*Autonomous Unammaned Aerial Vehicle Development*

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*Abstract*—

This semester, our autonomous unmanned aerial vehicle group has strived to produce an autonomous UAV (Unmanned Aerial Vehicle) quadcopter. With this drone, we cooperated with the autonomous surface vessel group to compete and meet the requirements of the Roboboat 2021 International Competition. We utilized computer vision algorithms, the drone’s buoyancy, information on receiving and delivering a payload, RTK (Real-Time Kinematic) GPS, and simulations to test the quadcopters real-time movements. By using these tools and equipment, we were able to construct a quadcopter capable of both remote and autonomous flight along with a quadcopter model used in our simulation to replicate the external effects against our drone. Our group conducted several tests learning added information to improve our quadcopter, simulated model, controller, GPS, and computer vision algorithm. The quadcopter has responded well remotely and needs refinement and tuning autonomously. Computer vision and RTK GPS have improved since our preliminary stages but need more testing this upcoming semester. Although we have made substantial progress within the past three months, there is still development with both our hardware and software that needs to be updated. According to our current timeline, we have met the goals set at the beginning of the semester and will continue to accomplish the rest entering the second semester.

# Introduction

This paper contains a description of the objectives, design, and development of an autonomous unmanned aerial vehicle. This project has been in development since the start of the fall 2021 semester. The development of this capstone project is guided by the competition requirements dictated by the Roboboat 2022 International Competition. Very briefly, the desired final product of this project is an unmanned aerial vehicle capable of autonomous and manual flight, including landing and taking off. Much work has been done to meet the requirements of this project, and development thus far has been successful. The timeline for future development has been created, strictly following this timeline will allow the group to reach completion in fulfilling the developmental requirements of the AUAV.

# Background

Over the last decade, unmanned flights have become a dominant front-runner in the world of aerial advancements. As drone flight continues to increase in popularity among private businesses and governments, research has shifted focus to a new advancement in the industry: autonomous flight.

An autonomous aircraft can be classified as one that “does not require pilot intervention in the management of flight” [1]. This is exactly what the autonomous unmanned aerial vehicle (AUAV) presented in this paper is designed to do. Specifically, the AUAV will be designed to assist the US (United States) Coast Guard in missions such as alien interdiction and search and rescue (SAR)

The USCG (United States Coast Guard) currently has only approved the operation of one *unmanned* aircraft platform: The Boeing ScanEagle. As a fixed wing drone, the ScanEagle has offered the service advanced capabilities in flying without the need for an onboard pilot. The ScanEagle, however, requires a flight deck and dedicated launching system. This means that the system can only be used on larger platforms, excluding many USCG units. The USCG is certainly interested in other unmanned aerial systems that would benefit smaller platforms; however, budget constraints have prevented the service from acting. Smaller units, such as small boat stations, have even resorted to using off-the-shelf quadcopters to conduct missions. Regarding unmanned surface and air systems in March 2021, USCG Commandant ADM Schultz said “We look at commercial-off-the-shelf; following, you know, our other fellow services and seeing what they're doing. We have just got a finite amount of R&D dollars… We just don't have a lot of that budgetary maneuver space to take high risks there.” [2] This quote signifies that the Coast Guard is not investing in its own development of an unmanned aerial system let alone an autonomous one. This means that an AUAV for Coast Guard use will only come into the picture after another service purchases and field tests one. This is a process that could take decades, although technology can be developed today for a low cost.

# Objective

This capstone group in conjunction with the Autonomous Surface Vessel (ASV) will be competing in the International RoboBoat Competition next June. As a part of this competition, the UAV will autonomously take off from the ASV, fly to and detect a specific area where it will deliver an object, then afterwards provide arial video feed for the ASV team to use while navigating their course before returning to the ASV and landing.

The most important part of all of this is being able to successfully take off and land successfully on the back of a moving boat. Both tasks can be accomplished in any manner but must be fully autonomous.

Once the UAV is in the air it must fly a search pattern until it finds the specific drop zone. Once detected the UAV will fly over and hover just above the target before delivering the pay load. The pay load is described as a ping-pong ball sized object as only required to be delivered and not picked up as it will be pre-loaded on the drone. This has significant design impacts as we only need a release mechanism rather than a claw which would be used to pick up the object as well.

During the competition, the ASV will be required to navigate a course fully autonomously. After completing the drone specific tasking, the UAV will locate itself above the ASV to provide an aerial lookout. This will come as live video feedback to both the ASV and UAV teams and will be utilizing the UAVs (Unmanned Aerial Vehicle) onboard image processing technology to help the ASV plan its trajectory through the course.

In addition to the above main objectives, the UAV has other niche requirements that must be met to compete. These include all pilots being certified by the FAA, the drone being able to float for 120 seconds, and the drone having a remote kill and various other protocols in place for loss of connectivity.

# system Design

The completed UAV is built on a framework of several independent systems. It is prudent to separate the system into its hardware components and its supporting frameworks. While each workflow in these two categories is certainly dependent, progress is largely made independent of every other element of the drone.

The hardware components of the drone include the S500 generic quadcopter frame, motors, electronic speed controllers (ESCs), a physical flight controller, and mechanisms for landing, floating, and transporting small objects. These elements are largely standalone except for the flight controller, which comprises a critical subsystem.

The UAV relies on the Pixhawk flight controller – a physical device capable of interfacing with the motors, sensors, and inputs – to enable flight. PX4 autopilot is an open-source project to enable autonomous, manual, and other flight modes. PX4 interfaces directly with the Pixhawk autopilot.

Diagram, schematic

Description automatically generated

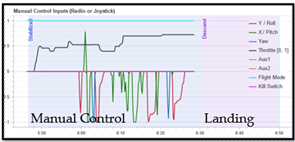
As depicted in figure [#], there are branching frameworks with distinct inputs and outputs at each stage. The Pixhawk alongside PX4 autopilot are the cornerstone of the UAV as it exists today. Each element, from the communications system to the RTK base station, ultimately relay their information to PX4 and enable other methods of control (manual, offboard, or fully autonomous).

The design as demonstrated facilitates all RoboBoat 2022 requirements and further brings more options for the needs of the United States Coast Guard. Demonstrating the capabilities of the low-cost autonomous UAV potentially can draw further funding and research into what similar platforms have to offer for the service.

# Results

This semester, our capstone group successfully built a quadcopter capable of stable, remote-controlled flight while holding all necessary electronics. The drone’s assembly is based on the Holybro S500 quadcopter frame and all component weights were 3D printed. The drone weighs 3.05 pounds. This weight does not include a payload carrying mechanism or floatation device but is approximately 7 pounds below the Roboboat threshold weight of 10 pounds. The drone’s stability was improved based on data from fixed bench testing and two outdoor test flights. The proportional-integral-derivative controller was tuned to balance stability with responsiveness.

To satisfy Roboboat safety guidelines and our prioritization of safe flight, our quadcopter was required to have a remote kill-switch as well as safely respond to a loss of radio control (RC) signal. The remote kill switch is currently located on our RC transmitter; it immediately turns off power to all four motors, regardless of the drone’s current position. Its operation was successfully tested while the drone was secured to our testing bench, and while powered on during an outside test, but not while in the air. Our drone is configured to read the received signal strength indicator (RSSI) values from our RC receiver. If these values fall below a threshold of 50% of full strength or if the RC signal is terminated for two continuous seconds, our drone enters a landing mode. If the drone is receiving GPS data, the drone will return to its original point of takeoff. If not, the drone will slowly lower and land from its current position. This mode was successfully, testing during our second test flight, as seen in Figure #.



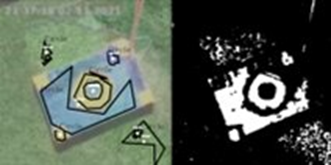
As part of the Roboboat competition guidelines, our drone must be positively buoyant for 120 seconds in the event of a water landing. Our objective was to make the drone indefinitely buoyant to minimize damage to electrical components. To meet this requirement, we fitted outriggers to each corner of the drone. These provide extra foam that, based on density and displacement calculations, will provide 6 pounds of buoyancy: nearly twice the 3.05-pound weight of the drone. Further, the wide spacing of these outriggers was designed to maximize the drone’s stability while on the water. We have not yet performed a buoyancy test of the outriggers while fitted to the drone, but we will provide test results when they are available.

To facilitate low-risk, safe, and cost-effective testing, our group successfully established a software-in-the-loop (SITL) testing environment. We utilized Gazebo, an open-source high performance engine, in combination with PX4, our autopilot software. We designed our drone in Solidworks, a computer-aided design program, to calculate its inertial tensors and to export its visual and collision properties. These files were added to Gazebo and, as a result, we were able to simulate our drone’s maneuvering characteristics. Further, we added a camera to our simulated drone to provide a video feed to our computer vision scripts. We were able to bridge communications between our simulated drone, ground control station, and computer vision scripts to successfully test RC and autonomous flight, as well as failsafe procedures and offboard flight modes.

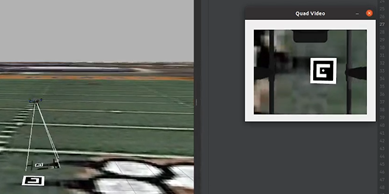


To perform object detection during autonomous flight, the group has used OpenCV, an open-source image recognition library, to write algorithms to detect the platform landing platform. Over the semester, these algorithms were refined to maximize the detection under different lighting conditions and orientations. These scripts yielded a 72% detection rate of the platform under indoor lighting. The in-flight, outdoor detection proved to be far-less successful and identified a need for improvement going forward.





Autonomously landing onboard the ASV is one of our group’s objective requirements. To meet this goal, our group identified a need to translate the computer-vision detection algorithms into drone control commands. Thus, we designed a proportional derivative controller that receives the relative bearing and distance to the target, and outputs the drone’s target velocities in a North, East, Down format. In SITL, we tested this controller in conjunction with a computer vision detection algorithm to send offboard velocity commands to the drone’s controller. It is important to note that this controller was not tuned, that the distance estimates did not change with altitude, and that the controller was clamped to prevent unbounded instability. However, the drone centered over the landing platform and slowly lowered before touching the platform. This test proved successful communications between the image detection algorithm, simulation environment, and controller.



# Conclusions

Our group has made great strides in meeting the given requirements of this project as outlined previously. There are several pieces of this project that were completed in the past three months, and many new concepts were researched and further explored by the group. To date, the group has created a quadrotor unmanned aerial vehicle capable of remote and autonomous flight; the group has begun initial testing of computer vision algorithms, and the group has completed several test flights to assess the quality of both. There is still much more to be completed before the group finds satisfaction with the drone’s performance. The parts of this project that have been completed must be built upon for the group to complete all necessary requirements. Moving into the next phase of this project, we have already created a rough timeline and plan for the implementation of the several required portions of the UAV that we have not yet developed. This includes further development of the computer vision algorithm and its communication to a controller to issue commands to the UAV, further optimization of the UAVs performance, the testing of the drone’s buoyancy, the development of a working payload delivery system, and more. After analyzing the work that has been completed thus far, and the work that has yet to be completed, the group is certainly meeting the timeline objectives to complete this project prior to the termination of the spring 2022 semester. The work ethic seen this past semester must be maintained as we continue future development of this project.

##### References

1. National Research Council. 2014. Autonomy Research for Civil Aviation: Toward a New Era of Flight. Washington, DC: The National Academies Press.https://doi.org/10.17226/18815.