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Autonomous Underwater Probe for Chemical and Gas Detection Design and Calibration for Aquatic Environmental Health Monitoring

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Abstract

The necessity for real-time, autonomous monitoring of gas and chemical levels in aquatic environments is increasing due to water quality concerns linked to industrial activities and environmental health. This research outlines the design and
preliminary testing of an autonomous underwater probe (AUP) equipped with gas and ultrasonic sensors, alongside control components like the ESP-32 and Arduino Uno. The probe's capabilities in real-time data transfer, adaptive navigation, and energy efficiency offer a scalable, low-cost solution for continuous environmental monitoring. Results from field testing indicate promising detection capabilities, with identified areas for
improvement in both durability andextended operation.

Keywords: Autonomous underwater probe, real-time monitoring, gas detection,environmental sampling, ESP-32, ultrasonic navigation.

Introduction

Monitoring of underwater pollutants is crucial to protect water resources impacted by industrial runoff and agricultural practices. Traditional water sampling techniques are often labor-intensive and limited in geographic reach. Autonomous underwater probes (AUPs) address these limitations by enabling remote, efficient sampling and data collection.

This research introduces an autonomous underwater probe for real-time gas and chemical detection, featuring modular components and adaptive functionalities to operate effectively across varied water conditions.

Literature Review

A. Sampling Systems for Autonomous Water Monitoring

In their study, Akiba and Tanaka [1] presented a sampling system that leverages intermittent suction to minimize contamination—a principle adaptable forcontinuous sampling systems. Similarly, Fornai et al. [4] devised a compact watersampling system optimized for tight spaces, which informs the design of our compact probe.

B. Control Algorithms and NavigationZhang et al. [2] designed an energy-efficient navigation algorithm for a gliding robotic fish, which supports efficient control methods in AUPs, while Leonard et al. [7] demonstrated adaptive path planning with a glider fleet to optimize sampling coverage—an approach that underpins our probe's navigational adaptability.

C. Real-Time Monitoring and DesignConsiderations

Ferri et al. [3] created a catamaran-based ASV that performs real-time water quality assessments, demonstrating how compact,stable structures enhance sampling capabilities. Hitz et al. [8] implemented real-time transmission in inland water
monitoring, guiding our approach to datatransfer using the ESP-32.

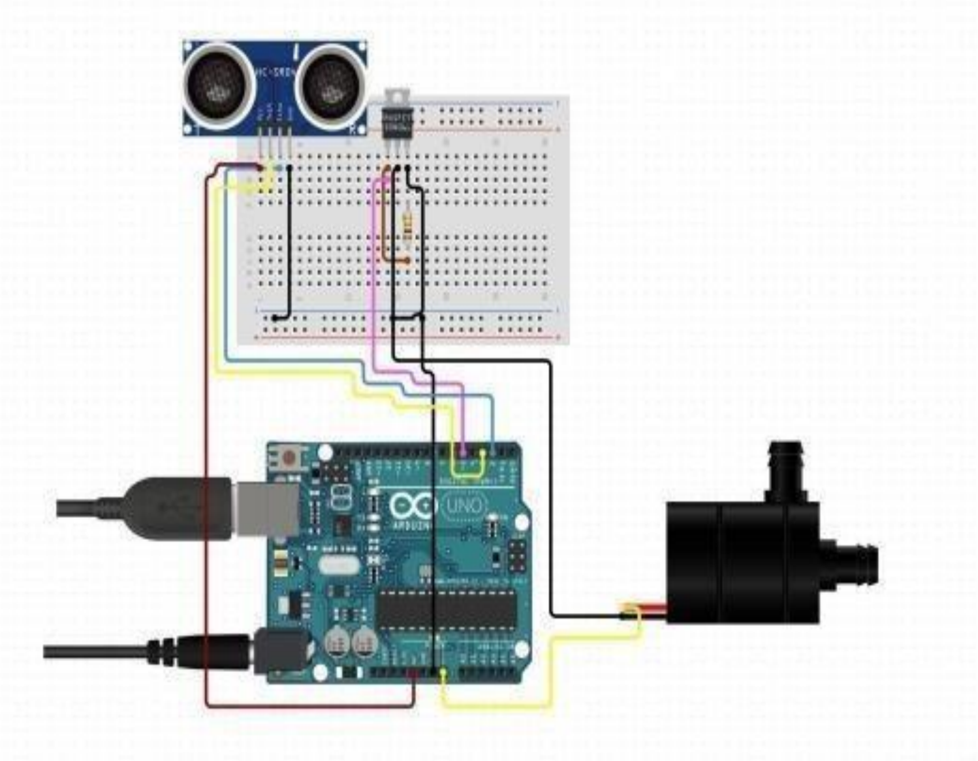
Design and Development of theAutonomous Underwater Probe

A. Mechanical and Structural Design

Our probe features an open framework housing the ESP-32, Arduino Uno, gas sensors, and ultrasonic sensors, which provides flexibility for testing and sensorplacement. Plans for future developmentinclude an external protective shell for enhanced durability in variable water conditions. Sampling and Detection System

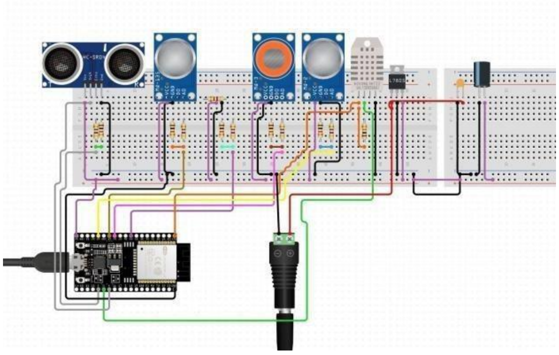
The probe's gas sensors are positioned to optimize chemical detection and minimizecross-ontamination, while ultrasonic sensors support navigation by measuring depth and detecting obstacles.

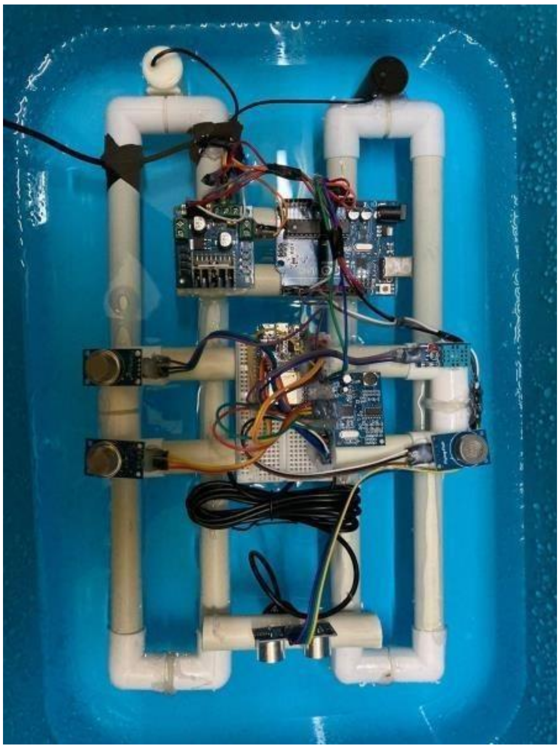
B. Control and Data Processing An ESP-32 processor handles data processing and wireless transmission, enabling the probe to relay information toremote devices in real time. The Arduino Uno manages navigation and processes
input from the sensors to make necessaryadjustments.



C. Data Transmission and RemoteMonitoring

Real-time data transfer is facilitated by the ESP-32, enabling immediate environmental assessment, a crucial feature for applications requiring rapidresponse.





Metal Oxide Sensor Formula:

$C=A*(R/R0)^{B}$

Where:

C represents the gas concentration in partsper million (ppm).

R is the resistance detected when gasis present.

R0 denotes baseline resistance in clearair conditions

A and B are constants specific to both the gas type and sensor, generally found in thedevice’s technical documentation.

2. Calibrating for Sensitivity

Each sensor requires calibration to ensure it provides accurate readings. This processinvolves exposing the sensor to known concentrations of the gas to establish a calibration factor. Calibration Formula:

In the case of linear calibration, where V

V is the output voltage from the sensor and

m

m is the slope of the calibration curve:

Formulae & Calculation

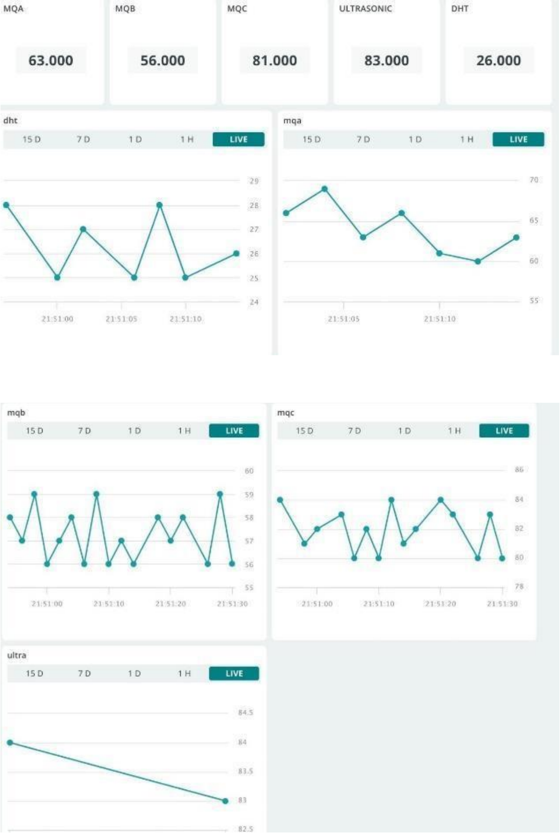
1. Calculating Gas Concentration fromSensor Output

Common gas sensors, including
electrochemical, metal oxide, and infraredtypes, produce outputs that correlate to theconcentration of the targeted gas. These signals, either analog or digital, are converted into concentration measurements using equations that may beeither linear or logarithmic, depending on the sensor.

For example, with a metal oxide semiconductor (MOS) sensor, gas concentration ‘C’ often depends on thesensor's resistance ‘R’ calculated as:

$C=m*(V-V0)$

C represents the gas concentration in ppm.V sensor’s output voltage when exposed tothe gas.
V0 baseline voltage in air.



MQA 63.000
MQB 56.000
MQC 81.000
ULTRASONIC 83.000
DHT 26.000

Materials and Methods

A. Materials and Components

Microcontrollers: ESP-32 for data processing and communication; Arduino Uno for managing navigation and sensors.

Sensors: Gas sensors for detecting specific chemicals, and ultrasonic sensors for depth and obstacle detection.

Power System: A rechargeable battery designed for field operations, with futureconsiderations for solar recharging.

B. Testing Procedure

Sensor Calibration: Conducted in
laboratory conditions to ensure accuracy.

Prototype Testing: Performed in a controlled tank to assess sensor accuracyand data transmission.
Field Testing: Conducted in natural waterbodies to test real-world functionality,
including navigation and data reliability.

C. Data Collection and Analysis

Data collected in real time is processed to evaluate sensor performance. Testing observations guide design improvements for durability and signal strength.

Experimental Setup

A. Lab-Based Testing and Calibration

Sensors are calibrated with known concentrations of chemicals to assess accuracy, while ultrasonic sensors aretested for reliable obstacle detection.

B. Prototype Testing in ControlledEnvironment

The prototype undergoes tests in a simulated environment to evaluate chemical detection, navigation, and datatransmission performance.

C. Field Testing

The probe is deployed in natural low-flowenvironments, allowing for real-world testing of chemical detection, navigationalaccuracy, and the durability of exposed components.

Results and Discussion

A. Sensor Performance and AccuracyThe probe's gas sensors display high

accuracy and sensitivity, while ultrasonicsensors effectively measure depth and avoid obstacles. Signal interference in shallow water points to potential improvements.

B. Data Transmission and Monitoring

The ESP-32 consistently transmitted datawith minimal delay, proving effective forreal-time applications. Occasional interruptions suggest a need for signalenhancement.

C. Navigation and Adaptive Path Control

Navigation, governed by the Arduino Uno,demonstrated effective path planning and obstacle avoidance. Exposed components may benefit from additional protective covering to extend durability.

D. Energy Efficiency and FutureEnhancements

Current battery life supports brief missions, but longer deployments may require solar charging. Future developmentwill focus on optimized energy management.

Conclusion and Future Work

The research successfully demonstrates an autonomous probe capable of real-time gas and chemical monitoring in aquatic environments. The modular design enables accurate navigation, reliable data transmission, and effective environmentalsampling.

Future Work

Design Enhancements: Addition of aprotective shell.
Energy Optimization: Integration of solarcharging.
Data Transmission Reliability: Testing ofalternative communication methods.
Extended Field Testing: Trials in diversewater conditions for robustness verification.

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