The Design of an Autonomous Underwater Vehicle for Water Quality Monitoring

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Abstract. This paper describes the development of a civilian-used autonomous underwater vehicle (AUV) for water quality monitoring at reservoirs and watercourses that can obtain real-time visual and locational information. The mechanical design was completed with CAD software Solidworks. Four thrusters—two horizontal and two vertical—on board enable the vehicle to surge, heave, yaw, and pitch. A specialized water sample collection compartment is designed to perform water collection at target locations. The vehicle has a central controller—STM32—and a sub-coordinate controller—Arduino MEGA 2560—that coordinates multiple sensors including an inertial sensor, ultrasonic sensors, etc. Global Navigation Satellite System (GNSS) and the inertial sensor enable the vehicle’s localization. Remote operators monitor and control the vehicle via a host computer system. Operators choose either semi-autonomous mode in which they set target locations or manual mode. The experimental results show that the vehicle is able to perform well in either mode.

1. Introduction
Through recent years, Unmanned Underwater Vehicles are proved to be efficient, cost-effective, and safe options to carry out maritime operations. UUVs reduce human losses in high-risk operations and decrease operational costs, and are therefore adopted by militaries and firms to perform tasks including oceanographic researches, environment monitoring, resource exploitation, maritime search and rescue, etc.

UUVs can be classified as Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicles (AUV). ROVs require tether connections for power supply and human operators at a remote base. Unlike ROVs, AUVs have power supply, propellant, and multiple sensors on board that enable them to operate individually. Via fiber optics, microwave transmission, communication satellites, and other communication media, remote controllers can supervise AUVs and give commands. Meanwhile, AUVs can operate individually according to given missions and send back data collected and processed by sensors and processors which reflect information about their surrounding environment and operation status. This work presents the development of an AUV used to monitor water quality at reservoirs and watercourses.

2. Vehicle Descriptions

2.1. Structure Design
The vehicle takes a streamlined configuration. It has a metal cover where a camera, a lightening device, antennas, and a switch locate. After all other components are fixed inside the vehicle, the cover is sealed with screws.
2.2. The Propulsion System
The propulsion system of the vehicle consists of four thrusters. Two horizontal thrusters enable the vehicle to surge and yaw; two vertical thrusters enable the vehicle to heave and pitch. An appropriate yaw angle can prevent the vehicle from swaying. Because the vehicle operates at reservoirs and inland rivers where winds and waves are weak, the vehicle rolls insignificantly.

2.3. The Water Sample Collection Compartment
Figure 3 displays the structure of water sample collection compartment which is composed of a pump compartment and sample bottle compartment. The seal of the pump compartment is strictly the same as that of the control system. The sample bottle compartment is sealed by a hinge and a locking pin. The pumps, sample bottles, and the outside water environment are connected by high pressure water pipes. The water bottles can be locked through rotation into the holders.
3. The Power System
The vehicle uses 24V ferric phosphate battery. Comparing with traditional lead-acid batteries, ferric phosphate battery is environmental friendly with greater energy density and better high temperature performance.

The horizontal thrusters require power sources of 24V 30A DC, vertical thrusters require power sources of 12V 40A DC, communication device requires a 12V power source, and the control module requires 5V power source. The ferric phosphate battery directly powers the horizontal thrusters. Power is supplied to vertical thrusters through a 24V to 12V converter. Because the thrusters require large currents, instead of the switch directly controlling the thrusters, the switch controls the thrusters through a relay.

4. The Control System
The control system consists of three modules: a propulsion module, a sensor module, and a central control module.

The propulsion module consists of four thrusters and their corresponding drivers. Thrusters in the horizontal direction use induction brushless motors and thrusters in the vertical direction use synchronous brushless motors.
Water quality sensor, water logging sensor, and underwater ultrasonic sensor are controlled by a subordinate controller (using Arduino MEGA 2560). The sensors and the controller constitute the sensor module.

Radio station, Global Navigation Satellite System (GNSS) and inertial sensor, and the central controller (using STM32) constitute the central control module. The central control module is responsible for receiving the instructions from the host computer system and, according to the instructions and data from sensor module, performing vehicle routing and task allocation.

![Diagram of the control system](image)

**Figure 5.** The diagram of the control system.

5. **The Host Computer System**

5.1. **The Login Interface**

The host computer system allows a user to control the vehicle and read sensors’ data after login. The system enables both manual control and autonomous control.
5.2. *The Manual Control Mode Interface*

The manual control mode interface displays the vehicle’s position, the monitor of the camera, and the vehicle operation status. Via the interface, a user controls the vehicle’s movements, starts water sample collection, and captures images from the camera. Due to errors in the simulation, the system enables modification of the vehicle’s parameters in the real environment. A user can modify the control parameters of three active disturbance rejection control (ADRC) channels, each for surging, pitching, and yawing.

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**Figure 6.** The login interface.

**Figure 7.** The manual control mode interface.
5.3. The Autonomous Control Mode Interface
The autonomous control mode interface (Figure 8) asks a user to set target locations on the vehicle will perform tasks accordingly without manual control. The interface allows a user to capture images from the camera. A user can also switch to the manual control mode.

6. Design Specifications
The vehicle has following specifications:

Table 1. Design specifications of the vehicle.

| Dimension (mm³) | Weight (kg) | Rated Load (kg) | Operation Depth (m) | Operation Range (km) |
|----------------|-------------|-----------------|---------------------|---------------------|
| 1100×400×320   | 70          | 7               | 20                  | 2                   |

| Mobility        | Maximum Speed (m s⁻¹) | Positioning Accuracy (m) | Image Resolution | Control Mode       |
|-----------------|-----------------------|--------------------------|------------------|--------------------|
| Surge, Heave, Yaw, and Pitch | 1                     | ±1                       | Standard Definition | Manual and Autonomous |
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Figure 8. The autonomous control mode interface.