Optimized Route Planning and Precise Circle Detection in Unmanned Aerial Vehicle with Machine Learning

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Abstract. This research paper presents a distributed architecture for optimized route planning and precise circle detection in unmanned aerial vehicle with machine learning. The architecture focuses on three key areas: motion planning, control, and the integration of a web application with machine learning (ML) for autonomous drones. By leveraging advanced planning and control algorithms, the architecture enables UAVs to navigate dynamic environments, execute complex maneuvers, and maintain stability. The ML-integrated web application enhances decision-making for detection, optimizing route planning. Extensive simulations and real-world experiments validate the effectiveness and scalability of the proposed architecture, making it a valuable tool for advancing research in autonomous UAV systems.

Keywords: Autonomous unmanned aerial vehicles · distributed architecture · motion planning · control · machine learning · web applications · experimentation

1 Introduction

In recent years, the field of intelligent unmanned aerial vehicles (UAVs) has grown quickly, and now it presents a wide range of distributed autonomous robotics research opportunities [1, 2]. With the aim of designing controllers that facilitate the autonomous flight of a UAV from one waypoint to another in comparison to prior research which has concentrated on low level control capabilities. The most frequent mission scenario entails positioning sensor pay-loads for data collection, with the data ultimately being processed offline or in real-time by ground workers. In recent combat scenarios, the use of UAVs in mission duties like surveillance [3, 4], videography, search and rescue [5] etc., has grown increasingly crucial and it is projected that they will continue to play crucial roles in any future conflicts.

In civil applications such as remote sensing, precision agriculture [6–8], etc., intelligent UAVs also play a vital role. There is a need to build more advanced UAV platforms for both military and civil uses which can offer more emphasis on the development of intelligent capabilities and capacity to communicate with human operators and other

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robotic platforms. Low- level control is no longer the primary focus of research. Instead of this, sophisticated software architectures that integrate low level and decision-level control are being used. These should thus function seamlessly with larger C4I2 systems with network-based architectures. These systems are necessary to provide the capabilities needed for the upcoming, more complicated mission requirements, and they serve as an excellent testing ground for distributed AI technology.

Path planning algorithms [9–11] that produce collision-free paths, precise controllers capable of executing such paths even in the presence of unfavorable weather conditions (such as wind gusts), and a dependable mechanism that coordinates the two are necessary for navigating in environments where there are many obstacles close to building structures.

In a distributed software architecture utilized in a fully deployed rotor-based unmanned aerial vehicle (UAV), a method for combining path planning techniques with a path execution mechanism—including a reliable 3D path following control mode—is described in this study. There are descriptions of many of the software parts utilized in the distributed architecture. The elements in charge of path execution are given special attention. The method considers the varied time properties and dispersed communication of a path-planning algorithm and a path-following control mode [12]. To operate UAVs in urban settings, they also feature a safety device.

Unique challenges posed by the specific scenario necessitate precision control, maneuverability, and payload delivery capabilities [13]. The scenario requires the drone to follow predefined flight paths, locate a tar-get, and execute precise payload deployment [14]. In this study highlighted the importance of developing a specialized quadcopter tailored to meet the specific requirements outlined in the problem statement. Following a thorough analysis of the challenge, devised a rigorous design strategy to construct a quadcopter capable of successfully accomplishing the assigned tasks. To optimize stability and longevity while minimizing weight, implemented a 505mm wheelbase and utilized lightweight yet durable materials. The frame construction incorporated aluminum rods for enhanced strength, while medium density fiberboard (MDF) provided structural support integrity. A true X-frame design was employed to ensure stability without compromising on the accommodation of essential hardware components.

This quadcopter's primary flight controller is the Pixhawk 2.4.8, which provides dependable and accurate control over the drone's flight parameters. The popular open-source autopilot program Ardupilot was loaded into Pixhawk's firmware. The control and navigational abilities required to carry out complex flying patterns were provided by this combination. Also installed a Raspberry Pi microprocessor on the quadcopter to precisely locate the target and carry out the payload delivery duty. This microcontroller was developed to carry out real-time image and video processing. The primary camera recorded and processed video inputs using sophisticated coding techniques, allowing the precise detection and identification of the target area. Numerous flying tests were conducted to experimentally evaluate quadcopter de-sign, replicating the tasks specified in the problem statement [15–17]. These experiments verified the viability of idea, as the quadcopter successfully carried out the intended flying patterns, located the target region, and dropped the cargo precisely. The data gathered from the testing shows that suggested quadcopter design is trustworthy and effective for the intended purposes (Fig. 1).

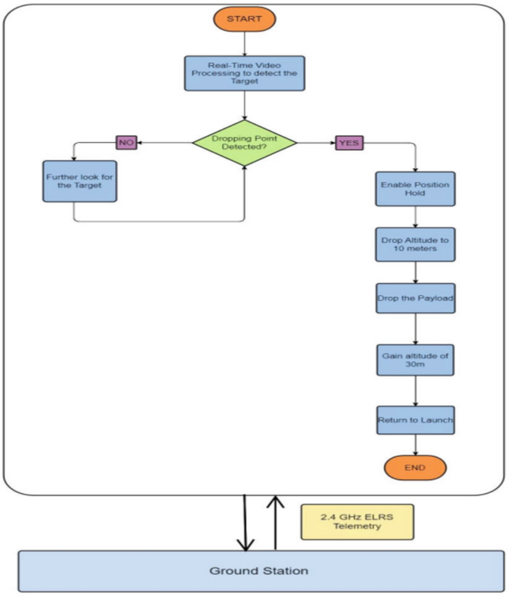


Fig. 1. Work Flow Flowchart

2 Design Process

Thoroughly examined the specifications outlined in the problem description during the design process of the drone frame. It was crucial to ensure that the frame could securely accommodate all the necessary components, allowing the drone to effectively fulfil the designated objectives of the research experiment. As to consider several things during the design process, including the size and weight of the individual parts, the necessity for structural stability, and the drone's overall balance. These factors had to be considered to guarantee that the frame could sustain the hardware while still performing at its best during flight.

2.1 Frame Selection

First, a 200-g package with dimensions of 5 × 10 × 10 cm^3 must be delivered by the drone on its own. Additionally, throughout the mission, the drone must maintain a flight altitude of 30 m.

During the design phase, considerable considerations were made in order to satisfy these needs. Choosing the right propellers and a propulsion system that could produce enough thrust to sustain the payload and maintain stable flight was an important consideration. 10-inch propellers were selected to accomplish this as they were discovered to produce the roughly necessary thrust for the load delivery.

It was crucial to strike a compromise between clearance and stability in order to guarantee appropriate clearance between the numerous components mounted on the frame. Therefore, it was decided that arms 20 cm in length were ideal. This length permitted a 2 cm clearance between the parts, guaranteeing adequate room for their proper operation without affecting the overall stability of the drone's construction.

3 Modelling of Frame

It was crucial to design the quadcopter's frame using 3D modelling software before beginning the construction process. This process made it possible to precisely visualize and evaluate the frame's structural features. Autodesk Fusion 360, a widely used application for design and engineering, was selected as the programmers for this job. The quadcopter's arms and body were designed together with the proper frame arrangement throughout the design phase. To make sure the frame configuration satisfied the needs for stability, maneuverability, and payload capacity, several factors were considered. In Fusion 360, the frame was digitally built when the arrangement was decided upon, considering the necessary dimensions and characteristics. A thorough structural analysis was carried out to evaluate the frame's performance and structural integrity. The material characteristics and structural dimensions were entered into the software for this study. The frame may be simulated both statically and dynamically under various forces, including thrust, gravity, and torque, thanks to Fusion 360's simulation capabilities. The software may assess the frame's performance in terms of static stability and dynamic response by applying computed force values to points inside the frame [18]. To enhance the drone's design, multiple iterations were conducted. The frame's configurations were modified at each iteration, and simulations were utilized to evaluate the frame's performance. The aim was to develop a frame that fulfilled the requirements of the operational stage while ensuring stability, durability, and maneuverability [19–21].

3.1 Weight Estimation

Carefully chose the quadcopter's important parts and considered the materials for the frame construction in order to satisfy the requirements of the problem description.

Estimated the overall weight of the drone to make sure it would stay within the allowed weight ranges. The data below shows the estimated weight distribution for some of the key elements.

After estimating the drone's weight and went on to compute the thrust needed to lift it. Maintaining a 2:1 thrust-to weight ratio is a usual guideline. The thrust needed for each motor was estimated to be around 700 g based on this ratio. If a quadcopter arrangement were used, the total thrust needed to lift the entire drone would be twice its own weight.

Drone Total Weight Approximation: 1400 g.

Drone Lifting Total Thrust Needed: 2800 g.

Each motor's thrust is 700 g.

These calculations made sure that the motor thrust, and the components chosen would be enough to achieve controlled and steady flying. Are able to create a quadcopter that could successfully carry out the specified flight maneuvers and payload delivery tasks mentioned in the challenge description by carefully evaluating the weight and figuring out the thrust needs.

3.2 Frame Design

- The materials used in the fabrication of the drone for the research experiment were meticulously selected to achieve an optimal combination of durability and lightweight design. Medium-density fiberboard (MDF) and aluminum were chosen as the primary materials to fulfil this objective.
- The drone's frame was constructed using MDF, which has a good strength-to-weight ratio. The overall weight of the drone is optimally maintained, while this material provides great structural integrity. The drone is kept lightweight by using MDF, enabling effective flight maneuvers and reducing battery usage.
- On the other hand, aluminum was chosen due to its outstanding durability and light weight. In locations that needed extra strength, such as crucial joints and supporting structures, it was employed strategically. The use of aluminum components improves the drone's overall resilience without considerably adding to its weight.

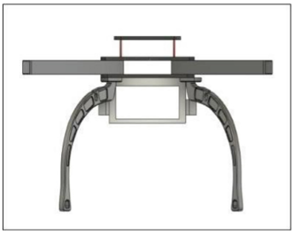


Fig. 2. Side View of Drone

Fig. 3. Isometric View

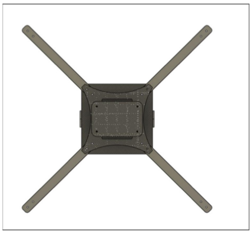


Fig. 4. Top View of Drone

- Drone design achieves a harmonious balance of lightweight construction, durability, and ease of maintenance by carefully examining the selection of materials and utilizing modern design and production techniques. This guarantees that the drone will function optimally and have an extended operational lifespan, even under the demanding conditions of its designated operational phase. As shown in Fig. 2, 3 and 4 the side, top and isometric views are available.
- Structural Properties of the material chosen: The stability, toughness, and general performance of the quadcopter are greatly influenced by the structural qualities of the materials used in its construction. In this instance, medium-density fiberboard (MDF) and aluminum were chosen as the materials. MDF is a composite wood product created by mixing resin and wood fibers under intense pressure and heat. When choosing the MDF for the quadcopter's construction, the following characteristics were considered: Measured carefully to establish a balance between weight and structural soundness, the MDF used had a thickness of 4.5 mm. Although thicker boards could offer more strength, they would also add to the quad-copter's weight, which might have an effect on how well it flies. The MDF used for this project has a density of 750 kg/m^3. For the quadcopter's construction to maintain an ideal weight-to-strength ratio, this figure, which represents the mass of the material per unit volume, is crucial.

Due to its light weight and excellent strength, aluminum was chosen in addition to MDF for some of the quadcopter's structural components. The aluminum used was considered for the following qualities:

The aluminum sheets that were used were 1 mm thick. To achieve minimal weight while maintaining appropriate strength for the components where aluminum was used, this relatively thin gauge was chosen.

Aluminum has a high modulus of elasticity (MOE), which is calculated to be 70300 N/mm^2. Due to this characteristic, aluminum parts can tolerate bending loads and keep their structural integrity during flying maneuvers.

Quadcopter design achieves a balance between weight, strength, and rigidity by carefully examining the structural characteristics of the selected materials, particularly MDF and aluminum. This makes it possible for the drone to endure the forces generated by the aerodynamics of flight, maintain stability, and fulfil the specific objectives outlined in the designated research tasks.

4 CG Calculation

4.1 The Word "Data" is Plural, not Singular

- Used a strict approach to precisely estimate the drone's center of gravity (CG). Firstly, it strung a thread from one of the drone's arms to the end of the drone. It made sure the string's line passed through its pivot point and remained perpendicular to the ground by paying close attention to it. By doing this, were able to create a reference line for our measurements.
- Again, then repeated the process by fastening threads to several spots along the drone's frame. To be more precise, we fastened strings to the pivot point where the arm and cover plate converge, the border of the bottom plate, and the center of the top plate. Each string created a line from its connection point that crossed the earlier established reference line.
- Determined the precise location of the drone's center of gravity by examining the intersection locations of these lines. The intersection that was indicated represented the drone's estimated CG location. Through this process, we were able to establish that the drone's center of gravity (CG) was situated precisely 15mm above the top plate and at the center of the true X frame design.
- To ensure the drone's stability and balanced flight characteristics, it is crucial to carefully evaluate the center of gravity (CG). So, to improve the drone's performance, control, and maneuverability during the flight evaluation by accurately determining the CG location. Furthermore, utilizing this information, although can arrange additional components, such as the payload, in a manner that preserves the overall stability and flight dynamics of the drone.

5 Displacement Caused by Stress

Although carried out stress analysis with computer simulations to assess the drone frame's structural robustness as shown in Fig. 4. In order to replicate the highest load that the frame might encounter during flight, applied a force of 10N at the end of each arm in this analysis. Were able to ascertain the stress distribution inside the structure by applying these forces and considering the material characteristics of the frame.

Were able to evaluate the drone frame's structural integrity and pinpoint any potential weak places or regions that would encounter excessive stress thanks to the stress analysis. Able to locate areas of high stress concentration that may need reinforcement or design adjustment by analyzing the stress distribution. The Displacement caused by stress is also shown in Fig. 5.

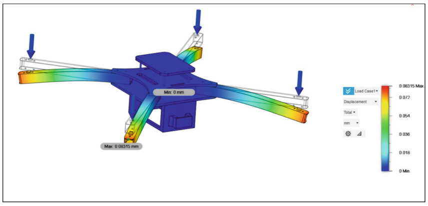


Fig. 5. Displacement Caused by Stress

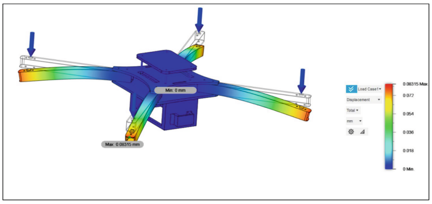


Fig. 6. Result of Stress Analysis

5.1 Fabrication of the Drone

- The fabrication procedure was started to assure the build's structural integrity and its capacity to withstand the predicted forces after carefully choosing the materials and performing a structural analysis of the quadcopter model (Fig. 6).
- Precision CNC cutting of medium-density fiberboard (MDF) sheets for the quadcopter's main body was the first step in the construction process. This method made sure that the structural components' dimensions were precise and constant. The aluminum arms were additionally saw- cut, ensuring their sturdiness and strength.
- Custom-designed 3D-printed pieces were integrated to further improve the quadcopter's appearance and operation. These components were created by additive manufacturing processes using PETG (Polyethylene Terephthalate Glycol) and ABS (Acrylonitrile Butadiene Styrene) filaments. This method made it possible to design complex components that were specially tailored to the needs of the quadcopter.
- The various parts of the quadcopter's frame were fastened and connected during the construction stage using M3 bolts of the ideal size. While minimizing extraneous weight, adequate fastening was ensured by the careful selection of bolt size.

5.2 Detailed Weight Breakdown

The comprehensive weight breakdown sheds light on the relative weights of the different quadcopter components. These parts include the top plate, bottom plate, and arms that make up the structure as well as crucial hardware like the Raspberry Pi, Pixhawk, GPS devices, webcam, and ESCs. Propellers, motors, a mounting plate, a standoff, a VTx, and a camera are additional parts that help the quadcopter function and perform.

The weight breakdown also takes into consideration the battery, GPS stand, dropping mechanism, ELRS data telemetry, and other wires and parts required to secure the peripherals. These elements are essential to fulfilling the objectives of the research experiment. When all the components stated above are considered, the quadcopter's overall weight is 1179g. This weight is a crucial factor in ensuring the quadcopter's optimum balance, stability, and flight qualities throughout the competition. Engineers and researchers are able to make educational decisions about component choice, location, and overall weight management thanks to the precise weight breakdown, which is helpful for the design and optimization of the quadcopter.

TensorFlow's Object Detection Mechanism:

There are several processes involved in object detection using TensorFlow:

The Single Shot Multibox Detector (SSD) and the You Only Look Once (YOLO) architecture are two pre-trained object detection models that are available through TensorFlow. As an alternative, you can use TensorFlow's APIs to train your own unique object identification model.

Training: When an object detection model is trained, labelled datasets are fed into it, and its parameters are optimized using methods like gradient descent. High-level APIs from TensorFlow, like the Object Detection API, make the training process easier.

Inference: After been trained, the object detection model can be applied to forecast new, unforeseen data. The trained model may be loaded, inference can be done on pictures or videos, and bounding box coordinates and class labels of detected objects can be extracted using TensorFlow's tools.

6 Dataset

A dataset is essential for the precise target identification and successful execution of the payload drop in the context of the given code and the research scenario [10]. To train and test machine learning models, datasets are collections of labelled samples. A picture or video with matching annotations that define the bounding boxes around the items of interest makes up the majority of datasets used in object detection. The object detection model is trained using these annotations as ground truth data.

Unmanned aerial vehicles (UAVs) use a variety of sensors and equipment to gather a wide range of data. These data are crucial for successfully completing UAV missions and getting insightful information for many applications. Here is a more thorough explanation of the kinds of information that UAVs gather: Imagery and Video Data: UAVs are fitted with cameras that record both still images and moving video. These cameras can include thermal, multispectral, hyperspectral, RGB (Red, Green, and Blue), and infrared cameras. While thermal cameras use infrared radiation to illustrate temperature differences, RGB cameras only record images produced by conventional visible light. In order to analyse certain vegetation or material qualities, multispectral and hyperspectral cameras record images in a number of or narrow bands across the electromagnetic spectrum.

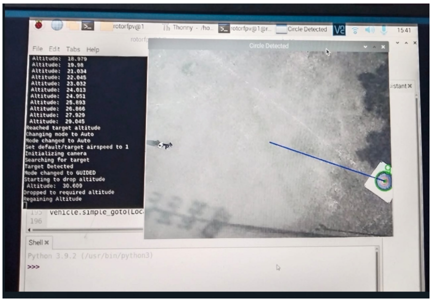
6.1 Information about GPS and Navigation: UAVs rely on GPS technology to determine their location and navigate securely. GPS data is necessary for flight planning, waypoint navigation, and preserving aircraft stability. UAVs may also employ a variety of navigation devices, including Inertial Measurement Units (IMUs), barometers, and compasses, to enhance their sensing and orienting abilities.

6.2 Info from Payload-Specific Instruments: Other data kinds might be gathered, depending on the mission and payload setup of the UAV. UAVs may, for instance, be equipped with sensors for monitoring animals, water quality, or air sampling in the course of scientific study.

6.3 Sensor Information: In order to gather information beyond imagery, UAVs are fitted with a variety of sensors. For weather forecasting and climatological studies, atmospheric sensors detect air pressure, temperature, humidity, and other meteorological factors. Gas detectors are useful for environmental monitoring, industrial safety inspections, and finding gas leaks since they can identify and measure a variety of gases.

7 Result

We accomplished the objectives of the experiment using our custom-built quadcopter, equipped with the Pixhawk flight controller and the Raspberry Pi microcontroller. By showcasing the design, implementation, and evaluation of our drone system in this research paper, we illustrated its effectiveness in addressing the challenges described in the problem statement. Here are some of the output photos are available where we see the terminal of Raspberry Pi and how drone is optimising after the circle detection in Fig. 7 and Fig. 8.



```
 Altitude:  18.979
 Altitude:  19.98
 Altitude:  21.034
 Altitude:  22.045
 Altitude:  23.032
 Altitude:  24.013
 Altitude:  24.951
 Altitude:  25.893
 Altitude:  26.866
 Altitude:  27.929
 Altitude:  29.045
Reached target altitude
Changing mode to Auto
Mode changed to Auto
Set default/target airspeed to 1
Initializing camera
Searching for target
Target Detected
Mode changed to GUIDED
Starting to drop altitude
 Altitude:  30.609
Dropped to required altitude
Regaining Altitude
```

```
195  vehicle.simple_goto(Loc
196
```

```
Python 3.9.2 (/usr/bin/python3)
>>>
```

Fig. 7. Circle detection by drone

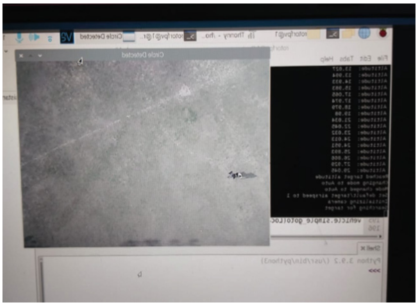


Fig. 8. Optimization in circle detection

8 Conclusion

In conclusion, the application of machine learning techniques in UAV route planning and circle detection has showcased promising results, providing a solid foundation for future research and development in the field. As the demand for efficient and accurate UAV operations continues to grow, these findings contribute to the advancement of autonomous systems and pave the way for new possibilities in various industries. With further refinement and validation, the optimized route planning and precise circle detection methods discussed in this paper can lead to safer, more efficient, and more intelligent unmanned aerial vehicles.

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