Construction and Application of Virtual Experiment Teaching System for Integrated Mapping of Unmanned Ship

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Abstract. At present, China's water pollution situation is still very serious, and water pollution prevention is an important part of ecological environment protection, and water quality monitoring and pollution traceability are the basis of prevention and control work. Unmanned ship system uses GNSS intelligent navigation and positioning technology, automatic obstacle avoidance technology, real-time communication technology, sonar sounding technology and manual control technology, etc., by collecting underwater terrain, water quality information and underground pipe detection, it can complete water quality detection unmanned, intelligent and efficient. In this paper, the system architecture and measurement principle of unmanned equipment are comprehensively expounded, and based on WebGL and virtual simulation technology, an open unmanned equipment virtual simulation training system is constructed, which can directly carry out assembly training of unmanned aircraft and unmanned ship and flight control training of unmanned aircraft on the Web side. Finally, the feasibility and development prospect of unmanned equipment in sewage monitoring are discussed with an application example.

Keywords: Sewage monitoring, virtual simulation, unmanned aerial vehicle, unmanned ship, WebGL.

1. Introduction
Water pollution monitoring is an important part of preventing and controlling water pollution. With the construction of ecological and civilized cities in modern China, water pollution has been highly valued by our country, but it still faces many problems. Industrial sewage discharge may be discharged into rivers without reaching the standard due to lax supervision; Although all kinds of urban domestic sewage have no toxic effect on rivers, they will do harm to the ecological balance of rivers; With the development of modern agriculture, a large amount of chemical fertilizer flows into the river to destroy the ecological balance. If the water pollution problem cannot be solved in time, the ecological environment of the river will face great harm and even affect people's normal life.

With the continuous improvement of China's scientific and technological innovation level, the emergence of sophisticated equipment such as unmanned aerial vehicles (UAVs) and unmanned ships have replaced the traditional manual measurement and become an important means to obtain
surveying and mapping geographic information data [1,2]. Automatic, intelligent and information-based unmanned ship measurement system can locate and detect synchronously, transmit the collected data to the computer in real time and remotely, and can sail autonomously and avoid obstacles automatically [3,4]. The hull of unmanned ship is made of composite material, which is light and flexible, and reduces the difficulty of shallow water measurement. Therefore, the application of unmanned ships in water pollution monitoring can effectively improve the efficiency of water source monitoring while reducing the input of manpower and material resources.

In this paper, the system architecture and measurement principle of unmanned equipment are comprehensively expounded, based on WebGL and virtual simulation technology, a virtual 3D scene is created to simulate the real environment by using B/S architecture, and the assembly training of unmanned aircraft and unmanned ship and the flight control training of unmanned aircraft can be carried out directly on the Web side. Finally, combining with practical application cases, the feasibility and development prospect of unmanned equipment in sewage monitoring are discussed.

2. Unmanned ship measurement system

2.1 Overview of Unmanned Ships

The unmanned ship is a full-automatic surface robot that navigates on the water surface according to preset tasks with the help of precise satellite positioning and self-sensing technology. It is integrated by hull, GNSS intelligent navigation and positioning technology, automatic obstacle avoidance technology, real-time communication technology, sonar sounding technology and manual control technology [5]. In the unmanned ship measurement system, the unmanned ship is a highly intelligent water-borne platform, equipped with single-beam sounder, multi-parameter water quality detector, side-scan sonar and other equipment, and combined with GNSS navigation equipment, wireless communication and shore-based computer to form an unmanned ship measurement system, which can remotely control, intelligently navigate, intelligently avoid obstacles, automatically sample and automatically perform tasks [6-8].

In this paper, the C170 intelligent mapping unmanned ship is used for underwater measurement and water quality monitoring. C170 small aquatic multifunctional application robot is a new generation of aquatic unmanned ship products, which integrates the latest composite materials technology, underwater power propulsion technology, autonomous navigation and automatic control technology. It has functions of automatically collecting water samples in large-scale water bodies, automatically patrolling water quality, investigating and tracking pollution sources, underwater topographic mapping and sediment measurement, etc. The main parameters of C170 intelligent mapping unmanned ship are shown in table 1.

| Table 1. Technical parameters of C170 intelligent mapping unmanned ship |
|--------------------------------------------------|
| **Index** | **Numerical value** |
| Size | 1700*840*480mm |
| Empty weight | 31kg |
| Load weight | 50kg |
| Wind and wave resistance grade | wind force scale:3, Wave level:2 |
| Endurance ability | No load for 4 hours |
| Speed of a ship or an airplane | Maximum speed: 4m/s, economic speed 2m/s |
| Communication distance of remote controller | ≤2km |
| Navigation mode | Manual and automatic; Navigation system: support GPS/ Beidou system |
| Lost connection protection | When the signal between the ground station and the ship is lost, it can automatically return to the designated position (such as the original starting point) |
Advantages of unmanned ship: convenient and easy to use: small size, light weight, easy to carry, professional hull design, anti-sinking, anti-collision and corrosion resistance, automatic water leakage detection, ultrasonic automatic obstacle avoidance; Automatic sampling: a regular fixed-point quantitative sampling mode that fully conforms to the national environmental protection industry standards; It has the functions of mixed collection and separate collection, and can collect multi-point water samples in one voyage and automatically generate sampling reports; Automatic monitoring: it can be equipped with multi-parameter water quality monitor; It can dynamically monitor, find and locate pollution sources, and obtain evidence on site; In case of emergency, you can go deep into the pollution restricted area and investigate and sample. Autonomous navigation: combined with GIS map, it can be accurately positioned by GNSS, and can set the sampling route independently for automatic navigation.

2.2 Measurement principle of unmanned ship

The measurement system of unmanned ship is mainly divided into two parts: probe ship and shore-based control system. The probe ship includes hull, propeller, ship-borne main control system, measurement system, basic power supply and wireless transmission system, etc. The shore-based control system mainly includes notebook computers and basic communication units [9]. With unmanned ship as carrier, high-precision positioning is carried out by GNSS, data is collected by the detector, and positioning and sounding data are transmitted to the working shore base in real time by transmitting antenna to realize real-time communication, so as to ensure that the shore base control system can receive effective hull operation parameters and collect data in real time, and the computer can obtain the coordinates of sounding points, bottom elevation and water quality by using a certain conversion formula [10]. A brief schematic diagram is shown in Figure 1.

![Figure 1. Schematic diagram of basic principle of unmanned ship measurement system](image)

3. Virtual simulation system

3.1 System architecture

In this paper, WebGL technology combined with JavaScript language is used to build a virtual simulation training system for unmanned equipment. The system is divided into two parts: front end and back end. The front-end mainly meets the functional requirements of users for virtual simulation systems, while the back-end mainly meets the management requirements of administrators for equipment models and training scenarios. The whole system framework can be divided into four parts: user layer, management layer, data layer and service layer, as shown in Figure 2.
Figure 2. System framework

The user layer shows the virtual training interface to the user through the Web browser and completes the corresponding interactive operation; The management layer provides an information management platform for administrators to manage unmanned equipment models and scenarios; The data layer provides storage space for three-dimensional model data and scene space data; The service layer serves the management layer and the user layer. Human-computer interaction management maintains the real-time interaction between users and virtual models, and database management is used to update models in time. Users, administrators and developers perform their duties without affecting each other, which improves the flexibility of the system.

3.2 Overall system development

Use 3D MAX to model, and use Three.js based on WebGL technology to analyze the model. 3D MAX modeling is powerful, extensible and practical. 3D models of unmanned aerial vehicles (UAV) and unmanned ship (UAV) and flight scene model of UAV are created in 3D MAX, and the analytical model of Three.js is imported in the format of obj 3D data. Three.js is a JavaScript 3D engine, which is a low-complexity and lightweight 3D library. Its main features are fast speed, rich functions, object-oriented, interactive support, strong scalability, and a powerful mathematical library to deal with problems in development. Get the data and render the model through JavaScript, render the unmanned equipment model, render the UAV flight scene into 3D graphics, make the web interactive 3D effect scene through HTML5, and display it in the browser. As the Obj format only supports the storage of static models, it cannot satisfy the movement, rotation and animation disassembly of unmanned aerial vehicles and unmanned ships in the platform. Therefore, the model is exported in FbX format, and imported into three.js by introducing FBXLoader() function and inflate.min.js plug-in. The 3D animation is resolved, and the disassembly group is realized by frame animation. Then, an interactive program is written for control, and the disassembly combination display is realized in the browser. Because Three.js solidifies the pick-up support, the operator can easily add interactive functions. The virtual simulation training platform based on unmanned equipment adopts B/S architecture design, and users can directly access the network services provided by the server without installing additional plug-in software [11], so that users can browse the virtual simulation system of unmanned equipment without the plug-in.

3.3 Manufacture of 3D Model of Unmanned Equipment

In this paper, DJI Elf 4 RTK UAV is taken as the prototype to model UAV. The model includes: UAV
fuselage, wing, UAV battery, rocker, etc. Taking Kewei C170 intelligent surveying and mapping unmanned ship as the prototype, the unmanned ship model is constructed. The main models to be built are: unmanned ship hull, 2.4G antenna, 900M antenna, RTK base station, communication link, water quality detector, sounder and other sensors, computers and other components. Unmanned equipment data models mainly include unmanned aerial vehicle models, unmanned ship models and their component models. The models are presented in the form of virtual three-dimensional models, which increases users' visual senses and improves their immersion in virtual reality. The process of drawing graphics from the Canvas tag of HTML5 is complicated. Therefore, this paper uses 3D MAX software with perfect 3D production and drawing functions to create a 3D model of unmanned equipment. There are many different modeling methods in 3D MAX, which have high flexibility and creativity [12]. The 3D MAX modeling process is shown in figure 3.

![3D MAX Modeling](image)

**Figure 3. 3D MAX modeling process**

Taking the establishment of the unmanned ship model as an example, firstly, the photo information of unmanned ship and its components is collected, and the initial three-dimensional figure of unmanned ship is created by taking photos as a reference. When the unmanned ship is created, based on the basic model of cuboid, the edited polygon is used to convert the created cuboid into an editable polygon, and the hull is perfected, finally completing the establishment of the three-dimensional model of unmanned ship and its assembled parts. At this time, the model has outline characteristics. However, the visual effects such as texture, texture, color and transparency are still lack realism. To make the final effect more realistic, we need to process the collected photos through Photoshop, load the photos into 3D MAX, map the models, and finally export them in Fbx data format, and load them into the 3D virtual scene. The unmanned ship three-dimensional model is shown in figure 4.

![Three-dimensional model of unmanned ship](image)

**Figure 4. Three-dimensional model of unmanned ship**

### 3.4 Scene rendering

Through a 3D scene created by three.js engine, the 3D model is imported into the scene in Fbx data
format for rendering, and light sources are arranged, viewpoints are adjusted and cameras are set for the scene. Set relevant parameters and correct environmental conditions before rendering. Determine the material, set the parameters such as ambient light, transparency and diffuse reflection, and add the material texture to the model; Establishing a light source, selecting a light source suitable for the scene, determining the position of the light source and completing the establishment of the light source; Set up the camera, place the target camera, determine the visual angle, place the viewpoint at the optimal position, and present a high-quality environment [13]. To render the 3D virtual scene, the rendering engine should be run after the above steps are completed [14]. Get the data and render the model through JavaScript, call the rendering function of the renderer to render the unmanned equipment model, render the UAV flight scene into 3D graphics, and realize the production of web interactive 3D effect scene through HTML5, which is integrated with the browser for display [15]. The scene rendering process is shown in Figure 5.

![Scene rendering flow chart](image)

**Figure 5. Scene rendering flow chart**

### 3.5 Human-computer interaction

Man-machine interaction is the key to the realization of a virtual reality trainer. The assembly of models, the rotation of scenes and the flight control of unmanned aerial vehicles all need to be realized by man-machine interaction technology. In this paper, the interaction between users and scenes is realized mainly through mouse events and keyboard events [16]. In the three-dimensional world, there are three axes, the X-axis points horizontally to the right, the Y-axis points vertically to the upper, and the Z-axis points outwards from the screen perpendicular to the XY plane. When the user uses the keyboard and mouse to control, the camera will move in the corresponding axes. Scroll the middle mouse button to scale the scene model, drag the left mouse button to rotate the scene model 720, and drag the right mouse button to translate the scene model. Click event is also indispensable in the assembly of unmanned equipment, which is the main body of interaction between users and the assembly scene of unmanned equipment. The design of human-computer interaction makes users more immersed in the assembly steps of unmanned equipment and the flight operation process of unmanned aerial vehicles, which not only gives users a new experience but also enables them to learn and train.

### 4. Function realization

The main purpose of designing the simulation system is to enable the operator to efficiently complete the training of unmanned equipment model assembly and unmanned aerial vehicle flight control operation, and help the user to be familiar with the assembly process of unmanned aerial vehicle and unmanned aerial vehicle flight control operation. These functions are realized based on 3DMAX modeling, WebGL rendering, animation display of three.js and man-machine interaction technology.

#### 4.1 UAV assembly simulation training

The modeling is completed by 3DMAX, and the virtual scene of UAV model is animated by WebGL rendering. The virtual simulation training interface for UAV assembly is shown in Figure 6. The middle part of the interface shows the UAV fuselage to be assembled, and the side shows that the
UAV components to be assembled include four propellers and UAV batteries. Human-computer interaction is realized through mouse events. Scrolling the middle mouse button to scale the UAV model, dragging the left mouse button to rotate the UAV model by 720°, and dragging the right mouse button to translate the UAV model. According to the system prompt information, the UAV can be assembled by clicking the event, selecting the components to be installed, clicking the correct installation position, and then the battery can be assembled after the wing assembly is completed. After assembly, start the UAV and the remote controller, and judge whether the UAV starts normally according to the indicator light of the remote controller. Interactive operations such as model scaling, rotation, splitting and combination are used in UAV virtual assembly simulation training, which improves the user's experience of hands-on operation, and enables users to reflect the details and assembly of UAV model more comprehensively.

Figure 6. Virtual simulation training interface for UAV assembly

4.2 Simulation training of unmanned ship assembly
Unmanned ship virtual simulation training can be divided into the following five modules: model display, model assembly, animation display, scoring and text prompt module, as shown in Figure 7.

Figure 7. Composition of virtual simulation training module for unmanned ship

The virtual simulation training interface of unmanned ship assembly is shown in Figure 8. The scoring module and animation display module are added to the virtual simulation training of unmanned ship assembly. The fuselage of unmanned ship to be assembled is displayed in the middle of the interface, and the components to be assembled on the side of the interface include 2.4G antenna, 900M antenna, RTK base station, water quality detector, sonde and other sensors. Meet the human-computer interaction through mouse events, roll the middle mouse button to scale the unmanned ship model, drag the left mouse button to rotate the unmanned ship model by 720°, and press the right mouse button to translate the unmanned ship model. To complete the assembly of unmanned ship
through mouse event, users need to install all parts of unmanned ship in sequence, the installation sequence is: 900M antenna - 2.4G antenna - RTK base station - sensor. If the installation is wrong, the system will give a reminder and demonstrate how to install it. If the installation is correct, the system will give a score. After the assembly, the unmanned ship should be linked with the computer, so as to monitor the data in real time and complete the operation.

Figure 8. Virtual simulation training interface for unmanned ship assembly

4.3 Flight simulation experiment of UAV
Unmanned aerial vehicle flight virtual simulation training is to simulate the practical test of surveying and mapping of Huifei UAV, and control the UAV to fly on the route. The realization of the system is embodied in scene display and scene control, and the UAV flight virtual simulation training module is shown in Figure 9.

Figure 9. Unmanned aerial vehicle flight virtual simulation training module

Set up scene matching in UAV flight scene, obtain data and render model through JavaScript, render UAV flight scene into 3D graphics, and make 3D virtual more realistic. The flight virtual simulation training interface is shown in Figure 10. Human-computer interaction is realized through mouse events and keyboard events. Unmanned aerial vehicle (UAV) rocker includes two modes: American hand and Japanese hand. Users can switch rocker modes and choose their own good mode for simulation exercises. By clicking on the event, the rocker mode is selected for simulation exercise, and the user controls the UAV's lifting and lowering, front and back, left and right, and fuselage rotation through keyboard event operation. In the system, the UAV is started by short pressing SD key and JK key to form "Inner Eight". W stands for left rocker pushing up, S stands for left rocker pushing down, A stands for left rocker pushing to the left and D stands for left rocker pushing to the right. I stands for right rocker pushing up, K stands for right rocker pushing down, J stands for right rocker pushing
pushing left, and L stands for right rocker pushing right. Japanese hand (right hand throttle)-left hand elevator and rudder, right hand throttle and aileron, American hand (left hand throttle)-left hand throttle and rudder, right hand lift and aileron. Users can be familiar with the operation of the rocker and skillfully control the flight of UAV through continuous practice.

![Figure 10. Unmanned aerial vehicle flight virtual simulation training interface](image)

5. Integrated application of water and land

In this paper, the waters in front of the Institute of Urban Environment, Chinese Academy of Sciences were investigated, and the collected data were divided into orthogonal images of unmanned aerial vehicles and underwater topography, water quality and concealed pipes of unmanned ships. Through the image data collected by unmanned aerial vehicle (UAV) flight, the social and natural environment near the survey area is analyzed, and the situation of pollution sources in the survey area is known. The unmanned aerial vehicle is put into water for underwater measurement to obtain relevant data, and the software is used for data analysis at the computer end, so as to obtain the water pollution situation in the survey area.

5.1 Orthophoto of UAV

In this paper, DJI Phantom 4 RTK rotary-wing UAV is used to collect data in the survey area. Before flying operation, it is necessary to check the UAV to ensure that it can be used normally and complete the flight operation according to the scheduled requirements. After checking, determine the take-off location. Before taking off, check whether there are tall buildings in the flight operation area to ensure that the flying height of UAV is higher than all buildings in the flight operation area. Then, select the planning method on the UAV remote control, plan the route and collect the orthophoto data. After the data collection, use Pix4D software to process the collected orthophoto to produce a complete orthophoto, as shown in Figure 11.

![Figure 11. Orthophoto of Chinese Academy of Sciences survey area](image)

5.2 Underwater survey of unmanned ship

In practical application, when unmanned ships measure underwater detection, they mainly collect
underwater topography by single-beam bathymeter, collect water quality by multi-parameter water quality detector, and check concealed pipes by side-scan sonar. By analyzing water pollution by combining these three kinds of data, we can get a more comprehensive and accurate understanding of water pollution and some pollution sources in the survey area.

1) Underwater topography and water quality

In this paper, C170 unmanned ship is used to collect data in the waters before Institute of Urban Environment, Chinese Academy of Sciences, so as to reflect the water pollution situation in this area. After all hardware devices are connected, enter HiMAX sounder software, create new projects, set relevant parameters, communication link, ship shape design, route design, call electronic chart and engineering base map according to requirements, etc. After all parameters are set, automatic data collection and recording can be started.

After data preprocessing by HiMAX software, the dat format file of measurement data is exported. The output data of single-beam sounder includes number, mapping code, plane coordinates and bottom elevation. Drawing underwater topographic map of lake area by CASS software in South China. The dat file is loaded by mapping and processing elevation points, DTM is established by discrete elevation points, isobath is generated, and 1: 500 underwater topographic map of the survey area is drawn, as shown in Figure 12.

![Figure 12. 1: 500 underwater topographic map](image)

The data exported by the unmanned ship multi-parameter water quality detector is an excel data table, which contains the serial number, longitude and latitude coordinates, measurement time, water temperature, conductivity, salinity, dissolved oxygen, turbidity, ammonia nitrogen, nitrate nitrogen, chloride and other information of discrete points. Some water quality detection data are shown in Table 2.

2) Side scan sonar

The waters in front of the Institute of Urban Environment, Chinese Academy of Sciences were scanned with OSM3 side scan sonar carried by C170 unmanned ship. The bright part of sonar scanning is the emission of objects. Because there is water in the pipeline, the reflection area of the pipeline part is longer, which generally extends to the embankment. Therefore, the shape of the nozzle can be directly displayed on the side scan image, such as the exposed nozzle and semi-buried state. Sonar can also extend to the inside of the pipeline to form a longer reflection area [17]. Since there is no obvious foreign matter and no obvious pipeline at the bottom of the survey area, the unmanned ship is driven into the middle of the pier with the pier as the target, and four bright spots can be clearly seen in Figure 13, where the pier is located.
Table 2. Some water quality monitoring data

| Number | Longitude   | Latitude   | Time       | Temp(℃) | Cond(mS/cm) | SpCond(mS/cm) |
|--------|-------------|------------|------------|---------|-------------|--------------|
| 1      | 118.057877  | 24.608004  | 2019-09-07 11:24:24 | 31.64   | 0.47        | 0.42         |
| 2      | 118.057853  | 24.608038  | 2019-09-07 11:24:19 | 31.74   | 0.48        | 0.42         |
| 3      | 118.057872  | 24.608072  | 2019-09-07 11:24:14 | 31.80   | 0.48        | 0.42         |
| 4      | 118.057903  | 24.608032  | 2019-09-07 11:24:09 | 31.58   | 0.48        | 0.42         |
| 5      | 118.057862  | 24.608033  | 2019-09-07 11:24:04 | 31.37   | 0.47        | 0.42         |
| 6      | 118.057837  | 24.608070  | 2019-09-07 11:23:59 | 31.35   | 0.47        | 0.42         |
| 7      | 118.057868  | 24.608107  | 2019-09-07 11:23:54 | 31.42   | 0.47        | 0.42         |

| Sal(psu) | Depth(m) | Turbidity(NTU) | DO(mg/L) | NH4+ - N(mg/L) | NO3- N(mg/L) | Cl-(mg/L) |
|----------|----------|----------------|----------|----------------|--------------|-----------|
| 1        | -0.12    | 9.90           | 8.75     | 4.17           | 28.07        | 22.66     |
| 2        | -0.12    | 9.83           | 7.77     | 4.17           | 28.13        | 22.18     |
| 3        | -0.12    | 9.76           | 8.41     | 4.17           | 28.20        | 21.74     |
| 4        | -0.12    | 10.16          | 8.58     | 4.19           | 28.27        | 21.22     |
| 5        | -0.11    | 10.83          | 7.64     | 4.21           | 28.25        | 20.86     |
| 6        | -0.11    | 10.91          | 7.60     | 4.20           | 28.24        | 20.47     |
| 7        | -0.11    | 10.81          | 7.24     | 4.20           | 28.24        | 20.19     |

**Figure 13.** Side scan example image

6. Conclusion
Using intelligent unmanned ship to detect water pollution is more convenient, simple, accurate, saves manpower and material resources, avoids the risk of artificial measurement, provides safe working conditions for workers, and is a good tool for water quality monitoring and pollution traceability, which can be effectively applied to sewage monitoring, making sewage detection more efficient and accurate. Unmanned ships can also combine the latest technologies such as unmanned aerial vehicles and underwater robots to provide real-time data in an all-round way, which can provide rapid and reliable basis for water pollution prevention and control, and has broad development space.

At the same time, aiming at the problems existing in the teaching of unmanned aerial vehicle and unmanned ship, this paper had taken DJI Phantom 4 RTK and Kewei unmanned ship as prototypes based on WebGL technology and virtual simulation technology. Refer to the practical test process of UAV in DJI. A virtual simulation training system has been developed and built for unmanned equipment. The system has solved the problems of high cost of unmanned equipment and constraints of equipment, site, time and other factors in the teaching process. Students can directly carry out assembly and flight control simulation training of unmanned aerial vehicles and unmanned ships on the Web side,
and can perform unlimited simulation exercises, which is of great significance for training talents such as unmanned aerial vehicles and unmanned ships. By investigating the water area and its surrounding environment in front of the Institute of Urban Environment, Chinese Academy of Sciences, the characteristics of automation, intelligence and informationization of unmanned equipment system are fully reflected in this process. Unmanned aerial vehicles and unmanned ships are used to scan and detect the survey area, and the data collection task is completed efficiently, and the collected data has high accuracy.

Although the system has achieved good results and solved the teaching problem of unmanned equipment assembly flight control, there are still some shortcomings: in the follow-up work, the virtual simulation system for data acquisition of unmanned aerial vehicles and unmanned ships can be developed to improve the whole teaching process of unmanned equipment.

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