Design of an Amphibious Drone based on Monocular Vision for Lake Monitoring and Rescue

Qiancheng Ma[1] and Jundong Qi[2*]

[1]College of Hohai-Lille, Hohai University, Nanjing 210098, China
[2]Southampton Ocean Engineering Joint Institute, Harbin Engineering University, Harbin 150001, China
*Corresponding email: 2021282211@hrbeu.edu.cn

Abstract. The freshwater available for direct human use is extremely scarce compared to the total amount of water on Earth. Most of this freshwater is located in freshwater lakes. As human civilization progresses, the ecological destruction of freshwater lakes has become increasingly common. Drones have become ideal tools for lake monitoring due to their high mobility and wide coverage. However, these drones mostly do not directly contact the water, which introduces some limitations. To overcome these limitations and improve lake monitoring efficiency, this paper proposes an amphibious drone. This drone directly contacts the water body. It is equipped with monocular vision sensors and water quality sensors. The study validates the feasibility of the floating structure by comparing the displacement to the displacement mass ratio. The feasibility of the vision and water quality modules is verified through practical testing. The study combines the YOLO algorithm with optimized neural network algorithms and the inverse concentration gradient algorithm. The monocular vision sensor and water quality sensor achieve precise positioning and dynamic tracking of pollutants. This study validates the superiority of amphibious drones in monitoring freshwater lakes. It provides a new solution for future protection and monitoring of freshwater lakes.

Keywords: Amphibious Drone, Monocular Vision, Environmental Monitoring, Pollutant Tracing, Freshwater Lakes

1 Introduction

On Earth, freshwater accounts for 2.5% of all water. However, of this 2.5% of fresh water, about 68.7% is in glaciers and permanent snow, and about 30.1% is in groundwater (most of which is deep and hard to use). Only 1.2% of fresh water is surface water and other accessible fresh water [1]. Of this 1.2% accessible fresh water, 87% is in freshwater lakes [2]. Therefore, freshwater lakes are the most important part of all usable freshwater resources. Protecting freshwater lakes is crucial for ensuring safe water for humans. In recent years, drone technology has been widely used in monitoring freshwater lakes. Drones equipped with high-definition cameras can monitor lake surface trash or algae without contacting the water. This greatly improves detection efficiency and reduces labor costs [1, 2].

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Most traditional quadcopters do not consider hovering on water. They only focus on flying and hovering in the air [3]. Traditional drones can only fly or hover above the lake during lake rescue and water quality testing. They cannot touch the water directly. This causes big limitations for traditional drones in rescue and water quality testing. For example, they can only test the water along the lake shore, not near the center of the lake. For lake rescue, they need to save half of their battery life to return. This lowers the rescue efficiency a lot. Thus, amphibious drones are necessary. They can test water quality anywhere in the lake [4]. They can use their full battery life for rescue. After the mission, they stay on the lake and wait for recovery. These features save a lot of manpower. Many factors affect water quality changes. It is often hard to track and monitor. Old data can cause big errors. Amphibious drones with water quality testing modules solve this problem well [5]. There are many similar issues. To solve these problems, amphibious drones have emerged [3-5].

This paper proposes a water-air amphibious drone. It addresses the shortcomings of traditional quadcopters in monitoring and rescue over freshwater lakes. The design improves the body of traditional quadcopters. The drone can float on water and is waterproof. Visual sensor image quality is crucial for accurate image recognition [6]. This study focuses on improving image processing algorithms. It enhances the drone's target positioning accuracy during flight. This ensures real-time performance and stability in monitoring tasks. The drone has a water quality detection module and a pollution source tracing module. These modules allow real-time water quality monitoring. They can locate pollution sources using a reverse concentration gradient algorithm [7]. The flight control and signal transmission systems are redesigned to be waterproof. This ensures the drone's stability and safety in both air and water applications. The study results provide a direction for amphibious drone technology development. They offer new solutions for freshwater lake environment monitoring and rescue [6-8].

To achieve the mentioned functions, this amphibious drone improves the design of traditional quadcopters. It can float on water. The monocular vision module sends captured images to the microcontroller. The images are identified using the YOLO algorithm and optimized neural network algorithms. The results are uploaded to the main computer for real-time recording. The drone collects water quality data from different areas using the water quality detection module. It analyzes the data from different areas. It locates the pollution source using the reverse concentration gradient algorithm.

2 Global Design

This amphibious drone uses a modular design. It has a body, wings, flight control system, monocular vision imaging system, water quality monitoring and pollution tracing system, and data transmission system. The body is made of ABS engineering plastic mixed with carbon fiber and 3D printed. This ensures it is lightweight, strong, and corrosion-resistant. It uses a LiPo battery with the right capacity to meet the drone's needs. Due to the heavy water quality sensors and the large body designed for floating, the drone uses the DJI E5000 Pro power system. This system integrates the ESC and motor and can produce up to 14kg of thrust, allowing the drone to take off, land, and hover.

After modeling and calculations in SOLIDWORKS, the body weight is around 5kg. When the drone is in water, it can produce 10kg of buoyancy, ensuring safe operation on the water surface. Global modeling was show in the Figure 1, and shows the structural design of the amphibious drone. Buoyancy analysis was show in the Figure 2, and show the principles and results of buoyancy analysis.

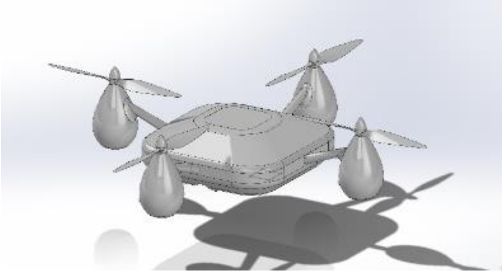

Fig. 1 Global modeling

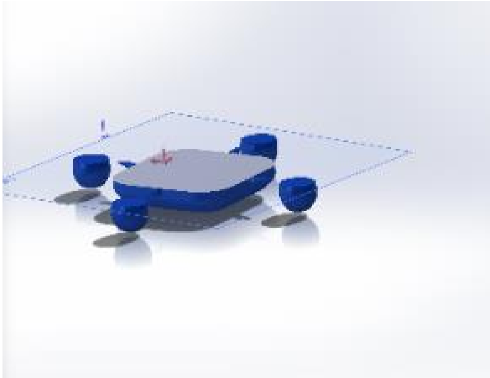

Fig. 2 Buoyancy analysis

The central control unit coordinates the operation of each subsystem. It ensures that each module functions properly without conflict. It receives data and information from each subsystem. Based on this data, it makes decisions to ensure efficient system operation. It uses an autonomous driving subsystem for automated operation. This reduces human error and increases monitoring efficiency. It uses a monocular vision imaging system to capture images and videos during monitoring. This information is used for later data analysis and processing. It uses a water quality detection module to monitor water quality in real-time. It traces pollutants using the reverse concentration gradient algorithm. Additionally, it has reserved interfaces for future functionalities. Plans include adding a solar power device for longer endurance and higher environmental benefits [9]. Overall design flow chart was show in the Figure 3, and show Control logic of amphibious drone [9].

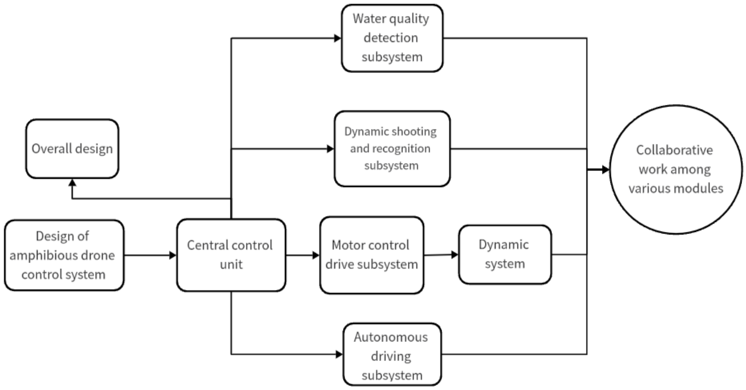

Fig. 3 Overall design flow chart

3. Monocular Vision Imaging System

Monocular vision imaging system is one of the core parts of the UAV design, and its application greatly improves the efficiency and accuracy of UAV mission execution in complex environments. The system captures environmental images in the water and air domains through the equipped high-list camera, and transmits the image data to the central control unit of the UAV in real time for processing. The central control unit uses the YOLO algorithm and the optimized visual neural network algorithm to recognize and locate the target in the image, to achieve the real-time monitoring of biological quantity, water quality and other information [10, 11]. Simulated identification of plastic bottles was shown in the Figure 4, and the simulation recognition of plastic bottles is demonstrated. By comparing various images of plastic bottles found online, this algorithm can accurately identify the type of object [10, 11].

Fig. 4 Simulated identification of plastic bottles

For the choice of camera, GoPro HERO9 Black is planned to use, which is a high-performance action camera that can realize 20 million pixel shooting and 4K video recording, and has waterproof function. It can be used in an underwater environment with a depth of 10 meters, which is suitable for underwater shooting and water sports, as well as meet the operational requirements of UAV such as shooting objects and search and rescue.

In the UAV, the code for image recognition is also integrated. YOLO algorithm ai is implemented by self-developed framework, the computer language used in the framework is C/C++, and the matrix used for calculation is implemented through arrays.

The realization process of image recognition mainly includes: The GoPro HERO9 Black camera is responsible for capturing real-time environmental images in the water and air domains during the flight of the UAV. These images are transmitted as input data to the UAV central control unit. After the image is transmitted to the central control unit, the image needs to be preprocessed first to improve the accuracy and efficiency of subsequent target recognition. Preprocessing includes denoising, image enhancement, size standardization and other operations. What's more, the central control unit uses the built-in image recognition algorithm to identify and locate the target in the image. These targets may be creatures, objects, or other specific objects, identified according to mission requirements. After identifying the target, the central control unit uses C/C++ language to calculate through the self-developed AI framework to realize the YOLO algorithm [11]. The framework converts the image data into a format suitable for algorithm processing, and performs target detection, classification and localization during matrix calculation. After the calculation is completed, the central control unit processes and integrates the recognized target information, and then outputs the results to the UAV control system. This information may include the number of targets, location coordinates, category labels, and so on. According to the identification results, the UAV can perform various tasks, such as photographing designated targets, conducting search and rescue operations, and monitoring water quality conditions. UAV can autonomously adjust flight paths and behaviors according to the recognition results, so as to improve the efficiency and accuracy of mission execution in complex environments. Flowchart of image recognition was shown in the Figure 5, and the process involves capturing images using monocular vision and then processing them through built-in algorithms

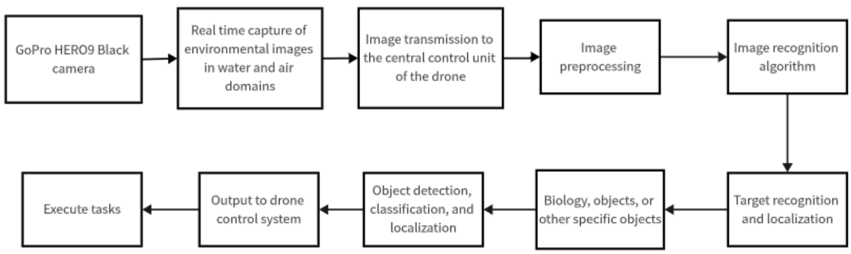

Fig. 5. Flowchart of image recognition

4. Water Quality Detection And Pollutant Traceability System

In order to realize the real-time monitoring of the water quality of freshwater lakes and the traceability of pollution sources, the UAV designed in this paper is equipped with a water quality detection module and a pollution source traceability module and plans to use Apure KPS-400. The equipment can obtain water quality parameters such as pH value, dissolved oxygen, turbidity and other key indicators by collecting water samples and conducting chemical analysis. The UAV dynamically traces the source of pollutants when driving in rivers and lakes and transmits the collected water quality parameter data to the central control unit, which conducts unified processing according to the water quality parameters. The water quality detection device intended for use on this UAV was shown in the Figure 6.

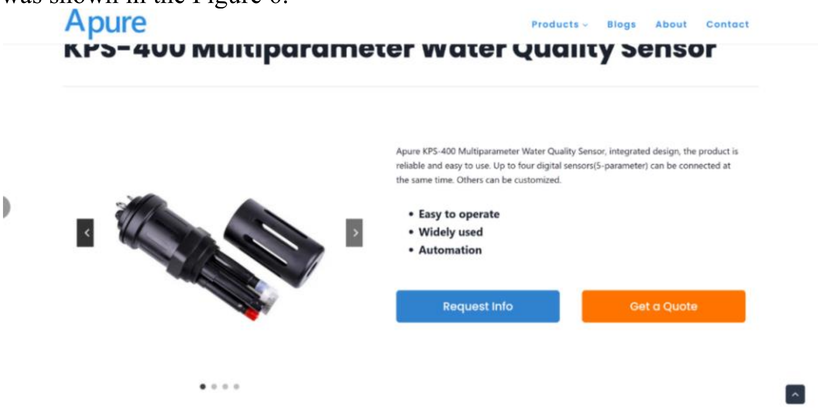

Fig. 6 Apure KPS-400

When the water quality is abnormal, the pollution source traceability module is activated. The inverse concentration gradient algorithm was used to analyze the concentration of pollutants in water samples. Combined with the GPS positioning system and wind field data carried by the UAV, the approximate location of the pollution source is determined, providing strong support for subsequent emergency response [13].

The main implementation process of this system is as follows:

a) Dynamic adjustment strategy of step size for pollution source tracking based on concentration gradient method

The low concentration area at the edge of the contaminated zone often has a large concentration change rate, coupled with the detection accuracy of the sensor, it is easy to lead to erroneous escape from the contaminated zone. The tracking step is attenuated with the increase of concentration change rate, and the adjustment formula is

$$s_n = s_{n-1}\left(1 - a\log\left|\frac{(c_n - c_{n-1})/c_{n-1}}{(c_{n-1} - c_{n-2})/c_{n-2}}\right|\right) \tag{1}$$

Among them, a is a coefficient that needs to be adjusted. A large number of test results show that when the value of a=0.25, the tracking effect of river pollution sources is the most ideal [14].

When the tracking is close to the source position, the concentration change rate will become more complicated, and a certain position may circle in situ. The search step size should be shortened to improve the search accuracy:

$$S_n = ps_{n-1} \tag{2}$$

(2) Where p (p<1) is the attenuation coefficient.

b) Confirmation of pollution sources

(1) The concentration change rate reaches a set value. Near the pollution source, affected by the water flow, the concentration in the lower reaches of the river is very high. In contrast, the concentration in the upper reaches decreases rapidly, which forms a large concentration change. The concentration change rate is in a peak:

(2) The concentration value has a maximum value

When the mobile water quality monitoring ship tracks and crosses the source position, the concentration value decreases due to the influence of the water flow. Therefore, in the historical detection data, there must have been a maximum concentration value, that is $c_n < c_{max}$, c_{max} is constantly updated during the tracking and positioning process, and the location is updated at the same time (x_{max}, y_{max}).

(3) The distance (step size) between the points where the contaminant was last detected before deviating from the contaminant zone reaches the threshold. Before confirming the source location, in order to avoid the local optimization problem caused by a single index, it is necessary to have a more comprehensive search for the entire studied water area. It is stipulated that before the search step size reaches the minimum (determined by the moving radius of the mobile water quality monitoring ship), even if the concentration change rate has exceeded the threshold, the search not stops. Only when the above three conditions are met, the pollution source is confirmed, and its location is $x = x_{max}, y = y_{max}$ [12-14].

5. Contact System With Upper Mechanism First Section

The data transmission and command control are carried out between the UAV and the host computer through wireless communication technology. The UAV sends the real-time collected environmental data, target recognition results and other information to the upper computer through the wireless communication network, and the upper computer analyzes and processes the received data and sends corresponding control instructions to the UAV. This kind of real-time data interaction and command control ensures the flexibility and efficiency of the UAV when performing tasks.

In order to ensure the speed of data transmission, it is proposed to use the IoT communication module of Quectel EC25 with UART interface. Quectel EC25 supports LTE Cat 4 technology, which can provide high-speed and stable 4G network connection for fast data transmission and low-latency communication. It also integrates GNSS

(Global Navigation Satellite System) positioning function, supports GPS, GLONASS, Galileo and other satellite systems, and realizes accurate positioning and navigation services. The communication device intended for linking with the upper computer system on this UAV was shown in the Figure 7.

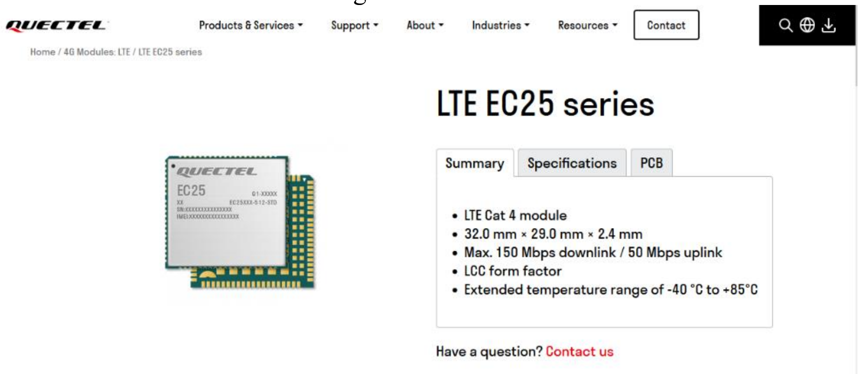

Fig. 7 LTE EC25 series

6. Clean Energy Collection Device First Section

In order to prolong the endurance of the UAV and reduce the operating cost, the UAV designed in this paper hopes to study how to integrate a clean energy collection system in the next step. The system intends to use solar panels and wind power generation devices to collect solar energy and wind energy, and convert it into electricity to store in the battery. The use of clean energy not only improves the energy efficiency of UAV, but also reduces the pollution and damage to the environment.

7. Conclusion

The main focus of this study lies in utilizing monocular vision imaging technology, coupled with the YOLO algorithm and optimized visual neural network algorithms, to achieve precise positioning and real-time tracking of dynamic targets. This advancement enhances the efficiency and accuracy of search and rescue operations and water quality monitoring. Additionally, the application of water quality detection modules and inverse concentration gradient algorithms provides effective means for tracing pollution sources, thereby offering robust support for environmental protection in lakes and other water bodies. Looking ahead, with the continuous advancement of drone technology and the expansion of application fields, amphibious unmanned aerial vehicles (UAVs) will play increasingly significant roles in environmental monitoring, emergency rescue, scientific exploration, and beyond. On one hand, further optimization of UAV design to enhance adaptability and stability in both water and air environments is warranted to cope with increasingly complex and dynamic conditions. On the other hand, exploration of additional application scenarios such as ocean monitoring, wetland conservation, and fisheries resource surveys will fully harness the multifunctionality and flexibility of amphibious UAVs.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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