**Autonomous Drone**

ECE4011 Senior Design Project

**AutoDrone**

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**Table of Contents**

[**Executive Summary**](#_eyxj2p2b6db) **2**

[**1. Introduction**](#_3i3hxla88j4e) **3**

[1.1 Objective](#_oxys55snf9o7) 3

[1.2 Motivation](#_ff77rhnw8q01) 3

[1.3 Background](#_qtcp08ceqi5j) 4

[**2. Project Description and Goals**](#_m0brxouoctoj) **5**

[**3. Technical Specifications**](#_io2jhkdiy0fx) **6**

[**4. Design Approach and Details**](#_k5hmqd4952ln) **9**

[4.1 Design Approach](#_kq9zq560ijmz) 9

[4.1.1 Hardware Design Approach](#_95hcpwyz6ms2) 9

[4.1.2 Software Design Approach](#_xylvm1js8p3) 11

[4.2 Codes and Standards](#_nbyqsg2vtquv) 14

[4.2.1 Federal Aviation Administration (FAA) part 107](#_2tr40xjw2ngb) 14

[4.2.1 IEEE 802.11](#_koq0x8mdyugl) 14

[4.2.3 National Marine Electronics Association (NMEA) 0183 and Global Positioning System (GPS)](#_j9y61roybu68) 14

[4.3 Constraints, Alternatives, and Tradeoffs](#_5l7fpeh2sd65) 15

[**6. Project Demonstration**](#_39smy9eof4q6) **16**

[**7. Marketing and Cost Analysis**](#_o0s8q28fl40z) **16**

[7.1 Marketing Analysis](#_9bqydjynq15n) 16

[7.2 Cost Analysis](#_64utofw740ee) 17

[**8. Current Status**](#_h5x79f6q9qx3) **21**

[**9. References**](#_dynb36g0y88f) **22**

[**Appendix A - Milestones, Task assignments and Risk Levels**](#_ba14ee542ete) **26**

[**Appendix B - Project Gantt Chart**](#_p99tx56vvb6p) **28**

[**Appendix C - Project PERT Chart**](#_atasymmznt3q) **29**

# **Executive Summary**

AutoDrone is an unmanned aerial vehicle that can perform three specific tasks without a drone operator: flying between designated points, tracking objects and 3-D reconstructing the environment it explored. The final product will include an autonomous drone, and a website where the drone’s users can give basic instructions and view the mapping.

Currently, there are several companies that provide drone imaging services, but they require an operator to fly the drone. This product is designed to allow users to take advantage of drone technology without having the knowledge to fly one. The users can also switch between a variety of flying modes depending on what task they want to accomplish.

The expected outcome of the project is a well-designed autonomous drone, that is able to perform the three tasks. The drone will be able to use GPS data to fly to a targeted destination. It will also be able to track and identify the features of an object and follow the object around. The third task will be exploring and mapping an environment. Under the exploration mode, the UAV will fly around an environment avoiding obstacles, and record image and depth data in that environment. That data will be sent through a Wi-Fi link to a computer where an algorithm can use the data to recreate a map of the environment.

The team will assemble the drone frame with the autopilot, on-board computer, camera, sensors, motors and speed controllers. The cost for all of the parts needed for a single drone will be $738.

**Autonomous Drone with Tracking and Mapping Capabilities**

# **1. Introduction**

The AutoDrone Team will design and build an autonomous quadcopter capable of tracking objects and aerial mapping. The team requests $738 to fund the prototype design.

## **1.1 Objective**

The objective of the project is to design a fully autonomous quadcopter. The end goal is to have the drone be able to fly without any human controls around a specific region, and gather data from that area. The data captured during the flight will be put through an algorithm that will recreate a model of the area on the computer. The drone will also be able to fly from point A to point B acquired from GPS coordinates. The drone will also have the ability to track an object.

This product has many applications ranging from amateure flying to inspection of industrial plants or first response after a natural disaster. Amateurs can buy the drone for aerial photography or to film extreme sports. Companies can use this drone to deliver packages in short distances. First responders can use the drone to scope out dangerous areas to be prepared to go into specific areas. Farmers can use the drone to remotely monitor their crops. The product will allow people to use drone technology without having the knowledge to fly a drone.

## **1.2** **Motivation**

Most companies and groups that are currently working on the Automatic Flying Drone are focusing on one of some specific tasks while there are drones similar to some aspects of the team’s targeted standards. The drone used for counting population by a biology professor, David Bird, costs $1,300 [1]. Some companies such as Domino’s pizza and Amazon are trying to implement the drones for delivery [2][3]. However, the team not only plans to perform certain task such as population counting or delivering, but also desires to combine three tasks: flying to the given destination, distinguishing and tracing objects, and mapping the environment. The drone designed by the team can be used for researchers to perform dangerous tasks in a safer manner, and provide a more convenient way for farmers to effectively monitor their crops.

## **1.3** **Background**

Currently there are some other teams and companies working on the unmanned aerial vehicles and a few products have already been in work.

A team of engineers in California launched the Burrito Bomber, a UAV that uses GPS coordinates to drop burritos by parachute [3] and Domino’s pizza tried to deliver pizza using a drone [2]. These are examples that teams or companies are still implementing and experimenting rather than make use of the drones for real-life tasks. Once these teams and companies succeed, the drones may be produced in a great amount to complete the tasks such as delivery.

Nowadays, most biology scientists perform tasks such as population counting and recording the wildlife by aircraft. However, some drones designed for researchers have already been used in research, since more scientists realize that dangerous tasks can be completed without human presence. For example, David Bird, a wildlife biology professor, used the self-designed drones to count the population of the birds [1]. The researchers, though successfully developed some of the drones for performing certain tasks, are not aiming at producing the drones in large quantity.

Moreover, there are some companies selling drones with advanced equipment. For instance, DJI is one of the companies that are selling different types of drones such as Phantom, Mavic, and Inspire to satisfy the requirements of different customers [4]. The drone companies sell drones with the ability to move to certain destinations and take photos of the environment. But advanced requirements such as feature recognition, object tracing, and aerial mapping, need to be implemented by the customers themselves. However, there are two companies that provide autonomous systems. Skysence [5] provides drone survey solutions to agriculture, defense and security, and AiroBitics [6] provides drone survey, inspection, mapping, and emergency response. But both companies only provide customized solutions to their clients, which is less accessible to the public.

Two of the key components for the drone are the flight controller and the on-board computer. The flight controller will consist of a GPS and an autopilot for speed and motor control. The on-board computer will be used for implementing the existing algorithm to perform the tasks.

# **2. Project Description and Goals**

The essential goal is to build a drone that can autonomously travel to different locations. The long term goal is to use a depth camera to track objects and map out the environment of the drone. There will be two main elements of the design, hardware and software. The hardware components will be integrated together to provide sensory feedback and control of the drone. The software component will provide the necessary guidelines for the drone to fly autonomously. GPS data will also be integrated into the software component and will allow the drone to travel to certain GPS waypoints. There will be a link between the drone and a local computer, the local computer will use the data collected by the camera to create a map of the drone’s environment. Table 1 shows the hardware and software components as well as the features of the final product.

**Table 1**. List of Features and Components.

|  |  |  |
| --- | --- | --- |
| **Hardware Components** | **Software Components** | **General Features** |
| * Onboard computer * Depth camera * GPS * Infrared sensor * Flight controller * Speed Controller | * Communication link between drone and remote computer * Sensory input configured for microcontroller * Algorithm for the drone to fly based on flight data * Algorithm for drone to recognize and track specific objects * Algorithm for drone to reconstruct the explored environment | * Simple user interface * Autonomously fly from point A to B * Recognize objects and track them * Map of explored environment * Cost less than $2000 |

# **3.** **Technical Specifications**

There are mainly four parts of the technical specifications: hardware, on-board computer, camera and other sensor and software. The specifications are listed in Table 2 - Table 5.

**Table 2**. Hardware Specifications

|  |  |
| --- | --- |
| **Hardware Specifications** | |
| Weight | 0.8 - 1.6 kg |
| Dimension | 450mm diagonally (from motor to motor) |
| Payload | 1.4 - 1.6 kg |
| Battery Capacity | 2000mAh - 7000mAh, 4S LiPo |
| Operating Power | 3.3 - 5V, Max 20A/rotor |
| Autopilot | Pixhawk |

**Table 3**. On Board Computer Specification

|  |  |
| --- | --- |
| **On Board Specifications** | |
| Frequency | 1.1 - 2 GHz |
| Memory | 2 GB |
| Cores | 4-8 cores |
| Power | <60 W |
| Operating System | ROS |
| Communication Portal | Wi-Fi |

**Table 4**. Depth Camera and Other Sensor Specification

|  |  |
| --- | --- |
| **Sensor Specifications** | |
| Frame Rate | 30-60 FPS |
| Resolution | Depth: 320x240, 480x360  Color: 320x240, 640x480, or 1920x1080 |
| Depth Range | Inside range: 0.5-3.5 m  Outside range: up to 10 m |
| GPS Resolution | <3m |

**Table 5**. Software Specification

|  |  |
| --- | --- |
| **Software Specifications** | |
| On Board Tracking Processing Speed | <100 ms per frame |
| Local Mapping Processing Speed | <300 ms per frame |
| Graphic User Interface | Yes. There will be graphic user interface, so users can give basic instructions to drone, and view the mapping of the area. |
| Localization Accuracy | <1 m |
| Communication between On Board Computer and Flight Controller | MavLink |
| Communication between On Board Computer and Local Computer | Use distributed ROS system, with nodes running on both local computer and onboard computer |
| Object Tracking | Yes |
| Used Sensor Information | RGBD images, GPS location, orientation, and distance |
| Path Planning | Optimize the steps, if destination is given. Do breadth-first search to explore the area. |

# 

# **4. Design Approach and Details**

## **4.1 Design Approach**

There are three main components to AutoDrone which can be separated into hardware and software design. The hardware design will be the physical build and components of the quadcopter. Within the software design, there is the localization algorithm and the autonomous movement algorithm.

### **4.1.1** **Hardware Design Approach**

All of the hardware components of a quadcopter must be compatible. So, when choosing components, they must all be able to communicate with each other to run the designed software. Since the quadcopter will be autonomous, the most important hardware will be the flight controller and the on board computer. The flight controller must have features such as self takeoff and landing , waypoint navigation, telemetry, and have an open source firmware [7]. The 3DR robotics Pixhawk flight controller is a good choice since it has all these features and also comes with a GPS module. With this flight controller, there are only a few onboard computers that are able to communicate with it [8]. The other parts of the quadcopter need to be selected based on the total weight of the quadcopter. The DJI flame wheel f450 frame will be used for the design as well as its complementary landing skids. The DJI e305 motor kit is compatible with the selected frame and contains four motors, four speed controllers, a power distribution board, and a propeller kit. The camera used will be the Intel Real Sense R200 depth camera. A Sharp infrared sensor will be used with the design to provide a distance reading from the bottom of the drone to the ground. The battery must be able to power the motors for at least 20 minutes so the battery selected must have a high discharge rate and three or four cells to be compatible with the motor kit. The GENS ACE 3300mAh 25C 4S battery was selected. A full list of the selected parts can be found in Table 6 below.

**Table 6**. Chosen and Unchosen Parts for the Autonomous Quadcopter.

|  |  |
| --- | --- |
| **Hardware** | **Part Name** |
| Flight Controller | Pixhawk Mini |
| Onboard Computer | ODroid XU4 |
| Battery | GENS ACE 3300mAh 25C 4S |
| Motors | DJI e305 motor kit |
| Frame | DJI Flame Wheel F450 |
| Camera | Intel Realsense R200 |
| IR sensor | Sharp GP2Y0A02YK0F |
| Landing Skid | DJI Flame Wheel 450 Landing Gear Set |

### **4.1.2** **Software Design Approach**



**Figure 1.** Main components for the software system.

There are two main components for the software system. A program on the on-board computer and a program on the local computer. Their relationships are shown in Figure 1 above. The flight controller and other sensors will provide sensory information that the on board computer will use to fly autonomously. The on board computer will also record the sensor data to send to the local computer for later processing.

The sensors on the drone include a depth camera, which feeds back RGBD images, a depth sensor, which feeds back depth information, a GPS unit, which gives location, and a gyroscope, which gives orientation information. Among them, GPS and gyroscope are integrated into the flight controller. The flight controller is responsible for carrying out the instructions from the on board computer by sending data to the speed controller which controls the motor speeds. MAVLink [9] is the protocol used between the on board computer and the flight controller. MAVLink has pre-defined messages that can be used directly for the communication between Pixhawk and ROS. Drivers for the sensors will be installed on the on-board computer. A distributed ROS system will be set up on the onboard computer and local computer through WiFi so that nodes on onboard computer and local computer can communicate with each other.



**Figure 2.** Communication between the On-Board Computer and the Local Computer.

The two programs on the on board computer and local computer run at the same time. They will communicate with each other to fly the drone as shown in Figure 2. The on board computer will manage the visual odometry and the mapping module, which make up the SLAM algorithm. It will fetch information from the sensors and give required visual and odometry information to predict drone’s position. The local computer will manage to send user input to the drone.

With known obstacle locations from visual odometry and path planning information, the on-board computer will give instructions to the flight controller to navigate around the obstacles. The path planning part of the program will be created from scratch, and visual odometry will be modified from ORB-SLAM’s tracking threads. The program on the local computer will have three parts: a GUI that takes in user’s instruction, a module that sends the instructions to the on board computer, and a module that reconstructs the map. The first two parts will be created from scratch, and the mapping part will be modified from the mapping threads of ORB-SLAM [10]. A mockup of the user interface can be seen in Figure 3 below.



**Figure 3.** A mock-up of the User Interface

## **4.2** **Codes and Standards**

The FAA part 107, the IEEE 802.11, and the NMEA 0183 codes are the three major codes and standards that are applicable to this project.

### **4.2.1 Federal Aviation Administration (FAA) part 107**

Part 107 of the FAA code discusses the rules and regulations of unmanned aircrafts. When designing and flying this drone, none of these rules must be broken. The code discuss where and when the unmanned can be flown. It also discusses drone flight regulations such as not exceeding a maximum ground speed of 100 mph, a maximum altitude of 400 ft above ground or a structure, cannot weigh more than 25 kg, and can only be flown in daylight [11]. When designing this drone, all the limitations and rules in the document must be heeded.

### **4.2.1 IEEE 802.11**

The IEEE 802.11 will be used to transfer images and commands over WIFI from the ground station to the quadcopter. Both the on board computer and ground station computer will need to implement and be aware of the proper protocols when transferring data via wifi to ensure reliable data transfer. This code also tells what frequency bands the drone and ground stations can use to communicate [12].

### **4.2.3 National Marine Electronics Association (NMEA) 0183 and Global Positioning System (GPS)**

The National Marine Electronics Association (NMEA) 0183 provides the specifications required to communicate for GPS units [14]. The on board computer of the quadcopter must be able to parse this data inputted from the GPS module and navigate the quadcopter to the final destination. The data read from the receiver includes the drone’s position, velocity, and time [13]. Since GPS only works when it locks onto satellite signals [15], the GPS function of the drone can only be used outdoors.

## **4.3** **Constraints, Alternatives, and Tradeoffs**

In the prototype is design there will not be any sensors for the drone to detect nearby objects except for an infrared sensor on the bottom of the drone to provide a vertical height measurement. The only way the drone will be able to detect nearby objects is from the data provided by the depth camera. Not including extra infrared or sonar sensors for safety will reduce the cost of components for the prototype as well as simplify the overall design.  
 There were several options for a microprocessor as well the flight controller components. Only certain microprocessors and flight controllers are readily compatible together. This which greatly reduced the number of components available for the prototype. The size of the battery also played a large role in the design of the prototype. A larger battery will provide a longer flight time but the increased weight will reduce the payload capacity that the quadcopter has for other hardware components.  
 The type of drone that will be used in the prototype is a multirotor quadcopter. Quadcopter drones are ideal for photography and aerial observation, but the short flight time is not ideal for large scale aerial mapping. For aerial mapping a fixed wing drone is preferred, but they are expensive and difficult to fly [16]. **5. Schedule, Tasks, and Milestones**

The Autodrone team will design and complete the tasks over the next 5 months from November to the end of April. The table in Appendix A lists all of the major milestones, people assigned to the tasks and the degrees of difficulty of the tasks. Appendix B provides the overall project time line in the form of a GANTT chart.

# **6.** **Project Demonstration**

There will be two tasks the drone will have to complete to demonstrate autonomous flight capabilities listed below:

1. Given a GPS coordinates, the drone will take off, fly to that coordinate, and land without hitting any obstacles.
2. Given the GPS coordinates the drone must stay within, the drone will fly around and take data in the area. The data will be sent over WIFI to a computer base station which will reconstruct a map of that area.

To prototype during the design process, there will be small milestones to demonstrate the drone’s capability to do smaller tasks listed below:

1. Tuning the flight controller so the drone can lift off and hold a constant altitude then land.
2. Using just the flight controller data, the drone will fly 10 meters in a straight line from the current location.
3. Demonstrating the drone can read/send out the GPS coordinates to the on-board computer
4. Using GPS coordinates to fly 10 meters in a straight line.
5. Demonstrating drone can find and track an object.
6. Demonstrating the drone can follow the tracked object from a distance.
7. Demonstrating connection between on board computer and ground control computer.
8. Demonstrating the ability of the ground control computer to recreate image and depth data from the drone.

# **7.** **Marketing and Cost Analysis**

## **7.1** **Marketing Analysis**

Mapping with an autonomous drone is a concept that is being adopted by end users since it is simple and cost effective compared to old methods. Surveying land is a task that traditionally requires several days to gather data, with a drone the task can be completed within one day. Surveyors in the field risk injury when surveying sites such as mines, but using a drone removes that risk of injury. Sense Fly has several autonomous aerial vehicles available that allow a user to directly input the area of coverage to be surveyed as well as the desired ground sampling rate [17]. Maps made easy offers users an IOS app to select the area of interest, the user must purchase their own drone and camera to gather the information. Maps made easy also allows users to upload their data to their website to produce a high resolution map [18]. Both of these companies use autonomous aerial vehicles to map land, but both of these companies require the user to be knowledgeable about either mapping software (Sense Fly) or drone hardware (Maps made easy). Sense Fly requires the user to be knowledgeable with the mapping software that they provide, while Maps made easy requires the user to build their own drone and equip it with a camera. The fact that potential users must have prior knowledge to use a certain product can be unattractive to them. Autodrone aims to produce a complete drone surveying kit with a simple user interface that anyone can operate to their desired needs.

## **7.2** **Cost Analysis**

The total cost for the development of a prototype Autodrone is $51,091. Table 7shows a breakdown of the costs of all of the components necessary to build the prototype. The cost for cabling and wiring is an estimate, since most components include necessary cables, any remaining cables and wiring components can be obtained without cost from the senior design lab. The price of each component was rounded up to the nearest dollar.

**Table 7.** Component Costs for Prototype

|  |  |
| --- | --- |
| **Item** | **Cost** |
| Pixhawk Mini | $199 [19] |
| ODroid XU4 | $123 [20] |
| GENS ACE 3300mAh 25C 4S | $48 [21] |
| DJI e305 motor kit | $149 [22] |
| DJI Flame Wheel F450 | $32 [23] |
| Intel Realsense R200 | $169 [24] |
| Sharp GP2Y0A02YK0F | $15 [25] |
| DJI Flame Wheel 450 Landing Gear Set | $20 [26] |
| Cables and Wiring | $10 |
| **Total** | **$765** |

There will be four engineers working to design and develop a prototype. The total amount of labor hours to develop a prototype per engineer is outlined inTable 8.

**Table 8.** Prototype Development Hours Per Engineer

|  |  |
| --- | --- |
| **Task** | **Hours** |
| Weekly meetings | 16 |
| Research | 16 |
| Assembly | 4 |
| Flight testing/trouble shooting | 8 |
| Code autonomous algorithm | 14 |
| Code tracking algorithm | 12 |
| Code algorithm to integrate GPS data | 8 |
| Code mapping algorithm | 24 |
| Testing debugging | 50 |
| **Total** | **152** |

**Table 9.** Total Development Costs

|  |  |
| --- | --- |
| **Development Component** | **Cost** |
| Parts | $765.00 |
| Labor | $17,396 |
| Fringe Benefits, % of Labor | $5,219 |
| Subtotal ( Parts, Labor, Fringe Benefits) | $23,380 |
| Overhead,% of Material, Labor, & Fringe Benefits | $28,056 |
| **Total Overall Development Costs** | **$51,436** |

The salary per engineer is assumed to $61,420 per year, which is the average starting salary for a BS in electrical engineering [27]. 152 hours per engineer totals $17,396 in labor costs. The analysis for total development cost assumes 30% fringe benefits of labor and 120% overhead on materials, labor, and fringe benefits. The total development cost is outlined in Table 9.

For production over five years it is assumed that 5000 units are sold within a five year span. The cost for the parts was estimated to be 10% less, since all parts will be purchased in bulk. Technicians will be hired at $20 per hour to assemble and test the product. Fringe benefit is assumed to be 30% of total labor and overhead is assumed to be 120% of materials, labor, and fringe benefits. Sales expense, in the form of marketing will be 7% of the final selling price. The final selling price will be $2,000 and the expected profit for each unit will be $148, and the percent profit is 7.4%. There will be an expected profit of $740,000, and the expected revenue will be $100,000,000 over a 5 year period. The selling price and profit per unit over a five year span is shown in Table 10.

**Table 10.** Selling Price and Profit Per Unit (Based on 5000 unit production)

|  |  |
| --- | --- |
| **Expense or Income Component** | **Cost** |
| Parts Cost | $689 |
| Assembly Labor | $40 |
| Testing Labor | $20 |
| Subtotal (Labor) | $60 |
| Fringe Benefits, % of Labor | $18 |
| Subtotal (Parts, Labor, Fringe Benefits) | $767 |
| Overhead, % of material, Labor, & Fringe Benefits | $920 |
| Subtotal, Input costs | $1,687 |
| Sales expense (7% of total cost) | $140 |
| Amortized Development Costs | $25 |
| Subtotal, All Costs | $1,852 |
| Profit | $148 |
| **Selling Price** | **$2,000** |

# **8.** **Current Status**

This project is currently in the late research phase. The development team has looked into different hardware to build the drone and different algorithms to implement. Most of the parts have been chosen and checked for compatibility to each other. There are still a few parts left that have not been decided on yet. The software and algorithm development will start in January of 2017.

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# **Appendix A - Milestones, Task assignments and Risk Levels**

|  |  |  |
| --- | --- | --- |
| **Task Name** | **Task Leader** | **Degree of Difficulty (Risk Level)** |
| **Class Related Tasks** | All | Low |
| Project Proposal Form | All | Low |
| Project Proposal Paper | All | Low |
| Design Review | All | Low |
| Oral Presentation | All | Medium |
| Final Project Demo | All | Medium |
| Design Expo | All | Low |
| **Hardware Tasks** | All | Medium |
| Order Parts | All | Low |
| Assembly parts | QW, YB | Low |
| Tuning motor/ controllers | QW, YB | Medium |
| Basic Flight Test with remote control | QW, YB | Medium |
| Troubleshooting | All | Medium |
| **Software Tasks** | All | Medium |
| Setup on board computer and communication | All | Medium |
| Autonomous Fly A to B based on flight controller data | QS, IB | Low |
| tracking a given object | QS, IB | High |
| Autonomous flying A->B based on GPS coordinates | QS, IB | Medium |
| reconstruct the explored environment | All | High |
| Troubleshooting | All | Medium |

# **Appendix B - Project Gantt Chart**

