

As for the cost, the budget in Table IV states that if the project is to be done in mass production it will cost a reoccurring price of \$678.70. If the mass production stage were to go into progression, the consumer would have to be charged at least above the asking price, but low enough for someone to buy it. Therefore, an appropriate price would be around \$1,000 for a unit of the multiple UAV coordination system. However, we are currently only in the research stage, which drops our price dramatically down to approximately \$305. A major reason the budget for a research-only design is so much lower than the mass production design comes from the fact that we have access to many of the big-ticket items, such as the AR Drone 2.0, ATmega328P microcontrollers, and AVR Dragon. After the previous items are reduced, the costs could once again be reduced by using less sophisticated emitters, but this would decrease the accuracy of detection by plus or minus 30 degrees on each emitter [5]. The largest priced item come from the AR Drone 2.0 (shown in Appendix D) which costs \$300 per iteration of production, along with this, the Skywalker quadcopters (shown in Appendix E) cost \$103.50, because there will be at least three Skywalker quadcopters per production [6]. Thus, the number one question the team must ask themselves is can the project be delivered on time and under budget? Currently, there are a few different ways this can occur. First, gathering information for previous design methods of UAV coordination. Then, the design of leader/follower configuration was considered from the different alternative designs discussed above. Lastly, data analysis of the information gathered, and the appropriate action to move forward with the project has been decided.

Project Timeline

- Major Goals
 - Progress Presentation: February 19th and 24th
 - Project Demonstration: March 26th and 31st
 - Final Presentation: April 9th and 14th
 - Student Expo: April 15th and 16th
 - Report Draft (Complete): April 16th and 21st
 - Poster Presentation to ECE Advisory Board: April 24th
 - Final Report: April 30 and May 5

Schedule Project Tasks

In appendix A the Gantt chart can be seen. As the Gantt chart states it is in terms of lab days, it shows that two lab days is equal to one week. In the Gantt chart it covers the major tasks for the UAV team's progress and needed goals. An overview of our tasks for the project come from doing the research on the correct elements for the design, after this we are able to order the correct parts, sensors, and start preliminary coding. Some of the biggest time constraints come from interfacing the onboard microcontroller and creating a PCB board. The PCB board must be created, and then shipped out to ordered which can take up to two weeks just for shipping, then every part that is bought or that is put into implementation must be interfaced with the controller. Once the interfacing portion is done, the sensor fusion, autopilot, and collision detection with the AR Drone must take up 10-20 lab periods.

Critical Path

1. Code ADC Mux to under 100 microseconds
2. Order Quadcopters, Sensors, Camera
3. Interface onboard Microcontroller
4. Code Collision Avoidance
5. Code Autopilot
6. Complete Assembly

Division of Labor

The division of labor will be split into four sections: Ethan Hoerr's division, Dakota Mahan's division, Alex Vallejo's division, and the team's division of labor. Ethan Hoerr will be working with the follower drones, Dakota Mahan will be working on the leader AR Drone, and Alex Vallejo will be working with hardware.

Ethan Hoerr

- Coding the ADC Mux for the SkyWalker to be under 100 microseconds
- Sensor interface
- Interface Skywalker's onboard microcontroller with Atmega328 Microcontroller
- Implementation of autonomy in C

Dakota Mahan

- Code collision avoidance
- Autopilot for the AR drone
- Onboard cameras sensor fusion for the AR drone

Alex Vallejo

- Ordering sensors
- Ordering quadcopters

- Ordering custom printed circuit board
- Interfacing and researching hardware
- Ordering camera

Team

- Progress presentation
- Complete assembly of the project
- Debugging
- Project demonstration
- Student expo
- Report draft
- Poster presentation to ECE advisory board
- Final report

Societal and Environmental Impacts

Societal Sections Affected

The people that will be most affected by this project are as follows: farmers, defense sectors, police, fire fighters, first responders, and civilians. The effect of this project on natural resources farmers will be able to direct fertilizer, pesticides, water, and other nutrients to the locations it is needed rather than blanket coating the field, leading to less run off into the environment by using the proposed project with near IR cameras. In the defense, police, fire fighters, and other first responder fields, they will be able to get an overhead view of any situation, increasing the ability for them to mitigate the destruction a natural disaster can do, and save lives. For civilians, this will allow prospective land buyers to get an overhead view of property, property owners to check on the status of their lawn and gardens, and allow them to check the status of roads in the morning in winter after a snow.

Safety

For safety, most of the concerns come from problems not related to our project, but to the quadcopters. The development of this product is safe due to working with existing products; however the existing products may contain a lithium ion or lithium polymer battery, which may contain safety concerns. Furthermore, quadcopters have rotary blades, these may be dangerous depending on if shielding is used, the material, and the speed of the rotation. The effect of the project on human welfare and rights is neutral in respect to rights by privacy being the same and a positive to welfare by causing better imaging of fields. What could go wrong with the project is what all quadcopters need to watch out for, namely that winds outside may cause it to crash into objects, and that indoor use is high risk. The potential of our project to contribute to accidents and harm is near zero, using the autonomous features in this product will cause the quadcopters to be able to react to stimuli faster than a human can, increasing the ability for it to avoid objects. The only way this could cause harm is by human error, namely using it indoors or in high wind conditions. This product is safe for humans, it will be flying at a height above humans besides takeoff and landing, which will be vertical, and if it gets below a certain range it will either attempt to climb back up immediately or shut itself off. A way for this product to be made safer would be to equip all quadcopters with a camera, however due to budget constraints the cameras will be unable to be accomplished in this project. The quadcopters have a safety cage built into their design except for the AR drone that is doing the image processing. In addition, this product is safe for children and disabled people, if disabled people or children were to use this product, the disabled people or children would need to put in GPS coordinates and send the autonomous drones on their way.

Furthermore, this product is unlikely to be used in an unsafe manner; it is entirely dedicated to obtaining an overhead view of an area. For this product to be used in an unsafe manner, it would require it to be indoors or disregarding high wind conditions of the outside. Thus, this product is safe.

Ethics and Law

To be used unlawfully, two criteria must be established for the project to be able to be used as such. The first would be to take pictures in a classified area. The second would be a no fly or no quadcopter zone. In either of these instances, the project will be unlawful. Unethically using this product without crossing the line into unlawful territory is impossible. This product is ethical, the worst the project may do is to take pictures of private property; however that has been decreed to be public view by various laws and judges. Therefore, the product can be used unlawfully, but not unethically, and the ability for them to do so is hindered by the fact that there are not that many places that prohibit picture taking and flying.

Risk and Liability

The risk to the consumer is zero when used outside in low wind conditions. The only risk is using it indoors or in high wind conditions. By applying warning labels, and providing documentation, the consumer will be made aware of issues and also decreases the liability. However the liability is not much to begin with, as the project is simply providing an interface to the drones already on the market. Finally, the risk of this product is less than the present situation on the market, due to quadcopters being controlled by humans, and allowing human error into the equation.

Mothership

As stated previously the multiple UAVs will have a leader follower configuration which will have the mothership being the intelligent leader. In Appendix B the mothership starts by initializing the front camera, and inertial measurement unit (IMU) which allows for the global positioning system (GPS) and image processing to properly boot. After having the two sensors initialized, then the flowchart moves to choosing between having an autopilot or manual override which will continuously check for safety and FAA regulations. Once there is an assurance of no manual override it will move to the image processing for collision detection and retrieve the GPS waypoint. As the AR Drone 2.0 checks the bearing for direction it will have a priority collision detection to see if there is anything to the left, right, or in front of the AR Drone 2.0 and the flock. The image processing will have priority, which will move the drone and the flock out of the way to assure there are no collisions. Finally, the drone will check for bearing after the processes in collision detection have been completed. If the bearing is going in the correct direction then the mothership will follow the course if not it will adjust. Then if the mothership has reached the waypoint then, it will check for another waypoint, if no other waypoint the quadcopter will land. Finally, the GPS waypoint will loop back around to continuously check for more waypoints until the mothership has landed.

Drones

In the designing of a follower configuration there must be a flowchart that shows how the non-intelligent followers should work. For the design in Appendix C, the flow chart starts off by initializing the ADC MUX, emitters, and receiver. Then it will check for the manual override, just like the mothership. If there is no manual override, the autopilot will compute and decide whether the sensors are to dim or bright for each configuration of the four sensors. The first three sensors will be in a tripod configuration, and the final sensor will be pointed in the upright position. If either of them is too bright or dim, then the drones will do the command as stated in the appendix. With all of this, the drones will follow a proportional-integral-derivative controller (PID controller) loop to avoid jittery effects.

Conclusion

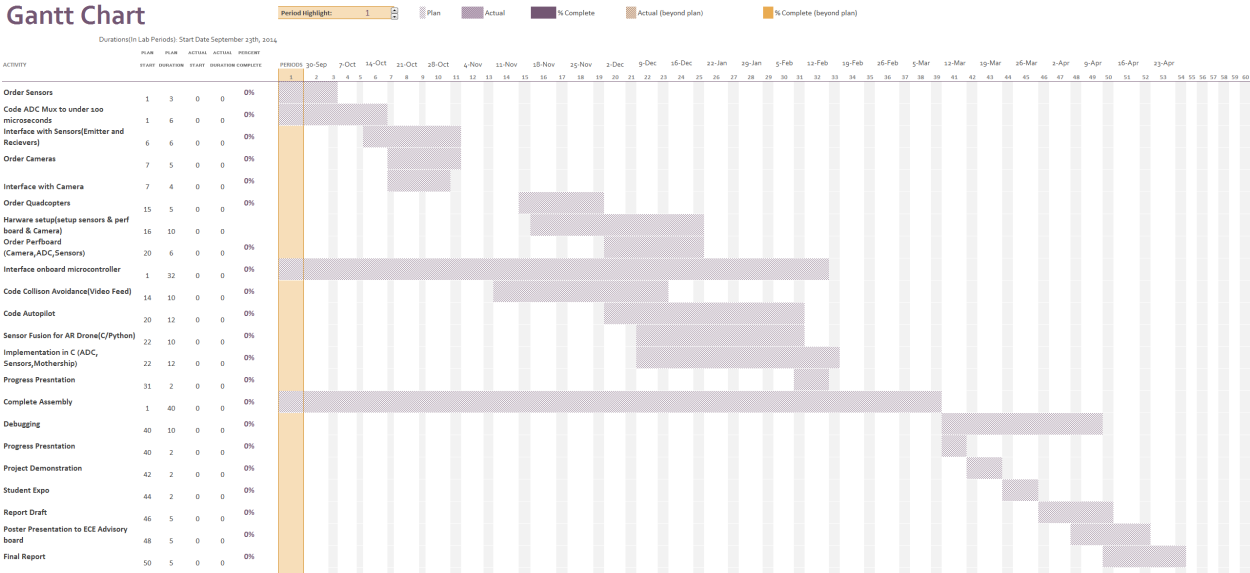
Based on the background information, related work, project timeline, and economical analysis there should be potential success in completing the multiple UAV coordination project. The team has organized a tentative division of labor to correspond with the project timeline to help completion. The critical path has been outlined, and it is apparent what is needed to be done; along with the various specifications that need to be filled to complete the project. Furthermore, there has been touched based on the previous work on leader/follower configurations, the requirements of multiple UAVs for parallel mapping, a project timeline with critical path, and the social/environmental impacts of this project. The basic background needed to complete the project is finished and the project should be conducive to the social, environmental, and ethical effects related when finalized.

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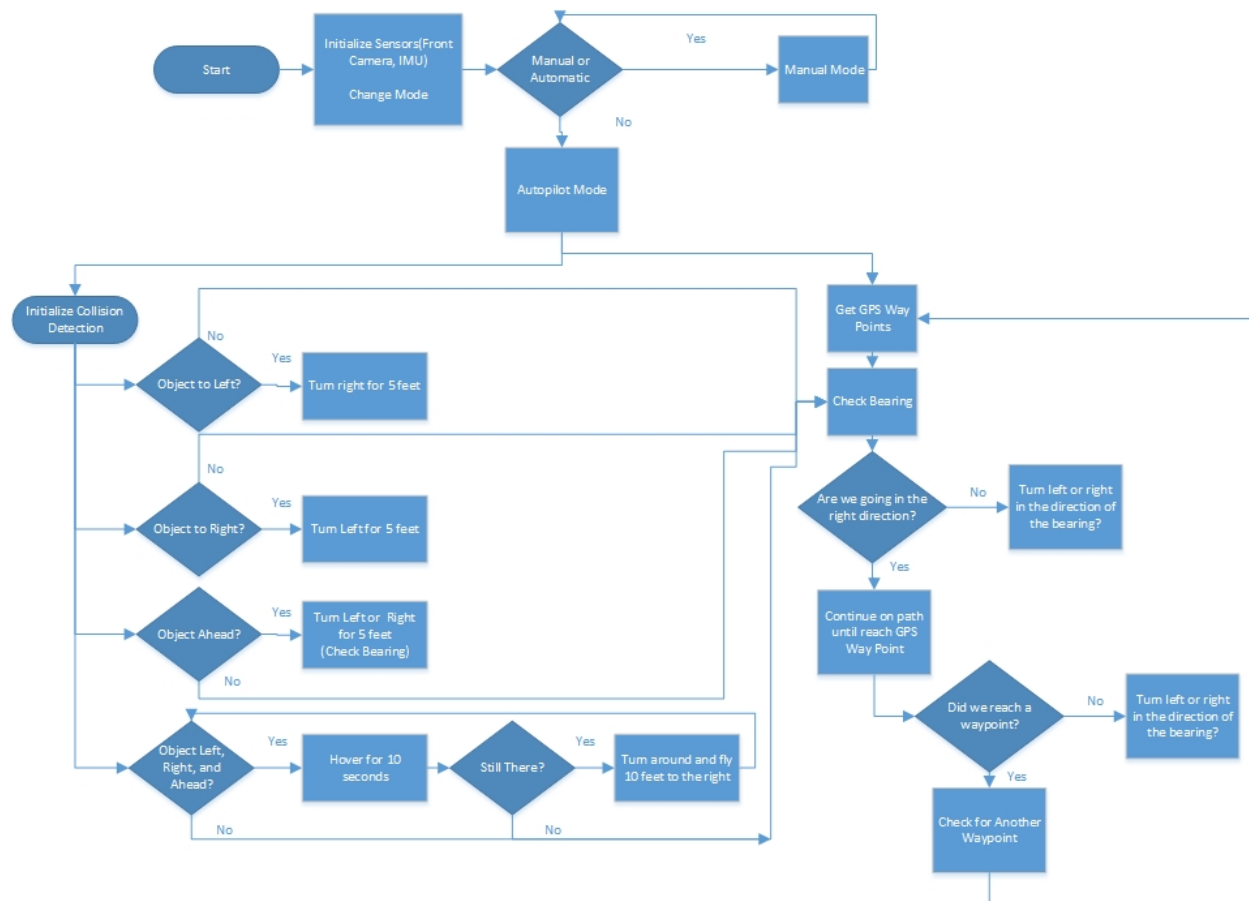
Appendix A

Gantt Chart

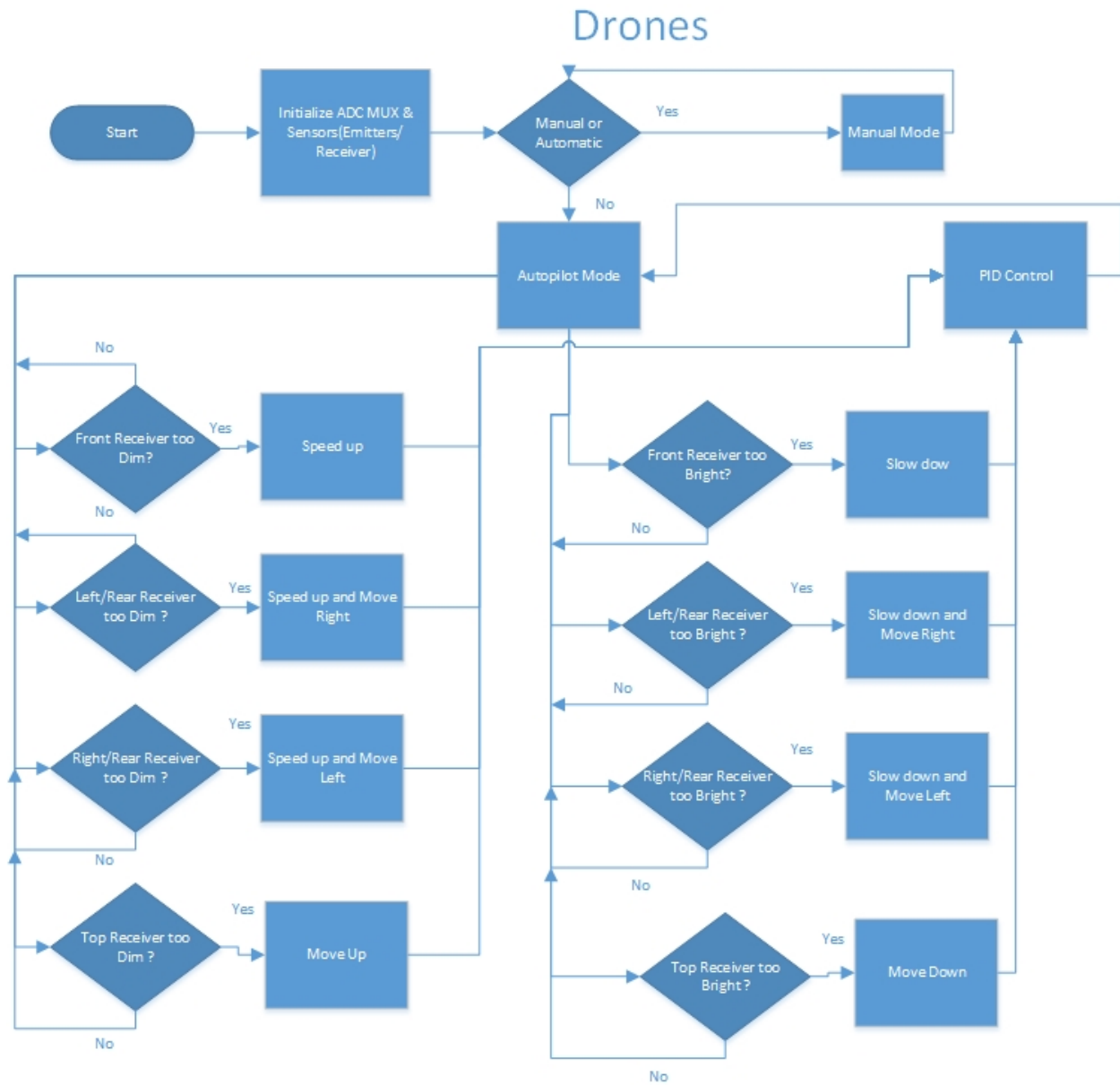


Appendix B

Mother Ship



Appendix C



Appendix D



Appendix E



Appendix F

Search For Location :



Map data ©2014 Google Imagery ©2014, DigitalGlobe, USDA Farm Service Agency | [Terms of Use](#) | [Report a map error](#)

Input

Add a location manually (also accepts [latitude,longitude])

Options

Fill Colour: Line Colour:

[Map Height : [Small](#) - [Medium](#) - [Large](#) - [Full Screen](#)]

Output : Current Area

6096.56 m²
 0.01 km²
 1.51 acres
 0.61 hectares
 65622.87 feet²
 0.00 square nautical miles

Current Perimeter

333.852m OR 1095.314feet

Appendix G

Table I – AR Drone Specifications

Front-facing camera object detection distance	1-10 meters
Takeoff and landing sequence height	0-3 meters from ground level

Table II – Skywalker Drone Specifications

Takeoff and landing sequence height	0-3 meters from ground level
Range of infrared detection of other drones	2 meters, omnidirectional
Aerial camera snapshot interval	One photo per second
Onboard analog-to-digital conversion rate for IR Receiver voltage	≥ 100 Hz
ADC input channels	4 ADC channels
ADC reference voltage, resolution	5V, 10-bit resolution

Table III – Other Project Specifications

Bradley Alumni Quad target surface area	6096.56 square meters
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Appendix F

Table V – Metrics

Objective:	Efficiency	Safety	Flocking	Autonomous
100	Able to get to the goal in all but the worst conditions; able to do multiple runs	Able to fly without causing injury in all conditions; able to be remotely shut off in all conditions	Always able to fly in a flock	Able to fly in a flock point to point in all conditions; able to map efficiently in all conditions
75	Able to get to the goal in all but the worst conditions	Able to fly without causing injury in all but the worst conditions; able to be shut off remotely in all conditions	Able to fly in a flock in all but the worst conditions	Able to fly in a flock point to point and map efficiently, however in the worst conditions the flock breaks apart and/or maps poorly
50	Unable to get to the goal in adverse conditions; otherwise is able to complete its task	Able to fly without causing injury in most conditions; able to be shut off remotely in all conditions	Unable to flock in adverse conditions, otherwise flocks	Able to fly in a flock point to point; unable to map efficiently
25	Only able to complete its goal in near perfect conditions, otherwise is unable to complete its goal.	Able to fly without causing injury in most conditions; able to be shut off remotely in most conditions	Flocks in near perfect conditions, otherwise unflockable	Able to fly individually point to point; unable to fly in a flock
0	Uses up all battery power before completing its goal	Unable to fly without causing an injury to others. Unable to be shut off remotely.	Not flockable in any conditions	Controlled manually

Appendix G

Table V – Numerical Evaluation Matrix

Design Constraints and Objectives	Mothership, Drones with Cages, Infrared Detection, Optical Beacons, Mothership Optical Collision Detection,	Mothership, Drones with Cages, Infrared Detection, IMU, Mothership Optical Collision Detection,	Mothership, Drones with Cages, Infrared Detection, GPS waypoints, Mothership Optical Collision Detection	Formation, Infrared Detection, Optical Collision Detection, Optical Beacons	Formation, Infrared Detection, Optical collision detection, IMU
C: Size					
C: Money					
C: At least 4 Quadcopters					
O: Efficiency	75	75	75	50	50
O: Flocking	75	75	75	75	75
O: Safety	75	75	75	100	100
O: Autonomous	50	50	75	50	50