Design & Implementation of an Autonomous Dissolved Oxygen Monitoring System for Remote Deployment

INTRODUCTION

This project applies low-power electronics, optical sensing, and autonomous systems. The goal is to enable continuous, in situ monitoring of dissolved oxygen in remote environments.

What is Dissolved Oxygen?

DO is a key parameter for assessing the ecological status of surface waters. It governs the survival and distribution of aquatic organisms and serves as an indicator of ecosystem health. Persistently low DO concentrations are associated with organic pollution, eutrophication, and altered hydrological conditions, potentially leading to long-term ecological degradation.

Legal Framework

Within the European Union, the Water Framework Directive (WFD) requires DO monitoring to verify compliance with the objective of "good ecological status". Conventionally, such monitoring is based on manual sampling and often fails to capture short-term dynamics such as daily oxygen fluctuations or pollution events.

PROBLEM STATEMENT

Cost Limitations
Dissolved oxygen monitoring systems are costly and centralized, limiting spatial coverage and excluding small or remote water bodies.

Energy Efficiency
Long-term autonomous monitoring requires strict energy constraints for battery-powered deployment.

Enclosure Requirements
Outdoor operation requires a weather-resistant enclosure for protection against UV and precipitation.

Maintenance & Biofouling
Some sensor types consume oxygen or require frequent calibration, limiting unattended operation. Optical DO sensors reduce calibration needs but still require measures to address biofilm formation.

Vandalism Risk
Field deployments in accessible locations are vulnerable to vandalism and accidental damage, increasing financial and operational risks.

Data Handling
Data from remote deployments must be transmitted and converted into human-readable formats.

Fig. 1: Commercial dissolved oxygen sensor station used as a reference system provided by the LINEG laboratory.

SOLUTION & IMPLEMENTATION

PHYSICAL ARCHITECTURE

The **power supply** is tailored to the requirements of the system components. It offers:
- A capacity of 2000 mAh
- Rechargeable Lithium-ion technology
- High energy density and compact form factor

The **microcontroller** is a ESP32-S3.
- Widely supported platform and mature development ecosystem
- Operates on low power to maximize energy efficiency
- Offers a sleep mode to reduce energy consumption even further
- Uses LoRa for wireless data transmission
- Sufficient processing performance for sensor control and data handling
- Compact form factor

The **enclosure** is made from a pipe and pipe plugs are made of **PVC**. The pipe–coupling connection is watertight for non-pressurized applications and offers long-term protection against splash water, rain, and submersion. Further properties:
- Cylindrical shape for increased structural stability
- Limited UV protection (Can easily be improved by coating)
- Condensation protection can be provided using silica gel
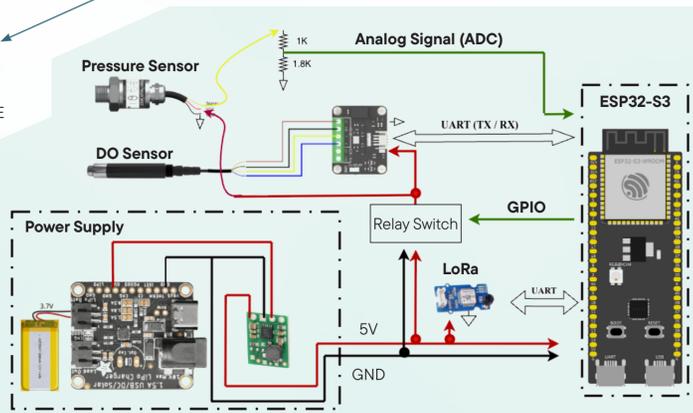- Very cheap and easily replaceable

The monitoring system has multiple sensors:
- a **pressure sensor**
- a **temperature sensor**
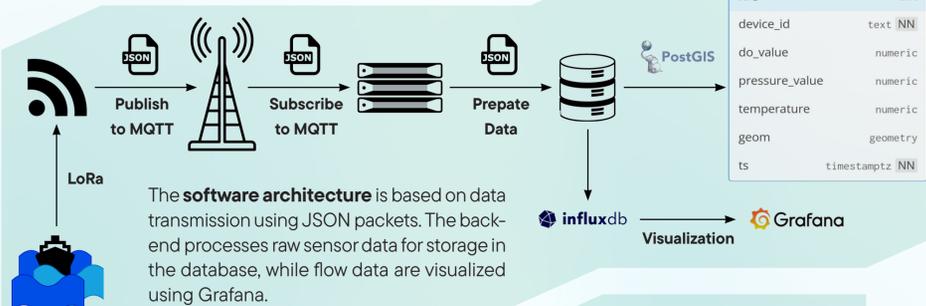- an **optical dissolved oxygen sensor**

A **copper mesh** covers the DO sensor to enhance the performance and increase the durability by preventing biofouling. Copper acts as an **antibacterial** and **antifungal** agent. When submerged, it releases copper ions that inhibit the growth of organisms (algae, bacteria, plants).
The mesh is fixed to the sensor with a custom cap designed using Fusion 360 and fabricated using 3D printing.

Fig. 2: AI-Generated with DALL-E (ChatGPT), further edited

The **hardware design** supports a tunable sleep–wake cycle and adjustable measuring intervals for efficient long-term power management.

DATA FLOW, PROCESSING & VISUALIZATION

The **software architecture** is based on data transmission using JSON packets. The backend processes raw sensor data for storage in the database, while flow data are visualized using Grafana.

measurements		
id 🔑		int
device_id	text	NN
do_value		numeric
pressure_value		numeric
temperature		numeric
geom		geometry
ts	timestamptz	NN

Grafana is used to implement the graphical user interface. It provides web-based visualization and monitoring of sensor data. The user can visualize data within a specific timeframe (picture below). The visualization itself be configured manually (picture on the right).

Fig. 3: Students documenting system requirements during the requirements engineering phase.

Fig. 4: Student project team during a site visit at the LINEG laboratory.

EVALUATION & SUMMARY

This project shows that an autonomous, low-cost dissolved oxygen sensor can be developed for long-term deployment in flowing waters. The prototype integrates optical dissolved oxygen sensing with low-power electronics and a robust mechanical design in outdoor environments.

To address the challenges of long-term monitoring, the system includes an environmentally friendly solution against biofouling, as well as a power supply tailored to the requirements of the components. The results contribute to reduced energy consumption and lower maintenance effort during deployments. Measured data are transmitted remotely and made available through a web-based visualization interface. This allows continuous monitoring without the need for frequent site visits. It also enables the observation of temporal oxygen dynamics that are difficult to capture with conventional sampling methods.

Although further field testing and long-term validation are required, the prototype demonstrates a practical and scalable approach for monitoring dissolved oxygen in remote locations and small water bodies.

REFERENCES

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