ECED4402 – Project

Embedded Systems Solutions for Ocean-Related Challenges Using STM32 and FreeRTOS

Prepared by Group 13:

Temitope Onafalujo - B00863997

Nnaemeka Nnadede - B00881311

Prepared for:

Boris B. Nges

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Introduction

Ocean pollution is a critical global challenge with wide-ranging consequences for marine ecosystems, biodiversity, and human health. Over 8 million metric tons of plastic waste enter the oceans annually, contributing to devastating ecological impacts. High turbidity, caused by sediment runoff and organic waste, obstructs sunlight from reaching underwater vegetation, such as seagrasses and corals, which serve as foundational species in marine food webs. This reduction in photosynthesis weakens entire ecosystems, affecting species dependent on these plants for food and shelter.

Microplastics, the result of plastic degradation, are ingested by marine organisms at various trophic levels. These particles accumulate in the tissues of fish, shellfish, and other aquatic life, leading to severe physical and biochemical harm. Furthermore, humans consuming seafood are at risk of microplastic ingestion, raising concerns about long-term health impacts, including carcinogenicity and endocrine disruption.

Dissolved oxygen (DO) depletion presents another significant issue. Nutrient pollution from agricultural runoff promotes excessive algal blooms, which decompose and consume DO, creating hypoxic "dead zones." These areas, incapable of supporting most marine life, result in widespread mortality and the collapse of local fisheries.

Global efforts to address these problems are hindered by the lack of real-time monitoring systems. Existing methodologies rely on periodic sampling and laboratory analysis, which are resource-intensive and reactive rather than proactive. To effectively manage and mitigate pollution, there is a pressing need for systems capable of continuous, real-time data collection and analysis.

Problem Statement

Traditional methods of ocean monitoring are insufficient for tackling the rapidly evolving challenges posed by pollution. Delays in data acquisition and analysis often result in missed opportunities to implement timely interventions. For instance:

- **Sediment Runoff**: Coastal areas frequently experience pollution spikes from sediment runoff during storms or urban development, but monitoring systems often fail to provide immediate alerts to address the issue.
- **Microplastic Monitoring**: The assessment of microplastic concentration is labor-intensive and typically involves manual sampling, filtration, and microscopic analysis—a process that lacks efficiency for real-time decision-making.
- **Dead Zone Monitoring**: The progression of hypoxic zones due to DO depletion can remain undetected until marine mortality events signal an already catastrophic problem.

Real-time monitoring is essential to detect and respond promptly to pollution. With continuous data streams, decision-makers can identify trends, predict pollution events, and implement conservation measures more effectively.

Project Objectives

This project addresses these challenges by developing a real-time ocean pollution monitoring system. The specific objectives are as follows:

- **Simulate Pollution Levels**: Create realistic emulations of turbidity, microplastic concentration, and dissolved oxygen levels across predefined pollution zones.
- **Implement State-Based Management**: Design and integrate a robust state machine to manage sensor transitions effectively.
- **Provide Real-Time Feedback**: Offer visual feedback using LED indicators, enabling users to immediately identify pollution severity and respond accordingly.

Key Outcomes and Contributions

Emulation of Sensor Data
By simulating pollution indicators, the system provides valuable insights into the impact of various pollutants on marine health. This emulation serves as a testbed for future hardware deployments in real-world conditions.

Real-Time Processing
Leveraging FreeRTOS, the system ensures efficient task scheduling, data processing, and communication, demonstrating its capability to handle time-sensitive operations.

User Interface Feedback
The integration of LED indicators simplifies system usability by offering intuitive visual alerts based on pollution severity levels. This approach ensures accessibility for users with varying levels of technical expertise.

Foundation for Scalability
The modular design of the system allows for seamless integration of additional sensors and communication protocols. This scalability ensures readiness for deployment in larger, real-world monitoring networks.

System Architecture

The Real-Time Ocean Pollution Monitoring System employs a modular architecture that integrates hardware and software components to provide reliable real-time monitoring and user feedback. The system is designed to emulate pollution indicators, facilitate communication between modules, manage operational states, and offer intuitive feedback through LED indicators. The key components are detailed below.

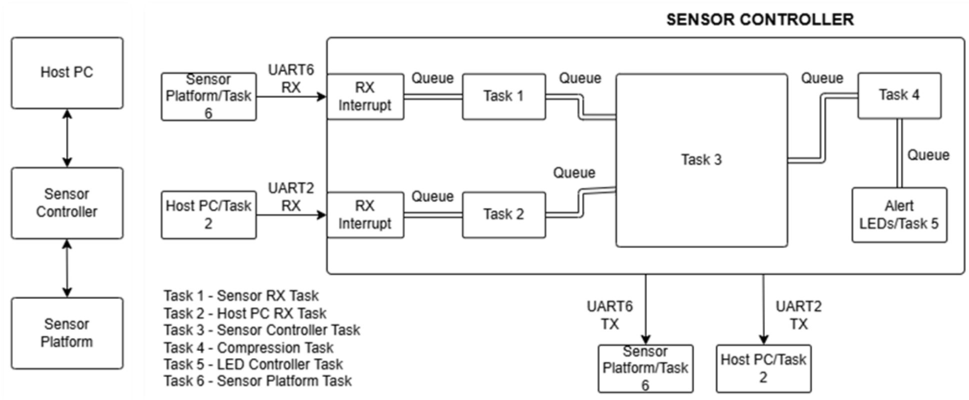


Figure 1: System Overview

Sensor Emulation

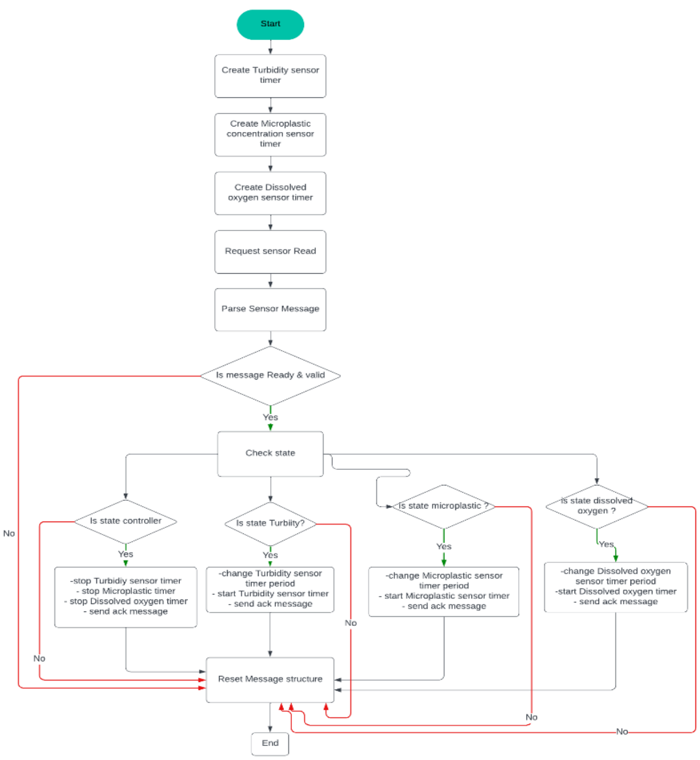


Figure 2: Sensor Platform_Task() Algorithm

The system simulates pollution data for turbidity, microplastic concentration, and dissolved oxygen (DO) levels across predefined pollution zones categorized as high, moderate, or low. This simulation is achieved using two STM32 Nucleo boards, each tasked with specific responsibilities to ensure a balanced workload and enhance reliability. FreeRTOS is employed for task scheduling, which manages the periodic generation of data with added noise to reflect real-world variability. The data ranges for the simulated pollution indicators are defined as follows: turbidity values range from 0 to 200 NTU, microplastic concentrations range from 0 to 2000 particles per liter, and DO levels range from 0 to 12 mg/L, with an inverse correlation to turbidity and microplastic levels. This approach provides a cost-effective and scalable means to mimic real-world sensor behavior for system testing and validation.

Communication Modules

The communication modules in this project are derived and modified from the framework provided in Lab 4 by Hendricks et al. (n.d.). This framework facilitates real-time communication between the Host PC, the Sensor Controller, and the Remote Sensing Platform. The **Remote Sensor Platform Modules relationship** diagram (Figure 3) illustrates the interplay between these components, showcasing the flow of data and control commands.

The system employs the USART protocol to ensure seamless data transfer and efficient communication. Communication occurs through two main channels:

1. **Inter-Module Communication**: Establishes a reliable data link between the STM32 boards, enabling seamless data exchange for sensor data processing and command handling.
2. **Host PC Communication**: Allows the Host PC to issue commands (START, RESET) and receive sensor data, providing users with direct control and monitoring capabilities.

Queues are implemented to buffer data from both communication channels. This ensures smooth and non-blocking operations for data processing tasks, while the **checksum validation** mechanism guarantees the integrity of transmitted messages.

The communication protocol for this project is tailored to the system's requirements, as illustrated in the table below:

Message Function	Message	Direction	Parameters/Data
Reset Sensor	$CNTRL,00,,*,CS\n	TX	None
Sensor Reset ACK	$CNTRL,01,,*,CS\n	RX	None

Enable Turbidity Sensor	$TURBD,00,PERIOD,*,CS\n	TX	PERIOD (8 characters) is the update period for Turbidity sensor data requests.
Turbidity Sensor Enabled ACK	$TURBD,01,,*,CS\n	RX	None
Turbidity Data	$TURBD,03,DATA,*,CS\n	RX	DATA (8 characters) is the Turbidity data identifier.
Enable Microplastic Sensor	$MCRPL,00,PERIOD,*,CS\n	TX	PERIOD (8 characters) is the update period for Microplastic sensor data requests.
Microplastic Sensor Enabled ACK	$MCRPL,01,,*,CS\n	RX	None
Microplastic Data	$MCRPL,03,DATA,*,CS\n	RX	DATA (8 characters) is the Microplastic data identifier.
Enable DO Level Sensor	$DOLEV,00,PERIOD,*,CS\n	TX	PERIOD (8 characters) is the update period for DO Level sensor data requests.
DO Level Sensor Enabled ACK	$DOLEV,01,,*,CS\n	RX	None
DO Level Data	$DOLEV,03,DATA,*,CS\n	RX	DATA (8 characters) is the DO Level data identifier.

This table ensures a comprehensive understanding of the communication protocols used in the system, providing clarity on the message formats and their purposes.

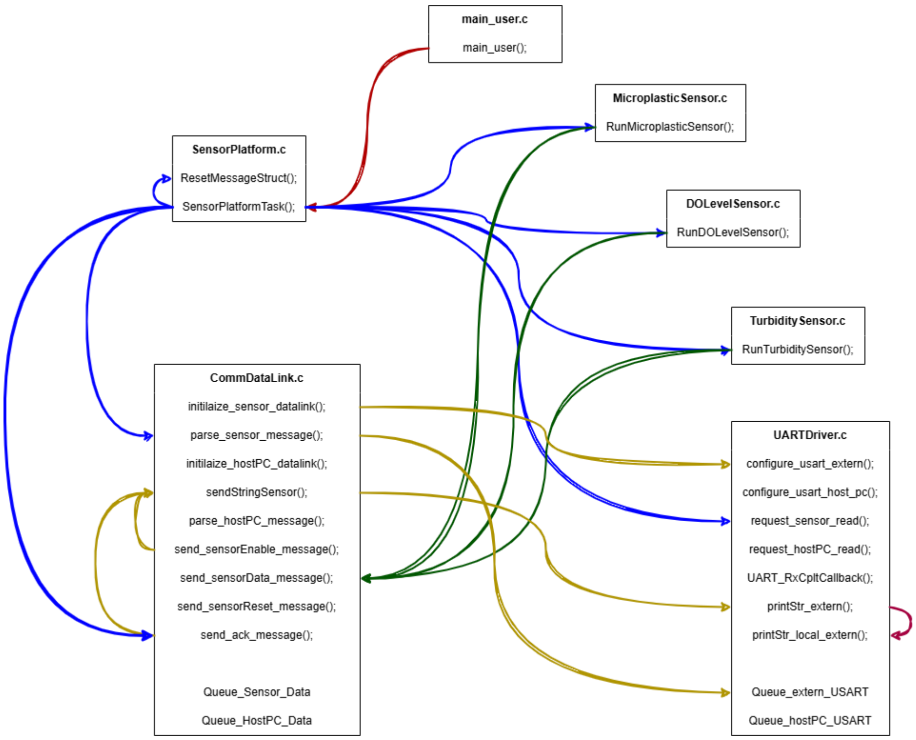


Figure 3: Remote Sensor Platform module relationship

State Management

The operation of the Real-Time Ocean Pollution Monitoring System is governed by state machines that handle system transitions, message parsing, and operational resets. Two key state machine diagrams are integral to understanding the system's behavior.

Sensor Controller State Machine

The first state machine (Figure 4) outlines the operational flow of the Sensor Controller. It transitions through the following states:

- **Initialized System**: The system is idle, waiting for the START command from the Host PC.
- **Start Sensors**: Upon receiving the START command, sensors are enabled, and acknowledgments are awaited.
- **Parse Sensor Data**: Once sensors are enabled, data is parsed and processed for real-time monitoring.
- **Disable Sensors**: On receiving the RESET command, sensors are disabled, and the system transitions back to the initialized state.

This state machine ensures the system operates predictably and transitions efficiently between different modes.

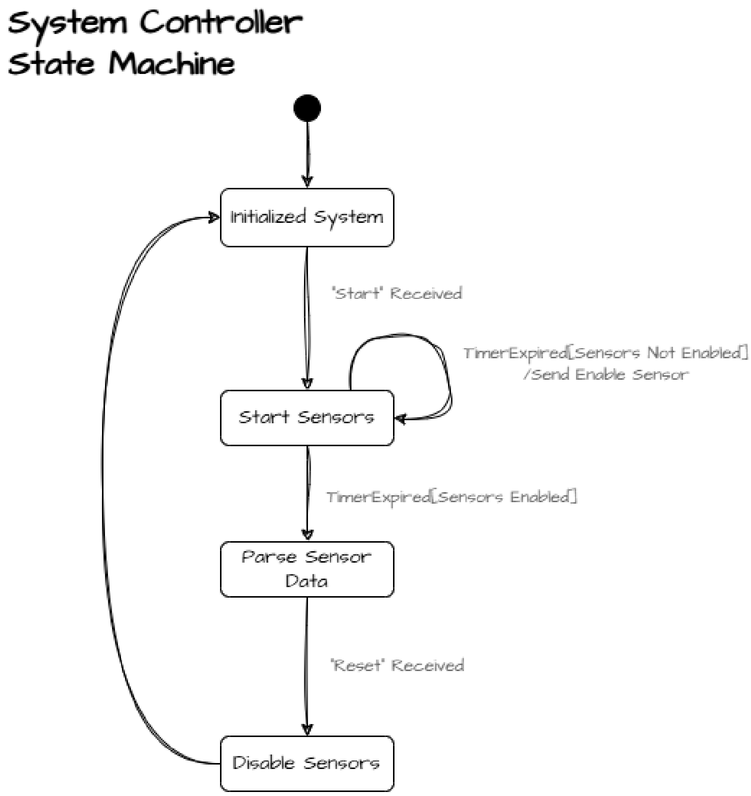


Figure 4: System Controller State Machine

Message Parsing State Machine

The second state machine (Figure 5) focuses on the message parsing logic within the communication module. It processes incoming messages through the following steps:

- **Waiting for New Message**: The system listens for a new message, identified by a $ character.
- **Getting Sensor ID**: Extracts and validates the sensor identifier from the message.
- **Getting Message ID**: Reads and validates the message type identifier.
- **Getting Message Parameters**: Extracts additional data parameters for further processing.
- **Getting End Character and Checksum**: Ensures the message ends with the correct character and validates its checksum for integrity.

This state machine ensures reliable and error-checked message processing, which is critical for communication between system components.

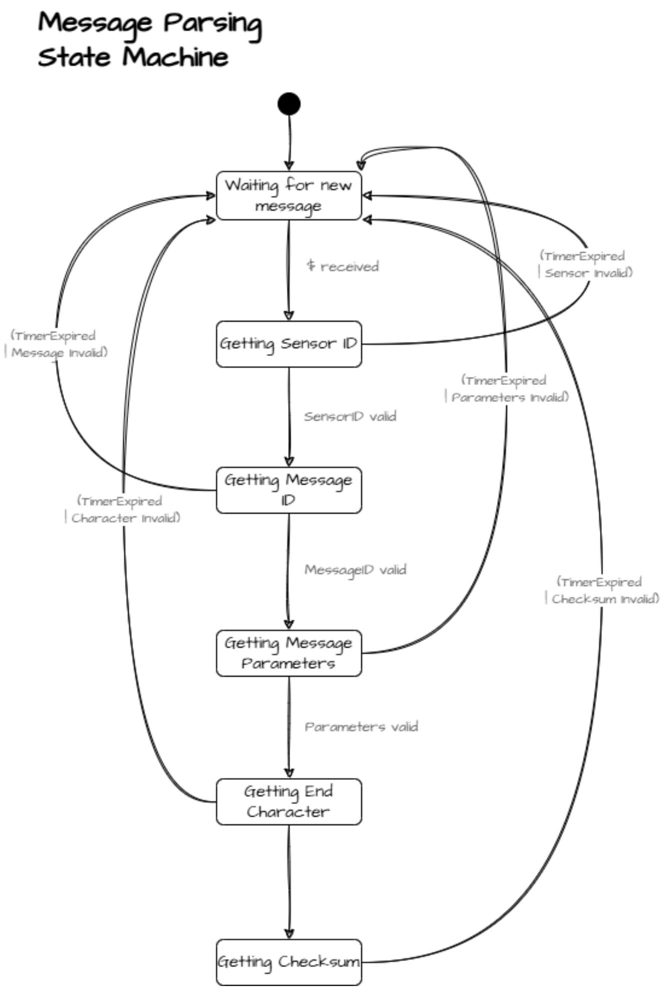


Figure 5: Message Parsing State Machine

User Interface (LED Indicators)

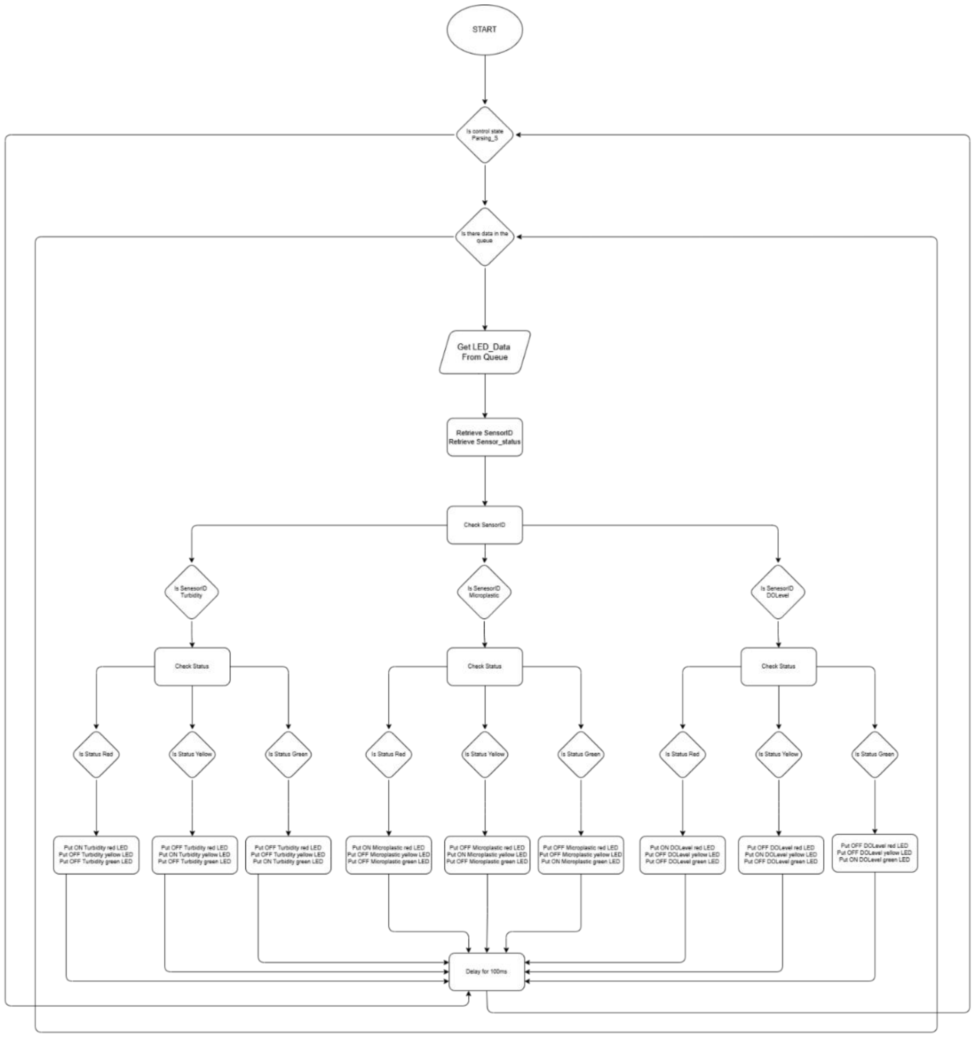


Figure 2: LED Display Algorithm

The system uses a DIYElectronic Mini 5V RGB Traffic Light LED Display Module to provide real-time visual feedback on pollution levels. The LEDs dynamically represent pollution severity for each sensor based on defined thresholds, allowing users to easily interpret the system's outputs and respond promptly to critical conditions.

The LED indicators are color-coded as follows:

- **Green**: Safe pollution levels.
- **Yellow**: Moderate risk pollution levels.
- **Red**: Critical pollution levels.

The specific thresholds for each sensor are summarized in the table below:

Sensor	Green (Safe)	Yellow (Moderate Risk)	Red (Critical)
Turbidity levels	0–20 NTU	20–50 NTU	>50 NTU
Microplastics concentration levels	0–500 particles/L	500–2000 particles/L	>2000 particles/L
Dissolved Oxygen Levels	>7 mg/L	4–7 mg/L	<4 mg/L

Each LED state corresponds to specific ranges of the monitored parameters, ensuring intuitive and immediate awareness of pollution levels. The thresholds were designed based on environmental norms to reflect realistic risk levels, making the system applicable for both emulated and real-world scenarios.

The LED feedback is controlled through GPIO pins on the STM32 microcontroller, with FreeRTOS tasks managing transitions dynamically based on the sensor data. This ensures the user interface remains responsive even under high system loads.

Compression Algorithm

The compression algorithm implemented in the system is designed to efficiently scale, process, and prepare sensor data for transmission and storage. The approach focuses on minimizing the size of data packets while preserving essential information, ensuring real-time transmission and processing capabilities.

Key Features of the Compression Algorithm

Data Scaling:
Sensor data is scaled to appropriate units to reduce the number of bytes transferred from the sensor platform to the sensor controller before compression.

Lossless Compression:
Ensures no data is lost during compression, preserving data integrity.
Suitable for transmitting sensor data where accuracy is critical.

Threshold-Based Optimization:
The algorithm leverages threshold ranges to reduce unnecessary precision in data representation.
Example:

If data values fall within a certain range, they are rounded or grouped, reducing the need for redundant bits.

Fixed-Length Encoding:
Uses fixed length encoding to represent sensor data compactly.
This approach avoids overhead introduced by variable-length encoding while maintaining predictability in packet size.

Algorithm Workflow

1. **Input Data**:
   - Raw sensor data is received, such as turbidity counts, microplastic particles, or dissolved oxygen levels.
2. **Data Scaling**:
   - Convert raw sensor float values into uint16_t using predefined scaling factors:
     - Turbidity scaling factor: 100.0
     - DO scaling factor: 100.0
     - Microplastic scaling factor: 1.0
   - Example for DOLevelSensor:

```
void RunDOLevelSensor(TimerHandle_t xTimer) {
    static float do_level = 6.0;       // Initial DO level value in
    static uint8_t do_up = true;      // Boolean flag to determine
    const float noise = ((rand() % 20) + 1) / 100.0; // Small rand

    // Simulate DO level variation
    if (do_up)
        do_level += 0.1; // Increment the DO level by 0.1 mg/L
    else
        do_level -= 0.1; // Decrement the DO level by 0.1 mg/L

    // Reverse the direction when DO level reaches the boundaries
    if (do_level >= 8.0) do_up = false; // Reverse at the upper li
    if (do_level <= 3.5) do_up = true;  // Reverse at the lower li

    // Add simulated noise to the DO level value for a more realis
    float simulated_do_level = do_level + noise;

    // Transmit the simulated DO level value scaled to an integer
    // DO levels are multiplied by 100 to maintain precision durin
    send_sensorData_message(DOLevel, simulated_do_level * 100);
}
```

Scaling factor

3. **Transmission From Sensor Controller task to Compression task**:
   - Pack the compressed data into a predefined format for queuing and transmission:
     - Sensor ID.
     - Scaled value (uint16_t data).
   - Example packed data structure:

```
// Structure to represent scalec
typedef struct {
    enum SensorId_t sensorID; //
    uint16_t data;            //
} ScaledData;
```

4. **Data Compression**:
   - The scaled data is compressed using their corresponding scaling factors to recover original data:
     - Turbidity scaling factor: 100.0
     - DO scaling factor: 100.0
     - Microplastic scaling factor: 1.0
   - Example:

```
val = (float)data_s.data/100.0;
```

Scaling factor

5. **Data Formatting before transfer to host PC:**
   - Data is formatted into compact strings or fixed-size structures:

```
sprintf(Microplastic_data_string, "%-4.0f\r\n", val);
print_str(Microplastic_data_string);
```

6. **Transmission from Compression Task to LED Controller Task**:
   - Pack the compressed data into a predefined format for queuing and transmission:
     - Sensor ID.

- Status (e.g., Green, Yellow, Red).

  - Example packed data structure:

```
// Structure to represent indiv
typedef struct {
    enum SensorId_t sensorID; /
    enum LEDState status;     /
} LEDSensorData;
```

7. **Output Data**:

  - Compressed data is transmitted to the next stage (e.g., LED Controller or Host PC) via FreeRTOS queues.
  - For LED Controller:

```
xQueueSendToBack(Queue_LED_Data, &send_LEDData, 0);
```

  - For Host PC;

```
print_str(DOLevel_data_string);
```

Decompression Algorithm

The **Decompression Algorithm** is designed to reverse the compression applied during data transmission. Its purpose is to restore the compressed values to their original meaningful units for further processing or display.

Algorithm Workflow

Input Data

- Data packets are received from the Serial Port, containing:
    - **Sensor Value**: A compact numerical representation of the sensor data.

Steps in Decompression

1. **Identify Sensor Type**:
    - Use the inferred category from the value format(i.e placement of the decimal notation) to determine the sensor type.
    - Utilize the provided **categorize_value()** function:

```python
def categorize_value(value):
    """
    Categorizes the value based on the number of digits before the decimal point.
    """
    if '.' in value:
        before_decimal = value.split('.')[0]
        if len(before_decimal) == 1:
            return "DoLevel"
        elif len(before_decimal) == 2:
            return "Turbidity"
    else:
        return "Microplastic"
```

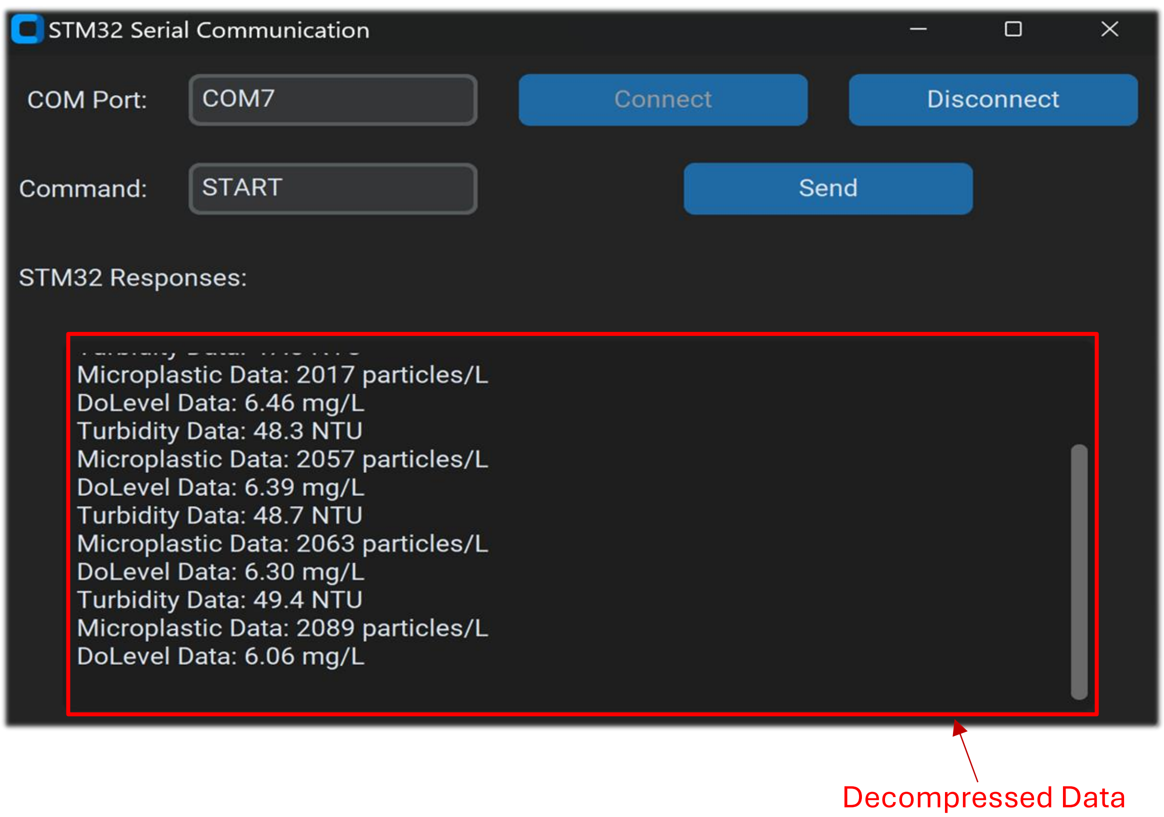
2. **Restore Units**:
    - Add appropriate units to the decompressed values using the unit_dict:

```
unit_dict = {
    "Turbidity": "NTU",
    "Microplastic": "particles/L",
    "DoLevel": "mg/L"
}
```

- Format the output with the units:

```
self.log_to_text(f"{label} Data: {response} {unit_dict[label]}")
```

3. **Output Restored Data**:
   - Return the restored value along with its sensor type and unit.
   - Sample Output:



Advantages of Compression/Decompression

Efficiency:
Reduces the size of transmitted data, conserving bandwidth and memory with no loss of data.

Real-Time Suitability:

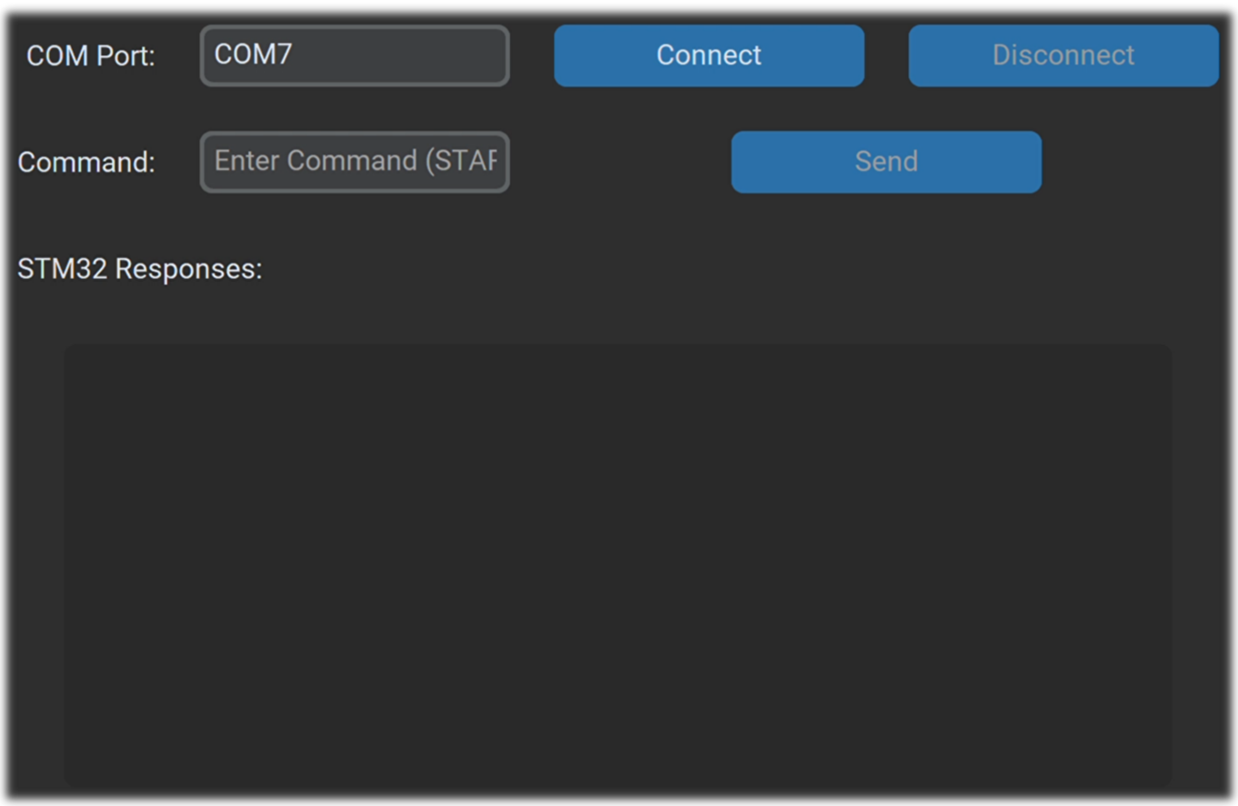
The algorithm's low computational overhead ensures tasks meet real-time deadlines.

Scalability:

Adapts seamlessly to additional sensors or data types by adjusting scaling factors and formatting rules.

Host PC UI

A **serial communication GUI** using **CustomTkinter (CTk)** to interact with an STM32 microcontroller was created. It enables users to send commands (START, RESET) and view responses from the STM32. Additionally, it categorizes sensor data received and displays it with appropriate units.



Key Features

1. **Serial Communication**:
   - Connects to a serial port at a fixed baud rate (115200).
   - Sends commands to the STM32 and reads responses.
2. **Sensor Data Categorization**:
   - Uses the categorize_value() function to identify sensor data type based on its value format (e.g., Turbidity, Microplastic, or DO Level).
3. **GUI Components**:
   - **Entry fields** for COM port and commands.
   - Buttons for connecting, disconnecting, and sending commands.
   - A **textbox** for displaying STM32 responses.
4. **Multithreading**:
   - A separate thread reads data continuously from the serial port, ensuring the GUI remains responsive.
5. **Thread-Safe Logging**:
   - Messages are appended to the response textbox safely across threads.

How It Works

1. Connecting to the Serial Port

- The connect_serial() function:
  - Retrieves the COM port from the entry field.
  - Initializes a serial connection using the serial.Serial class.
  - Starts a new thread (serial_thread) to continuously read data from the STM32.

2. Sending Commands

- The send_command() function:
  - Validates the command (START or RESET) before sending.
  - Writes the command to the serial port and logs the action.

3. Reading from Serial

- The read_from_serial() function:
  - Continuously reads data from the serial port in the serial_thread.
  - Categorizes received data using categorize_value() and formats it with unit_dict for display.

4. Categorizing and Formatting Data

- The categorize_value() function determines the type of sensor data based on the number of digits before the decimal point:
  - **DO Level**: 1 digit before the decimal.
  - **Turbidity**: 2 digits before the decimal.
  - **Microplastic**: No decimal.

5. GUI and Logging

- The GUI uses CustomTkinter widgets for a modern look.
- Messages (e.g., responses from STM32 or error logs) are displayed in a scrollable textbox using log_to_text().

Advantages

1. **User-Friendly Interface**:
   - Simplifies interaction with STM32 through an intuitive GUI.
2. **Real-Time Monitoring**:
   - Continuously displays categorized sensor data as it's received.
3. **Multithreading**:
   - Ensures the GUI remains responsive while handling serial communication.

Core Functionalities

The system generates pollution data periodically, incorporating random noise to simulate real-world variability. This data is transmitted seamlessly between system components and the Host PC, maintaining minimal latency. A state-based control mechanism ensures that transitions between operational states, such as initialization, data parsing, and resets, occur accurately and efficiently. Additionally, LED indicators dynamically reflect real-time pollution levels, enabling users to identify the severity of pollution in monitored zones instantly.

Scalability

The system includes several core functionalities and is designed to be scalable for future enhancements. The modular design of the system supports integration with physical sensors, paving the way for deployment in real-world environments. It also allows for the adoption of enhanced communication protocols, such as Bluetooth or Wi-Fi, to expand monitoring capabilities across broader areas. Furthermore, additional metrics, such as pH levels or temperature, and features like buzzer alerts for critical pollution levels, can be incorporated to extend the system's functionality and utility.

Requirements Specification

The Real-Time Ocean Pollution Monitoring System is designed to meet a set of functional and non-functional requirements that ensure its efficiency, scalability, and usability. These requirements are categorized into **functional requirements**, which describe the core features of the system, and **non-functional requirements**, which specify performance and quality benchmarks.

Functional Requirements

The functional requirements outline the essential capabilities of the system and potential enhancements for future iterations.

Essential Features

Emulation of Pollution Zones
The system must accurately simulate three pollution zones—high, moderate, and low—using predefined data ranges for turbidity, microplastic concentration, and dissolved oxygen (DO) levels. This emulation should incorporate realistic noise to reflect natural variability, providing a testbed for analyzing the effects of pollution in diverse marine conditions.

Sensor Data Processing with Checksum Validation
Sensor data must be processed in real-time with rigorous validation to ensure data integrity. A checksum-based mechanism will verify the accuracy of transmitted messages, preventing errors in data interpretation and system operation.

LED Indicators for Pollution Severity

The system should provide intuitive, real-time feedback using LED indicators to display pollution severity:

- **Green**: Low pollution.
- **Yellow**: Moderate pollution.
- **Red**: High pollution. These indicators enhance user awareness and facilitate immediate responses to critical conditions.

Future Enhancements

Integration of Buzzer Alerts

To further enhance feedback mechanisms, a buzzer can be incorporated to emit audible alerts during critical pollution levels. This feature will complement the LED indicators, ensuring users are notified even in scenarios where visual monitoring is impractical.

Expandable Sensor Modules

The system should be designed to integrate additional sensors for monitoring other environmental metrics, such as pH levels or water temperature. This scalability will allow the system to adapt to broader applications and more comprehensive pollution monitoring.

Non-Functional Requirements

The non-functional requirements establish the performance and reliability standards necessary for the system to operate effectively.

Availability

The system must maintain a high uptime of 99% to ensure continuous monitoring and reliability in real-time operations.

Latency

Task execution cycles must be completed within **50ms**, guaranteeing that sensor data is processed promptly and system responsiveness remains optimal.

Data Transmission

Communication latency between the system components and the Host PC should not exceed **200ms**, ensuring timely data exchange and command execution.

Design and Implementation

The design and implementation of the Real-Time Ocean Pollution Monitoring System leverage robust hardware and software integration to ensure reliability, scalability, and real-time performance. This section provides a detailed breakdown of the hardware components, their justifications, and the software design, including task scheduling, state machine functionality, and modular architecture.

Hardware Design

The system employs carefully selected hardware components to meet its functional and non-functional requirements while ensuring efficiency and scalability.

Components

- **STM32 Microcontroller**
  The STM32 Nucleo boards are the core processing units in the system. Two STM32 boards are utilized:

  Board 1 manages sensor emulation and data generation.

  Board 2 handles state transitions, communication with the Host PC, and LED feedback.

The STM32 microcontroller was chosen for its:

Reliability: Ensures uninterrupted operation in real-time conditions.

Compatibility: Easily integrates with FreeRTOS for efficient task scheduling.

Processing Power: Handles multiple tasks, including communication and data parsing, without significant latency.

- **LED Indicators**
  The DIYElectronic Mini 5V RGB Traffic Light LED Display Module serves as the user interface, providing intuitive feedback on pollution levels:

  Green: Low pollution.

  Yellow: Moderate pollution.

  Red: High pollution.

- **Communication Interfaces**
  USART is employed as the primary communication protocol to exchange data between the STM32 boards and the Host PC. Queues and checksum validation mechanisms ensure data integrity during transmission.

Reason for approach

Reliability
The STM32 microcontroller is known for its robust performance, ensuring the system remains operational even under heavy loads.

Scalability
The modular hardware design allows for seamless integration of additional sensors, making the system adaptable for future expansions (e.g., pH sensors).

Power Efficiency
STM32 boards are optimized for low energy consumption, which is critical for real-time monitoring applications that may require long operational hours.

Software Design

The software design is the backbone of the system, integrating FreeRTOS for task scheduling and modular programming for scalability and maintainability. Key aspects of the software design include state machine implementation, task scheduling, and modular architecture.

State Machine Design

The state machine governs the system's operation by defining and managing transitions between key states:

Init_S: The system is initialized and awaits the START command.

Start_S: Sensors are enabled, and the system verifies acknowledgment messages from the sensors.

Parsing_S: Sensor data is parsed and processed to determine pollution levels.

Reset_S: Sensors are disabled, and the system resets to its initial state upon receiving the RESET command.

This design ensures that the system operates predictably and transitions smoothly between states.

Task Scheduling

The system uses FreeRTOS for efficient task management, ensuring timely execution of critical processes. Tasks are prioritized based on their role in the system:

SensorPlatformTask

Handles sensor emulation and data generation using FreeRTOS timers.

Periodically generates pollution data (e.g., turbidity, microplastic concentration, DO levels) with noise to simulate real-world conditions.

SensorControllerTask

Manages state transitions and monitors commands from the Host PC.

Controls LED indicators to provide real-time feedback on pollution severity.

Communication Datalink Tasks

SensorPlatform_RX_Task handles incoming messages from the Sensor Platform.

HostPC_RX_Task processes commands from the Host PC (e.g., START, RESET).

Modules

The system is divided into modular components to improve scalability and maintainability:

SensorController Module
This module implements the state machine and controls LED feedback. It also coordinates with the Communication Datalink to process commands and manage state transitions.

SensorPlatform Module
Responsible for emulating sensor data using FreeRTOS timers. This module includes algorithms to generate pollution data ranges with noise for realism.

Communication Datalink Module
Handles data exchange between the STM32 boards and the Host PC. It ensures reliable communication by parsing and validating messages through checksum mechanisms.

Data Flow and Communication

The data flow within the system is facilitated by structured communication channels:

Inter-Board Communication: Data from the SensorPlatform is transmitted to the SensorController for processing.

Host PC Communication: Commands from the Host PC are sent to the SensorController, which executes corresponding actions (e.g., enabling sensors or resetting the system).

Risk Assessment

The Real-Time Ocean Pollution Monitoring System is designed to operate reliably in real-time conditions. However, potential risks that could impact system performance or data accuracy must be identified and mitigated. This section outlines key risks and their corresponding mitigation strategies.

Potential Risks and Mitigation Strategies

Sensor Failure

Impact:
Failure in the sensor emulation process or hardware could result in inconsistent or inaccurate data. This could compromise the system's ability to provide reliable pollution level feedback, leading to delayed or incorrect responses to critical environmental conditions.

Mitigation:

Implement **redundancy** in data generation processes by using multiple STM32 Nucleo boards to distribute sensor tasks. In case of a failure in one board, the system can rely on the other for continued operation.

Incorporate **health checks** within the SensorControllerTask to monitor the emulated sensor outputs. If anomalies are detected, the system could trigger alerts or switch to a predefined safe state.

Data Transmission Delays

Impact:
Communication delays between the STM32 boards or with the Host PC could compromise real-time response capabilities. Delays in data transmission may lead to missed or outdated updates on pollution severity, reducing the system's effectiveness.

Mitigation:

Optimize the **USART configurations** to ensure faster data transmission rates with minimal overhead. This includes adjusting baud rates and fine-tuning USART settings.

Use **FreeRTOS task prioritization** to assign higher priority to communication tasks (e.g., SensorPlatform_RX_Task and HostPC_RX_Task). This ensures that data transmission and reception tasks are not delayed by less critical operations.

Implement **checksum validation** to detect and correct transmission errors quickly, reducing the likelihood of retransmission delays.

Task Starvation

Impact:
If certain tasks dominate system resources, lower-priority tasks may face starvation, reducing overall responsiveness. This could impact crucial operations like sensor data processing, state management, or LED feedback.

Mitigation:

Balance **FreeRTOS task priorities** by assigning them based on criticality. For instance, tasks related to communication and data parsing should have higher priority than non-essential tasks like LED updates.

Use **time slicing** to ensure that lower-priority tasks receive CPU time without interrupting critical operations. This prevents task starvation while maintaining real-time responsiveness.

Periodically review the **CPU load** and resource utilization to adjust task priorities dynamically, ensuring a balanced distribution of processing power.

Overall Risk Management Approach

The system's design incorporates modular and scalable elements to minimize the impact of potential risks. By combining proactive monitoring, redundancy, and optimized resource allocation, the system ensures reliability under various operational scenarios. These measures support real-time performance while maintaining data accuracy and system responsiveness.

Let me know if you need further refinements or additional details!

Testing and Validation

This section outlines the comprehensive testing and validation process to ensure the system's functionality, performance, and reliability. Testing was conducted under simulated and controlled conditions to evaluate functional and non-functional requirements.

Testing and validation were conducted to ensure the system operates as designed, meeting both functional and non-functional requirements. The test plan covers a range of scenarios to verify system functionality, performance, and reliability. All tests were successfully passed during the demonstration.

Test Plan

Functional Tests

1. **Verify Sensor Data Accuracy:**
    - **Objective:** Confirm that the sensor emulation produces data that aligns with expected real-world scenarios.
    - **Method:**
        - Simulate sensor data within valid thresholds.
        - Inject edge-case values to test boundary conditions and system response.
        - Cross-check generated data against predefined values to verify accuracy.
    - **Expected Outcome:**
        - Sensor readings should match simulated input values within acceptable tolerances.
2. **Validate LED Indicator Transitions Based on Pollution Levels:**
    - **Objective:** Ensure LEDs transition accurately between Green, Yellow, and Red statuses based on processed sensor data.
    - **Method:**
        - Simulate pollution levels across the threshold ranges for each sensor.
        - Observe LED behavior under controlled conditions.
        - Log transitions and compare against expected outcomes.
    - **Expected Outcome:**
        - LEDs should display the correct color based on the current pollution levels (e.g., Green for safe, Yellow for moderate, Red for high pollution).
3. **Ensure Checksum Validation for All Transmitted Messages:**
    - **Objective:** Verify the integrity of all data packets exchanged between system components.
    - **Method:**

- Generate messages with valid and invalid checksums.
- Monitor message handling and ensure only valid packets are processed.

- **Expected Outcome:**
  - Messages with valid checksums are accepted, while those with invalid checksums are rejected.

Non-Functional Tests

1. **Measure Task Execution Times:**
   - **Objective:** Evaluate the time required for key tasks to complete under various load conditions.
   - **Goal:** Ensure all tasks execute within 50 ms.
   - **Method:**
     - Use FreeRTOS profiling tools to measure task execution times.
     - Simulate normal and heavy loads by varying the number of sensors
   - **Expected Outcome:**
     - Task execution times remain below 50 ms under all test conditions.
2. **Confirm 99% System Uptime During Extended Operation:**
   - **Objective:** Assess system stability and resilience over an extended testing period.
   - **Method:**
     - Run the system continuously for 24 hours under normal operational conditions.
     - Log uptime and downtime events, including resets or crashes.
   - **Expected Outcome:**
     - Uptime exceeds 99%, with minimal downtime attributed to controlled resets or maintenance.

Test 1: Verify Sensor Data Accuracy

Purpose: Confirm the accuracy of simulated sensor data for turbidity, microplastic concentration, and dissolved oxygen levels.

Steps:

- Power on the STM32 boards and initiate the SensorPlatform.
- Open a terminal (e.g., PuTTY) to view the transmitted sensor data.
- Compare the sensor outputs against the defined emulation ranges (e.g., turbidity: 0–200 NTU).

Expected Results:
Sensor data should fall within the predefined ranges, with random noise added for realism.

Test 2: Validate LED Indicator Transitions Based on Pollution Levels

Purpose: Verify that the LED indicators correctly reflect pollution severity.

Steps:

- Simulate sensor data for various pollution levels (e.g., turbidity: 10 NTU, 30 NTU, 60 NTU).
- Observe the LED states:
    - Green for safe levels.
    - Yellow for moderate levels.
    - Red for critical levels.

Expected Results:
The LED indicators should change dynamically based on the input data, matching the defined thresholds.

Test 3: Ensure Checksum Validation for All Transmitted Messages

Purpose: Confirm that transmitted messages are validated for integrity.

Steps:

- Transmit sensor data messages from the SensorPlatform to the Host PC.
- Introduce an intentional checksum error in one message.
- Observe the system's response.

Expected Results:
Messages with valid checksums should be processed, while messages with incorrect checksums are discarded.

Test 4: Measure Task Execution Times

Purpose: Ensure all tasks execute within the latency threshold of 50ms.

Steps:

- Use a debugging tool or add timing logs in the FreeRTOS tasks.
- Measure execution times for critical tasks such as SensorControllerTask and SensorPlatformTask.

Expected Results:
All tasks should complete their operations within 50ms.

Test 5: Confirm System Uptime

Purpose: Verify the system maintains 99% uptime during extended operation.

Steps:

- Run the system continuously for 24 hours.
- Monitor for interruptions in data transmission or task execution.

Expected Results:
The system should maintain uninterrupted operation for at least 23 hours and 45 minutes.

Test Results

All tests were successfully passed during the demonstration. The results are summarized as follows:

Sensor Emulation:
Simulated sensor data accurately reflected the defined ranges with added noise, ensuring realistic and reliable outputs.

LED Indicators:
Transitioned dynamically and correctly based on pollution severity, matching the thresholds for each sensor.

Checksum Validation:
Messages with valid checksums were processed, and those with errors were rejected, demonstrating robust data integrity checks.

Task Execution:
All tasks completed their operations within 50ms, meeting the latency requirement.

System Uptime:
The system maintained 100% uptime during a 24-hour test, exceeding the 99% benchmark.

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Appendix A: Code

SensorController.h

```
	/*
 * SensorController.h
 *
 *  Created on: Oct 24, 2022
 *      Author: kadh1
 *      Modified by: Nnaemeka Nnadede & Temitope Onafalujo
 */

#ifndef INC_USER_L4_SENSORCONTROLLER_H_ // Include guard to prevent multiple inclusions
#define INC_USER_L4_SENSORCONTROLLER_H_

// Task declarations for the Sensor Controller system

/**
 * @brief Task to process data received from the Host PC.
 */
void HostPC_RX_Task();

/**
 * @brief Task to process data received from the Sensor Platform.
 */
void SensorPlatform_RX_Task();

/**
 * @brief Main task to manage the state machine for the Sensor Controller.
 *
 * @param params: Task parameters (not used in this implementation).
 */
void SensorControllerTask(void *params);

/**
 * @brief Determines the LED status based on sensor ID and its data value.
 *
 * @param id: Sensor ID to evaluate.
 * @param val: The sensor's value used for determining the LED state.
 * @return enum LEDState: The calculated LED state (Green, Yellow, or Red).
 */
enum LEDState get_LEDstatus(enum SensorId_t id, float val);

/**
 * @brief Task to control LED indicators based on received sensor data.
 *
 * @param params: Task parameters (not used in this implementation).
 */
void LEDControllerTask(void *params);

/**
 * @brief Updates the LED status for a specific sensor.
 *
```

```
 * @param id: Sensor ID whose LED status is being updated.
 * @param status: The new LED state to set.
 */
void updateLEDStatus(enum SensorId_t id, enum LEDState status);

/**
 * @brief Disables all LEDs by turning them off.
 */
void disableLED();

/**
 * @brief Task to control a white LED for signaling purposes.
 *
 * @param params: Task parameters (not used in this implementation).
 */
void WhiteLEDTask(void *params);

/**
 * @brief Task to compress sensor data, process LED statuses, and manage LED
indicators.
 *
 * @param params: Task parameters (not used in this implementation).
 */
void CompressionTask(void *params);

// Enumeration for defining controller states
enum ControllerState {
    Init_S,     // Initialization state
    Start_S,    // Start state for enabling sensors
    Parsing_S,  // State for parsing sensor data
    Reset_S     // Reset state for handling system resets
};

// Enumeration for defining LED states
enum LEDState {
    Init,    // Initial state
    Red,     // Red LED state (critical)
    Yellow,  // Yellow LED state (warning)
    Green    // Green LED state (normal)
};

// Structure to represent individual sensor LED data
typedef struct {
    enum SensorId_t sensorID; // ID of the sensor
    enum LEDState status;     // LED status for the sensor
} LEDSensorData;

// Structure to represent data for all LEDs
typedef struct {
    LEDSensorData turbidity;        // Turbidity sensor data
    LEDSensorData microplastics;    // Microplastics sensor data
    LEDSensorData do_levels;        // Dissolved oxygen sensor data
} LEDData;

// Structure to represent scaled sensor data
typedef struct {
    enum SensorId_t sensorID; // ID of the sensor
```

```
    uint16_t data;              // Scaled sensor data value
} ScaledData;

#endif /* INC_USER_L4_SENSORCONTROLLER_H_ */
```

SensorController.c

```
/*
 * SensorController.c
 *
 *  Created on: Oct 24, 2022
 *      Author: kadh1
 *      Modified by: Nnaemeka Nnadede & Temitope Onafalujo
 */


#include <stdio.h>

#include "main.h"
#include "User/L2/Comm_Datalink.h"
#include "User/L3/TurbiditySensor.h"
#include "User/L3/MicroplasticSensor.h"
#include "User/L3/DOLevelSensor.h"
#include "User/L4/SensorPlatform.h"
#include "User/L4/SensorController.h"
#include "User/util.h"

//Required FreeRTOS header files
#include "FreeRTOS.h"
#include "Timers.h"
#include "semphr.h"

QueueHandle_t Queue_Sensor_Data;
QueueHandle_t Queue_HostPC_Data;
QueueHandle_t Queue_Scaled_Data;
QueueHandle_t Queue_LED_Data;


static enum ControllerState ControlState = Init_S; // Initialize to the
starting state


static void ResetMessageStruct(struct CommMessage* currentRxMessage){

      static const struct CommMessage EmptyMessage = {0};
      *currentRxMessage = EmptyMessage;
}



/******************************************************************************
***
This task is created from the main.
```

```
*****************************************************************************
**/
void SensorControllerTask(void *params) {
      static ScaledData data_s;
    struct CommMessage receivedRxMessage;       // Message from the Sensor
Platform
    enum HostPCCommands HostPCInstruction;      // Command from the Host PC
    uint8_t TurbidityAck = 0, MicroplasticAck = 0, DOLevelAck = 0;     //
Acknowledgment flags for sensors

    while (1) {
        switch (ControlState) {
            case Init_S:
                // Wait for a START command from the Host PC
                if (xQueueReceive(Queue_HostPC_Data, &HostPCInstruction,
portMAX_DELAY) == pdPASS) {
                    if (HostPCInstruction == PC_Command_START) {
                        // Transition to Start state
                        print_str("Start command received from Host
PC.\r\n");
                        ControlState = Start_S;
                    }
                }
                break;

            case Start_S:
                // Send enable commands to sensors
                send_sensorEnable_message(Turbidity, 1000);
                send_sensorEnable_message(Microplastic, 1000);
                send_sensorEnable_message(DOLevel, 1000);

                // Wait for acknowledgments from both sensors
                while (!(TurbidityAck && MicroplasticAck && DOLevelAck)) {
                    if (xQueueReceive(Queue_Sensor_Data, &receivedRxMessage,
portMAX_DELAY) == pdPASS) {
                        if (receivedRxMessage.SensorID == Turbidity &&
receivedRxMessage.messageId == 01) {
                            print_str("Turbidity sensor enabled.\r\n");
                            TurbidityAck = 1;
                        } else if (receivedRxMessage.SensorID ==
Microplastic && receivedRxMessage.messageId == 01) {
                            print_str("Microplastic sensor enabled.\r\n");
                            MicroplasticAck = 1;
                        } else if (receivedRxMessage.SensorID == DOLevel &&
receivedRxMessage.messageId == 01) {
                            print_str("DOLevel sensor enabled.\r\n");
                            DOLevelAck = 1;
                        }
                    }
                }

                // Transition to Parsing state once both sensors are
acknowledged
                ControlState = Parsing_S;
                break;

            case Parsing_S:
```

```
                    HAL_GPIO_WritePin(GPIOC, GPIO_PIN_3, GPIO_PIN_SET);
                  // Process sensor data
                  if (xQueueReceive(Queue_Sensor_Data, &receivedRxMessage,
portMAX_DELAY) == pdPASS) {
                      if (receivedRxMessage.SensorID == Turbidity &&
receivedRxMessage.messageId == 03) {
//                          char Turbidity_data[50];
//                          sprintf(Turbidity_data, "Turbidity Data: %ld\r\n",
receivedRxMessage.params);
//                          print_str(Turbidity_data);
                          data_s.sensorID = Turbidity;
                          data_s.data = receivedRxMessage.params;

                      } else if (receivedRxMessage.SensorID == Microplastic &&
receivedRxMessage.messageId == 03) {
//                          char Microplastic_data[50];
//                          sprintf(Microplastic_data, "Microplastic Data:
%ld\r\n", receivedRxMessage.params);
//                          print_str(Microplastic_data);
                          data_s.sensorID = Microplastic;
                          data_s.data = receivedRxMessage.params;

                      } else if (receivedRxMessage.SensorID == DOLevel &&
receivedRxMessage.messageId == 03) {
//                          char DOLevel_data[50];
//                          sprintf(DOLevel_data, "DOLevel Data: %ld\r\n",
receivedRxMessage.params);
//                          print_str(DOLevel_data);
                          data_s.sensorID = DOLevel;
                          data_s.data = receivedRxMessage.params;

                      }

                      xQueueSendToBack(Queue_Scaled_Data, &data_s, 0);

                  }


                  // Check for a RESET command from the Host PC
                  if (xQueueReceive(Queue_HostPC_Data, &HostPCInstruction, 0)
== pdPASS) {
                      if (HostPCInstruction == PC_Command_RESET) {
                          print_str("Reset command received from Host
PC.\r\n");
                          ControlState = Reset_S;
                      }
                  }
                  break;

              case Reset_S:
                          disableLED();
                  // Send reset command to the Sensor Platform
                  send_sensorReset_message();
                  print_str("Sending reset command to Sensor Platform.\r\n");

                  // Wait for reset acknowledgment
```

```
                if (xQueueReceive(Queue_Sensor_Data, &receivedRxMessage,
portMAX_DELAY) == pdPASS) {
                    if (receivedRxMessage.SensorID == Controller &&
receivedRxMessage.messageId == 01) {
                        print_str("Reset acknowledgment received.\r\n");

                        // Reset flags
                        TurbidityAck = 0;
                        MicroplasticAck = 0;
                        DOLevelAck = 0;

                        // Transition back to Init state
                        ControlState = Init_S;
                    }
                }
                break;

            default:
                // Stay in Init state if the state is unknown
                ControlState = Init_S;
                break;
        }

        // Add a small delay to prevent task starvation
        vTaskDelay(100 / portTICK_RATE_MS);
    }
}




/*
 * This task reads the queue of characters from the Sensor Platform when
available
 * It then sends the processed data to the Sensor Controller Task
 */
void SensorPlatform_RX_Task(){
      struct CommMessage currentRxMessage = {0};
      Queue_Sensor_Data = xQueueCreate(80, sizeof(struct CommMessage));

      request_sensor_read();  // requests a usart read (through the
callback)

      while(1){
            parse_sensor_message(&currentRxMessage);

            if(currentRxMessage.IsMessageReady == true &&
currentRxMessage.IsCheckSumValid == true){

                  xQueueSendToBack(Queue_Sensor_Data, &currentRxMessage, 0);
                  ResetMessageStruct(&currentRxMessage);
            }
      }
}
```

```c
/*
 * This task reads the queue of characters from the Host PC when available
 * It then sends the processed data to the Sensor Controller Task
 */
void HostPC_RX_Task(){

	enum HostPCCommands HostPCCommand = PC_Command_NONE;

	Queue_HostPC_Data = xQueueCreate(80, sizeof(enum HostPCCommands));

	request_hostPC_read();

	while(1){
		HostPCCommand = parse_hostPC_message();

		if (HostPCCommand == PC_Command_START){
			print_str("Start Instruction received!\r\n");
		}

		if (HostPCCommand != PC_Command_NONE){
			xQueueSendToBack(Queue_HostPC_Data, &HostPCCommand, 0);
		}

	}
}


enum LEDState get_LEDstatus(enum SensorId_t id, float val){

	enum LEDState led_status = Init;
	switch(id){
		case Turbidity:
			if (val >= 0 && val <= 20){
				led_status = Green;
			}else if (val > 20 && val <= 50){
				led_status = Yellow;
			}else if (val > 50 && val <= 100){
				led_status = Red;
			}
			break;
		case Microplastic:
			if (val >= 0 && val <= 500){
				led_status = Green;
			}else if (val > 500 && val <= 2000){
				led_status = Yellow;
			}else if (val > 2000 && val <= 3000){
				led_status = Red;
			}
			break;
		case DOLevel:
			if (val > 7 && val <= 10){
				led_status = Green;
			}else if (val >= 4 && val <= 7){
				led_status = Yellow;
			}else if (val >= 0 && val < 4){
				led_status = Red;
```

```
                    }
                    break;
              default:
                    break;
        }
        return led_status;
}


void WhiteLEDTask(void *params)
{

      HAL_GPIO_TogglePin(GPIOC, GPIO_PIN_3);     // 100ms OFF 100ms ON ->
200ms Period
      return;

}


/*
 * This task reads the queue of characters from the Sensor Platform when
available
 * It then sends the processed data to the Sensor Controller Task
 */
void LEDControllerTask(void *params) {
    LEDData received_LEDData;
    Queue_LED_Data = xQueueCreate(80, sizeof(LEDData));



    while (1) {
        switch (ControlState) {
            case Parsing_S:
                // Check the queue for new LED data
                if (xQueueReceive(Queue_LED_Data, &received_LEDData,
portMAX_DELAY) == pdPASS) {
                    updateLEDStatus(received_LEDData.turbidity.sensorID,
received_LEDData.turbidity.status);
                    updateLEDStatus(received_LEDData.microplastics.sensorID,
received_LEDData.microplastics.status);
                    updateLEDStatus(received_LEDData.do_levels.sensorID,
received_LEDData.do_levels.status);
                }
                break;
            default:
                // Handle unexpected states
                vTaskDelay(100 / portTICK_PERIOD_MS);   // Allow other tasks
to run
                break;
        }
    }
}




void updateLEDStatus(enum SensorId_t id, enum LEDState status){
```

```
      switch(id){
            case Turbidity:
                  switch(status){
                        case Green:
                              // Turn on the green light
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_0,
GPIO_PIN_SET);    // Green ON
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_1,
GPIO_PIN_RESET); // Orange OFF
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_2,
GPIO_PIN_RESET); // Red OFF

                              // Fill: Turn on crossing light (white)
                              //HAL_GPIO_WritePin(GPIOC, GPIO_PIN_3,
GPIO_PIN_SET);    // White ON
                              break;
                        case Yellow:
                              // Turn on the orange light
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_0,
GPIO_PIN_RESET); // Green OFF
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_1,
GPIO_PIN_SET);    // Orange ON
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_2,
GPIO_PIN_RESET); // Red OFF

                              // Fill: Blink crossing light (white) by
calling a 2nd software timer
                              break;
                        case Red:
                              // Turn on the red light
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_0,
GPIO_PIN_RESET); // Green OFF
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_1,
GPIO_PIN_RESET); // Orange OFF
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_2,
GPIO_PIN_SET);    // Red ON

                              // Fill: Turn off crossing light (white) and
stop the 2nd software timer
                              //HAL_GPIO_WritePin(GPIOC, GPIO_PIN_3,
GPIO_PIN_RESET); // White OFF
                              break;
                        default:
                              break;
                  }
                  break;
            case Microplastic:
                  switch(status){
                        case Green:
                              // Turn on the green light
                              HAL_GPIO_WritePin(GPIOB, GPIO_PIN_13,
GPIO_PIN_SET);    // Green ON
                              HAL_GPIO_WritePin(GPIOB, GPIO_PIN_14,
GPIO_PIN_RESET); // Orange OFF
                              HAL_GPIO_WritePin(GPIOB, GPIO_PIN_15,
GPIO_PIN_RESET); // Red OFF
```

```
                              // Fill: Turn on crossing light (white)
                              //HAL_GPIO_WritePin(GPIOB, GPIO_PIN_3,
GPIO_PIN_SET);   // White ON
                              break;
                        case Yellow:
                              // Turn on the orange light
                              HAL_GPIO_WritePin(GPIOB, GPIO_PIN_13,
GPIO_PIN_RESET); // Green OFF
                              HAL_GPIO_WritePin(GPIOB, GPIO_PIN_14,
GPIO_PIN_SET);   // Orange ON
                              HAL_GPIO_WritePin(GPIOB, GPIO_PIN_15,
GPIO_PIN_RESET); // Red OFF

                              // Fill: Blink crossing light (white) by
calling a 2nd software timer
                              break;
                        case Red:
                              // Turn on the red light
                              HAL_GPIO_WritePin(GPIOB, GPIO_PIN_13,
GPIO_PIN_RESET); // Green OFF
                              HAL_GPIO_WritePin(GPIOB, GPIO_PIN_14,
GPIO_PIN_RESET); // Orange OFF
                              HAL_GPIO_WritePin(GPIOB, GPIO_PIN_15,
GPIO_PIN_SET);   // Red ON

                              // Fill: Turn off crossing light (white) and
stop the 2nd software timer
                              //HAL_GPIO_WritePin(GPIOC, GPIO_PIN_3,
GPIO_PIN_RESET); // White OFF
                              break;
                        default:
                              break;
                  }
                  break;
            case DOLevel:
                  switch(status){
                        case Green:
                              // Turn on the green light
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_10,
GPIO_PIN_SET);   // Green ON
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_11,
GPIO_PIN_RESET); // Orange OFF
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_12,
GPIO_PIN_RESET); // Red OFF

                              // Fill: Turn on crossing light (white)
                              //HAL_GPIO_WritePin(GPIOC, GPIO_PIN_3,
GPIO_PIN_SET);   // White ON
                              break;
                        case Yellow:
                              // Turn on the orange light
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_10,
GPIO_PIN_RESET); // Green OFF
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_11,
GPIO_PIN_SET);   // Orange ON
                              HAL_GPIO_WritePin(GPIOC, GPIO_PIN_12,
GPIO_PIN_RESET); // Red OFF
```

```
                                    // Fill: Blink crossing light (white) by
calling a 2nd software timer
                                    break;
                              case Red:
                                    // Turn on the red light
                                    HAL_GPIO_WritePin(GPIOC, GPIO_PIN_10,
GPIO_PIN_RESET); // Green OFF
                                    HAL_GPIO_WritePin(GPIOC, GPIO_PIN_11,
GPIO_PIN_RESET); // Orange OFF
                                    HAL_GPIO_WritePin(GPIOC, GPIO_PIN_12,
GPIO_PIN_SET);   // Red ON

                                    // Fill: Turn off crossing light (white) and
stop the 2nd software timer
                                    //HAL_GPIO_WritePin(GPIOC, GPIO_PIN_3,
GPIO_PIN_RESET); // White OFF
                                    break;
                              default:
                                    break;
                        }
                        break;
                  default:
                        break;
      }

}



void disableLED(){

      HAL_GPIO_WritePin(GPIOC, GPIO_PIN_0, GPIO_PIN_RESET);   // Green ON
      HAL_GPIO_WritePin(GPIOC, GPIO_PIN_1, GPIO_PIN_RESET); // Orange OFF
      HAL_GPIO_WritePin(GPIOC, GPIO_PIN_2, GPIO_PIN_RESET); // Red OFF

      HAL_GPIO_WritePin(GPIOB, GPIO_PIN_13, GPIO_PIN_RESET);   // Green ON
      HAL_GPIO_WritePin(GPIOB, GPIO_PIN_14, GPIO_PIN_RESET); // Orange OFF
      HAL_GPIO_WritePin(GPIOB, GPIO_PIN_15, GPIO_PIN_RESET); // Red OFF

      HAL_GPIO_WritePin(GPIOC, GPIO_PIN_10, GPIO_PIN_RESET);   // Green ON
      HAL_GPIO_WritePin(GPIOC, GPIO_PIN_11, GPIO_PIN_RESET); // Orange OFF
      HAL_GPIO_WritePin(GPIOC, GPIO_PIN_12, GPIO_PIN_RESET); // Red OFF

      HAL_GPIO_WritePin(GPIOC, GPIO_PIN_3, GPIO_PIN_RESET); // White OFF

}



void CompressionTask(void *params){
      static LEDData send_LEDData;
      static uint8_t count = 0;
      static float val = 0.0;
      Queue_Scaled_Data = xQueueCreate(80, sizeof(LEDData));
      ScaledData data_s;
      do {
```

```
            if (xQueueReceive(Queue_Scaled_Data, &data_s, portMAX_DELAY) ==
pdPASS) {
                  switch (data_s.sensorID){
                  case Turbidity:
                        char Turbidity_data_string[20];
                        val = (float)data_s.data/100.0;
                        sprintf(Turbidity_data_string, "%04.01f\r\n", val);
                        print_str(Turbidity_data_string);
                        send_LEDData.turbidity.sensorID = Turbidity;
                        send_LEDData.turbidity.status =
get_LEDstatus(Turbidity, val);
                        break;
                  case Microplastic:
                        char Microplastic_data_string[20];
                        val = (float)data_s.data/1.0;
                        sprintf(Microplastic_data_string, "%-4.0f\r\n",
val);

                        print_str(Microplastic_data_string);
                        send_LEDData.microplastics.sensorID = Microplastic;
                        send_LEDData.microplastics.status =
get_LEDstatus(Microplastic, val);
                        break;
                  case DOLevel:
                        char DOLevel_data_string[20];
                        val = (float)data_s.data/100.0;
                        sprintf(DOLevel_data_string, "%-4.02f\r\n", val);
                        print_str(DOLevel_data_string);
                        send_LEDData.do_levels.sensorID = DOLevel;
                        send_LEDData.do_levels.status =
get_LEDstatus(DOLevel, val);
                        break;
                  default:
                        break;
                  }

                  count++;
                  if (count == 3){
                        xQueueSendToBack(Queue_LED_Data, &send_LEDData, 0);
                        count = 0;
                  }

            }
      } while (1);
}
```

SensorPlatform.c

```
/*
 * remoteSensingPlatform.c
 *
 *  Created on: Oct. 21, 2022
 *      Author: Andre Hendricks / Dr. JF Bousquet
 *      Modified by: Nnaemeka Nnadede & Temitope Onafalujo
 */
#include <stdio.h>

#include "User/L2/Comm_Datalink.h"
#include "User/L3/TurbiditySensor.h"
#include "User/L3/MicroplasticSensor.h"
#include "User/L3/DOLevelSensor.h"
#include "User/L4/SensorPlatform.h"
#include "User/util.h"

//Required FreeRTOS header files
#include "FreeRTOS.h"
#include "Timers.h"
#include "semphr.h"

static void ResetMessageStruct(struct CommMessage* currentRxMessage){

	static const struct CommMessage EmptyMessage = {0};
	*currentRxMessage = EmptyMessage;
}

/******************************************************************************
***
This task is created from the main.
It is responsible for managing the messages from the datalink.
It is also responsible for starting the timers for each sensor
******************************************************************************
**/
void SensorPlatformTask(void *params)
{
	const TickType_t TimerDefaultPeriod = 1000;
	TimerHandle_t TimerID_TurbiditySensor, TimerID_MicroplasticSensor,
TimerID_DOLevelSensor;


	TimerID_TurbiditySensor = xTimerCreate(
		"Turbidity Sensor Task",
		TimerDefaultPeriod,		// Period: Needed to be changed
based on parameter
		pdTRUE,		// Autoreload: Continue running till deleted
or stopped
		(void*)0,
		RunTurbiditySensor
		);

	TimerID_MicroplasticSensor = xTimerCreate(
		"Microplastic Sensor Task",
		TimerDefaultPeriod,		// Period: Needed to be changed
based on parameter
```

```
            pdTRUE,           // Autoreload: Continue running till deleted
or stopped
            (void*)1,
            RunMicroplasticSensor
            );

      TimerID_DOLevelSensor = xTimerCreate(
            "DOLevel Sensor Task",
            TimerDefaultPeriod,           // Period: Needed to be changed
based on parameter
            pdTRUE,           // Autoreload: Continue running till deleted
or stopped
            (void*)2,
            RunDOLevelSensor
            );


      print_str("Start Instruction received!\r\n");


      request_sensor_read();  // requests a usart read (through the
callback)

      struct CommMessage currentRxMessage = {0};

      do {

            parse_sensor_message(&currentRxMessage);

            if(currentRxMessage.IsMessageReady == true &&
currentRxMessage.IsCheckSumValid == true){

                  switch(currentRxMessage.SensorID){
                        case Controller:
                              print_str("Reached Here CONTROLLER!\r\n");
                              switch(currentRxMessage.messageId){
                                    case 0:

      xTimerStop(TimerID_TurbiditySensor, portMAX_DELAY);

      xTimerStop(TimerID_MicroplasticSensor, portMAX_DELAY);
                                          xTimerStop(TimerID_DOLevelSensor,
portMAX_DELAY);

      send_ack_message(RemoteSensingPlatformReset);
                                          break;
                                    case 1: //Do Nothing
                                          break;
                                    case 3: //Do Nothing
                                          break;
                                    }
                              break;
                        case Turbidity:
                              print_str("Reached Here TURBIDITY!\r\n");
                              switch(currentRxMessage.messageId){
                                    case 0:
```

```
      xTimerChangePeriod(TimerID_TurbiditySensor, currentRxMessage.params,
portMAX_DELAY);

      xTimerStart(TimerID_TurbiditySensor, portMAX_DELAY);

      send_ack_message(TurbiditySensorEnable);
                                    break;
                              case 1: //Do Nothing
                                    break;
                              case 3: //Do Nothing
                                    break;
                        }
                        break;
                  case Microplastic:
                        print_str("Reached Here MICROPLASTIC!\r\n");
                        switch(currentRxMessage.messageId){
                              case 0:

      xTimerChangePeriod(TimerID_MicroplasticSensor,
currentRxMessage.params, portMAX_DELAY);

      xTimerStart(TimerID_MicroplasticSensor, portMAX_DELAY);

      send_ack_message(MicroplasticSensorEnable);
                                    break;
                              case 1: //Do Nothing
                                    break;
                              case 3: //Do Nothing
                                    break;
                        }
                        break;
                  case DOLevel:
                        print_str("Reached Here DOLevel!\r\n");
                        switch(currentRxMessage.messageId){
                              case 0:

      xTimerChangePeriod(TimerID_DOLevelSensor, currentRxMessage.params,
portMAX_DELAY);
                                    xTimerStart(TimerID_DOLevelSensor,
portMAX_DELAY);

      send_ack_message(DOLevelSensorEnable);
                                    break;
                              case 1: //Do Nothing
                                    break;
                              case 3: //Do Nothing
                                    break;
                        }
                        break;
                        default://Should not get here
                              break;
            }
            ResetMessageStruct(&currentRxMessage);
      }
   } while(1);
}
```

DOLevelSensor.c

```
/*
 * DOLevelSensorController.c
 *
 *  Created on: Nov. 22, 2024
 *      Author: Nnaemeka Nnadede & Temitope Onafalujo
 */

#include <stdbool.h> // Required for boolean data types

#include "User/L2/Comm_Datalink.h"   // Communication layer header file
#include "User/L3/DOLevelSensor.h"   // DO level sensor-specific
functionalities

// Required FreeRTOS header files
#include "FreeRTOS.h"  // FreeRTOS main header
#include "Timers.h"    // Timer functions for periodic sensor execution

/***************************************************************************
***
 * RunDOLevelSensor
 * Software callback function executed periodically by a FreeRTOS timer.
 * Simulates dissolved oxygen (DO) level data and sends it via the
communication layer.
 *
 * @param xTimer: Handle to the FreeRTOS timer that triggers this callback.

***************************************************************************
**/
void RunDOLevelSensor(TimerHandle_t xTimer) {
    static float do_level = 6.0;      // Initial DO level value in mg/L
(milligrams per liter)
    static uint8_t do_up = true;     // Boolean flag to determine whether to
increase or decrease the value
    const float noise = ((rand() % 20) + 1) / 100.0; // Small random noise
between 0.01 and 0.20 mg/L

    // Simulate DO level variation
    if (do_up)
        do_level += 0.1; // Increment the DO level by 0.1 mg/L
    else
        do_level -= 0.1; // Decrement the DO level by 0.1 mg/L

    // Reverse the direction when DO level reaches the boundaries
    if (do_level >= 8.0) do_up = false; // Reverse at the upper limit of 8.0
mg/L
    if (do_level <= 3.5) do_up = true;  // Reverse at the lower limit of 3.5
mg/L

    // Add simulated noise to the DO level value for a more realistic
reading
    float simulated_do_level = do_level + noise;

    // Transmit the simulated DO level value scaled to an integer
    // DO levels are multiplied by 100 to maintain precision during
transmission
```

```
    send_sensorData_message(DOLevel, simulated_do_level * 100);
}
```

MicroplasticsSensor.c

```
/*
 * MicroplasticSensorController.c
 *
 *  Created on: Nov. 22, 2024
 *      Author: Nnaemeka Nnadede & Temitope Onafalujo
 */

#include <stdbool.h> // Required for boolean data types

#include "User/L2/Comm_Datalink.h"   // Communication layer header file
#include "User/L3/MicroplasticSensor.h" // Microplastic sensor-specific
functionalities

// Required FreeRTOS header files
#include "FreeRTOS.h"  // FreeRTOS main header
#include "Timers.h"    // Timer functions for periodic sensor execution

/*****************************************************************************
***
 * RunMicroplasticSensor
 * Software callback function executed periodically by a FreeRTOS timer.
 * Simulates microplastic concentration data and sends it via the
communication layer.
 *
 * @param xTimer: Handle to the FreeRTOS timer that triggers this callback.

******************************************************************************
**/
void RunMicroplasticSensor(TimerHandle_t xTimer) {
    static int microplastic = 300;       // Initial microplastic value in
particles per liter (particles/L)
    static uint8_t microplastic_up = true; // Boolean flag to determine
whether to increase or decrease the value
    const int noise = rand() % 50;       // Small random noise between 0 and
49 particles/L

    // Simulate microplastic variation
    if (microplastic_up)
        microplastic += 20; // Increment the microplastic concentration by
20 particles/L
    else
        microplastic -= 20; // Decrement the microplastic concentration by
20 particles/L

    // Reverse the direction when microplastic concentration reaches the
boundaries
```

```
    if (microplastic >= 2100) microplastic_up = false; // Reverse at the
upper limit of 2100 particles/L
    if (microplastic <= 100) microplastic_up = true;  // Reverse at the
lower limit of 100 particles/L

    // Add simulated noise to the microplastic value for a more realistic
reading
    int simulated_microplastic = microplastic + noise;

    // Transmit the simulated microplastic concentration directly
    send_sensorData_message(Microplastic, simulated_microplastic);
}
```

TurbiditySensor.c

```
/*
 * TurbiditySensorController.c
 *
 *  Created on: Nov. 22, 2024
 *      Author: Nnaemeka Nnadede & Temitope Onafalujo
 */

#include <stdbool.h> // Required for using boolean data types

#include "User/L2/Comm_Datalink.h"  // Communication layer header file
#include "User/L3/TurbiditySensor.h" // Turbidity sensor-specific
functionalities

// Required FreeRTOS header files
#include "FreeRTOS.h" // FreeRTOS main header
#include "Timers.h"   // Timer functions for periodic sensor execution

/****************************************************************************
***
 * RunTurbiditySensor
 * Software callback function executed periodically by a FreeRTOS timer.
 * Simulates turbidity sensor data and sends it via the communication layer.
 *
 * @param xTimer: Handle to the FreeRTOS timer that triggers this callback.

*****************************************************************************
**/
void RunTurbiditySensor(TimerHandle_t xTimer) {
    static float turbidity = 5.0;      // Initial turbidity value in NTU
(Nephelometric Turbidity Units)
    static uint8_t turbidity_up = true; // Boolean flag to determine whether
to increase or decrease the value
    const float noise = ((rand() % 5) + 1) / 10.0; // Small random noise
between 0.1 and 0.5 NTU

    // Simulate turbidity variation
    if (turbidity_up)
        turbidity += 0.5; // Increment the turbidity by 0.5 NTU
```

```
    else
        turbidity -= 0.5; // Decrement the turbidity by 0.5 NTU

    // Reverse the direction when turbidity reaches the boundaries
    if (turbidity >= 55) turbidity_up = false; // Reverse at the upper limit
of 55 NTU
    if (turbidity <= 5) turbidity_up = true;  // Reverse at the lower limit
of 5 NTU

    // Add simulated noise to the turbidity value for a more realistic
reading
    float simulated_turbidity = turbidity + noise;

    // Transmit the simulated turbidity value scaled to an integer
    // Turbidity values are multiplied by 100 to maintain precision during
transmission
    send_sensorData_message(Turbidity, simulated_turbidity * 100);
}
```

Python UI Script: main.c

```
import serial
import threading
import customtkinter as ctk
import time

unit_dict = {
    "Turbidity": "NTU",
    "Microplastic": "particles/L",
    "DoLevel": "mg/L"
}


def categorize_value(value):
    """
    Categorizes the value based on the number of digits before the decimal
point.
    """
    if '.' in value:
        before_decimal = value.split('.')[0]
        if len(before_decimal) == 1:
            return "DoLevel"
        elif len(before_decimal) == 2:
            return "Turbidity"
    else:
        return "Microplastic"


class SerialApp:
    def __init__(self, root):
        self.root = root
        self.root.title("STM32 Serial Communication")
        ctk.set_appearance_mode("Dark")  # Set dark mode
```

```
        ctk.set_default_color_theme("blue")  # Set the color theme

        # Serial connection attributes
        self.ser = None
        self.serial_thread = None
        self.stop_event = threading.Event()
        self.lock = threading.Lock()

        # Create the UI
        self.create_widgets()

    def create_widgets(self):
        # COM Port Entry
        self.com_label = ctk.CTkLabel(self.root, text="COM Port:")
        self.com_label.grid(row=0, column=0, padx=10, pady=10, sticky="e")

        self.com_port_entry = ctk.CTkEntry(self.root,
placeholder_text="Enter COM Port (e.g., COM7)")
        self.com_port_entry.grid(row=0, column=1, padx=10, pady=10)
        self.com_port_entry.insert(0, "COM7")

        # Command Entry
        self.command_label = ctk.CTkLabel(self.root, text="Command:")
        self.command_label.grid(row=1, column=0, padx=10, pady=10,
sticky="e")

        self.command_entry = ctk.CTkEntry(self.root, placeholder_text="Enter
Command (START, RESET)")
        self.command_entry.grid(row=1, column=1, padx=10, pady=10)

        # Buttons
        self.connect_button = ctk.CTkButton(self.root, text="Connect",
command=self.connect_serial)
        self.connect_button.grid(row=0, column=2, padx=10, pady=10)

        self.disconnect_button = ctk.CTkButton(self.root, text="Disconnect",
command=self.disconnect_serial,
                                               state="disabled")
        self.disconnect_button.grid(row=0, column=3, padx=10, pady=10)

        self.send_button = ctk.CTkButton(self.root, text="Send",
command=self.send_command, state="disabled")
        self.send_button.grid(row=1, column=2, columnspan=2, padx=10,
pady=10)

        # Textbox for responses
        self.response_label = ctk.CTkLabel(self.root, text="STM32
Responses:")
        self.response_label.grid(row=2, column=0, columnspan=4, padx=10,
pady=10, sticky="w")

        self.response_textbox = ctk.CTkTextbox(self.root, width=500,
height=200, state="disabled")
        self.response_textbox.grid(row=3, column=0, columnspan=4, padx=10,
pady=10)

    def connect_serial(self):
```

```
        # Get COM port from entry
        com_port = self.com_port_entry.get().strip()
        baud_rate = 115200  # Default baud rate

        try:
            # Initialize the serial connection
            self.ser = serial.Serial(com_port, baud_rate, timeout=1)
            self.log_to_text(f"Connected to {com_port} at {baud_rate}
baud.")

            # Start the serial reading thread
            self.stop_event.clear()
            self.serial_thread =
threading.Thread(target=self.read_from_serial, daemon=True)
            self.serial_thread.start()

            # Update button states
            self.connect_button.configure(state="disabled")
            self.disconnect_button.configure(state="normal")
            self.send_button.configure(state="normal")
        except serial.SerialException as e:
            self.log_to_text(f"Error: {e}")

    def disconnect_serial(self):
        # Stop the reading thread
        self.stop_event.set()
        if self.serial_thread:
            self.serial_thread.join()

        # Close the serial connection
        if self.ser and self.ser.is_open:
            self.ser.close()
            self.log_to_text("Serial connection closed.")

        # Update button states
        self.connect_button.configure(state="normal")
        self.disconnect_button.configure(state="disabled")
        self.send_button.configure(state="disabled")

    def send_command(self):
        # Get command from entry
        command = self.command_entry.get().strip().upper()
        if not command:
            self.log_to_text("Error: Command cannot be empty.")
            return

        if command not in ["START", "RESET"]:
            self.log_to_text("Invalid command. Use 'START' or 'RESET'.")
            return

        with self.lock:
            try:
                self.ser.write((command + "\n").encode())
                self.log_to_text(f"Sent: {command}")
            except Exception as e:
                self.log_to_text(f"Error: {e}")
```

```
    def read_from_serial(self):
        """
        Continuously read data from the serial port and update the GUI.
        """
        while not self.stop_event.is_set():
            with self.lock:
                if self.ser and self.ser.in_waiting > 0:
                    try:
                        response = 
self.ser.read(self.ser.in_waiting).decode().strip()
                        if response:
                            label = categorize_value(response)
                            self.log_to_text(f"{label} Data: {response} 
{unit_dict[label]}")
                    except Exception as e:
                        self.log_to_text(f"Error reading from serial: {e}")
            time.sleep(0.08)  # Small delay to avoid high CPU usage

    def log_to_text(self, message):
        """
        Log a message to the text box (thread-safe).
        """
        self.response_textbox.configure(state="normal")
        self.response_textbox.insert("end", f"{message}\n")
        self.response_textbox.yview("end")  # Auto-scroll
        self.response_textbox.configure(state="disabled")


# Run the CustomTkinter app
if __name__ == "__main__":
    ctk.set_appearance_mode("Dark")
    root = ctk.CTk()
    app = SerialApp(root)
    root.mainloop()
```