Project Title: Solar-Powered IoT Water-Quality Buoy

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1. Introduction

A floating, self-powered station that periodically measures key water-quality parameters (pH, turbidity, dissolved oxygen, conductivity, temperature) and transmits data wirelessly to an online dashboard. Designed for long-term deployment in ponds, lakes, or slow-moving rivers.

2. Objectives

- **Continuous Monitoring**: Capture multi-parameter water quality at configurable intervals.
- **Low-Power Operation**: Use solar energy and efficient power management for autonomous operation ≥ 6 months.
- **Long-Range Communication**: Transmit data via LoRaWAN (or NB-IoT) to gateways up to several kilometers away.
- **Outreach & Education**: Provide real-time data visualization for community and school engagement.

3. System Overview

1. **Sensors**: pH probe, optical turbidity sensor, optical dissolved-oxygen (DO) sensor, conductivity probe, DS18B20 temperature sensor.
2. **Controller**: STM32L4 microcontroller running **C firmware** with STM32Cube HAL.
3. **Power**: 5 W solar panel charging a 6 Ah $LiFePO_4$ battery through an MPPT charge controller.
4. **Comms**: LoRaWAN radio module (e.g., RFM95) via SPI; fallback NB-IoT modem (SIM800C).
5. **Enclosure**: IP67-rated waterproof housing with buoyant float and tether.

4. Hardware Components

Component	Model/Spec	Qty	Est. Cost
Microcontroller	STM32L476RG (Cortex-M4)	1	\$15
pH Probe	Analog 0–14 pH probe	1	\$80
Turbidity Sensor	Optical 0–1000 NTU	1	\$50
Dissolved Oxygen Sensor	Optical DO (0–20 mg/L)	1	\$120
Conductivity Probe	0–2000 µS/cm	1	\$40
Temperature Sensor	DS18B20 waterproof module	1	\$5
LoRaWAN Module	RFM95W (915 MHz)	1	\$12
$LiFePO_4$ Battery	6 Ah, 12.8 V	1	\$40
Solar Panel	5 W, 12 V	1	\$20

Component	Model/Spec	Qty	Est. Cost
MPPT Charge Controller	1 A @ 12 V $LiFePO_4$ support	1	\$15
Waterproof Enclosure	IP67 ABS plastic	1	\$25
Floats & Hardware	PVC, stainless fasteners	1	\$15
Total (est.)			**\$437**

5. Software Architecture

1. **Firmware (STM32)**
2. Written in **C** using STM32Cube HAL and CMSIS.
3. Sensor drivers (I^2C/SPI/ADC), calibration routines, and power state logic.
4. LoRaWAN communication via MCCI LoRaMAC library.
5. **Backend & Server**
6. **Go microservice** (e.g., Gorilla/Mux) for REST API and MQTT ingestion.
7. MQTT broker (Eclipse Mosquitto) routes packets from LoRa gateway.
8. Persists data to InfluxDB time-series database.
9. **GUI Dashboard**
10. **Python** desktop application (PyQt5) for real-time plots (matplotlib) and alerts.
11. SQLite local cache for offline operation.

6. Power Management

- **Harvesting**: Solar panel → MPPT → $LiFePO_4$ battery.
- **Budget**: MCU sleep ~5 µA; per-sensor read ~80 mA for 2 s; LoRa transmit ~120 mA for 2 s.
- **Estimation**: ~10 mAh per cycle; hourly → ~240 mAh/day; battery + solar for months.

7. Communication Strategy

- **Primary**: LoRaWAN (915 MHz) uplinks every 15 min.
- **Fallback**: NB-IoT/2G (SIM800C) on comm failure.
- **Security**: AES-128 (LoRaWAN) and HTTPS/TLS for backend.

8. Mechanical & Enclosure Design

- **Buoyancy**: Dual-part closed-cell foam housing electronics.
- **Mounting**: Tether line allows vertical float motion.
- **Sensor Probes**: 3D-printed arm with cable glands and spring-loaded depth control.

9. Data Management & Dashboard

- **Time-Series DB**: InfluxDB for high-frequency data.
- **Visualization**: Optional React dashboard; primary Python GUI.
- **Alerts**: Threshold-based notifications via Twilio/email.

10. Development Plan & Timeline

Phase	Duration	Deliverables
Requirements & Design	3 weeks	Final design doc, BOM
Hardware Prototype	6 weeks	PCB, enclosure, sensor basics
Firmware Development	4 weeks	C drivers, power mgmt, LoRa comms
Backend & Dashboard	4 weeks	Go service, InfluxDB schema, Python GUI MVP
Integration & Testing	3 weeks	Field calibration, endurance tests
Outreach Prep	2 weeks	Guides, demos, community materials

11. Testing & Validation

- **Lab calibration** against known standards.
- **Field trials**: ≥ 30 days deployment.
- **Environmental tests**: thermal cycling, waterproof soak.

12. Outreach & Community Engagement

- Partner with local schools/watershed councils.
- Host live data demos and hands-on workshops.
- Distribute monthly water-quality reports.

13. Budget & Resources

- **Hardware**: ≈\$450/unit (recommend 2 units).
- **Hosting**: \$10–\$20/month.
- **Total**: ≈\$920 for 2 units + 6 months hosting.

14. Risks & Mitigation

Risk	Impact	Mitigation
Sensor drift/calibration loss	Data inaccuracy	Scheduled recalibration
Winter power shortfall	Downtime	Adjust panel size or interval
Comms failure (no gateway)	Data gaps	NB-IoT fallback

15. C Module Interactions (UML)

```
classDiagram
    class sensor_module_h {
```

```
        +float measure_temperature(void)
        +float measure_ph(void)
        +float measure_turbidity(void)
        +float measure_do(void)
        +float measure_conductivity(void)
    }
    class power_manager_h {
        +void pm_sleep(void)
        +void pm_wake(void)
        +void pm_manage_charging(void)
        +float pm_get_battery_level(void)
    }
    class comm_module_h {
        +bool comm_send_data(const DataPacket *packet)
        +DataPacket comm_encrypt(const DataPacket *packet)
        +bool comm_fallback_send(const DataPacket *packet)
    }
    class firmware_main_c {
        +int main(void)
        +void run_cycle(void)
        +void calibrate_sensors(void)
        +void power_state_machine(void)
        +void enqueue_data(void)
    }
    class gateway_server_js {
        +void receive_data(DataPacket packet)
        +void store_data(DataPacket packet)
        +void forward_to_db(void)
    }
    class dashboard_py {
        +void visualize_data(TimeSeries data)
        +void check_alerts(const DataPacket *packet)
        +void fetch_latest(void)
    }

    sensor_module_h --> firmware_main_c : calls
    power_manager_h --> firmware_main_c : calls
    comm_module_h --> firmware_main_c : uses
    firmware_main_c --> gateway_server_js : LoRaWAN uplink
    gateway_server_js --> dashboard_py : API feed
```

End of Design Document.