Autonomous Microcontroller-Based Aerial Water Sampling Device

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Abstract

Water quality testing starts with sampling. Traditional methods may cause water quality properties to change due to the limitation of sampling methods. In addition, it is difficult and risky to take samples in parts of special terrain, such as ravines and swamps, where manpower is difficult to reach. To this end, we combine a single-chip machine STM32-based sampling device with a UAV that can span complex terrain to solve the above problems. The characteristics of water quality without human intervention and equipment automation are of great significance.
Keywords: WIFI, intelligent home, ad hoc network, remote control, monitoring

1. Introduction

At present, more than 420 billion m3 of sewage is discharged into rivers, lakes and seas worldwide each year, polluting 5.5 trillion m3 of freshwater, which is equivalent to more than 14% of the total global runoff; As people drink contaminated water, this is one of the main causes of disease and even transmission.

This design mainly solves the problem of long distance water quality sampling. Compared with other designs, it has the advantages of low cost, flexibility, simple design structure and dexterity, adaptability and high operational accuracy. Using the most common microcomputer STM32 series combined with cost-effective miniature drones, the automated water quality aerial sampling device is designed cleverly. The most advanced approach is to collect small water samples for laboratory analysis, as many of the characteristics of interest to them cannot be measured in situ easily or efficiently at cost.

Through these water samples in the laboratory, they can measure chemical properties, including phosphate, total phosphate, nitrate/nitrite, nitrogen and ammonia, as well as biological properties such as the presence of toxic microcystidins. Certain properties can be measured on site, but they require a large number of devices. These include temperature, conductivity, pH, dissolved oxygen, light, turbidity, and Secchi transparency. So we can bring the collected water samples back to the laboratory for water quality testing. In this way, we know if the water quality is healthy.

2. Hardware Design

In our approach, we use miniature drones to easily ship them in cars or backpacks to research locations. These flight robots are computer-controlled, light, commercially available, and can carry a small payload of 750g for up to 20 minutes. Fortunately, the UAV's limited payload is not a critical disadvantage, as water samples do not have to be very large (20 ml = 20g) to be scientifically useful. The UAV's limited battery flight allows it to travel nearly a kilometre back and forth, which is close enough for many water sampling applications.

The method proposed in this work is sampling from the air. The sampling device is controlled remotely by the staff using the mobile terminal to reach the designated sampling point and descend to the sampling height [1]. The sampling device is driven to move along the moving guide rail to directly above the detection hole by setting the motor and control line inside, and the air inside the rubber-tipped drip tube is discharged by squeezing the rubber-tipped drip tube through the squeezing mechanism. After the air is discharged from the tip drip tube, the telescopic mechanism retracts downwards so that the lower end of the tip drip tube is submerged under the water surface, then the squeezing mechanism is reset so that the air is pushed by air pressure into the inside of the tip drip tube, and at the same time the sample liquid is pushed into the inside of the tip drip tube. This design mainly solves the problem of long-distance water quality sampling. There are other designs compared with the advantages of low cost, flexibility, simple and dexterous design structure, adaptability, high operational accuracy UAV range is stronger4.

This paper designs flight control system with STM32 F103 series of chips as the core, including sampling device module, quad rotor UAV module, power supply module, sensor module, wireless communication module and PWM electronic speed control module and other functional modules. Fig.1 is the module contact diagram of this design.

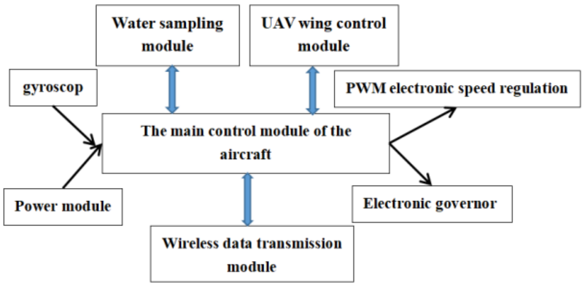

Fig 1 Design of the module contact diagram

For the sampling device workflow: the upper end of the housing is fixed with a signal receiving antenna, the upper end of the housing is embedded with a chip and a control circuit, the upper end of the housing is fixed with a field-shaped moving rail, and the lower end of the moving rail is sliding with a connecting column; The lower end of the connecting column is fixed with a vertical downward-set telescopic mechanism. The lower end of the telescopic mechanism is fixed with a squeezing mechanism that shrinks laterally. The compression plates are fixed on both sides of the lower end of the extrusion mechanism. Fig.2 shows the side view of the structure of the design.

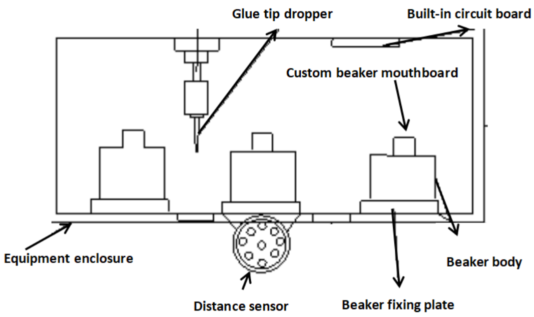

Fig 2 Side view of the structure

The internal fixing of the moving rail is equipped with motor and control line driving the movement of the connecting column. Together, the connecting column, motor and control line form the driving structure of the sampling device. The signal receiving antenna is electrically connected to the chip as well as the control circuit by wire. The sampling device design structure is shown in Fig.3.

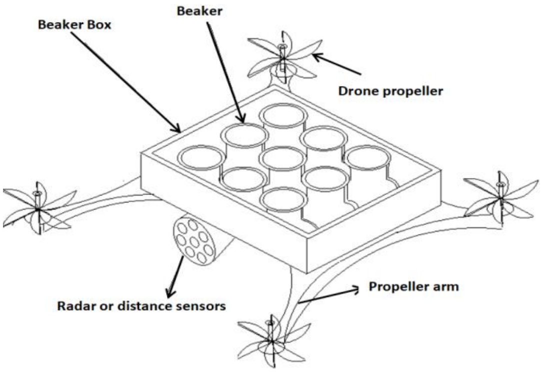

Fig 3 The sampling device design structure

3. Minimum height that can be maintained while sampling

The outdoor height control assessment was carried out on Tianta Lake in Tianjin. The water depth at this location is 2-3m. For these outdoor tests, we chose a calm day with a handheld anemometer measuring wind speeds of less than 0.38m/s. We recorded the ultrasonic, pressure sensor and Kalman filter height estimates. In this study, drones always fly at low altitudes. The figure shows that at a higher level, the software system implements a finite state automaton (FSA). Fig.4 is the structure diagram of the sampling process.

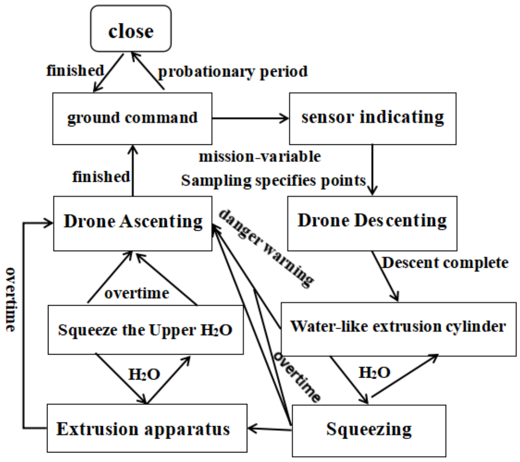

Fig 4 Diagram of the sampling process

Wind is a key environmental factor in any aerial field deployment. In the steady state of the flight system, the sampling system is specified to operate in winds of up to 10 m/s and, in our experience, it can remain roughly in position in open areas in winds of up to 15 m/s. However, when close to water, even wind speeds of less than 10 m/s can disrupt the system's ability to successfully sample water in several ways (1) The wind changes the air pressure around the body, resulting in large and rapid changes in the height recorded by the pressure altimeter. (2) The wind deflects the rubber-tipped dropper at an angle (5°), reducing the effective aspiration length and requiring the UAV to descend in altitude again, resulting in the flight system remaining in a critically stable state. (3) The wind disrupts the flow of water at the needle, resulting in less water entering the capture bottle. We know from experience that wind can interfere with altitude control and can bring the vehicle surprisingly close to swimming. However, The mission of this work required us to fly very close in order to achieve a high sampling success rate. During the sampling process this article set a 'target height' which the UAV attempted to maintain as it headed the dropper into the vial [2]. Overall, the flight system was able to operate the system normally without significant impact at water surface wind speeds ≤10m/s.

4. Reliability of Water Sampling Device

We tested the reliability and effectiveness of water sampling systems both indoors and outdoors. Indoors, we perform autonomous tasks, launching drones to 1m, flying over the tank, descending to the fully submerged sampling height of the glue drip, sampling, and then ascending to 1.5 m.

Overall, 139 of the 150 samples collected continuously from Chamber Lake (3 out of 50 tests) met the requirements (about 95% were successful). To better understand the relationship between success rates and the use of our ultrasound and pressure height controllers, half of the samples were collected using the height reported by the Vicon motion capture system. After adjusting for the controller, the success rate is 97.5%, which is ideal data. Then we tested the water samples collected (as shown in Figure 8), showing that the water samples collected using our water quality sampling device are closer to reality, and the error is about 66.23% smaller than the water samples collected manually. Fig.5 is a physical diagram of the sampling process.

Fig 5 Physical diagram of the sampling process

The research is based on the definition of the classical quadrotor UAV system dynamics model and defines the angle ψ of rotation along the z-axis of the carrier coordinate system as the yaw angle, which is represented by the rotation matrix R2 (ψ). The angle of rotation ϕ along the x-axis of the carrier coordinate system is defined as the roll angle and is represented by the rotation matrix Rx (ϕ). The angle of rotation 0 along the y-axis of the carrier coordinate system is defined as the pitch angle and is represented by the rotation matrix Ry(0). The rotation matrix R(ϕ) is also introduced to define the rotation relationship for the conversion of the quadrotor UAV carrier coordinate system B to the inertial coordinate system E [1].

$$\boldsymbol{R} = \begin{bmatrix} C_\psi C_\theta & C_\psi S_\theta S_\phi - S_\psi C_\phi & C_\psi S_\theta C_\phi + S_\psi S_\phi \\ S_\psi C_\theta & S_\psi S_\theta S_\phi + C_\psi C_\phi & S_\psi S_\theta C_\phi - C_\psi S_\phi \\ -S_\theta & C_\theta S_\phi & C_\theta C_\phi \end{bmatrix}$$

Each test consists of six samples, then examine the water sample bottle. Any amount less than the top of the sample vial "neck" is recorded as less than full. We completed 50 trials in total. Each test will take 2-3 minutes to fly and about 8 minutes to set up the flight system, take out water samples and regularly replace the UAV batteries.

5. Conclusion

In this work, we show a new mechanism for automatic water intake from drones, which requires less effort than existing technologies and is almost an order of magnitude faster. The system can safely fly at close range, collecting 9 30ml samples per flight. Finally, we conducted 150 outdoor tests on 6 samples in the range of 5-10m/s wind speed and found that the device can sample effective water samples with wind speeds less than 10m/s. The equipment solves the sampling of hard-to-reach terrain, such as ravines, swamps, etc., which not only improves the sampling efficiency, but also improves safety.

Future efforts include further operation and development of the system outdoors, in particular how the platform can be used in conjunction with adaptive sampling, sampling at greater depths and with other sensing and sampling mechanisms deployed in the water column. We plan to describe our risk management framework as part of a long-term analysis of failure modes and system reliability. We are seeking ways to measure the amount of water in a vial. We intend to explore how the system might operate on a wide variety of water bodies, including those with continuous flow and waves.

References

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