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Advanced Soil Testing Probe: Design, Development & System Engineering

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Abstract

Soil testing plays a vital role in achieving optimal plant growth, maintaining soil health, protecting the environment, and ensuring cost-effective and sustainable agricultural practices. However, the traditional soil testing methods face several problems since it involves labour-intensive, time consuming, cost associated with transportation and handling. Further the soil properties can vary widely within a short distance so it becomes difficult to have representative samples that accurately reflect the entire area with distance. Hence, there was a need for design and development of advanced soil testing probes that can be used at the field locations for rapid testing and having accuracy, efficiency and cost effectiveness. However not much work is reported on advancement in soil testing probes. The present paper deals with the design and development of an Advanced Soil Testing Probe for in field monitoring of the critical soil parameters such as Nitrogen (N), Phosphorus (P), Potassium (K), pH, moisture, and temperature. The system is developed with STM32 Microcontroller and ESP32 WiFi interface and the MathWorks Thing Speak Internet of Things (IoT) cloud platform to provide real-time data collection, transmission, and analysis. The system is equipped with calibrated sensors, collects data on soil nutrient levels and environmental conditions, transmitting this information via Wi-Fi to the Thing Speak cloud for continuous monitoring. Users can access and visualize the data through Thing Speak's dashboards, facilitating an intuitive understanding of soil health. The field-testing results indicates that stable nitrogen, phosphorus, and potassium levels, consistent pH, and moisture content, with expected temperature variations, highlighting the reliability and accuracy of the system. This real-time data enables optimized fertilization, irrigation, and crop management practices, contributing to improved soil health and agricultural productivity. This Advanced Soil Testing Probe represents a significant step towards precision agriculture, offering farmers and agronomists a powerful tool for enhancing crop yield and sustainability. Details are presented.

Keywords: Soil analysis, Internet of Things (IoT), Precision Agriculture, Thing Speak Cloud Platform.

Introduction

Soil testing is a crucial practice in agricultural, environmental management, and construction industries [1]. It provides essential information about soil properties that is useful in Optimizing

Crop Production by managing the nutrients and pH of the soil [2], Efficient Use of resources such as water and fertilizers [3], Protection of Environment by detection of contaminant and monitoring erosion and degradation of soil [4], understanding the soil structure and composition [5], land use planning [6], to implement precision agriculture [7], and lastly to comply with the environmental regulations[8]. Traditional soil testing methods, despite their widespread use and foundational role in soil science, face several notable problems such as Collecting and preparing soil samples for laboratory analysis is labour-intensive and time-consuming [9], Laboratory analyses can take days or even weeks, delaying the implementation of management decisions[10], Testing multiple samples for a comprehensive analysis can be expensive [11], Costs associated with the transportation and handling of soil samples add to the overall expense [12], further Soil properties can vary widely within a short distance making it challenging to obtain representative samples that accurately reflect the entire area[13], Traditional methods often involve taking a limited number of samples which may not capture the full variability of the soil properties in a given field or site [14] and the use of chemical reagents in testing can generate hazardous waste posing environmental risks if not properly managed [15]. Therefore, there was a need for design and development of portable soil testing probes that can be used at the field locations, can do rapid testing, can do measurements automatically or semi-automatically, having accuracy, efficiency and cost effectiveness. Lambe et al has shown simple mechanical design-based probe for Soil Sampling [16]. Wu et al made effective use and integration of capacitive sensors for monitoring the moisture in the soil [17]. Reyes et al discussed the use soil spectroscopy for rapid, in-field soil testing [18]. Hautefeuille et al. discussed the use of MEMS based soil sensors for Precision Agriculture [19]. Valente et al has shown the design and use of micro-sensor for accurate soil pH measurement [20]. 21.Parameswari et al has reviewed the literature on development and use of nanosensors for soil health monitoring. Tisdale et al has reported on problems and opportunities of soil testing probes for environmental monitoring and remediation efforts [22]. Venkadesh et al has developed portable kits having Integration of multiple sensors for in field soil analysis [23]. However not much work is reported on advancement in soil testing probes and the present paper deals with the design and development of an Advanced Soil Testing Probe capable of carrying out in field measurements, having integration of various sensors as to acquire number of parameters, having precise sampling mechanism, real time data saving on the cloud, user friendly design, durable construction. Further details are presented in the subsequent section.

Experimental

A) Block Level Diagram and Design the Advanced Soil Testing Probe System

Designing an advanced soil testing probe process involved integrating multiple sensors, signal conditioning components, a microcontroller, and communication interfaces into a compact, efficient, and user-friendly device. The Figure 1 shows the block level design of the advanced soil testing probe.
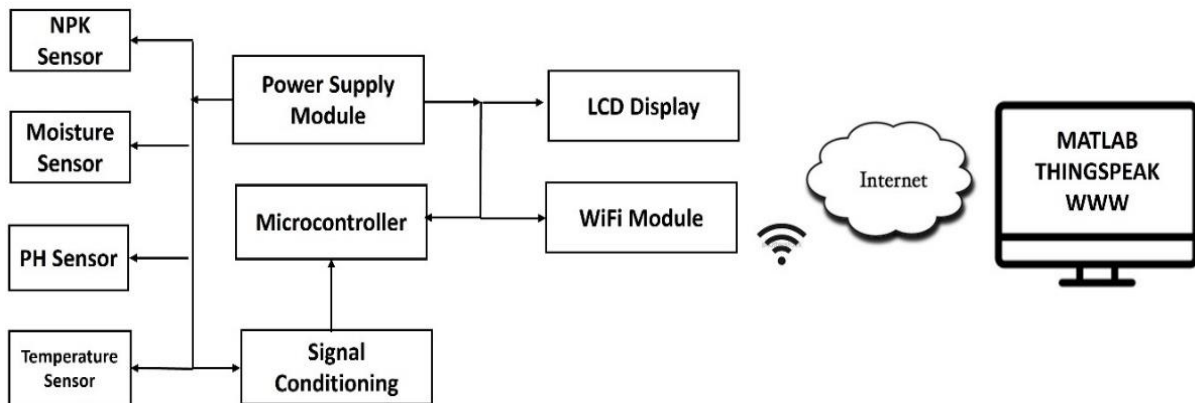

Figure 1: Block Level Diagram and Design of the Advanced Soil Testing Probe

The block level design consists of use of various sensors such as NPK sensor for monitoring the compositional value of Nitrogen, Phosphorus and Potassium, moisture sensor, pH sensor and temperature sensor to monitor the moisture, pH and temperature of the soil under consideration. The output of these sensors is subjected to signal conditioning circuit before giving it to the microcontroller (MCU) so as to ensure the accuracy and reliability of sensor readings and suit the requirements of the MCU. Post this the MCU processes the acquired data from the sensors is then the obtained information is displayed on the Liquid Crystal Display (LCD) and sent to WiFi module to transfer the data with the help of Internet to the cloud platform.

B) Design Considerations and Selection of Hardware Components and Software Tools

The below are the design considerations followed for the selection of various Hardware Components for the Advanced Soil Testing for designing such a probe.

i) Selection of Sensors and Signal Conditioning Circuit: The core of the soil testing probe is the sensors used for measuring the various parameters such as Nitrogen(N), Phosphorus (P), Potassium (K), moisture content, pH, and temperature of the Soil.

(a) NPK Sensor: The JXBS-3001 of Weihai JXCT Electronic Technology Co. Ltd company Soil NPK Sensor is selected to measure the Nitrogen (N), Phosphorus (P), and Potassium (K)

content in the soil because of its range, accuracy, resolution and response time. Further, when sensor is interfaced with microcontrollers the MAX485 module it allows for reliable and robust communication over longer distances using the RS485 protocol. Therefore, we need to use MAX485 to RS485 converter module. The cost of the sensor is low as compared with the similar range of sensors and warranty terms of supplier were better as compared to other.

(b) Moisture Sensor: An Arduino compatible LM393 based capacitive soil moisture sensor module is selected to measure the moisture content in the soil. The module has LM393 interface which provides analogue voltage corresponding the moisture content present in the soil. The module is easily available and low in cost and do not require any specific signal conditioning.

(c) pH Sensor: An Industrial Grade Analog pH Sensor module EC-4743 from Constflick Technologies Limited is used. The selected module had direct analogue output it has integrated signal conditioning circuit working at 5 V and having response time less than 2 min.

(d) Temperature Sensor: The PT100 temperature sensor is selected, it is a type of Resistance Temperature Detector (RTD) that is widely used for measuring temperature in various applications and well known for its known for their accuracy, stability, and wide temperature range and do not require any specific signal conditioning circuit.

ii) Selection of LCD Display: The 3.5" ILI9486 TFT Touch Shield LCD Module with a resolution of 480x320 is Selected looking at its popularity and usefulness in such projects. Further the display driver supports SPI communication interface which significantly reduces the interconnections between MCU and display driver.

iii) Selection of WiFi Module: The ESP32 is a powerful microcontroller with integrated Wi-Fi and Bluetooth capabilities, making it ideal for a wide range of IoT projects. In the current project the ESP32 is used to send the data onto the cloud platform.

iv) Selection of Microcontroller: The STM32F103C8T6 development board is selected because of its ARM Cortex-M3 core, performance, number of GPIO, USARTS, Low cost and power consumption, in addition to this the documentation, libraries and community support of the same is good.

v) Selection of the IDE for Programming of Microcontroller: Keil μVision, is a comprehensive Integrated Development Environment (IDE) for ARM microcontroller development. It is widely used in the embedded systems industry for programming, debugging, and simulating ARM-based microcontrollers.

vi) Selection of the Cloud Platform: Choosing a cloud platform for the project is a crucial decision, we have chosen ThingSpeak Cloud Platform because of the ease of implementation, real time data collection and visualization, support for data analysis and processing, security and cost effective.

vii) Selection of the Power Supply Module: A 12V DC adaptor followed by a DC 12V to multi output 12V, 5V, and 3.3 V power supply module is used to best fit the requirement.

C) System Integration of Advanced Soil Testing Probe
i) Integrated Schematic of the Advanced Soil Testing Probe Soil

The advanced soil testing probe system is designed to measure various soil parameters including NPK (Nitrogen, Phosphorus, Potassium) levels, temperature, moisture, and pH. The data collected by the probe is transmitted to a cloud platform for real-time monitoring and analysis. With the selected components as specified in Section B of the Experimental. The Integrated schematic for the system is prepared using Easy EDA tools as shown in the Figure 2.
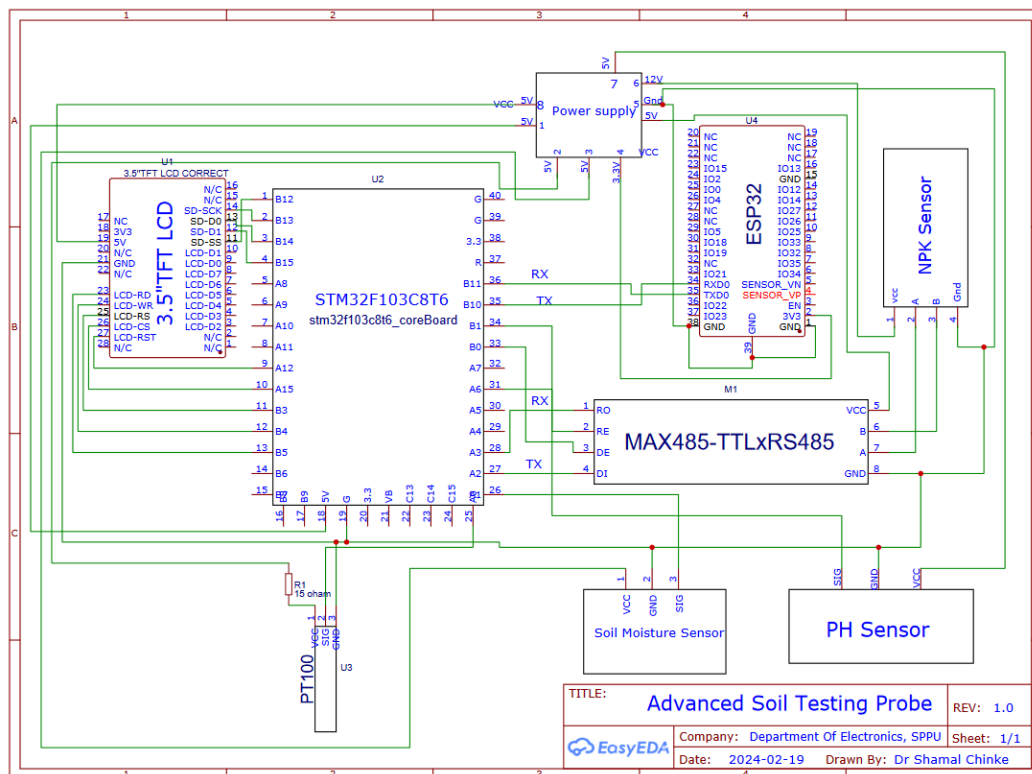

Figure 2: The typical schematic for the Advanced Soil Testing Probe

As shown in the schematic the NPK sensor is provided DC 12 V for biasing, followed by the output of the NPK sensor in the form of A and B pins of the MAX485 is connected to the A and B pins of the MAX485 to RS485 converter. The DI and RO pins at the output of the RS485

converter are connected to Tx and Rx pins of the STM32F103C8(STM MCU) development board to receive the NPK data from sensor and RE and DE pins are connected to GPIO B1 and B0 respectively. The outputs of temperature sensor, moisture sensor, and pH sensor are connected to the analogue input pins A0, A1 and A6 of the STM MCU respectively. The data received from the all the sensors is then processed and displayed on the 3.5-inch TFT LCD. The TFT LCD is interfaced with the STM MCU with Serial Peripheral Interface (SPI) protocol. The said processed data is also sent to ESP32 via pin B11 and B10 to the R_X and Tx pins of the ESP32. Post this the data is sent to MathWorks Things peak Cloud platform.

ii) Algorithm/ Software Development: Creating a flowchart for programming a advanced soil testing probe involves outlining the key steps required for initializing, collecting data from sensors, processing the data, and displaying the results and sending the results to the cloud platform. The typical flow chart showing the algorithm for the implementation of the Advanced Soil Testing Probe is as shown in Figure 3.
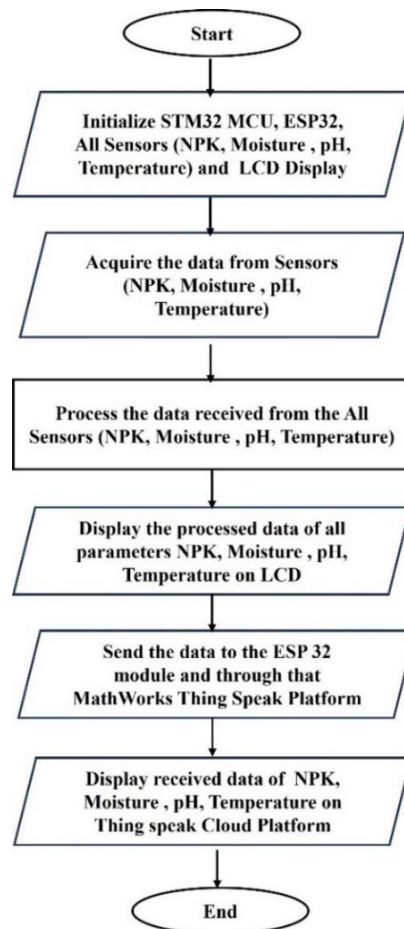

Figure 3: typical flow chart showing the steps for the implementation of the Advanced Soil Testing Probe

This flowchart provides a structured approach to programming the soil testing probe, ensuring each step is executed in sequence for accurate data collection and display.

iii) MathWorks Thing Speak Cloud Platform Development

We have used MathWorks ThingSpeak platform to monitor and analyse data from sensors. For this we have first setup a Thing Speak account, created channels, and did the necessary programming so that the ESP32 device to send data to ThingSpeak platform and this helped in monitoring soil parameters in real-time, analyze the data, and set up alerts for any conditions that require attention.

Results and Discussion

i) Field Testing Results: The developed Advanced Soil Testing System has been tested in the laboratory as well as at filed locations. After setting up the Thing Speak-based Advanced soil monitoring system, various parameters such as Nitrogen (N), Phosphorus (P), Potassium (K), pH, Moisture, and Temperature were successfully monitored. Below are the results tabulate in the Table 1.

Time	Nitrogen (ppm)	Phosphorus (ppm)	Potassium (ppm)	pH	Moisture (%)	Temperature (°C)
11.40	32	38	47	6.5	21	24
11.42	34	37	44	6.5	21	24
11.44	32	37	46	6.5	21	24
11.46	33	39	47	6.5	21	24
11.48	33	37	46	6.5	22	24
11.50	32	38	47	6.5	22	24
11.52	34	36	46	6.5	22	24
11.54	33	37	46	6.5	21	24
11.56	32	38	47	6.5	21	24
11.58	33	37	47	6.5	22	24

Table 1: Various Parameter values recorded on the ThingSpeak Platform

The Figure 4 (a) shows the typical photograph showing the testing of the developed Soil Testing Probe System and the from Figure 4 (b) to (h) shows the Graphical User Interface and Recorded data for various soil parameters using MathWorks Thing Speak platform.
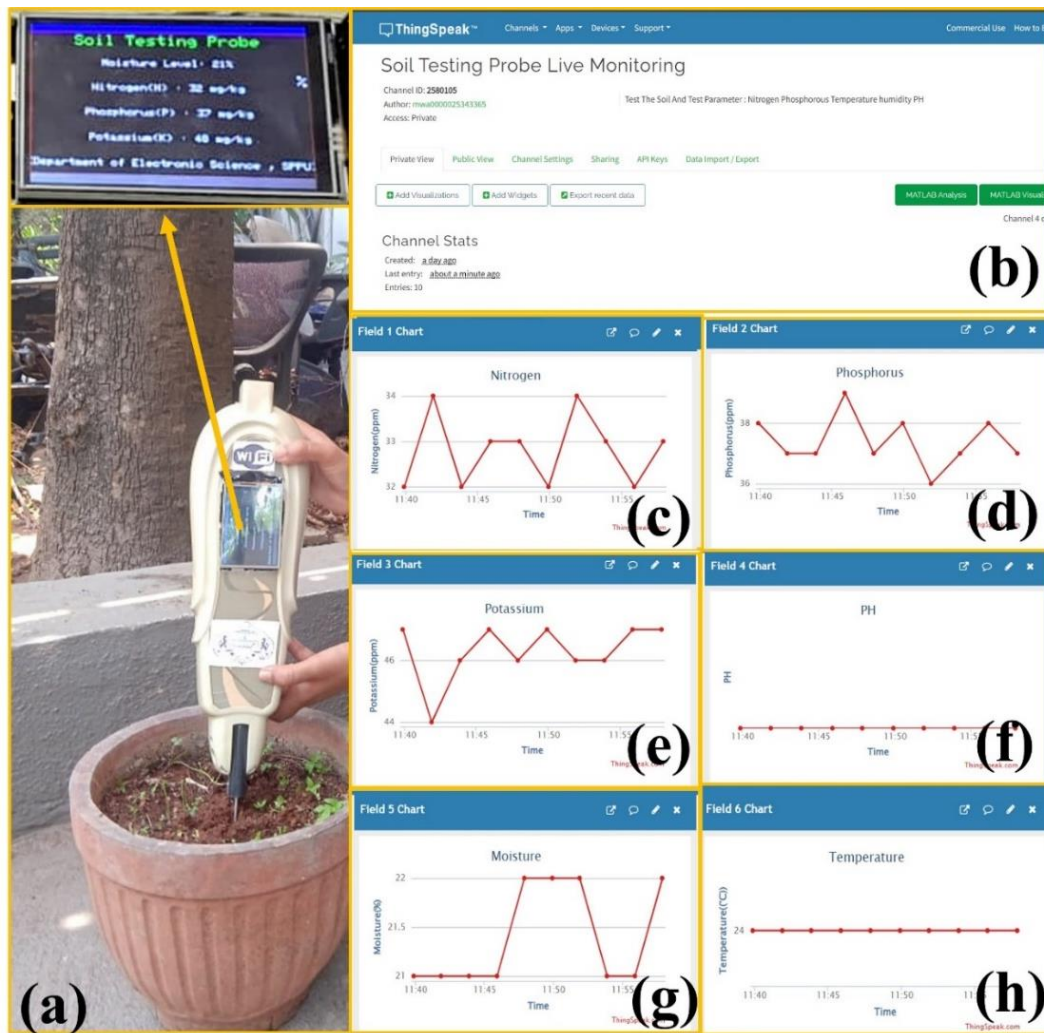
Figure 4: (a) Typical Photograph showing the testing of the developed Soil Testing Probe System, (b) Thing Speak Platform Webpage, Recorded data in ppm for (c) Nitrogen, (d) Phosphorus, (e) Potassium, (f) Recorded data for pH, (g) Recorded data for soil moisture in % , (h) Recorded data for temperature in ^{0}C.

ii) Discussion on Field Testing Results

(a) The trends and observations made from the results of field testing

The nitrogen levels varied slightly but generally remained within a narrow range. This suggests stable nitrogen content in the soil during the monitoring period. Phosphorus levels also showed minor fluctuations, indicating consistent nutrient availability. Potassium levels followed a similar pattern to nitrogen and phosphorus, with small variations suggesting balanced soil fertility. The pH levels stayed relatively stable, indicating a neutral to slightly acidic soil, which is ideal for most crops. Moisture levels showed some variation, likely due to irrigation or rainfall. Consistent monitoring can

help in optimizing water usage. The temperature readings fluctuated with the ambient conditions, providing insights into the diurnal temperature variations affecting soil health.

(b) Impact on Soil Health and Crop Productivity

The obtained data has provided a valuable insight for optimizing fertilizer application. For instance, stable nitrogen levels indicate that current fertilization practices are adequate. Maintaining a stable pH within the ideal range ensures nutrient availability and absorption by plants. Monitoring moisture levels helps in efficient water management, reducing wastage and ensuring adequate soil moisture for crops. Understanding temperature variations helps in planning planting schedules and protecting crops from temperature extremes.

(c) System Performance Matrices

Reliability: The developed soil testing probe system proved reliable in collecting and transmitting data in Real time.

Accuracy: Sensor calibration ensured that the data collected was accurate and reflective of actual soil conditions.

User Interface: ThingSpeak's visualization tools provided an intuitive way to interpret the data, making it accessible even to users with limited technical expertise.

Response time: The developed system logs the data on the Thing Speak Server after every minute.

Cost effective: Compared the cost of the other probes and methods for soil analysis the Advanced Soil testing probe is proven to be best candidate for in field soil analysis.

(d) Future Improvements

When deployed in the field, feedback from the stake holders have been taken, with the suggestion of them we would like to add few more sensors to get information on soil conductivity and organic matter content so as to get more comprehensive understanding of soil health. Setting up automated alerts for critical thresholds (e.g., low moisture levels, high pH) to enable proactive soil management.

Conclusion

The developed Advanced Soil Testing Probe system enabled effective monitoring of critical soil health indicators, facilitating informed decision-making for soil management and crop productivity enhancement. The use of ThingSpeak for monitoring soil parameters provided a robust platform for real-time data collection, transmission, and visualization. The developed system has been calibrated and tested for its reliability, accuracy, and response time. Further the feedback of the trial users the developed system is found to be user friendly and cost effective. The system is capable of integrating with automated systems to further optimization of soil health and agricultural outputs. By and large the developed Advanced Soil Testing Probe system is not only useful in the field of Agriculture but also in environment management, construction, education and research fields.

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Conflict of Interest

There is no conflict of Interest.