DESIGN AND DEVELOPMENT OF SURFACE WATER QUALITY AUTOMATIC SAMPLING SYSTEM BASED ON UAV

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To solve the problems that most water quality sampling UAVs cannot quantitatively collect water samples at specified depth and cannot obtain water samples at multiple sampling points in one flight, the design and development of airborne pump suction water quality sampling device and the ground station are carried out in this paper. It is realized that water samples at three sampling points can be obtained at specified depth in one flight. Through on-site experimental evaluation, the water quality sampling system can greatly improve the temporal and spatial resolution of obtaining water samples, and reduce the cost and workload.

Keywords: UAV, water quality sampling, pump suction type, ground station

1. Introduction

Water quality monitoring technology can be used to determine the types and distribution of pollutants in water bodies, and then trace the sources and pollution routes of pollutants. Water quality sampling is the key link of water quality monitoring. In the process of sampling preparation, it is necessary to select appropriate techniques according to specific sampling targets, otherwise the water quality testing results will be biased. Sampling is carried out in a qualitative or quantitative manner. When the purpose of research is to obtain quantitative data of samples, accurate sampling equipment must be selected to avoid inaccurate final results. This was particularly important when collecting samples were used for regulatory or legal purposes[1]. At present, the large-scale water quality sampling work was using the traditional manual sampling method: researchers drove a boat to collect water samples. The manual sampling method required a large number of on-site personnel, which increased the labor cost of the entire

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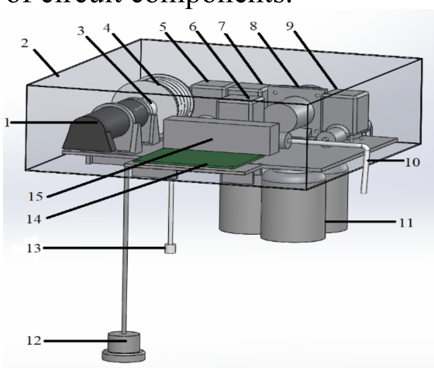
sampling process. At the same time, due to the bad sampling location, the bad weather and extremely polluted water conditions, the sampling staff might fall into the risk of health, safety and biological safety. The current sampling method also included unmanned vessel water quality sampling. Compared with manual sampling, this method had the advantages of low personnel cost and was a more economical and practical way. However, the disadvantage of this method was that it was difficult for unmanned vessels to enter narrow and remote waters, or there were a large number of floating objects, which made it limited in application[2].

The application of UAV in the field of water quality sampling could help researchers sample in the face of dangerous or inaccessible harsh geological conditions, and could ensure the safety of the sampling process[3-5]. In the past decade, ready-made UAVs (such as Ascending Technologies Firefly and LAB645 multi rotor UAV)[6-8] and customized platforms[9,10] have been combined with specially designed water quality sampling devices and applied to water quality sampling. At present, the research of UAV in the field of water quality sampling was not deep enough. Most water quality sampling UAVs could only collect surface water samples, but could not quantitatively collect water samples at specified depth, and could not obtain water samples at multiple sampling points in one task. With the rapid development of UAV technology, including the increase of payload weight of UAV platform, the extension of flight time, and the growth of battery endurance, new opportunities have been provided for the research of UAV in the field of water quality sampling[11].

2. Design of pump suction water sampling system based on UAV

2.1. Overall structure of airborne pumping suction water sampling device

The airborne pumping water quality sampling device was mainly composed of a six rotor UAV and a pumping suction water quality sampling device. The 3D model of sampling device and physical picture were shown in Fig.1. The detachable installation platform was fixed below the UAV, which formed a holding chamber with the UAV, and the pump suction water quality sampling device was installed in the holding chamber. The core components were marked in Fig.1 (a), in which, 1-DC reduction motor; 2 - Waterproof cover; 3 - Rotary joint; 4 - Tube winding drum; 5. 6, 7 and 9 were solenoid valves; 8 - Peristaltic pump; 10 Sampling hose; 11 Water sample collection bottle; 12 Water immersion sensor; 13 - Filter screen; 14 - Water quality sampling control panel; 15 - Battery. The DC reducer motor was connected to the winding drum through the connecting gasket, bearing and bracket and fixed on the removable installation platform. The winding drum with guide groove was convenient for the hose to be wound in the fixed direction. One end of the winding drum was connected to the DC reducer motor and the other end was connected to the rotary joint. The inner part of the winding drum was a hollow structure. After assembly, the water outlet of the rotary joint was located inside. The hose connecting the water outlet of the rotary joint could extend from the opening and be wound on the winding drum through the guide groove. The rotary joint was fixed by the rotary joint fixing frame, which was fixed on the removable installation platform. The connecting end of the rotary joint and the rotary joint fixing frame remained stationary during operation, and the other end rotated with the roller to make the front and rear ends rotated relatively. At this time, the water could flow smoothly. The rotary joint was connected with the water inlet of the peristaltic pump through the hose, and the peristaltic pump was fixed on the removable installation platform by the peristaltic pump fixing frame. The water outlet of the peristaltic pump was respectively connected to the water inlet of four solenoid valves through a four-branch pipe, and the water outlet of three solenoid valves was connected to the water sample collection bottle through a water pipe. The fixing seat of the water sample collection bottle was fixed below the bottom plate, and its upper end was provided with three connecting holes and a water pipe hole. The connecting hole was used to fix the bottom plate with screws, and the water pipe hole was used to let the water pipe enter the water sample collection bottle through the hole. Its internal thread could be connected with the external thread of the water sample collection bottle for easy disassembly. The water outlet connecting pipe of the remaining solenoid valve was placed in the atmosphere, and the water quality sampling control circuit board was fixed on the removable installation platform. The battery was fixed on the removable installation platform, the water immersion sensor was placed under the bottom plate, and the camera was fixed on the bottom of the removable installation platform. DC reduction motor, water immersion sensor, 4-way solenoid valve, peristaltic pump and battery were connected with corresponding interface of water quality sampling control board. The waterproof cover and removable installation platform formed a closed space to prevent short circuit of circuit components.



(a) 3D model of sampling device (b) Physical picture

Fig.1. Overall structure of airborne pumped suction water quality sampling device

2.2. Design of pump suction type water quality sampling device

The pumping type water quality sampling control system was composed of airborne water quality sampling control module and water quality sampling ground station. A pair of ATK-LORA-01 wireless communication modules were also used for communication between the two modules. PIC32MK1024MCF064 was the main microcontroller chip. The airborne water quality sampling control module consisted of a DC reduction motor with an encoder, a water immersion sensor, a peristaltic pump, and four solenoid valves. Serial HMI touch screen was selected as the interactive screen of the ground station. The block diagram of the pump suction water quality sampling control system was shown in Fig.2.

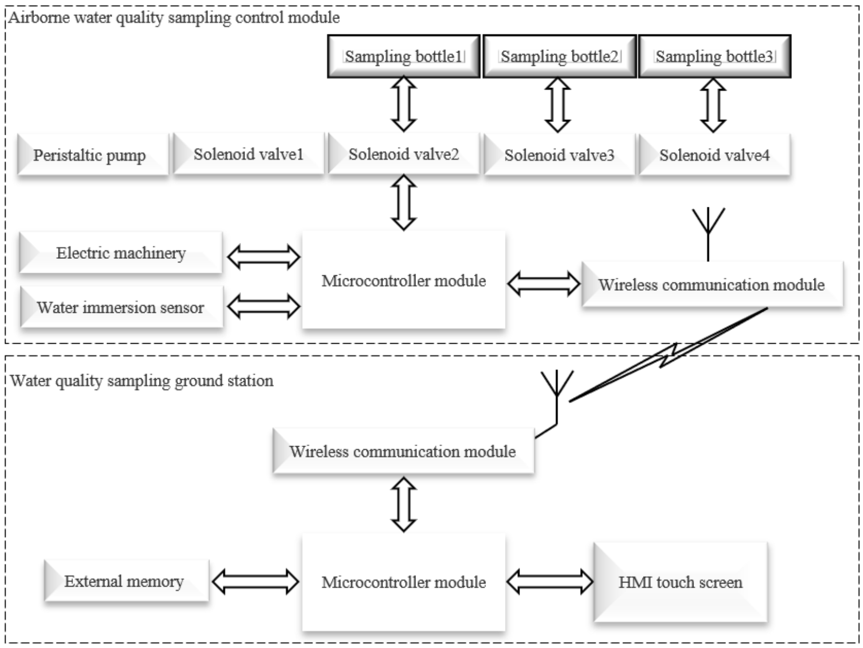


Fig.2. Block diagram of pumped water quality sampling control system

2.3. Design and development of water quality sampling ground station

The water quality sampling ground station was the long-range control terminal of the water quality sampling device. Its hardware structure included: ground station control board, HMI display touch screen, LoRa communication module, and power supply. The power supply was 5V lithium battery. The water quality sampling ground station had the functions of receiving the status of the airborne water quality sampling device in real time, selecting the sampling depth, moistening, selecting the water sample collection bottle, controlling the opening or closing of each component on the airborne water quality sampling device, and giving an alarm prompt for the height of the unmanned aerial vehicle from the water surface. These functions could be completed on the HMI display touch screen. The sampling task preparation interface was shown in Fig.3.

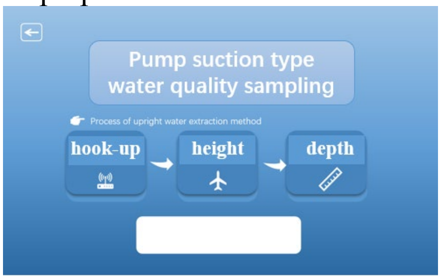


Fig.3. Sampling task preparation interface

3. Experimental test

3.1. Field water quality sampling in section of Qiantang River estuary

3.1.1 Overview of field sampling sites

The Fuyang section of the Qiantang River estuary is a braided channel with many islands. There are several sewage outlets in Fuyang section, and the upstream and downstream reaches of the sewage outlets are water source protection areas, so the water environment requirements are high. Therefore, it is very necessary to investigate the water environment in this reach for the protection of water environment.

(1) Sampling section layout. At the head of the north branch of Dongzhou Island, there was a Fuyang urban sewage outlet. It was set as background section about 500m upstream of the sewage outlet (the section with smooth water flow and no pollution source). The sampling background section was set with three sampling verticals, marked 1-1, 1-2 and 1-3, according to the right bank, the middle channel and the left bank. A total of 3 sections were arranged at 150m, 300m and 800m around the sewage outlet at downstream respectively. The three sampling vertical lines were also arranged at each section, as shown in Fig.4. The 3 perpendiculars of the second section were marked 2-1, 2-2 and 2-3 respectively,

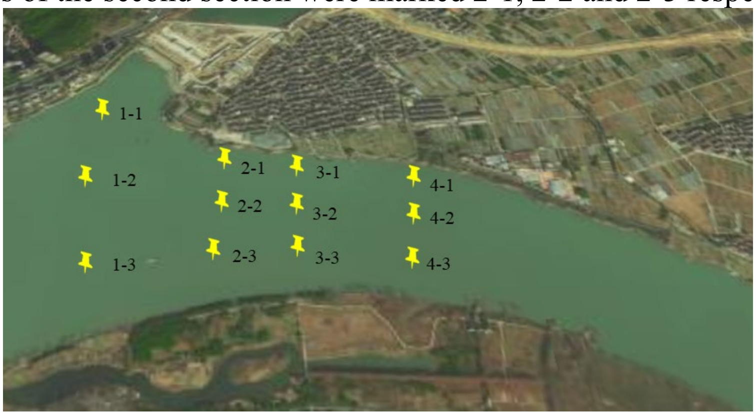


Fig.4. Layout of sampling verticals

and similarly, the 3 perpendiculars of the three section and the four section were marked 3-1, 3-2, 3-3 and 4-1、4-2、4-3 respectively. The longitude and latitude of the sampling vertical line were shown in Table 1. The layout of sampling vertical lines was shown in Fig.4.

Table 1 .

Longitude and latitude of sampling vertical line

Point position	Longitude	Latitude
1-1	119°59'3.01"	30°3'27.92"
1-2	119°58'59.01"	30°3'25.75"
1-3	119°58'54.12"	30°3'26.77"
2-1	119°59'8.07"	30°3'25.83"
2-2	119°59'2.54"	30°3'21.58"
2-3	119°58'55.72"	30°3'20.60"
3-1	119°59'26.70"	30°3'22.67"
3-2	119°59'24.39"	30°3'17.88"
3-3	119°59'21.38"	30°3'14.42"
4-1	119°59'51.47"	30°3'14.50"
4-2	119°59'49.93"	30°3'11.41"
4-3	119°59'47.49"	30°3'7.43"

(2) Monitoring means. In order to verify the reliability and scientific effectiveness of the two sets of water quality sampling systems, in this paper two methods were used to obtain water samples at the sampling points. The first sampling method adopted the traditional sampling method. The sampling staff took a boat to the sampling place in turn and used the vertical water quality sampler to obtain water samples at each sampling point. The second method used a pumping water sampling system based on UAV to sample water, and one flight mission could obtain water samples at three locations.

(3) Monitoring indicators. Dissolved oxygen, total nitrogen, nitrate nitrogen and ammonia nitrogen were included to verify the effectiveness of the water quality sampling system based on UAV. Based on the fact that the UAV water quality sampling system might cause deviation due to photosynthesis during transportation, dissolved oxygen needed to be measured on site. The total nitrogen, nitrate nitrogen and ammonia nitrogen were measured in the laboratory.

3.1.2 Experimental results and analysis

According to the designed sampling and experiment scheme, 48 sampling points were sampled by manual sampling, and the sampling staff measured the dissolved oxygen on board. Then, the same sampling points were sampled by the pump type water quality sampling system based on UAV, and the dissolved oxygen of water samples was measured on site. This paper made statistics on the manpower and total time consumption of the two sampling methods, shown in Table 2.

Table 2 .

Statistics of manpower and total time consumption for the two sampling methods

Sampling method	Labor	Total time
Manual sampling	5 persons	3.5 hours
UAV pump sampling	3 persons	1 hour

From the above table, the water quality sampling system based on UAV could effectively reduce both the labor consumption and the time cost compared with manual sampling. Moreover, it only needed to operate on the shore, and the personnel did not need to enter the sampling, so it could ensure the safety of the sampling personnel. Because the water sampling system based on UAV could obtain water samples at three points in one task, it saved more time.

Table 3 .

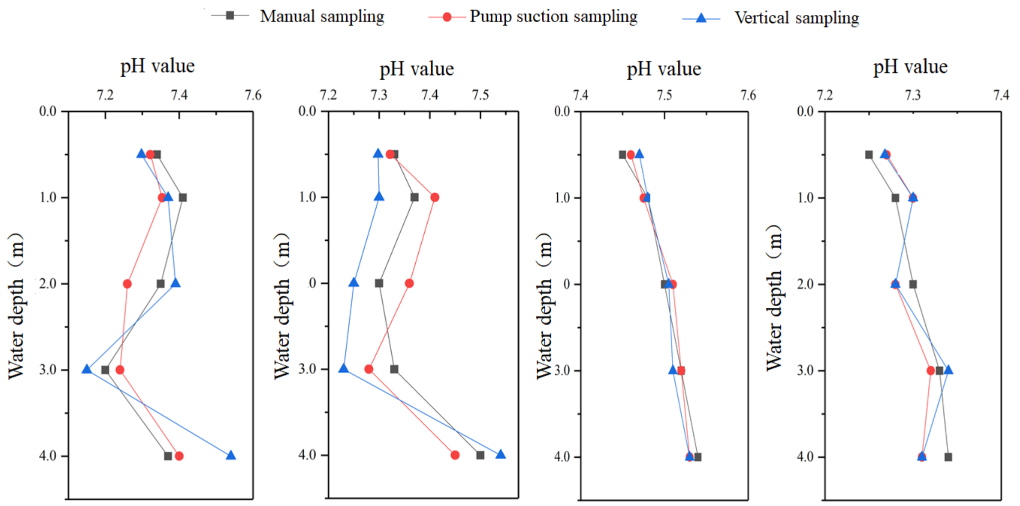
Detection methods of water quality indexes

Indicators	Unit	Method
Dissolved oxygen	mg/L	JPB-607A
nitrate nitrogen	mg/L	Ultraviolet spectrophotometry
Ammonia nitrogen	mg/L	Phenol sodium hypochlorite colorimetry
Total nitrogen	mg/L	HACH Total nitrogen reagent

After obtaining water samples in two ways, each water sample shall be tested, the value of dissolved oxygen shall be measured on site, and the water sample shall be taken back to the laboratory for measurement of total nitrogen, nitrate nitrogen and ammonia nitrogen. Water quality index detection methods were shown in Table 3.

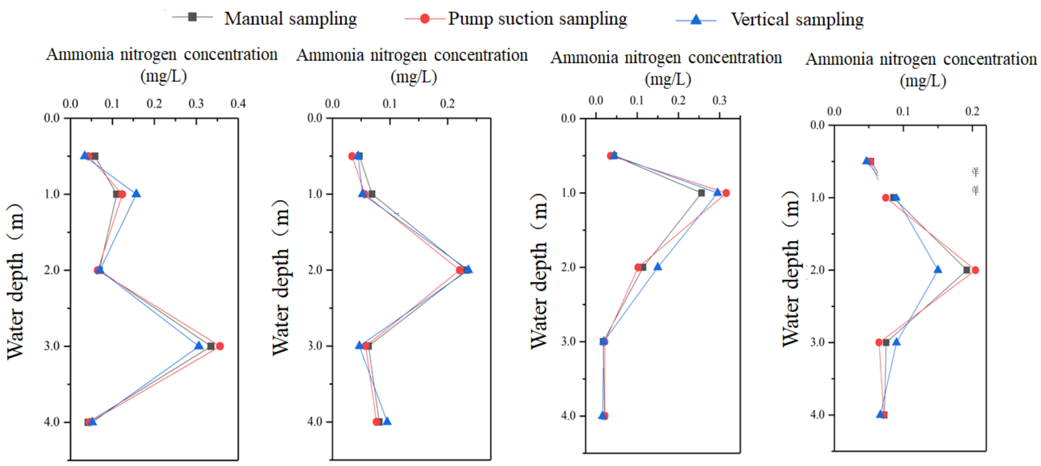
In order to compare the influence of pumping water sampling system based on UAV and traditional sampling mode on the acquisition of water samples at specified depth, according to the measured values of the middle vertical lines of four sections, it is studied whether the water sampling system designed in this paper was effective when the sampling water depths were 0.5m, 1m, 2m ， 3m and 4m. This article brings back indicators of pH value, ammonia nitrogen, nitrate nitrogen, and total nitrogen of water samples. The changes in pH value, ammonia nitrogen, nitrate nitrogen, and total nitrogen data at different depths of the middle vertical line under three sampling methods are shown in Fig.5, Fig.6, Fig.7 and Fig.8. The third sampling method described as Vertical sampling in Fig.5-Fig.8 has been developed for still water and open water sampling points by the authors in 2020. The third sampling method is sampler drop type, not pump suction type.

The vertical axis represents different water depths, while the horizontal axis represents pH value, ammonia nitrogen content, nitrate nitrogen content, and total nitrogen content. The numerical deviation of the three sampling methods at each sampling point is the distance along the horizontal axis. From Fig.5, Fig.6, Fig.7 and Fig.8, it can be seen that the maximum deviation of the three sampling methods on pH value is within 0.2; The maximum deviation of ammonia nitrogen concentration is 0.12 mg/L; The maximum deviation of nitrate nitrogen is within 0.15mg/L; The maximum deviation of total nitrogen concentration is 0.2mg/L.



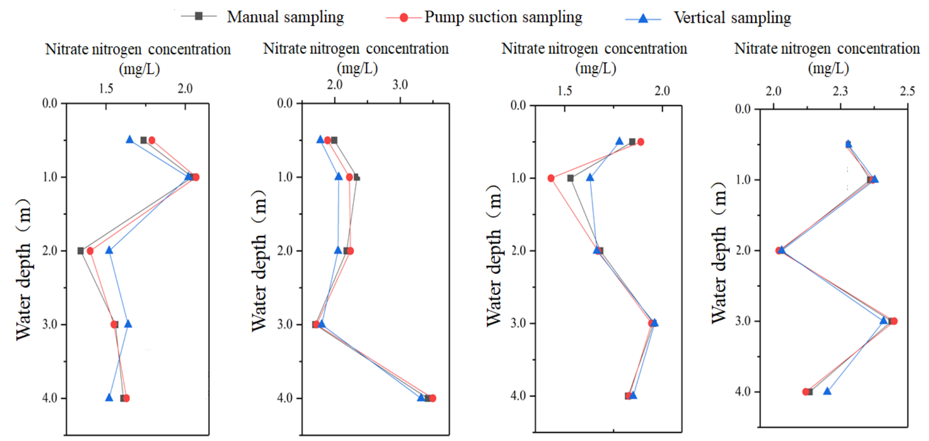
(a) 1-2 Sampling Verticals (b) 2-2 Sampling Verticals (c) 3-2 Sampling Verticals (d) 4-2 Sampling Verticals

Fig.5. Changes in pH values at different depths of the middle vertical line under three sampling methods



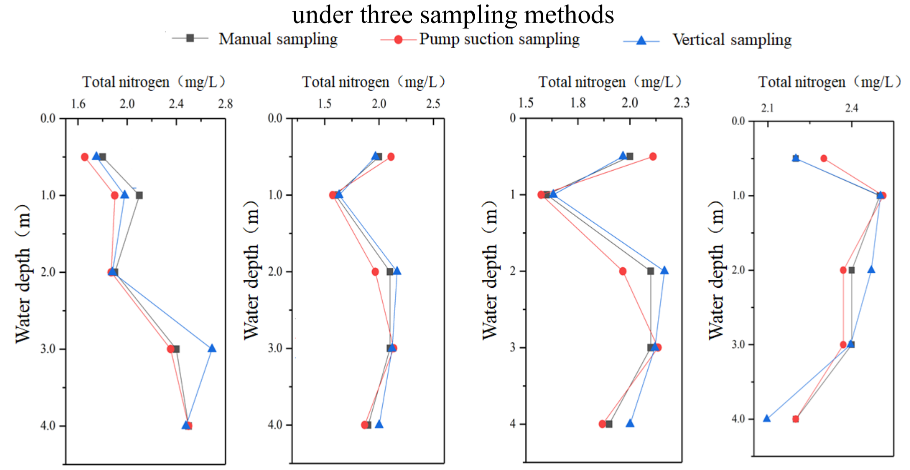
(a) 1-2 Sampling Verticals (b) 2-2 Sampling Verticals (c) 3-2 Sampling Verticals (d) 4-2 Sampling Verticals

Fig.6. Changes in ammonia nitrogen concentration at different depths of the middle vertical line under three sampling methods



(a) 1-2 Sampling Verticals (b) 2-2 Sampling Verticals (c) 3-2 Sampling Verticals (d) 4-2 Sampling Verticals

Fig.7. Changes in nitrate nitrogen concentration at different depths of the middle vertical line under three sampling methods



(a) 1-2 Sampling Verticals (b) 2-2 Sampling Verticals (c) 3-2 Sampling Verticals (d) 4-2 Sampling Verticals

Fig.8. Changes in total nitrogen concentration at different depths of the middle vertical line under three sampling methods

The reason for this deviation may be that the water sample is not exactly from the same time and the detection process is artificially biased. But the overall trend of change is consistent at different depths, and the values of most of the sampling points tend to be the same. The percentage difference on same water quality index between sampling methods is very small. Therefore, using the unmanned aerial vehicle based water quality sampling systems designed in this article for water quality sampling work is almost the minimum acceptable error for different sampling methods, and can be used for water quality sampling work.

4. Conclusions

In this paper, the airborne pump suction water quality sampling system was designed and developed, which enriched the methods of water sampling. The main research achievements of this paper are described as follows. The water quality sampling system developed in this paper could realize quantitative and variable depth collection in the specified points, and improve the efficiency of water quality sampling, and provide more data support for understanding the temporal and spatial distribution of water environment. The water quality sampling system was sampled and tested in the sewage outlet located at Fuyang section of Qiantang River estuary. The traditional manual method and the pump suction sampling system based on UAV were used to sample according to the scheme, and the data of dissolved oxygen, total nitrogen, nitrate nitrogen and ammonia nitrogen indicators of water samples were analyzed. The percentage difference of water quality indicators at the same sampling point under the two methods was very small. In addition, the cost of manpower, material resources and time of water quality sampling system based on UAV were greatly reduced compared with traditional manual sampling. The water quality sampling system based on UAV was proved to be efficient, safe and effective.

Acknowledgements

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