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Microcontroller-Based Soil Fertility and PH Meter Design

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ABSTRACT

This research aims to design and build a soil pH and fertility measuring device based on a microcontroller. Fertile soil is crucial for plant growth, and one of its indicators is soil pH. This device is designed to help farmers understand the quality of their soil, especially in areas less accessible to modern technology. The methods used in this research include hardware and software development. A pH sensor, soil moisture sensor, and temperature sensor are used to measure relevant parameters. The data obtained is displayed via an OLED LCD and can be accessed wirelessly using the ESP32, the main processor. This research indicates that the developed device can provide accurate information regarding soil pH and fertility. Farmers can better understand their soil conditions by using this device, which in turn can improve agricultural yields. This research also aims to stimulate public interest in microcontroller technology and its applications in agriculture, as well as to contribute positively to increasing agricultural productivity in rural areas.

Keywords*: Soil pH; Humidity; Fertility;*

INTRODUCTION

Soil is a natural medium essential for farming activities. Plants will grow and develop well if the soil is fertile. Several factors influence soil fertility, one of which is nutrient content. The amount of nutrients in the soil is an indicator of soil fertility levels, which will affect the process of plant growth and development. Soil fertility levels are influenced by several factors, one of which is soil pH. Nutrients are more easily absorbed by plants at a pH of 6-7 because, at this pH level, most nutrients dissolve in water.(Vera et al., 2021)

In the current digital era, many people in remote rural areas still rely on the rainfall system to determine soil pH and acidity levels. Therefore, a soil pH and fertility meter is needed to assist the community in preparing the land before planting.

In the design of the soil pH meter, both software and hardware were developed. The sensors used in this design include a pH meter sensor, a soil moisture sensor, and a DS18B20 temperature sensor. For digital processing, an ESP32 microcontroller was used as the main processor. Data is displayed on an OLED LCD screen. Additionally, this device can be integrated with Internet of Things (IoT) technology to facilitate remote monitoring and digital data storage. This allows farmers to monitor soil conditions from anywhere at any time and store historical data for further analysis.(Gani et al., 2023)

Based on this background, this research will focus on the design and development of a microcontroller-based soil pH meter and fertility sensor. This study aims to develop a device that can provide accurate and real-time information about soil conditions while being easy to use and cost-effective.

METHOD

In this research, the system development method used is the R&D model. The R&D (Research and Development) method is a process used to create and develop new products or services, as well as to improve existing ones. This method consists of several main stages:

- Problem or Opportunity Identification: Determining the area or problem that requires research and development. This can involve market analysis, customer feedback, or technological trends.

- Preliminary Research: Researching to gain a deeper understanding of the problem or opportunity. This can involve literature reviews, surveys, or other relevant data collection.
- Concept Development: Developing ideas or concepts that could serve as solutions to the identified problem or opportunity. This often involves brainstorming and the creation of initial prototypes.
- Testing and Validation: Testing the concepts or prototypes to ensure they are effective and meet the identified needs. This can involve laboratory trials, user testing, or simulations.
- Product Development: Building the actual product or service based on the results of testing and validation. This can involve detailed design, manufacturing, and preparation for launch.
- Launch and Commercialization: Introducing the product or service to the market. This involves marketing strategies, distribution, and sales.
- Evaluation and Improvement: Collecting feedback from the market and making continuous improvements to the product or service. This ensures that the product or service remains relevant and meets customer needs.

RESULT AND DISCUSSION

- Needs Analysis

At this stage, all system requirements for the pH meter and soil fertility sensor are identified and documented. These requirements include the core functions that the pH meter and soil fertility sensor must have.

- Hardware Requirements: The hardware needs for the pH meter and soil fertility sensor include several key components necessary to ensure the functionality and performance of the system.
  1. The ESP32 microcontroller is used as the brain of the system, controlling and processing all operations and data communication between inputs and outputs.
  2. A pH sensor is required to detect the acidity levels in the soil, which will serve as a reference for achieving optimal soil conditions.
  3. A soil moisture sensor is used to detect the moisture levels in the soil, which will serve as a supporting parameter for soil fertility.
  4. The DS18B20 temperature sensor is used to detect the temperature of the soil, which will serve as a supporting parameter for soil fertility.
  5. An LCD OLED 128x64 is used to display the results from the sensors that detect soil conditions. (Kusumah & Pradana, 2019)

  All hardware components must be carefully selected to ensure compatibility and effectiveness in supporting the functions of the pH meter and soil fertility sensor.
- The software requirements for the pH meter and soil fertility sensor include several key components. First, the microcontroller software (ARDUINO IDE), which uses C++ programming language, is necessary to upload the program to the microcontroller for managing the input and output from the sensors and LCD.
  1. Board Manager

     Board Manager It is needed to initialize the microcontroller used for the pH meter and soil fertility sensor, which is the ESP32.
  2. Libraries Manager

     Libraris Manager It is necessary to initialize the sensors used in designing the pH meter and soil fertility sensor, including the pH sensor, soil moisture sensor, temperature sensor, and LCD OLED.

All software components must be carefully selected to ensure proper initialization and connectivity in programming the hardware, ensuring compatibility and effectiveness in supporting the functions of the pH meter and soil fertility sensor.

- Design

After the needs have been analyzed and defined, the system design phase is carried out. Based on the collected requirements, the development team designs the system architecture, including hardware and software design..

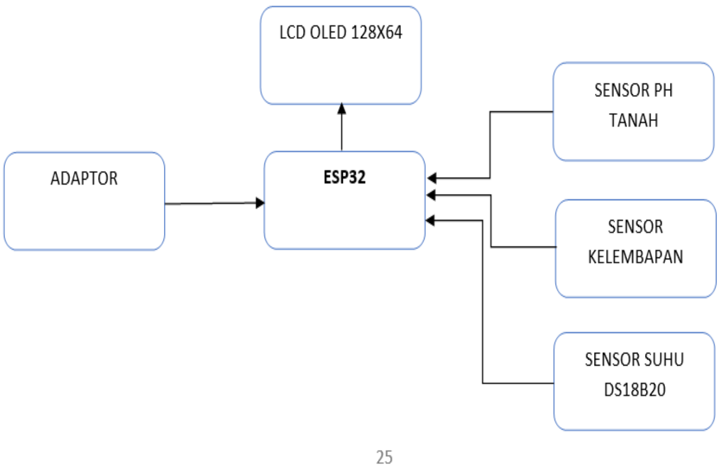
- Device Design

  The design of the microcontroller-based soil pH and fertility measurement system involves several key steps to ensure functionality and effective integration between hardware and software

components. The goal is to design and build a measurement system that can automatically measure and monitor soil pH and fertility.
This product is developed using the ESP32, soil pH sensor, soil moisture sensor, and temperature sensor (DS18B20). The choice of the ESP32 microcontroller for this project is based on its key feature, which is the built-in WiFi module. This allows the system to connect directly to the internet without needing additional devices, facilitating the transmission of measurement data to a server or website. Despite its small size, the ESP32 provides a sufficient number of GPIO (General Purpose Input/Output) pins to connect the various sensors required for the project. The soil pH sensor will be used to measure soil parameters, while the moisture and temperature sensors will ensure optimal measurement conditions.(Imran & Rasul, 2020)
The primary goal of designing the microcontroller-based pH and soil fertility measurement device is to enhance the efficiency and effectiveness of soil management and condition monitoring.
These objectives are designed to provide innovative technological solutions for soil management, assisting farmers and land managers in improving soil quality and agricultural yields. The goals not only enhance the accuracy and reliability of soil management but also make the monitoring process easier and more interactive, encouraging more people to adopt technology in their land management practices.

- Block Diagram

Block Diagram is a graphical representation of a system that shows the main components and the flow of information or signals between these components. In the final project (TA) focusing on the design and development of a pH meter and soil fertility sensor, the block diagram can help illustrate how each part of the system functions and interacts with one another. Here is an example block diagram for a soil pH measurement system that uses a pH sensor, microcontroller, and user interface.



Figue 1. Diagram Block system

Based on the diagram above, there are three blocks: the input block, which includes the soil pH sensor, soil moisture sensor, and DS18B20 temperature sensor; the processing block, occupied by the ESP32 as the central controller for data input and output; and the output block, occupied by the LCD OLED 128x64 for displaying the sensor data results.

- **Soil pH Sensor:** In the design and development project of the pH meter and soil fertility sensor, it is used to read the pH content in the soil, with the data being sent to the ESP32.
- **Soil Moisture Sensor:** Used to detect the moisture level in the soil, providing the percentage of soil moisture content.
- **DS18B20 Temperature Sensor:** Used to detect the temperature of the soil, with the input data being sent to the ESP32.

  LCD OLED: In this project, the LCD is used to display information related to the results from the three sensors and the calibration from the microcontroller. By combining all these components, the project "Design and Development of a pH Meter and Soil Fertility Sensor" can offer an interactive and informative experience for farmers in determining soil pH levels and provide ease in soil management and monitoring.

- Software Design

Software Design for the project "Design and Development of a pH Meter and Soil Fertility Sensor" involves several key components: microcontroller programming, sensor initialization, board manager configuration, and library manager setup for the connected components.
The steps for configuring the Arduino IDE for Arduino are as follows:

1. Operating the Arduino IDE
   a) Download the IDE application from Google or the official Arduino website.

   b) Match the IDE application version with the version of Windows used on the laptop/PC.

Figure 2: download IDE

To use the IDE application, first open the IDE, then prepare the essential components for the project, such as libraries, microcontroller board, and port settings.
Then, create a new project. In this research, the ESP32 is used, as the project involves several analog pins and WiFi connectivity.

2. Downloading the ESP32 Board on the Arduino IDE

The ESP32 can be programmed using the Arduino IDE software. However, the standard Arduino IDE software does not include the ESP32 board library. Therefore, before installing the ESP32 board, uploading the program will often result in errors because the detected board in the software does not match the board selected. Here are the steps to install the ESP32 board :

a. Installing the ESP32 Library Online

First, open the Arduino IDE and go to the **File** menu – select **Preferences**. Then, in the **Additional Boards Manager URLs** field, enter the URL provided below in the designated column.

https://dl.espressif.com/dl/package_esp32_index.json

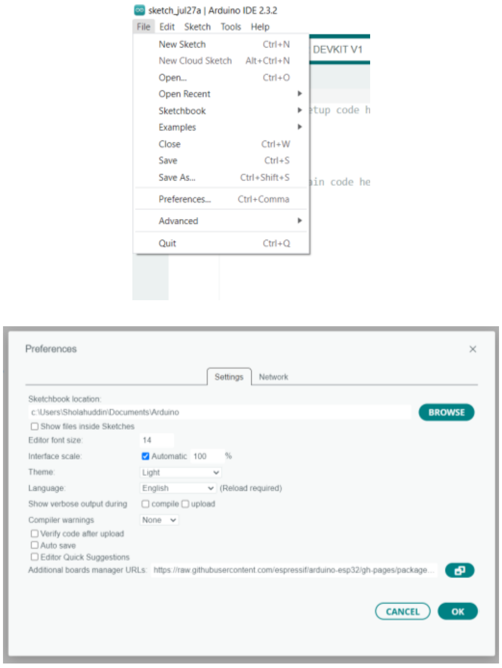


Figure 3: preference

After adding the URL to the **Additional Boards Manager URLs** field, go to the **Board Manager** (Tools – Boards – Boards Manager). Then, search for **ESP32** in the search bar for convenience. Click **Install**, and this is the image of the installation process.

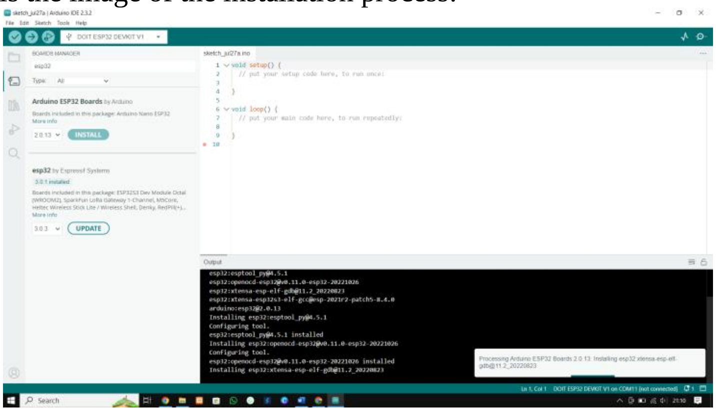


Figure 4. board manager

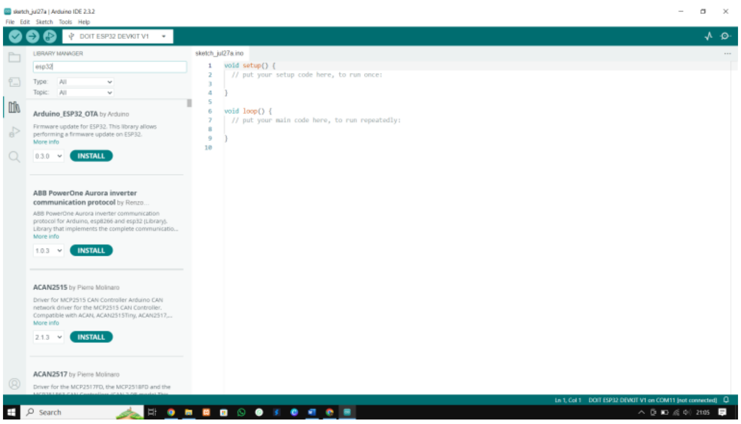


Figure 5. library manager

Once the installation is complete, reopen the Arduino IDE, go to **Tools – Boards**, and then select the appropriate ESP32 board type that you have.

b. Installing the ESP32 Library Offline

First, download the NodeMCU ESP32 board library from the provided link. After downloading, extract the ZIP file. Then, copy all the files from the extracted folder. Open the Arduino IDE, go to **File** – **Preferences** (or press **Ctrl + Comma**), and click on the path **C:\Users\sholahuddin\Documents\Arduino**. Delete all files in the Arduino folder (**C:\Users\sholahuddin\Documents\Arduino**), then paste the copied files from the ZIP into the Arduino folder. After completing the file copy process, close the Arduino folder and reopen the Arduino IDE. Go to **Tools** – **Boards**, and select the appropriate ESP32 board type that you have.

c. Installing Drivers for ESP32 (CP210x)

First, download the NodeMCU ESP32 board library from the link. Choose the CP210x driver and download it. After downloading, extract the ZIP file containing the driver. Open the extracted folder and run the CP210xVCPInstaller_x64.exe file. Follow the installation instructions until completion. Connect the ESP32 board to the computer using a USB cable. Windows will detect the new device and automatically use the installed driver.

Figure 7. Installing Drivers

Verify Installation: Open **Device Manager**, look at the **Ports (COM & LPT)** section, and find **Silicon Labs CP210x USB to UART Bridge (COMx)**, where x represents the port number connected to the ESP32. In the example, COM11 is shown.

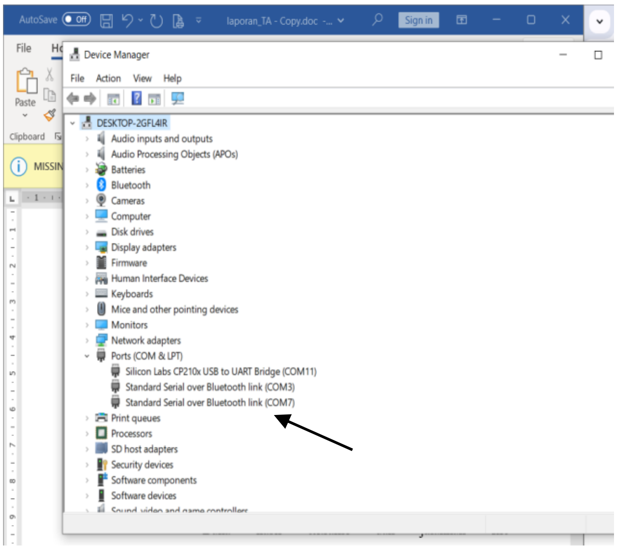


Figure 8. Fiture of verify installation

Once the driver is detected, prepare the program according to the designed project and it should be ready for upload.

- Hardware Circuit

a. Circuit Design

In this circuit design, the ESP32 microcontroller is used as the main controller, which will initialize and process data from several sensors: the soil pH sensor, soil moisture sensor, and temperature sensor. The ESP32 receives input data from these sensors, processes and calibrates it to determine soil fertility. The calibrated sensor data is then sent to the OLED LCD, which serves as the output display for the system.

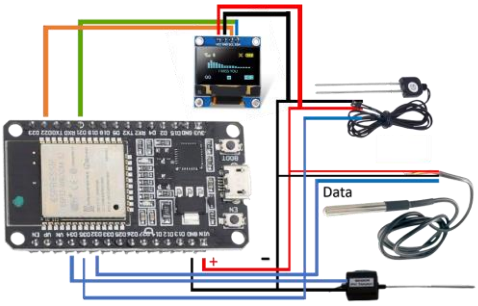


Figure 9. Device Schematic

Below are the pins that are connected:

- **pH Sensor Pins**
  Data = D34
  GND = GND / G
  VCC = 5 V
- **Soil Moisture Sensor Pins**
  Data = D35
  VCC = 5 V
  GND = GND / G
- **Temperature Sensor Pins**
  Data = D32
  VCC = 5 V
  GND = GND / G
- **OLED LCD Pins**
  VCC = 5 V
  GND = GND / G
  SCL = D21
  SDA = D22

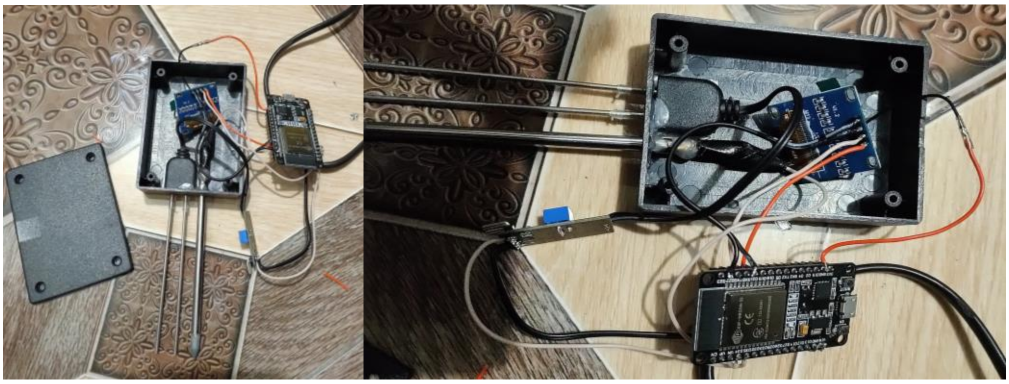


Figure 10. Component of circuit Design

Discussion

- Hardware Output Display

This image shows the display of the designed device. The device will be placed on a soil sample, where it will measure the pH, moisture, and temperature levels of the soil.

Here is the device display. It will show numbers indicating the pH level, moisture content, and temperature of the soil on the OLED LCD. The following is how the display looks when the device is placed on a soil sample,

Figure 11: Fiture of hardware

- Testing

The testing phase is conducted to ensure that all components function correctly and meet the specified requirements. The test results will be displayed in the table below. Comparative testing of the sensors used in the project is performed to evaluate the effectiveness of the soil moisture and pH sensors against a benchmark sensor, which is a conventional, commercially available, and standardized pH sensor (3-way type). The test data is provided in the table below.

Tabel 1. result of the testing phase

PH METER Value	SENSOR PH	Range	ERROR
6.77	6.9	0.13	0.018
6.75	6.9	0.16	0.021
6.74	6.8	0.06	0.008
6.70	6.8	0.1	0.014
6.68	6.8	0.12	0.017
6.69	6.8	0.11	0.016

CONCLUSIONS

The conclusion of this research is that the soil pH meter designed using the pH sensor and ESP32 microcontroller has been successfully implemented, providing adequate accuracy for agricultural and research needs. Its compact and simple design makes the device highly portable and easy to use in the field, with an intuitive user interface requiring no special training. Additionally, the device features real-time data storage through Bluetooth and WiFi connectivity to web applications or IoT monitoring, enabling more effective and efficient data analysis. The cost-effective production using affordable components makes the device accessible to farmers and researchers with limited budgets. Overall, the device meets the criteria of being accurate, portable, easy to use, and economical, thus having significant potential to enhance the efficiency and effectiveness of soil management in agricultural and research practices.

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