Engineering Fellow (Autonomy) - Technical Assessment Submission - Zachary Friedman-Hill

I. Introduction

This report is separated into 4 sections. Section II outlines the selected components and their sourcing for the UAV and reasoning for each. Section III details the autonomous and operator capabilities of the UAV. Section IV outlines other possibilities for functionality and limitations on the UAV. Finally, Section V outlines a set of testing benchmarks that could be used for verification of the system.

II. Component Selection

A. UAV functionality and relevant components

1) Path Following: To enable predetermined path following based on current tide conditions or geo-location data, a low cost GPS/GNSS sensor was chosen which would be capable of communicating with a micro-controller. The **ArduSimple simpleRTK2B** sensor offers approximately 1.5-meter accuracy, with the option for centimeter precision through SSR corrections. While a standalone GPS/GNSS sensor can provide rough path following, its positioning capabilities can be enhanced with the addition of an Inertial Measurement Unit (IMU) and a camera for position verification. I chose the **MPU-6050 IMU** and **OV5640 Camera** for their affordability and adaptability to various micro-controller types.

2) Propeller Driven: The given UAV design already has selected propellers. However, to calculate an appropriate power system and battery, a theoretical propeller, the **Blue Robotics T500 Thruster**, was chosen. This thruster provides an adequate level of thrust for a large UAV like the Plastic Hunter and is scalable for larger modular devices. At a supply voltage of 16 volts, the thrusters can supply 20.4 lbf of thrust at 25.1 Amps.

3) Battery Life: The battery was selected to ensure a minimum capacity of 2 hours under worst-case scenarios, assuming the motors operate at 75% capacity for the entire duration. Factoring in a safety factor of 1.25, an assumed UAV weight below 1000 lbs, and a minimum final battery charge of 25%, the required capacity was calculated to be 46.875 Ah. Consequently, the **PowerHouse Lithium 16V 48Ah Deep Cycle Battery** was chosen. It was vital to choose a marine battery designed for deep-cycling, as it will undergo frequent charge cycles and maintaining battery health is crucial.

4) System Control and Communication: A Long Range (LoRa) radio was chosen for communication with a home computer on land due to its adaptability to any chosen micro-controller and its long-distance capabilities. The **BulletAC-IP67** was selected for its small footprint, low price point, and long range of up to approximately 5km when equipped with the **LoRaWAN Glass Fiber Antenna**. To control the various sensors, a **BeagleBone Black board** was chosen for its powerful computational resources, Linux-based operating system, and built-in PWM, I2C, and USB.

B. Part List and Sourcing

Component	Vendor	Model/Type	Cost
Motion			
Propeller	Blue Robotics	T-500 Thruster	$690.00
Thruster ESC	Blue Robotics	ESC 500	$105.00
Power			
Battery	Power House	Lithium 16V 48Ah Deep Cycle Battery	$524.99
Sensing			
GPS/GNSS	ArduSimple	simpleRTK2B - Budget	$197.80
GNSS Antenna	GNSS OEM	ANN-MB Multi-Band, High Precision GNSS antenna	$60.79
IMU	Adafruit	MPU-6050 6-DoF Accel and	$12.95
Camera	Adafruit	OV5640 Camera Breakout	$19.95
Communication / Control			
Antenna	RobotShop	Dragino LoRa / LoRaWAN Glass Fiber Outdoor Antenna	$25.00
Radio	Winncom	airMax Bullet Dual-band AC IP67	$129.00
Controller	DigiKey	BeagleBone Black	$52.50

Figure [1] Part and Vendor List

C. Wire Connections and Mounting

1) Power Cables: To accommodate the 40A max current draw of the battery, 8 awg wire connected by XT60 connectors for easy connection/disconnection would be used. The radio requires 24V so a 16V-24V Step Up Transformer will have to be used.

2) Electronic Mounting: All the sensors will be able to be internally mounted in a payload to increase modularability because of their small form factor. The antenna will need to be mounted externally to not impede signal strength. In order to reduce the weight and cost of wiring, the sensors and battery can be mounted close to the propellers in the back.

III. Autonomous and Operator Control

The control system of the UAV would consist of a path generator, PID controller, an Extended Kalman Filter, and a waypoint system.

*1) **Path Generator**:* Receives target headings from the GPS system and generates a set of points from its predicted current position to the goal position.

*2) **Waypoint System**:* Tracks and calculates the error between the current UAV state and target state. This is then passed to the PID controller.

*3) **PID Controller**:* Controls three degrees of freedom: heading, global longitude, and global latitude. The UAV depends on the position of its center of mass and buoyancy to accurately control its motion. Therefore, when the modular device is assembled, the program would need adjustment based on the size it is built to be. The result is a vector of required forces from the two thrusters which would take into account the surge and heave contributions from each.

*4) **Extended Kalman Filter (EKF)**:* The EKF takes sensor data from the GPS, vision, and IMU to estimate the current position in real time. An EKF was chosen over other filters because of its fast prediction operations compared to other Kalman Filters and relatively lower computational complexity. To enhance positioning capabilities in crucial areas like the docking station, vision targets, such as April Tags, could be integrated into the camera vision system for more precise location estimation.

To facilitate manual control of the UAV, the Path Generator and Waypoint System would be interfaced through a locally hosted system. This could be accessed via a radio connection, with waypoints manually set to control the UAV's movements. Additionally, since the thrusters are directly controlled by the micro-controller, a manual control system could be designed for full motion control of the UAV using a joystick.

IV. Other Possibilities, Considerations, and Limitations

1) Limitations & Considerations: This design and choice of sensor suite could be limited by various factors affecting the UAV's capabilities. Extreme weather conditions, such as high winds, rough tides, or icy conditions, might impact navigation, stability, and sensor performance, preventing the UAV from following its predetermined paths. A limited communication range due to distance, obstructions, or signal interference could also restrict the device's manual operational range and real-time monitoring capabilities. The UAV's positioning algorithms' effectiveness also heavily relies on the onboard sensors' accuracy and reliability. Any limitations in resolution, range, and environmental interference would affect its ability to accurately track its position. Lastly, even though the battery capacity calculations include a safety factor and consider a worst-case scenario, the battery might still deteriorate over time or the UAV could get stuck during operations, causing it to lose power before returning and potentially becoming stranded. My proposed design greatly depends on the environment remaining unchanged. It can detect new or moving obstacles like wildlife or other boats through a camera-based vision system. However, without advanced sensors such as sonar or stereo-graphic cameras, the UAV's ability to estimate distance and adapt would be significantly limited.

2) Other Possibilities: Accurate pose estimation of the UAV is the most difficult and susceptible to error parts of the vehicles design. One possible way to improve this would be through swarm robotics. With multiple UAVs operating within the same body of water, the different UAVs would be able to determine their distances from each other through triangulation of radio signals and relative distance from signal strength. Distributed localization algorithms would allow groups of three or more UAVs to distributively filter their locations and compare sensor data for a more comprehensive understanding of their environment.

V. Testing Performance Benchmarks

In order to verify that the autonomous and manual operational controls of the UAV were successful, a set of tests would need to be developed. Below is a list of ways that this could be tested.

1) **Navigation Accuracy Tests**: Validating the accuracy of the navigation system by comparing its estimated position readout to a known location it's placed in.
2) **Autonomous Navigation Test**: Having the UAV navigate through a predetermined closed course to prevent possible damage to the UAV or environment.
3) **Communication Range Tests**: Measure the reliability and range of the communication link between the UAV and the control station under different environmental conditions and interference levels.
4) **Emergency Response Tests**: Simulating failure scenarios such as loss of communication, propeller failure, or adverse weather conditions to assess the vehicle's ability to execute predefined emergency procedures and reduce the risk to itself and the environment.
5) **Regulatory Compliance Tests**: Verifying that the vehicle complies with regulations and standards for unmanned maritime systems such as safety and EPA regulations.

References

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