RoboCopter: Autonomous Hunter Drone

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***Abstract* — This project's objective is to design, build, and test an autonomous unmanned aerial vehicle system with commercial off-the-shelf (COTS) components that can detect, track, and collide with multiple prey hobby drones. This project aims to improve on current technologies for obstacle avoidance and target detection with symbology for tracking. The vehicle will also include various flight modes and safety features to allow a safe flight for the drone and bystanders. The features presented are important for future applications, such as military defense applications, search and rescue missions, and optimization for general consumer uses.**

***Index Terms* — Autonomous Systems, Closed Loop Systems, Computer Vision, Power Distribution, Streaming Media, Unmanned Aerial Vehicles.**

I. INTRODUCTION

The use of Unmanned Aerial Vehicles (UAVs) has been rapidly increasing for many different purposes including photography, agriculture, landscaping, and military surveillance. Most Commercial-Off-the-Shelf (COTS) UAVs, however, are remote controlled and do not possess the ability to autonomously modify their behavior based on changes in their environment. This project, sponsored by Lockheed Martin Missiles and Fire Control Applied Systems Sensor Research and Technologies, aims to serve as a challenging ground in which mechanical, aerospace, electrical, computer, and software engineers must work harmoniously to develop an autonomous UAV system encompassing propulsion, telemetry, aviation, and robot vision systems.

The purpose of this project is to design, build & test, and demonstrate an Unmanned Aerial Vehicle (UAV) RoboCopter that performs autonomous detection, tracking, and pursuit of multiple criminal UAVs (aka prey) by using multiple sensing technologies.

II. COMPETITION GUIDELINES

The Lockheed Martin RoboCopter competition consists of three teams and their autonomous predator drones competing for the most points by disabling enemy prey drones. Points will be awarded and deducted based on the ability of the predator drone to quickly identify and track the prey drones while avoiding obstacles placed on the field.

Points are awarded as follows:

+5 points for colliding with a prey drone such that it continues to fly.

+10 points for colliding with a prey drone such that it falls to the ground.

-5 points for each time the drone goes out of bounds.

-15 points for inoperable symbology & video datalink.

Drones will compete on a course with defined boundary lines and may not fly higher than approximately 25 feet.

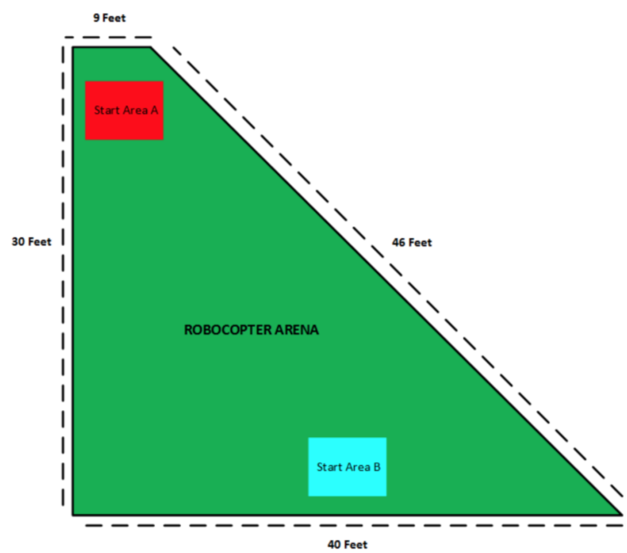

Fig. 1 Competition Arena

The drone must be protected by a cage which cannot exceed four cubic feet, including any appendages extending outside of the cage. The drone must make use of at least one type of sensor to detect and track the prey, but it is suggested to use at least two. The drone must also have four modes of operation for the competition.

Required Operational Modes:

Search mode: Predator drone is autonomously searching for and identifying prey drones to pursue.

Pursuit mode: Autonomously tracks the prey drone and attempts to collide while avoiding obstacles.

Reset mode: Drone autonomously returns to original position to resume searching for prey drones.

Repair mode: Flight controller switches to be controlled manually to the team’s “medic” to replace any damaged parts or a dead battery.

The drone must also transmit a real-time, first person view, stream from the camera onboard the drone. The video must contain zymology representing the actions of the searching and tracking algorithms. A blue box must be placed around identified drones and a red box must be placed around drones that are being pursued.

Each team will be able to participate in two, ten minute rounds. The best score of the two rounds will be the team’s final score. Scores will be determined by the four judges at each corner of the arena. Any points awarded or deducted will be left to discretion of these four judges, the maximum of their recorded scores will be the score used for the round.

Prey drones will be randomly swapped in and out by designated prey drone pilots because of their short flight time. They are about 4 x 4 x 4 inches with a flight time of about 5 minutes. To confuse the drone detection, pictures of the prey will be placed as obstacles, as well as balloons, streamers, and office furniture.

III. SYSTEM COMPONENTS

Given the various topics that the design of an autonomous aircraft covers, a lot of research had to be done to ensure that the best components were selected across the board.

A. Pixhawk

There is a very wide variety of flight controllers on the market; however, there is a limited number of them with enough developer, software, and hardware support to allow for autonomous flight. Factors such as, the MCU, memory modules, the sensors, the hardware and the supported software were chosen to help assess the best flight controller for our objectives.

After evaluating quite a few flight controllers including the APM 2.8, we ended up choosing the Pixhawk PX4 2.4.8, due to the wide hardware and software support that is available, the abundant libraries, tutorials, and forums that can help during the testing and debugging process. This flight controller uses the STM32F427 processor, which is a 32-bit ARM Cortex M4 core with onboard Floating-Point Unit (FPU) for improved accuracy and reduced computational time. The Pixhawk, by default, runs with “a very efficient real-time operating system (RTOS), which provides a POSIX-style environment” [1]. It includes multiple gyros, accelerometers, magnetometer, GPS, a MicroSD card for data logs, 5 UARTs, CAN, I2C, SPI, and ADC, among others. The Pixhawk only weighs about 38g and it has a dimension of (2.0” x .6” x 3.2”). Additionally, it contains four key sensors: a high precision barometer, a 14-bit accelerometer, a 16-bit gyroscope and a 6 axis magnetometer.

B. Raspberry Pi

While the chosen flight controller, the Pixhawk, can easily handle both manual and planned autonomous missions given its memory and computing power, it is not made to handle any significant additional computations. This is especially true for wayfinding and computer vision algorithms. Therefore, an on-board companion computer was necessary, since all processing had to be done onboard of the vehicle. After evaluating the Arduino Tan, the Odroid-XU4 among a few others, the Raspberry Pi 3B ended up as the computer of choice because it provided a nice balance between the criteria considered (size, weight, processor, cost, compatibility, and performance) in the selection process. The Raspberry Pi is a very popular, commonly used single board computer which features a Quad Core Broadcom BCM2837 SoC. It also includes four high-performance ARM Cortex-A53 processing cores running at 1.2GHz with 32kB Level 1 and 512kB Level 2 cache memory, a VideoCore IV graphics processor, and is linked to a 1GB LPDDR2 memory module on the rear of the board” [2].

An advantage that the Raspberry Pi provided was its compatibility with various types of software. Due to its popularity, software is easily accessible and functional out-of-the-box for this single board computer. During testing, we found that, although the Raspberry Pi’s processing power was considerably lower than that of the ODROID XU4, its detection algorithms using OpenCV ran much faster and smoother, even in similar out-of-the-box software environments. Although, in hindsight, the XU4 may have served this project better due to the complexity of the overall system, the PI allowed one of the most important components of the project, the prey identification and detection, to run as quickly as possible.

C. Mobius Action Cam

Since the drone and to be fully autonomous and be able to track down prey drones, a lot of thoughts had to go into the camera selection process as it was the main component of the vision system. The hardest part was to figure out which type of camera (dedicated FPV cam or an HD camera) was more appropriate for the given task. The ultimate goal was to select a camera that was budget friendly, not too heavy, can at least shoot 720P at thirty frames per second with decent resolution, and most importantly not too high of a latency value. After evaluating quite a few options which included the Intel RealSense Depth D435, the Pixy CMUcam5, the Runcam Split 2 and a few others, the final camera of choice was the Mobius mini action camera. The Mobius mini Cam is a HD camera that only weighs about 27 grams with a dimension of 50 x 25.4 x 12.7 mm. It's capable of shooting both Full HD and HD at 60 frames per seconds, and it has a resolution of 4 MegaPixels.

D. HC-SR04 Ultrasonic Sensor

The sensor of choice to be used for obstacle avoidance is the HC-SR04 ultrasonic sensor. Ultrasonic sensors send out a high-frequency sound pulse that gets reflected back off the object and returns to the sensor [3]. The sensor consists of two pieces, the transmitter and the receiver. The ultrasonic sensor uses the speed of sound and the time that it takes to transmit the sound pulse to the object and then receive the sound pulse to determine how far the object is from the drone.

Characteristics such as price, range, accuracy, and power of these sensors affected the decision. These sensors are consistent and reliable. The sensors operate at a voltage of 5V and have a maximum range of approximately 5 meters with a measuring angle of about 30 degrees. The sensors cost approximately two dollars per sensor which allows for the purchase of spares for testing purposes.

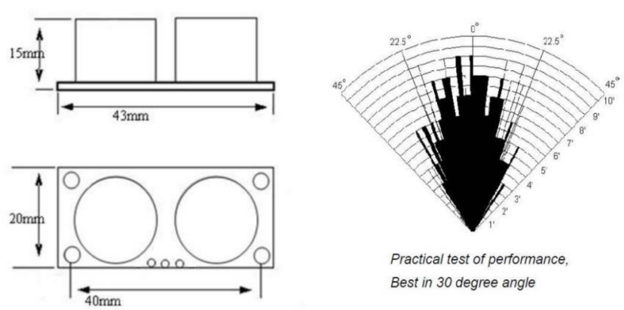

Fig. 2 Ultrasonic Sensor Performance

E. LIDAR Lite v3

The use of a laser distance sensor allows for faster and longer distance measurements than the ultrasonic sensors. The sensor emits a pulse of light and measures the time for that signal to be reflected back off the object and onto the sensor. The LIDAR Lite V3 is a compact, high performance sensor that is used in multiple drone or robotic applications.

As for the specifications of the sensor of choice, the LIDAR Lite V3 has a maximum range of 40 meters and operates at the same 5V as the ultrasonic sensors. This rangefinder can be combined with other sensors to give a good approximation of the location of the drone in areas with limited access to a solid and reliable GPS signal.

F. PX4FLOW

The use of a GPS receiver in drone navigation brings quite a few benefits, such as position hold, autonomous flight, return to home feature etc. However, flying a UAV with GPS in certain environments can be very unpredictable, not to add to the fact that using GPS heavily depends on external infrastructures. To counteract that, the PX4Flow sensor was chosen as an alternative to GPS. The PX4FLOW (Optical Flow) Sensor is a specialized high resolution downward pointing camera module and a 3-axis gyro that uses the ground texture and visible features and a separate rangefinder to determine aircraft ground velocity [1]. As far as specifications, it has a resolution of 752×480 pixels and calculates optical flow on a 4x binned and cropped area at 400 Hz, giving it a very high light sensitivity. Comparing it GPS, the PX4Flow sensor has the ability to work in low light outdoor conditions, and indoors without the use of any additional LED. It is also reprogrammable; therefore, it gave the flexibility to program it to achieve low-level computer vision task.

G. Batteries

The drone uses two lithium polymer batteries for operation. The primary battery is used to power the four motors and the secondary battery is used to power the electronics. The primary battery is a 5400mAh Venom three cell LiPo. This means the battery has a nominal voltage of 11.1 volts and has a C rating of 20 and is able to safely providing 108 continuous amps. The motors used are said to have a surge of about 26 amps for a maximum total of about 104 amps which this battery can easily deliver [4]. The capacity of this battery will allow it to deliver about 26 amps for the entire ten-minute round without draining it below 20% capacity. The power is distributed to the ESCs by using the power distribution system already integrated in the frame of the drone. This allows the XT60 connector and the ESCs to be soldered directly on the bottom connector plate which allows the power to safely be distributed with minimal resistance. A power module is connected between the battery and the frame and connects to the power port on the Pixhawk which provides 5 volts and also gives information about the voltage level and current draw from the battery. During the competition the voltage level will need to be monitored to avoid draining the battery too low, an additional battery will be on standby in the event that the battery is being drained too quickly.

The secondary battery is a 1000mAh Turnigy two cell LiPo having a nominal voltage of 7.4 volts with a C rating of 20. This lightweight battery is to independently power the electronics without the risk of causing a "brownout" or loss of any functions due to spikes in the current draw from the primary battery. This battery connects directly to the designed PCB using a JST connector. From the PCB the Pixhawk, microprocessor, Raspberry Pi, and all sensors can be powered. The primary battery already powers the Pixhawk but this connection serves as a sort of backup to keep everything running to be able to switch out the primary battery in the middle of the competition without losing any functionality and requiring the Pixhawk to reboot costing valuable time during the competition. The battery is able to provide 20 amps continuously which is more than enough current needed and provide 800mAh without being in danger of damaging the battery. Since the competition lasts ten minutes a round, this means the battery has the capacity to prove 4.8 amps the entire round.

H. Motors

The drone uses four brushless outrunner motors with 10-inch carbon fiber propellers. This setup with a three cell LiPo can provide a maximum of 840 grams of thrust while drawing about 10 amps per motor. The motors are 800KV which are fairly efficient for the propeller size being used providing about 7 grams of thrust per watt and are relatively small and lightweight for the thrust produces at 22 by 16 mm and 75 grams each.

IV. SYSTEM CONCEPTS

To make an autonomous obstacle avoidance system a lot of components of the system must work together.

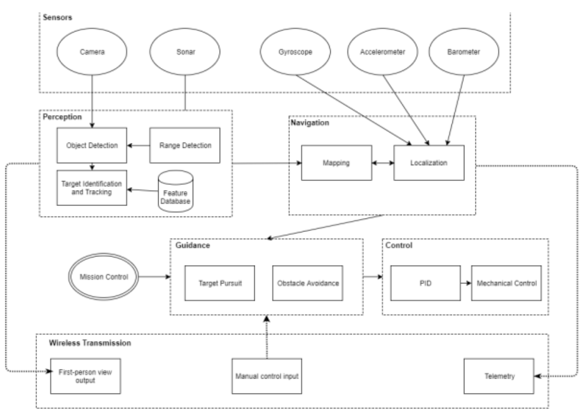

Fig. 4 Software System Decomposition

A. Object Detection

As stated in the objectives above, the drone must have the ability to quickly identify and track the prey drones while avoiding obstacles placed on the field; therefore, the vision aspect played a vital role in this entire system.

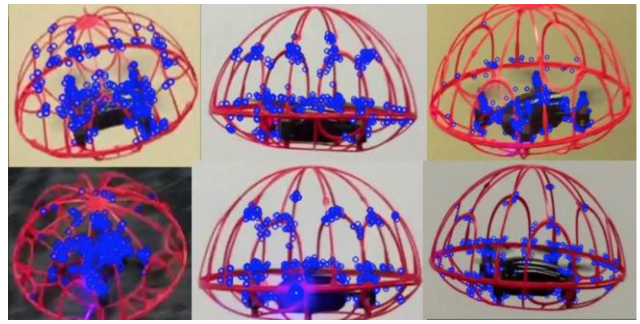

Fig. 3 Feature Detection

The Object detection algorithm used is strictly based on feature detection. Feature detection includes methods for computing abstractions of image information and making local decisions at every image point whether there is an image feature of a given type at that point or not. The resulting features will be subsets of the image domain, often in the form of isolated points, continuous curves or connected regions [5]. The features that typically gets focused on the most using feature detection include corners, edges, region of interest points and ridges. Applying the above concept to this project, the live feed from the camera gets used as input, to the object detection process. Each frame of the live input feed gets analyzed one after the other. At first, it extracts the features of the current frame then it compares that frame to the known features / key points. The known features are learned from thousands of video frames that were sampled in the training stage. If there is a match, a bounding box gets fit around the target object, and it keeps tracking the detected object in the following frames.

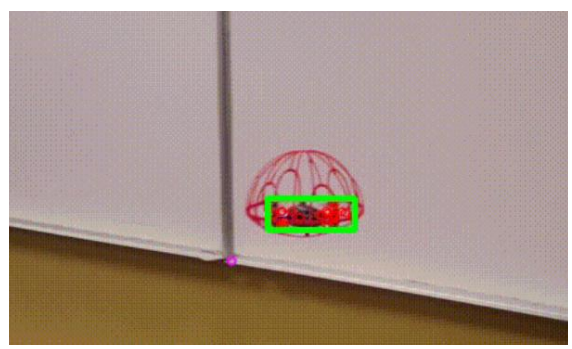

Fig. 5 Prey Detection

B. Obstacle Avoidance

When flying drones indoors or outdoors obstacle avoidance technology is a must. The various obstacles that can be within the drone’s path can affect the drone’s flying capabilities and ease of use for the pilot.

The use of obstacle avoidance sensors or cameras allow drones to be more stable in flight and allow the pilot controlling the drone to be able to safely fly the drone in conditions or areas that are out of direct sight. Essentially, the use of these sensors keep drones at a safe distance from obstacles that cause significant and costly impacts to the drone. Obstacle avoidance technologies have significantly reduced the fear of consumers crashing these expensive devices.

The drone uses three HC-SR04 ultrasonic sensors to achieve its obstacle avoidance capabilities. The position of these sensors covers the entire frontal side of the drone. One sensor points directly forward and each of the two remaining sensors point at a 45-degree angle to the left and right. The 30 degree viewing angle of each sensor allows the drone to sense objects at distances deemed dangerous for the drone and allows the system to adjust back to safety.

The program running on the Atmega chip will communicate with the onboard computer. The serial communication between the two will transmit the values from the ultrasonic sensors. The search and pursue modes will use the values received to adjust flight during the competition.

C. First Person View

One of the requirements throughout the RoboCopter competition was that the drone must transmit a live video stream down to a ground station. That video stream will be a first person look at what the drone is able to see and will essentially allow viewers to see how the drone behaves during the competition. The stream will also be used by the judges as part of the scoring system. An additional requirement was that the stream have to show bounding boxes that are fitted around the detected prey drones. To achieve all of that, the live feed from the Mobius mini action camera will be fed to an object detection algorithm that's running on the Raspberry Pi. The object detection algorithm will detect the prey drones, fit bounding boxes around the detected drones, and output video frames as JPEG images. Those images will be used to create a Gstreamer pipeline that will be streamed over the network using Real-time Transport Protocol. Information about the drone current status will also be displayed on that stream, such as current altitude, current speed, and which mode the drone is currently in. On the ground side, there will be a laptop to receive and display the stream using Gstreamer; that laptop will also be used to show the feed to the judges.

D. Environment

Due to the various environments and communication protocols that are involved in the system, a message passing system or middleware was used in ROS. ROS uses the traditional publish-subscribe architectural approach for efficient and simplified message communication. This allowed for the major software component within the Raspberry Pi — vision, navigation, and video transmission — to be developed concurrently and integrated towards the end of the project. Direction vector commands generated on the Pi are sent via the well-supported MAVLink communication protocol to the PixHawk flight controller. The PixHawk, in turn, uses its built in Extended Kalman Filter based off all available sensors to send the appropriate commands to the Electronic Speed Controllers, which control how the motors behave. This flow, from the sensory equipment to the processing unit to the flight controller to the motor, creates a stable closed-feedback loop system.

E. Localization

One of the toughest challenges of this project was the uncertainty of the competition venue, which was unexpectedly caused by scheduling complications out of the scope of our project. Due to this, our system was required to be versatile enough to function in both indoor and outdoor environments. As was noted in Section II, the drone must be able to stay within the boundaries of the venue. In an outdoors environment with strong GPS signal, this process is simple, as pre-set absolute coordinates relative to the WGS84 coordinate system. This allows the closed-feedback loop to periodically check whether the current location is out-of-bounds, and immediately return to an allowed location.

GPS signal is very helpful as it can also be used to provide important telemetry such as heading, which allows the vehicle to be precise with a maximum error of approximately ten meters. Due to the small size of the expected competition venue, as well as the possibility of it being an indoor, GPS inhibited location, it was pivotal to ensure that enough sensory data could be obtained for accurate movement and position estimation.

Besides GPS data, our flight controller comes out-of-the box with Inertial Measuring Unit (IMU) — which include accelerometers and magnetometers — as well as a barometer. This allows for an accurate yet limited stream of data that is used by the controller's Extended Kalman Filter (EKF) — a mathematical state estimator — to control the change of state in the percept of the drone. Without the presence of navigational aids — like GPS — serving as markers for more accurate position estimation, however, the default sensory information is not enough. In order to provide the EKF with enough data to confidently estimated changes in position, two new sensors were acquired: and optical flow camera and a rangefinder.

The optical flow data is a high-resolution downwards pointing camera which can be used to sense movement; it also includes an additional 3-axis IMU which is used by the EKF for additional pitch, roll, and yaw correction. The rangefinder is an optical distance measuring solution which is required in this setup to provide accurate altitude. This component is required in this indoor setup due to the barometer's sensitivity to changes in pressure, which can easily occur when a door is opened or when there is a change in ventilation.

Using the sensors mentioned above, the EKF can perform dead reckoning — estimating a new position based on previous position and calculated displacement — to localize itself and stay inbounds. This method, although prone to drift, allowed us to address movement using predominantly compass and creating a local frame of reference.

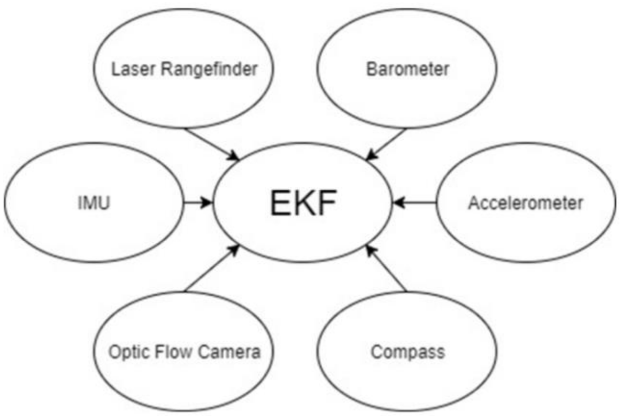

Fig. 6 EKF Data for Dead Reckoning (Indoor Navigation)

V. BOARD DESIGN

A. Functionalities and Design Software

The purpose of the designed printed circuit board is to receive information from the ultrasonic sensors to be used in obstacle avoidance and to provide voltage conversion from a lithium polymer battery to the electronics used in autonomous function such as the flight controller, ultrasonic sensors, lidar sensors, etc. The board was designed using EagleCAD because of the availability of resources in terms of component libraries and a large community to research any issues or concerns. This software was also chosen because it is relatively easy to learn, free, and is so widely used that the board file could be uploaded to be manufactured rather than generating Gerber files.

B. Microprocessor

The circuit board houses an ATmega328p surface mount package with pins connected to the trigger and echo pins of the ultrasonic sensors to measure the distance between the drone and an obstacle, these measurements will then be sent to the Raspberry Pi to be converted into flight controls to steer the drone away from an impending collision with an obstacle. The Atmega is powered by the 5 volts provided from the onboard voltage conversion. An in-system programming header is included on the board to burn the coding environment and upload the program for sensor readings. An additional header connected to the RX and TX pins was included to transmit the readings to the Raspberry Pi. A tactical switch is also used to act as a reset for the MCU as well as two 1206 LEDs and two pins connected to a header to aid in debugging and troubleshooting any issues on the board. A 16MHz crystal is used for the clock and additional 1206 capacitors are used to filter any oscillating voltage.

C. Voltage Conversion

Voltage conversion was achieved by using a design created in Texas Instruments WEBENCH design tool to create a high efficiency switching converter that plugs into a two-cell lithium polymer battery with a nominal voltage of 7.4 volts and a capacity of 1000mAH and a C rating of 20 to provide a constant voltage of 5 volts. This design used TI's TPS565201 regulator with a 3.3µH inductor. This regulator is designed to handle up to four amps which is more than sufficient for the electronics being used. At the estimated amount of current, this regulator will have an efficiency of more than 97%, a small footprint, and a very low bill of materials cost which made it an obvious solution for providing the power needed. Because of the nature of the switching regulator, it is necessary to filter out any oscillating voltage. This was achieved by placing three 100nF 1206 capacitors from Vcc to ground. This

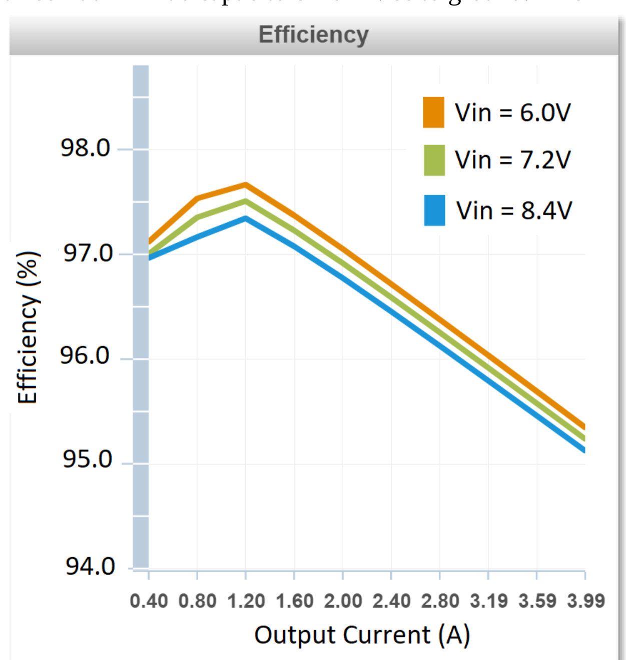

Fig. 7 Efficiency of Regulator Designed in WEBENCH

will allow the oscillating voltage to pass through and act as a short for the DC voltage. A 1206 LED was also used from Vcc to ground to display that the board is being powered.

D. Component Placement and Routing

Once the schematic was created, components were placed, and routes were traced in EagleCAD's board view. The routes were placed manually to ensure the shortest path for components that required quick transfer of information like the crystal, trigger and echo pins for the ultrasonic sensors. It was also important to create the largest traces possible for the battery input because this is where a lot of energy could be lost, or high temperatures could become a problem. The design used a copper pour

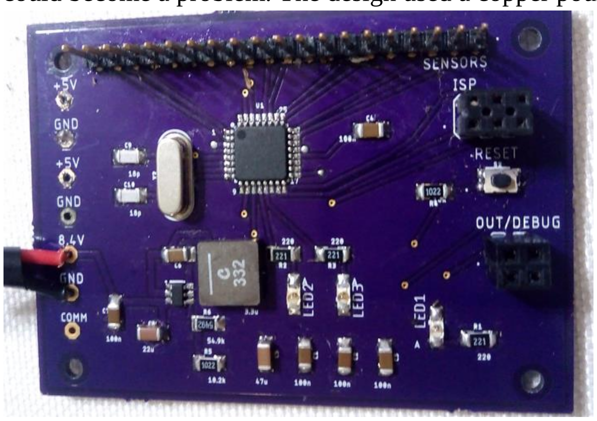

Fig. 8 Completed printed circuit board with components

for a ground and Vcc to eliminate the need for large traces to be taking up space across the whole board. This also immensely simplified the routing process because of the number large number of connections that needed to be made to ground and Vcc that could be made using only a via.

E. Manufacturing and Testing

After the board was designed, Shark was chosen as the manufacturer because of their quick production times and being located in the US eliminated the long shipping times that can come from many Chinese fabrication companies. They also have a reputable name and relatively low prices for three boards. A simple ordering process was also necessary because in order to purchase the board through the sponsor, directions needed to be written out which could get confusing to someone unfamiliar with PCB design. Once the board was received and all components were soldered, the measured voltage to the electronics when connected to the Lip ended up being 4.85 volts when connected to the LiPo which is less than expected but still within the working voltage range per the manuals and datasheets of the components. This could be attributed to the voltage drop across the selected components or a variance in the 1206 resistance used. Issues also arose from the programming of the Atmega which was unresponsive and unrecognized when using the Arduino IDE.

VI. CONCLUSION

Unmanned aircraft are becoming increasingly popular and accessible in recent years and with it arises the need to be able to identify possible threats and a way to deal with these threats. This project is a precursory attempt at understanding the scope of what creating a drone that deals with these issues would entail. This has proven to be a challenging endeavor given the available technology, time frame, and limited budget. The experience gained from the attempt, however, has been invaluable and can hopefully be used as a resource for future projects as an example of what does and does not work well.

In hindsight, the biggest hurdles were not in creating the necessary computer vision algorithms for tracking or detecting obstacles, but in implementing these functions in practice and integrating the hardware with the existing requirements in multirotor flight. One of the biggest constraints was maintaining an acceptable thrust-to-weight ratio with all the additional electronics required for autonomous flight and prey detection. A larger frame, motor, and propellers would be more capable of carrying the additional mass but would have required a larger budget which was already quite large and would be less agile.

BIOGRAPHIES

Dominic Williams is a 21-year old senior graduating with a Bachelor of Science degree in Computer Engineering. His interest in Engineering started around the age of twelve or thirteen years old. During high school is when he decided to direct his focus towards Computer Engineering specifically because of the courses he took and the projects he became involved with.

During his time at the University of Central Florida he became involved with multiple organizations such as the Caribbean Students' Association and the National Society of Black Engineers, where he held executive board positions in both organizations. After graduation he will be pursuing his interests in a software engineering role and hopes to gain more knowledge within the field so he can then give back to help the next generation of engineers.

Ley will be graduating with a Bachelor's degree in Computer Engineering, along with a minor in Technological Entrepreneurship. He developed an interest in math and engineering at a very young age, as he was always trying to break into any electrical devices. Coming into college, he declared his major as a computer engineer; However, it wasn't until the end of his sophomore year that he started developing a burning passion for the field of software engineering. Ley has been able to use his passion for the field to better himself as a software engineer. He had the opportunity to intern with a couple industry leaders such as Intel, Dell, and Deloitte. From those experiences, he gained some relevant working experiences in most of the phases within the software development cycle, application development, process automation and software testing.

Julian will be graduating with a Bachelor of Science Degree in Computer Engineering. His high school courses helped grow his interest in programming and software engineering. He enjoys working with people and developing efficient embedded systems. Julian's previous experience comes mainly in the form of Virtual Reality, embedded systems, service management, and database development; this comes from research and extracurricular opportunities, as well as from internships with a consulting and a launch services company. He is comfortable performing a wide range of tasks including programming, scripting, IP networking, etc.… as well as working with low level software. Furthermore, he enjoys using his engineering knowledge in various fields to smoothly integrate hardware with software for full transition and functionality.

Maverick Dusan is graduating with his Bachelor's degree in Electrical Engineering at the University of Central Florida. A combined interest in physics and electronics drew him to the Electrical Engineering field and the coursework proved to be the most rewarding. Curiosity about the power generation, electric motors, circuit design, and filters has made his academic career fulfilling and job prospects exciting. His internships and

elective coursework have drawn him towards a career working in communications or signal processing.

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