Open-source Handheld pH Sensor with Mobile App

A Design Project Report

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Abstract

Master of Engineering Program

School of Electrical and Computer Engineering

Cornell University

Design Project Report

Project Title: Open-source Handheld pH Sensor with Mobile App

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Abstract: The project aims to develop a compact, portable device for measuring pH in seawater, utilizing the spectrophotometric method. Addressing the need for less bulky and expensive equipment, this device will feature simple, cost-effective and durable hardware, and integration with an Android app and Cloud storage. The final deliverable will consist of a benchtop prototype, paired with an intuitive Android application and Web Cloud integration. This setup will facilitate comprehensive device control, data transmission, storage, and analysis capabilities.

Executive Summary

Traditional methods for measuring oceanic pH levels are hindered by high costs, operational complexities, and the bulky nature of existing equipment. Our primary goal was to design a system that democratizes ocean carbonate chemistry research by making pH measurement accessible to a broader audience, including non-experts and researchers. Recognizing these challenges, our team focused on developing a portable, robust, cost-effective, and user-friendly pH measurement device combined with mobile app and cloud system. We divided the project into two parts: hardware and software.

As for the hardware implementation, we designed the embedded system of the small, portable and accurate pH sensor using the spectrophotometric pH measurement method. This system comprises a microcontroller board, an optical sensor, a temperature sensor, a real-time clock module, and a battery management module with different communication protocols. This pH device is not only capable of delivering precise and real-time pH data from marine environments but also compact and lightweight.

As for the software architecture, we divided it into 3 levels: Microcontroller, Android application and Web Cloud. We designed the microcontroller software to control and manage the acquisition of light intensity and temperature, calculate the pH value, store the data, and transmit it to the Android app via Bluetooth LE. For usability and data management, we developed an Android app which enables users to interact easily with the pH sensor and visualize data efficiently. We leverage the http protocol to transfer the data from Android app to web cloud. On the website, we enable public sharing for further statistical analysis of the data, and visualize the pH values by location using Google Maps.

Through rigorous testing, we have verified that the integration of hardware with the mobile app and cloud platform is successful, ensuring the system operates effectively in real-world conditions.

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1. Introduction

Ocean Acidification is negatively affecting the physiological processes of marine organisms, altering biogeochemical cycles, and changing chemical equilibria throughout the world's oceans. A significant challenge in studying these changes is the difficulty of measuring pH broadly due to the high costs, bulkiness, and technical expertise required for accurate pH measurement technology.

Creating an accurate, affordable, and easy-to-use carbonate sensor can greatly advance carbonate chemistry research by removing many of the current obstacles. This new sensor, capable of measuring two key seawater carbonate system parameters without relying on costly, intricate equipment, enables both researchers and hobbyists to more easily study the impacts of ocean acidification in local environments.

This development promises to democratize ocean carbonate chemistry research, inviting broader participation from various communities. Such widespread involvement will open up fresh opportunities for understanding and exploring the effects of ocean acidification on marine ecosystems, making a significant impact in this scientific field.

In Section 2, we describe the design problems and requirements that need to be solved. In the third section, we discuss spectrophotometric pH measurement methods and make comparisons with other pH measurement methods. In section 4, we introduce our system architecture, hardware and software design and implementation. In Section 5, we show the testing strategy and results of our design. In the remaining section, we describe and summarize what has been done and what is to be done in the future as well as individual contribution.

2. Design Problems and Requirements

The primary challenges in developing this sensor include ensuring its portable, user-friendliness, cost-effectiveness, and integration with a mobile application and cloud platform. Each aspect requires careful consideration and specific solutions to meet the needs of potential users and ensure the device's practical utility in real-world conditions.

2.1 Design Problems

1. High Cost and Complexity: Existing technologies for measuring carbonate chemistry are expensive and require technical expertise, limiting access for non-experts and individuals with limited resources.
2. Lack of Accessibility: The bulkiness of current high-accurate devices prevent their use in ocean environments, particularly by amateur researchers.
3. Integration Challenges: Effective integration of hardware with software (mobile application) and data management systems (cloud platforms) is essential yet challenging, needing seamless interaction for user convenience and data reliability.

2.2 Design Requirements

To address these problems, the development of the pH sensor must meet the following requirements:

1. Accuracy

   The precision should be at least < 0.02 pH units, the good precision is < 0.01 and the ideal is < 0.005 at 1 stddev compared with some standard pH devices.
2. Usability
   - pH Sensor Interface: The sensor must feature a simple, intuitive interface that can be easily used by non-technical users without extensive training.
   - Mobile App Interface: Develop an Android application which should allow users to easily operate the sensor, view results in real-time, and understand the data without specialized training.
   - Website Interface: Develop a straightforward website for user and oceanic carbonate chemistry research community to manage and share pH data.
3. Cost-Effectiveness
   - Affordability: The design and production costs of the sensor should not exceed $500 to ensure it is accessible to a broader range of researchers and interested individuals.
4. Technology Integration
   - Bluetooth Connectivity: Implement reliable Bluetooth communication to enable real-time data synchronization and remote sensor operation via the Android application. This setup must ensure less latency and high data integrity.

- Cloud Data Management: The Android application should be capable of securely uploading pH data to a cloud database. This requires a robust data transfer mechanism to ensure data integrity, security, and timely synchronization for effective remote analysis and storage.

5. Compact Design
    - Portability: The sensor must be compact and lightweight, enhancing its portability and making it suitable for field use in the ocean. Its small size should facilitate easy transport and deployment without sacrificing functionality or durability.
    - Water proof: The sensor should be waterproof, since the project is mainly aimed at measuring the pH value of seawater.
    - Duration: The sensor's power can ensure that researchers can continue working at sea for a week without charging. It betters have wireless charging to improve portability.
    - Time recording: It is necessary for the sensor to record the current time, which can facilitate subsequent observation of changes in measurement data.
    - Local storage: It is necessary to add localized storage as temporary storage when working at sea without a network.

3. Overview of pH measurement

3.1 pH Spectrophotometric Measurement Method

The method used for pH measurements is the Spectrophotometric pH measurements method. Briefly, the method measures the equilibrium of the indicator meta-Cresol Purple (mCP) with hydrogen ion concentration in solution.

$$HL^{-} \leftrightharpoons H^{+} + L^{2-}$$

where HL− and L2− are the first and second deprotonated forms of the mCP indicator, which have absorbance peaks at 434 nm and 578 nm, respectively. In seawater, the fully protonated form of mCP (H2L) is insignificant and, hence, the equilibrium is dominated by the second apparent acid dissociation constant.

$$pH_T = pK_a' + log_{10}\frac{R-e_1}{e_2-Re_3}$$

where e1, e2, and e3 are ratios of the molar absorption coefficients associated with wavelengths of 578 and 434 nm, and pH_T is what we want.

$$R = \frac{A_{578}}{A_{434}}$$

where Aλ is the absorbance at a wavelength λ and A is

$$A = -\log_{10}\left(\frac{I_{\lambda}}{I_{\lambda 0}}\right)$$

So first, about 3 mL of sample solution is added to the sample cuvette, using a dropper or by submerging the device directly in the water. Use the light sensor (e.g. Adpd4101) to measure I_{λ} at both wavelengths. Then add indicator dye to the sample, therefore $I_{\lambda 0}$ can be tested. Finally, what we need to test is pK_a' by following equation when the salinity is 35:

$$pK_a' = -241.462 + \frac{7085.72}{T} + 43.8332 * ln(T) - 0.0806406 * T$$

When the mCP is unpurified, we can correct the equation by following equation:

$$pK_a' = \frac{7085.72}{T} + 43.8332 * ln(T) - 0.0806406 * T - 0.3238 * S^{0.5} + 0.0807 * S - 0.01157 * S^{1.5} + 0.000694 * S^{2} - 240.825$$

Finally, we can get the pH_T value.

In practice, after completing the communication between temperature and light intensity sensor, we can do calculations to get the pH value. The procedure is as follows:

1. Turn on 434nm LED, and then get light intensity data through LTC2984.
2. Turn off 434nm LED and turn on 578 nm LED, and then get light intensity data through LTC2984.
3. Then after users confirm they have already added dye indicator to the seawater sample, they repeat steps 1 and 2 to get another two light intensity values.
4. And then get the temperature data through ADPD4101.
5. Then calculate the second term through total 4 light intensity data, and the first term through temperature data. Finally, we can get the pH value.

3.2 Other pH Measurement Methods

1. Glass Electrode pH Meters

The most widespread method for measuring pH, glass electrode pH meters use a glass electrode and a reference electrode to measure the hydrogen ion activity in a solution. The potential difference between these electrodes provides the pH value.

- **Advantages**: High accuracy and reliability across a wide range of pH levels..
- **Disadvantages**: Glass electrodes can be fragile and require regular calibration and maintenance. They are also sensitive to temperature variations and may have response issues in solutions with low ion concentrations.

2. ISFET pH Meters (Ion Sensitive Field Effect Transistor)

These devices use a semiconductor-based technology where the hydrogen ion concentration is measured by the effect on the field effect transistor, similar to how a traditional pH meter functions but without a glass electrode.

- **Advantages**: Durable, less fragile than glass electrodes, and can be miniaturized for applications in confined spaces.
- **Disadvantages**: Generally less accurate than glass electrode meters and can be more expensive. They also require calibration and can be affected by the buildup of substances on the sensor.

3. Colorimetric pH Tests (pH Paper)

These are simple, disposable strips of paper coated with pH-sensitive dyes. The color change after dipping the paper into a solution indicates the pH.

- **Advantages**: Very easy to use, inexpensive, and no need for calibration.
- **Disadvantages**: Offers only approximate pH values and is less accurate.

3.3 Comparison

For the development of a small, portable, user-friendly, and cost-effective device for accurate pH measurement in seawater, particularly for ocean carbonate chemistry research, several factors must be considered:

- **Accuracy and Precision**: While glass electrodes generally offer higher precision and accuracy, they may not be ideal in non-clear solutions like seawater. However, spectrophotometric methods, which can perform well in turbid or colored samples.
- **Maintenance and Durability:** Spectrophotometric methods typically require less maintenance compared to pH meters that need regular calibration and can suffer from electrode wear and tear and fragile glass electrodes. The robustness of spectrophotometric methods makes them ideal for harsh ocean fieldwork conditions.
- **Cost and Accessibility:** Although glass electrode pH meters are generally more cost-effective for routine measurements, the spectrophotometric methods, despite

their higher initial cost, offer long-term benefits in specialized research environments due to lower maintenance needs and greater durability.

Considering the specific requirements for seawater analysis and the challenges associated with traditional pH measurement methods in such environments, the spectrophotometric method emerges as the most appropriate choice.

4. Design and Implementation

4.1 System Architecture

The system architecture is designed for a pH measurement and monitoring system that integrates a pH sensor, Android app and cloud platform. The main purpose of this system is to collect, transmit, store, and analyze pH data from marine environments.

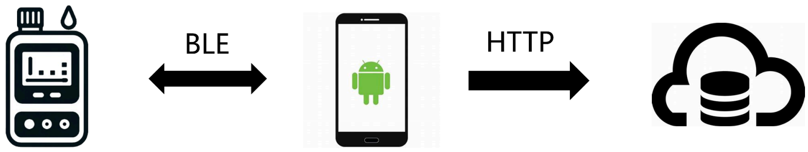

Figure 4.1: System Architecture (From left to right: pH sensor, Android app and cloud platform)

The system comprises three components:

1. **pH sensor**: This is the core element of the system, designed specifically for measuring pH levels. It uses Bluetooth Low Energy (BLE) technology to transmit data directly to the Android app, enabling real-time monitoring and updates.
2. **Android app**: Serving as the central interface, the Android app acts as an intermediary by receiving data from the pH sensor via BLE and then forwards it to the cloud platform using HTTP protocols. This setup facilitates seamless user interaction with the system.
3. **Cloud platform:** It hosts a database that securely stores all collected data, supporting large-scale data management. Additionally, it features a website interface where the data can be viewed and updated through graphical representations or dashboard views.

4.2 Hardware Design

4.2.1 ItsyBitsy nRF52840 Express

The Adafruit ItsyBitsy nRF52840 Express is a powerful, compact microcontroller board featuring the Nordic nRF52840 System-on-Chip (SoC). At the core of this board lies a 32-bit ARM Cortex-M4 processor running at 64 MHz, combined with 1 MB of Flash and 256 KB of RAM. It provides rich resources for programs that require efficient execution and wireless connectivity.

Why we selected ItsyBitsy nRF52840 Express apart is also because of its integration of Bluetooth Low Energy (BLE), making it ideal for wireless communication with our mobile app in the project. It is only 1.4" long by 0.7" wide shown in Figure 2.1, but the board includes multiple GPIO pins and supports communication protocols like SPI, I2C, and UART, which provides our embedded system more choices for modules.

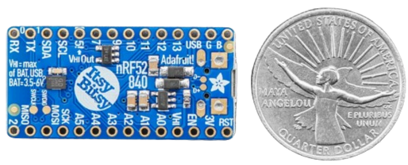

Figure 4.2 ItsyBitsy nRF52840 Express comparison with a coin

4.2.2 ADPD4101 Optical Sensor

The ADPD4101 is a highly integrated, multichannel optical sensor from Analog Devices, designed for precision light measurement in various applications. It integrates an advanced photometric front end with programmable signal processing capabilities to measure a wide range of optical signals. With support for up to eight optical channels, the sensor can simultaneously measure light across different wavelengths or directions, which is suitable for the spectrophotometric pH measurement method that we implemented in this project.

The ADPD4101 is designed with low power consumption, which includes power management to ensure continuous monitoring in power-constrained environments, making it suitable for wearable devices and other portable applications like this handheld ocean pH sensor. It communicates efficiently with microcontrollers via standard I2C interfaces.

Figure 4.3 ADPD4101 optical sensor

4.2.3 LTC2984 Temperature Sensor

The LTC2984 is a multi-sensor temperature measurement system from Analog Devices designed to interface seamlessly with various temperature sensors. It has a 20-bit analog-to-digital converter (ADC) that ensures high-resolution and highly accurate temperature readings across all sensor types. The LTC2984 communicates via the SPI protocol, ensuring efficient data exchange with the main control system.

Figure 4.4 LTC2984 temperature sensor

4.2.4 DS3231 Real-time Clock Module

The DS3231 is a highly accurate real-time clock (RTC) module. It's designed to provide precise timekeeping in various electronic applications. It features an integrated crystal oscillator that provides a high degree of accuracy. The module tracks seconds, minutes, hours, day of the week, date, month, and year. A battery input allows the DS3231 to continue functioning during power failures, keeping accurate time. It communicates via an I2C bus, making it compatible with a wide range of microcontrollers.

4.2.5 MAX17040 Battery Management

The MAX17040 is a fuel gauge IC designed to monitor single-cell lithium-ion (Li-Ion) batteries accurately. It employs the ModelGauge algorithm to estimate battery state-of-charge without the need for complex modeling or learning cycles. It communicates with microcontrollers via I2C and the IC is designed to consume minimal power.

4.2.6 Hardware Design and Integration

The hardware design features a modular architecture centered around the ItsyBitsy nRF52840 Express microcontroller, as shown in Figure 3.4. This board serves as the core processing unit of the system, coordinating the operation of all connected components and efficiently processing data. It implements key spectrophotometric pH algorithms while managing communication through BLE to the Android application.

As for other components, the ADPD4101 light sensor captures light intensity and forwards the data to the microcontroller using the I2C protocol. The LTC2984 temperature sensor, communicating via SPI, provides accurate temperature readings necessary for precise pH measurements. The microcontroller also manages the SD card for local data storage and an RTC module for accurate time-stamping, ensuring reliable record-keeping for further analysis.

The battery system measures the battery voltage directly, providing the microcontroller with information of state-of-charge, allowing efficient energy management for continuous operation.

By integrating these components together on a board, this pH sensor design can ensure that all components work cohesively, enabling seamless data acquisition, precise pH measurements, and secure data storage.

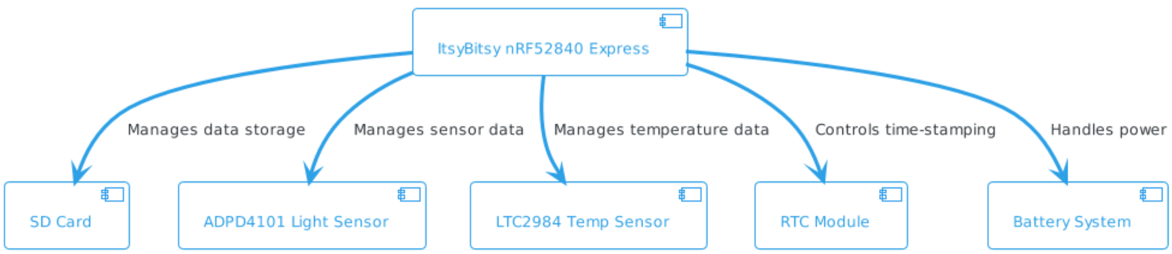

Figure 4.5 pH sensor hardware architecture

4.3 Low-level Software Design

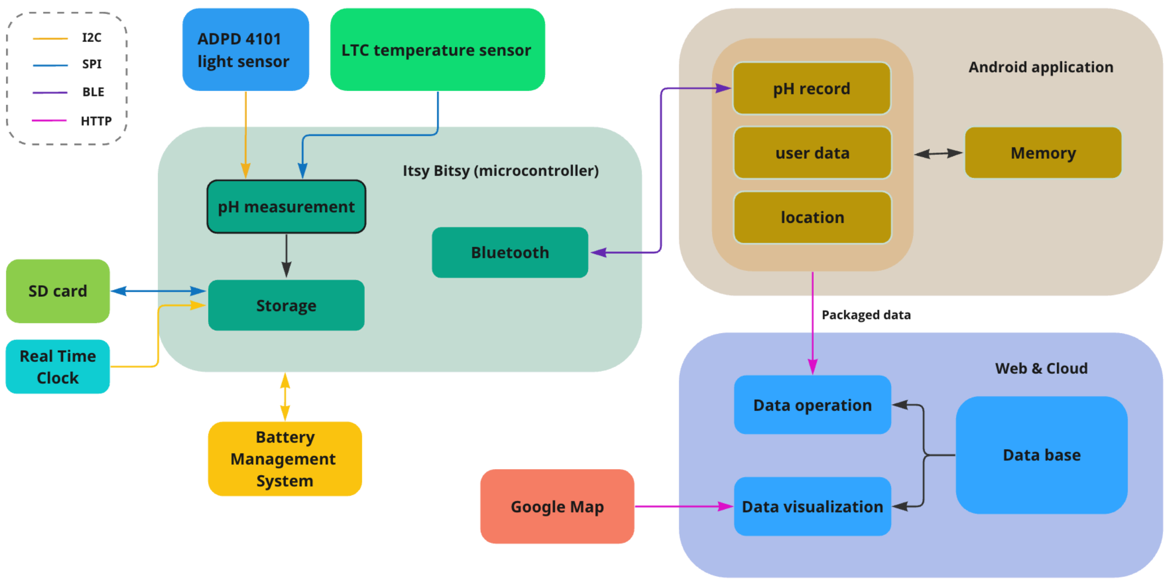

Figure 4.6 pH sensor software architecture

Our system architecture is clearly divided into 3 levels: Microcontroller, Android application and Web Cloud.

4.3.1 Microcontroller Design

The microcontroller software is designed to control and manage the acquisition of light intensity and temperature data, calculate the pH value, store the data, and transmit it to an Android application via Bluetooth. It includes a comprehensive suite of tasks and modules as shown below.

1. **Light Intensity Data Acquisition:** The module initializes the LTC2984 sensor and LED control GPIO, manages the switching of 434nm and 578nm LEDs, acquires light intensity data via SPI, and stores this data in respective buffers.
2. **Temperature Data Acquisition:** The module initializes the ADPD4101 sensor, reads ambient temperature data via I2C, and stores the data in a temperature buffer.
3. **pH Value Calculation:** The module retrieves data from the light intensity and temperature buffers, calculates the pH value using Spectrophotometric formulas, and stores the calculated pH value in the buffers.
4. **Data Storage:** The module initializes the SD card and file system, formats the data and combined time information,, and writes it to the SD card for temporary storage.
5. **Data Transmission:** The module initializes the Bluetooth module, establishes a Bluetooth connection, reads stored data from the SD card, and transmits it to an Android application via Bluetooth.

4.3.2 Android App Design

The Android application serves as the user-facing layer and intermediary of the system, providing a seamless interface that bridges the microcontroller and cloud platform. It enables users to interact easily with the pH sensor and offers a comprehensive suite of features as shown in Figure 3.5.

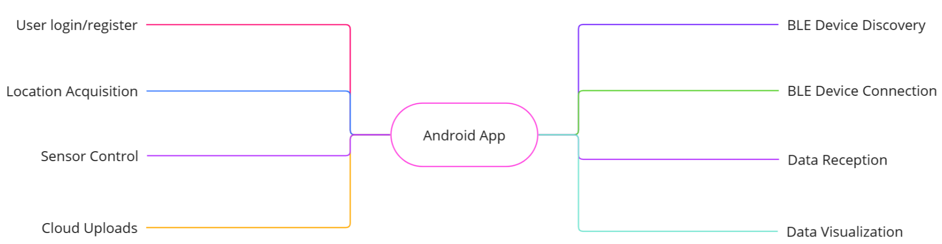

Figure 4.7 Android app features

1. **User login/register**: The app allows users to create an account and log in. This ensures secure access to personalized data and settings while maintaining data continuity across devices. User information is also uploaded to the cloud alongside the pH data through HTTP.
2. **Bluetooth Device Discovery and Connection**: The app identifies nearby BLE devices through UUIDs, enabling users to establish a connection with their desired BLE device. In this system, the pH sensor acts as a BLE central device, facilitating real-time data monitoring and synchronization between the sensor and the mobile app. In the implementation, we enable and set up the Bluetooth service in the Android Studio, including service discovery, connection, disconnection, service closure, broadcast update, callback and so on.
3. **Data Reception and Visualization**: Once connected via BLE, the app decodes and extracts data as it is received. For this purpose, we create Bluetooth-related functions like characteristic read, characteristic write, characteristic change, and characteristic notification, enabling real-time data transmission and user interaction. The app also collects pH data, user data, and location information from the sensor and presents them visually for better understanding.
4. **Direct Sensor Control**: Users can directly control the sensor's operational settings via the app, simplifying pH measurement management. The app enables users to control device operations, such as turning the device on and off and starting or stopping optical and temperature measurements..
5. **Geographical Location Acquisition**: The app integrates with the phone's GPS functionality to tag each pH reading with precise location data, including latitude, longitude and additional address information provided by users. This geographic context is crucial for further analysis.
6. **Cloud Uploads**: The app packages the data according to a predefined structure shown in Figure 3.6. It utilizes Retrofit, a type-safe HTTP client for Android, to structure and securely transmit data to the cloud platform. This approach allows for efficient and reliable data uploads, ensuring accurate storage and remote accessibility.

Data Structure	
string	user name
string	email
float	latitude
float	longitude
float	pH
float	temp
float	salinity
bool	isShared
string	time

Figure 4.8 Packaged data structure

4.3.3 Webside & Cloud Design

1. **Database:** Our system leverages MongoDB Atlas Cloud as the primary database solution to ensure robust stability and heightened data security, particularly in scenarios where server disruptions occur. The database architecture is designed with two distinct sub-databases:
    - Users: This sub-database manages user authentication and profile information, facilitating secure access and personal data management.
    - pH Records: Dedicated to storing pH measurement data, this sub-database includes fields for data ownership and sharing permissions, which allows users to control the visibility of their data within the community.

    These sub-databases are intricately linked, enabling efficient data retrieval and integrity between user profiles and their corresponding pH records. Each record includes a configurable field that determines its shareability, enhancing user control over data distribution and privacy.

2. **Frontend Development:** The frontend of the system is developed using Vue.js, a progressive JavaScript framework that offers a reactive and component-driven architecture. The frontend is segmented into three primary modules:
    - User Authentication System: Supports user login and registration processes, equipped with security measures to protect user information. The front-end will send the username/email and password entered by the user to the

back-end after certain form verification. After receiving the data successfully returned by the back-end, the page will jump to the personal data center.

- Personal pH Records Management: Allows users to upload, manage, and review their pH measurement records in a user-friendly interface. Specifically, we set up a `shared` button for users to decide whether to share their uploaded pH records with the public, `upload` button for users uploading data via web page, and `deleted` button for users deleting pH data records.
- Public pH Record Visualization: Facilitates the graphical representation of publicly shared pH data, promoting an interactive platform for community engagement and data analysis. In detail, The web page will show a list of pH records, including basic location, time, pH value information, as well as the user name and email address of the person sharing it, to facilitate communication. And the inserted map shows the approximate location of the record by Google map Api.

3. **Backend Infrastructure:** Our backend is crafted using Node.js, chosen for its efficiency in handling asynchronous operations and its compatibility with JSON data handling. The backend serves as the conduit between the frontend, the database, and the Android application, ensuring seamless data flow and functionality across the system. It supports essential operations such as user management, data processing, and real-time updates, providing a robust foundation for the system's interactive features.
    - Query or create users in the MongoDB database, return to the front end whether the login/registration is successful, and the generated token is used to verify the user's identity.
    - Provides an interface for pH data records additions, deletions, modifications and queries in the database.

5. Testing and Results

5.1 pH Sensor Prototype

Firstly, to verify the functionality of each component, we developed simple test functions for reading, writing. For example, we read data from a specific register to know the status and then use the write function to write some data into a register. After that, we used the read function to get the data from that register to check if they are the same. If so, we can say that the component and the functions that we used work.

For the integrated pH sensor prototype, we developed testing to verify the microcontroller can receive the data from different components and calculate the pH value by simulating with fake data. Since we didn't test with the seawater sample and compare with other pH devices, we cannot know the accuracy. The result is a sophisticated pH sensor prototype, as shown in Figure 4.1. The testing results are listed in Table 4.1.

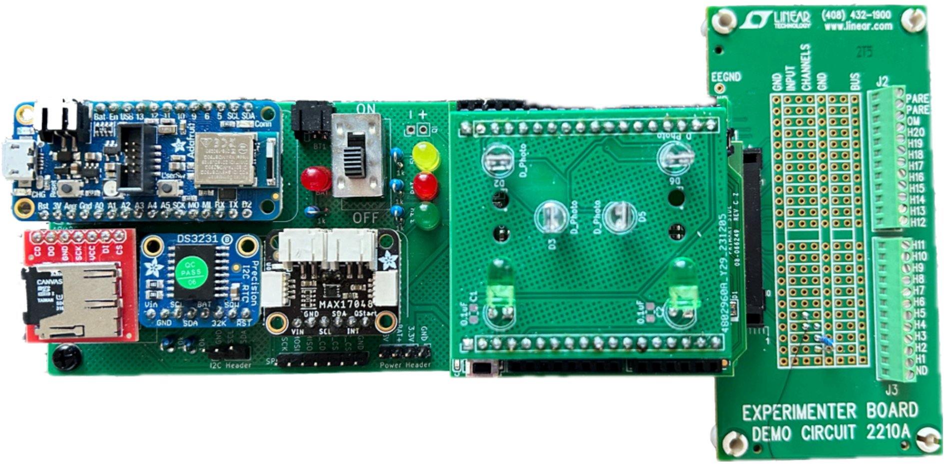

Figure 5.1 pH Sensor Prototype (created by Jonathan Pfeifer and WHOI)

Table 5.1 Testing Results

Functionality	Description	Expected Result	Actual Result	Status
Sensor Data Flow Test	Ensure seamless data flow from temperature and light sensors to the microcontroller.	Data transmitted correctly.	Data flow is smooth.	Passed
pH Measurement Accuracy	Check pH value with results of other pH devices.	The difference of results should be in a specific range.	Using fake data and no comparison.	Not passed
BLE Data Flow Test	Ensure seamless data flow between the pH sensor and Android app.	Data transmitted correctly.	Data flow is smooth.	Passed
Response	Measure the time taken	Quickly finish the	Responds within	Passed

Time	to finish calculating pH and transmitting data.	whole process of calculation and transmission.	acceptable range.	

5.2 Android App

The testing aimed to ensure that the Android application functioned effectively as an intermediary, facilitating smooth interactions between the user, the pH sensor, and the cloud platform. The app was tested across various dimensions including usability, functionality, and integration with manual and automated testing

1. User Login/Register System

To verify the account creation and login processes ensure data continuity, we developed manual testing with multiple accounts and automated tests to simulate network responses. When the app gets the username and password that user inputs, the app will send http requests to the backend, and the backend will query the database to check whether the user exists. All tests passed successfully. The user authentication worked flawlessly and data continuity across devices was confirmed. The login interface is shown in Figure 4.2.

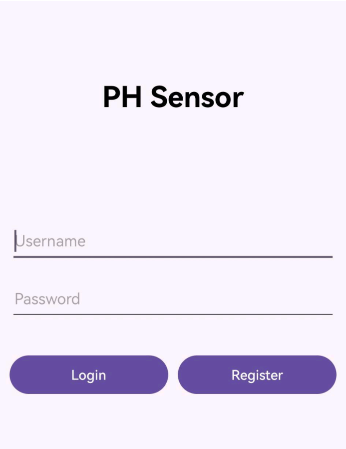

Figure 5.2 The login and register system

2. Bluetooth LE Connectivity

To ensure that the app correctly identifies and connects to nearby BLE devices using UUIDs, we tested with multiple BLE devices in varied environments to check for robustness and reliability. We found that the device discovery was consistent and reliable. Connections were stable even in environments with multiple BLE devices, with the app maintaining high performance without significant delays or errors. Figure 4.2 shows the Android app to get the nearby bluetooth device and find ItsyBitsy through BLE.

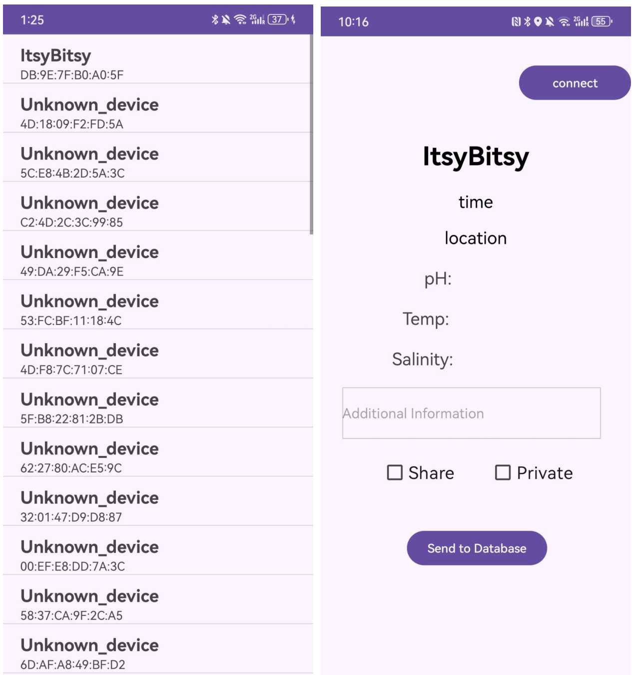

Figure 5.3 The Bluetooth LE test result

3. Data Reception and Visualization

To confirm accurate data decoding, extraction, and visualization, we developed tests to simulate the continuous data transmission from the pH sensor to the app. The app successfully decoded and displayed the pH values, temperature, salinity, time, location information and so on. Users can also decide whether to publicize these data by choosing the checkbox. Visual representations were clear and updated dynamically with each data receipt.

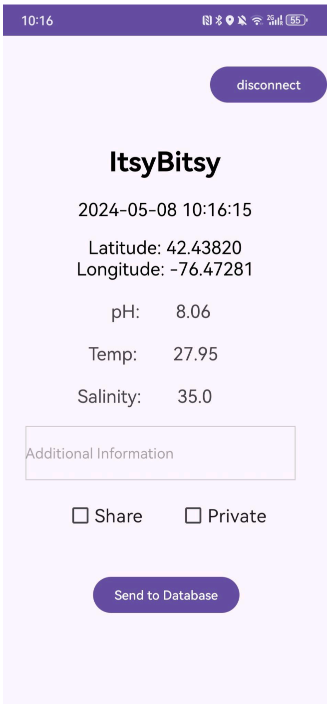

Figure 5.4 The pH records sent from ItsyBitsy combined with other information

Table 5.2 Testing Results of Android app

Functionality	Description	Expected Result	Actual Result	Status
User Login	Ensure users can login in Android app	Users can login in without errors.	User can login in.	Passed
BLE Data Flow Test	Ensure seamless data flow between the pH sensor and Android app.	Data transmitted correctly.	Data flow is smooth.	Passed
Location Acquisition	Ensure the latitude and longitude is correct.	The latitude and longitude of the current position is correct.	The location information is correct.	Passed
Uploading data records to Cloud	Test Android app to upload data records to Cloud.	Cloud gets data records and stores them correctly.	Data can be uploaded.	Passed
Direct Sensor control	Cooperate with Embedded Device to calculate pH value.	The Embedded Device follows the instructions from the Android app to correctly perform the next step.	Device executes incorrectly.	Not passed
Response Time	Measure the time taken to transfer data between the Android app, pH sensor, and cloud.	Timely response in BLE and HTTP.	Responds within acceptable range.	Passed

5.3 Website & Cloud

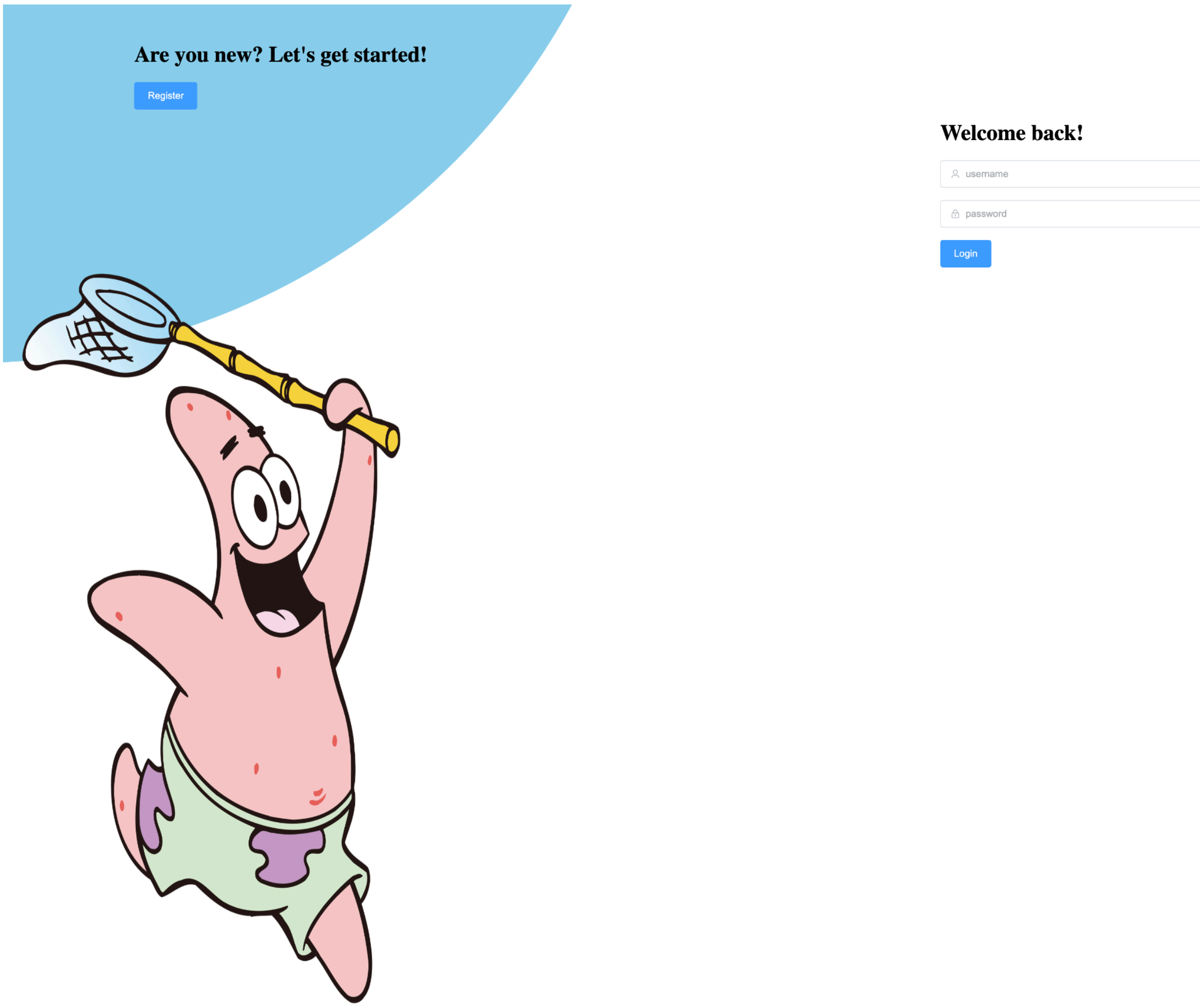

Figure 5.5 Login and register system

Our website provides the system features with login & register functions and pH data records management and public sharing data center.

Date	pH Value	Latitude & Longitude	Location	Contributor
2024-02-01	7	(41.551761 , -70.647946)	Woods Hole Oceanographic Institution 266 Woods Hole Road Woods Hole, MA 02543-1050 U.S.A.	tengyp
2024-02-04	6.9	(41.551761 , -70.647946)	Woods Hole Oceanographic Institution 266 Woods Hole Road Woods Hole, MA 02543-1050 U.S.A.	tengyp

Figure 5.6 Visualization through Google Maps

With the help of Google Maps, it’s easier for users to quickly understand the pH value of places in each record. And we support users to download records from the website for further analysis.

Table 5.3 Testing results of Websites & Cloud

Functionality	Description	Expected Result	Actual Result	Status
Registering	Functions for logging in and registering on our website.	Users can login and register on our website.	Data flow is smooth.	Passed

Data Visualization	Web page (frontend) displays pH records and corresponding locations on Google Maps.	Web pages show the information in the database and corresponding locations on Google Maps.	Data flow is smooth.	Passed
Uploading Data Records to Cloud	Upload data records to the cloud via our web page.	Cloud receives data records and stores them correctly.	Data flow is smooth.	Passed
Sharing Center	Users can decide whether to show their uploaded records to the public.	The shared center only shows public data records. Users can see and decide whether to share their uploaded data in their personal center.	Data flow is smooth.	Passed
Response Time	Time taken to respond to user requests.	Web pages load smoothly and the backend API responds in a timely manner.	Responds within an acceptable range.	Passed
Respond Time	Time to respond to the user's requests.	Web page skips smoothly and the backend API can respond in a timely manner.	Responds within acceptable range.	Passed

6. Individual Contribution

6.1 Yuzhong Zheng’s Contributions: Android App Development

- Problem to be Solved: Develop an Android application to interface with the pH sensor and cloud platform, allowing for real-time data acquisition, transmission, and control.
- Review of Possible Options for Solution: Evaluated different mobile development frameworks and Bluetooth communication protocols, deciding on native Android development with BLE for its compatibility and performance.
- Best Solution Formulation: Native Android development was chosen for its robust support of BLE and seamless integration with the sensor hardware. Retrofit was utilized for secure and efficient data transmission to the cloud.
- Documentation of Design Implementation: Documented the app development process, covering user login/register functions, Bluetooth device discovery, data reception, visualization, and control of sensor operations.
- Testing of Final Results: Performed comprehensive testing to ensure reliable Bluetooth connectivity, accurate data reception, and real-time updates. Ensured the app's performance remained stable across various devices and environments.

6.2 Yapeng Teng's Contributions: Website Development

- Problem to be Solved: Develop a web platform to manage pH data records, user authentication, and data visualization.
- Review of Possible Options for Solution: Considered various frameworks and cloud platforms, ultimately choosing Vue.js for the frontend and MongoDB Atlas for the cloud database due to their robustness and ease of use.
- Best Solution Formulation: Vue.js was selected for its reactive and component-driven architecture, providing a user-friendly interface for data management and visualization. MongoDB Atlas was chosen for its stability and security, particularly for handling large-scale data.
- Documentation of Design Implementation: Documented the development process, including user authentication system, data management modules, and public data visualization features.
- Testing of Final Results: Conducted extensive testing to ensure seamless data flow, user-friendly interfaces, and accurate data visualization. Verified that the website operates smoothly under various conditions and handles user requests efficiently.

6.3 Joint Contributions: Hardware Design and Testing, BLE implementation

- Problem to be Solved: Design and integrate hardware components for a portable pH sensor that communicates with an Android app and cloud platform.
- Review of Possible Options for Solution: Evaluated different sensors, microcontrollers, and communication protocols. Selected components for their accuracy, power efficiency, and compatibility with advice of Hunter and Jonathan.
- Best Solution Formulation: Choose the ItsyBitsy nRF52840 Express for its BLE capabilities, ADPD4101 for light intensity measurement, and LTC2984 for temperature sensing with advice of Hunter and Jonathan. We coded BLE connections, and BLE and communication protocol unit tests.
- Documentation of Design Implementation: Both Yapeng Teng and Yuzhong Zheng documented the hardware design, including PCB layout, sensor integration, and power management. Jonathan handled the physical assembly and testing coordination.
- Testing of Final Results: Yuzhong Zheng and Yapeng Teng collaborated on testing the entire system, ensuring data accuracy and reliability across the hardware-software interface. Jonathan provides necessary unit tests about hardware functions.

7. Future Work

A prototype enclosure and physical design will be created, ensuring it's functional and durable. A lab testing and verification of the measurement method will be conducted as well as the precision improvement.

8. Conclusion

The Open-source Handheld pH Sensor with Mobile App project successfully addresses the need for an affordable, portable, and user-friendly solution for measuring pH in seawater. By leveraging the spectrophotometric method, we developed a compact device that eliminates the bulkiness and high costs associated with traditional pH measurement technologies. The integration with an Android application and cloud storage further enhances the usability and accessibility of the device, enabling real-time data acquisition, transmission, and analysis.

Throughout the development process, we meticulously designed and implemented both the hardware and software components of the system. The hardware architecture, centered around the ItsyBitsy nRF52840 Express microcontroller, integrates sensors for light intensity and temperature measurements, ensuring accuracy and reliability. The modular design and careful arrangement of components resulted in a streamlined and efficient prototype.

The software architecture, encompassing the microcontroller firmware, Android application, and cloud platform, provides a seamless and intuitive user experience. The microcontroller firmware efficiently manages data acquisition, pH calculation, and Bluetooth communication, while the Android application offers a user-friendly interface for device control and data visualization. The cloud platform ensures secure data storage and facilitates remote access and analysis.

Testing and validation of the prototype confirmed the functionality and accuracy of each component, as well as the overall system's performance. The pH sensor demonstrated stable operation under varied conditions, with reliable data transmission and storage capabilities. The Android application and cloud platform effectively supported user interactions and data management.

Looking ahead, future work will focus on refining the physical design and creating a durable enclosure for the sensor, as well as conducting extensive lab testing to verify the measurement method and improve precision. Additionally, further enhancements to the Android application and cloud platform will aim to provide more advanced features and better user experience.

In conclusion, this project represents a significant contribution to the field of ocean carbonate chemistry research by making accurate pH measurement technology more accessible and user-friendly. The successful integration of hardware and software components paves the way for broader participation in ocean acidification studies, fostering new opportunities for understanding and addressing the impacts of ocean acidification on marine environments.

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References

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