Team Raim UAV design report for maritime RobotX challenge (2024)

***Abstract*—This report is aimed to provide the vision of team Raim by outlining the design, development, and testing of a quadcopter UAV built for the Maritime RobotX Challenge, optimized for image processing using Python. The quadcopter platform was selected for its stability and maneuverability, crucial for precise tasks like real-time data collection. Key design features included centralized weight distribution and a modular structure for easy repairs. Testing was divided into hardware and image processing. Hardware components, including motors and sensors, were validated independently, while the image processing system was tested using Python and OpenCV for distance measurement, shape, and colour detection. Initial remote-controlled flight tests revealed stability issues, which were addressed through redesign and PID tuning. Testing was divided into hardware and image processing. Hardware components, including motors and sensors, were validated independently, while the image processing system was tested using Python and OpenCV for distance measurement, shape, and color detection. Initial remote-controlled flight tests revealed stability issues, which were addressed through redesign and PID tuning.**

I. INTRODUCTION

As the use of unmanned arial vehicles (UAVs) becomes more popular in industry, the research and development that goes into these devices becomes of greater interest. By undertaking a hands-on research project and utilizing engineering principles, a UAV with multiple capabilities was built and tested. By entering the Robotx competition the UAV was optimised in order to complete a list of specified tasks, discussed in section 2 , 3 and 4.

II. COMPETITION STRATEGY

When revising a plan that would give the team a good competition advantage, these main points were a priority.

1. Ease of Repair (Modular Design Approach)

To minimize downtime due to repairs or component upgrades, we prioritized a modular system design. This allows for quick replacement of parts without the need for a complete redesign. In a competition where accidental crashes during testing and performance are likely, this design offers a faster turnaround for repairs, giving us a clear operational advantage. A more complex, integrated design would have required advanced repair skills and tools, increasing both the time and effort needed for maintenance.

2. Familiarity and Team Expertise

Given the competition's time constraints, we leveraged existing team expertise, choosing tools and technologies that team members were already familiar with. For instance, we opted to use Python for image processing, even though other languages or software could offer more advanced capabilities. This choice allowed the team to be more efficient and productive in achieving core project goals within the limited timeframe, avoiding the learning curve associated with unfamiliar tools.

3. Cost Effectiveness

Budget management was critical to ensuring that we could sustain progress throughout the competition. By limiting large expenditures and opting for cost-effective components, we ensured that funds were available for backup parts and unexpected costs. This approach allowed us to prepare for potential issues closer to competition time, enabling us to replace components easily without affecting overall project timelines or performance. Having readily available backups provided us with an important buffer against setbacks.

4. Power Consumption and Flight Time

For tasks 7 and 8, which required extended flight times, we prioritized a higher-capacity battery to provide the necessary endurance. To complement this, we deliberately chose less power-hungry components, such as a lower-resolution camera and simpler sensors. Although these components may not offer the highest level of sophistication, they enabled us to achieve the longer flight times required to complete competition tasks efficiently. This trade-off in sophistication vs. flight time was crucial, as the ability to operate longer without compromising task completion was a significant advantage in the competition.

III. DESIGN STRATEGY

1. Quadcopter as the UAV Platform

A quadcopter was chosen as the body for the UAV based on the following advantages:

Stability and Hovering Capabilities: The quadcopter's four rotors provide excellent stability and hovering abilities, allowing it to stay stationary for precise image processing and data collection tasks like surveillance, inspection, and mapping.

Vertical Takeoff and Landing (VTOL): The quadcopter design offers VTOL capabilities, ideal for environments without a runway or with limited space.

Weight Distribution and Balance: The symmetrical configuration of the four motors and the centrally mounted camera and range finder ensure even weight distribution, which is essential for flight stability and maneuverability.

2. Component Placement and Wiring

Power Management and Motor Wiring: The motors were wired directly to the power distribution board (PDB), ensuring reliable and direct power supply. The camera also requires more than 12 volts, so it was wired to the same PDB. This setup ensures that all critical systems receive the necessary power without additional converters, minimising complexity.

Battery Placement: The battery was mounted on the bottom of the UAV using a camera mount for balance. Placing the battery at the bottom helps maintain a low center of gravity, which improves stability and ensures the quadcopter remains flat during flight, reducing unwanted tilting that could interfere with image processing accuracy.

Power Board Placement : The power distribution board was mounted below the other components to reduce electromagnetic interference (EMI). Electromagnetic interference can disrupt sensor readings, particularly for the camera and range finder. By placing the PDB lower in the stack, further away from sensitive electronics, we minimized this interference, preserving the accuracy of the sensor data.

Accessibility and Modularity : All critical components (camera, flight controller, GPS, sensors, etc.) were mounted on the top of the UAV, making them easily accessible for maintenance and adjustments. This configuration allows for quick component swaps without dismantling the entire structure.

Hot-Swappable Components: The design incorporates the use of pin connectors between components, allowing for hot-swapping parts when necessary. For example, the camera or range finder can be replaced quickly without extensive rewiring. This modular approach increases the repairability and upgradability of the UAV, minimizing downtime during field operations.

3. Material Choice and Weight Distribution

Minimal Material Usage: The design philosophy was to use the least material possible to maintain the structural integrity of the UAV while reducing unnecessary weight. Lightweight material was selected as carbon fibre to ensure that the UAV is strong but doesn’t sacrifice endurance or efficiency due to excess weight.

Weight Balance: Special care was taken to ensure that the overall weight balance is centered, as an off-balance quadcopter consumes more energy and reduces flight efficiency. This careful design consideration improves the flight time and helps maintain smooth, stable flights, which is critical for the precision required in tasks like object detection and mapping.

Figure 1. UAV component assembly

A circular mount was designed to compliment the structure of the quadcopter by also considering the importsnce of blanace within the system.

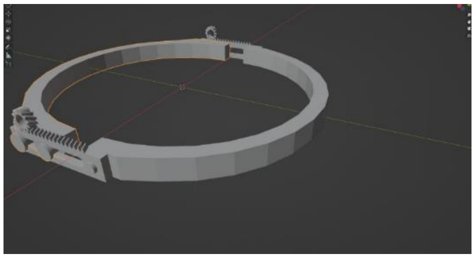

Figure 2. UAV mount

III. CALCULATION CONSIDERATIONS

The lift generated by each rotor:

$$L = c_l \cdot 0.5 \cdot \rho \cdot A \cdot v^2 \qquad (1)$$

The thrust produced by each motor and rotor system:

$$T = c_T \cdot \rho \cdot n^2 \cdot D^4 \qquad (2)$$

Power required by the motors and system:

$$P = V \cdot I \qquad (3)$$

Flight time based on battery capacity:

$$t = (C \cdot \eta)/p \qquad (4)$$

IV. TESTING STRATEGY

The testing strategy of the UAV was devised into two different sections in the early stages in order to maintain time efficiency. These were image processing and hardware, this sectioning of the UAV can be seen in figure…. in which key components and the software used are identified.

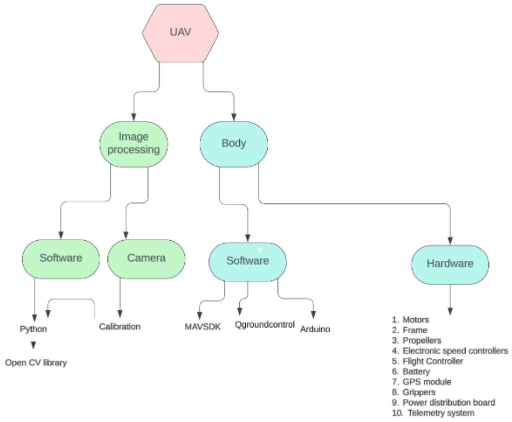

Figure 3. Flow chart of UAV testing strategy

Individual component in lab testing:
Before the system is put together, various components are tested independently.

Camera

The first step in the testing of image processing was to recalibrate the camera and redefine the key properties such as aspect ratio and focal length in pixels. This was done by utilising python using a checkerboard method with the camera in various angles and positions as seen in figure….. . As this stage of the UAV development is still in the early stages, an external power source of 12V is used to power the camera for testing.

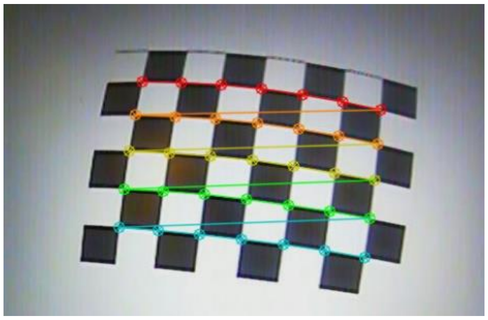

Figure 4. Camera calibration

Once the camera properties are confirmed, the coding associated with the image processing in python using open CV is tested using the props required for the tasks, in this early phase of testing only distance , centroids , shape identification and colour detection are tested with the camera in various angles and positions.

Hardware

Each hardware component was individually tested to ensure proper functionality before integrating the image processing system. The motors were tested using QGroundControl software, which was interfaced with the Pixhawk autopilot system, a key component of the UAV that supports custom-built configurations. The GPS, gyroscope, telemetry and other essential sensors were also verified using this software to confirm their accuracy and responsiveness. The rangefinder however was teste using Arduino, which allowed the verification that it gave the correct outputs for the distance. Additionally, the required power inputs were thoroughly tested using laboratory power supplies to ensure safe and adequate power delivery to all components.

Remote controlled flight testing

The first flight test was conducted using a remote-control system, this was done in order to ensure that the correct settings had been applied and that the components all worked correctly. After the first flight test, challenges were presented in which the stability of the UAV needed to be investigated, the take-off and landing proved to present challenges in balance, when the drone frame was damaged time was taken to improve on these defects.

After the framework was redesigned, the testing strategy became clearer, the flight testing was then split into:

1. Take off and landing – Could it take off and land without tipping over?
2. Hovering – Could it hover at a set altitude without drifting or wobbling
3. Internal stability – Could it perform maneuvers and return without losing stability?

These testing goals were achieved through PID tuning and the monitoring of pitch, yaw and roll. Again, it is important to note that the safety of the UAV was considered by having a return to home feature when flying.

4.3 Unmanned flight testing

In order to achieve unmanned flight, testing the telemetry system with Mavsdk and python on a computer was crucial. The following goals to be achieved were set.

1. Successful data collection of UAV status, such as GPS location, pitch, yaw, roll , battery status and heartbeat messages.
2. Arming and disarming the UAV
3. Achieving flight whilst being able to switch from manual to autopilot mode
4. Realising the competition task objectives

4.4 Elements testing

One of the most crucial aspects of testing the UAV was seeing how it would perform in different environments, such as weather conditions, and checking whether the waterproofing and floating capabilities were optimal. Flight tests were conducted in windy conditions both manned and unmanned to see if stability would remain. The tests that involved bodies of water were conducted in the following way.

1. Static water test – will the UAV float, or submerge to some degree?
2. Propeller spray test – Will the UAV remain stable whilst the propellers are powered on ?
3. Water contact test – Is the waterproofing sufficient ?

V. ACKNOWLEDGMENTS

We would like to acknowledge and thank Dr Shou-Han Zhou for his efforts in supporting us and supervising the project. We are also greatly appreciative and thank our sponsors who helped us achieve our goals, South Wales Institute Of Engineers Educational Trust (SWIEET), Australian Institute Of Marine Science , James Cook University Australia and Cardiff University. We are thankful to Vadex for supporting us in the electronics lab.

REFERENCES

[1] RobotX Challenge, [Online]. Available: https://robotx.org/. [Accessed: Oct. 8, 2024].

[2] AUVSI Foundation, "Unmanned Systems: A Comprehensive Overview," [Online]. Available: https://www.auvsi.org/. [Accessed: Oct. 8, 2024].

[3] J. S. Frew, "Design of a Low-Cost Autonomous UAV System," in Proc. IEEE Aerospace Conf., Big Sky, MT, USA, Mar. 2017, pp. 1–8.

[4] T. W. McLain, "An Introduction to Small Unmanned Aerial Systems," in University of California, Berkeley, Course Materials, 2018, [Online]. Available: https://courses.engr.berkeley.edu. [Accessed: Oct. 8, 2024].

[5] E. G. D. S. A. A. A., "An Introduction to the Use of Drones in Engineering Education," in Engineering Education, vol. 20, no. 4, pp. 65–72, Nov. 2019.

[6] J. D. Anderson, Fundamentals of Aerodynamics, 5th ed. New York, NY, USA: McGraw-Hill, 2010, pp. 245–270.