Portable Soil Nutrient, pH, and Moisture Monitoring Device with the Application of Arduino Probe Sensors

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APPROVAL SHEET

This is to certify that this study titled **Portable Soil Nutrient, pH, and Moisture Monitoring Device with the Application of Arduino Probe Sensors** prepared and submitted by **Luke Andrei Mungcal Besas, Sean Lugene Rosete Gener, Takayuki Velasco Kawamura, Jun Perez Luzano, And Kassandra Andrea Perez Tabian** in partial fulfillment of the requirements of Inquiries, Investigations, and Immersion (III) is hereby accepted.

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The study is hereby officially accepted and approved as a partial fulfillment of the requirements in Capstone.

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ABSTRACT

Soil is an important, yet often ignored component of our natural systems. Plants heavily rely on soil as a source of essential nutrients such as Nitrogen, Phosphorus, and Potassium that may affect their health and growth. The manual techniques to monitor soil health discourage people to carry these out as they are challenging and prone to human error. In accordance with this, the researchers developed a Portable Soil Monitoring Device by utilizing Arduino-compatible Probe Sensors. The device is designed to gather data about the levels of pH, Nitrogen, Phosphorus, Potassium, and Moisture with utmost accuracy while having the ability to be carried anywhere. The said device was compared to its manual counterpart to evaluate the difference between the two techniques in terms of accuracy, time efficiency, and overall difference. After experimentation, the researchers utilized the Chi-square Goodness of Fit Test to evaluate the functionality test of the device, the Paired T-test for the accuracy and time-efficiency test of the manual and automated testing, and the Bland-Altman plot to further distinguish the similarities of the two measuring techniques. The results of the study are as follows: The device exhibited expected functionality, with data from both manual and automated testing being consistent and identical across all properties tested. The automated testing also provided faster readings while maintaining accuracy. With these results, the device proved to be a reliable and efficient tool for soil analysis.

Key Words: *Monitor, Arduino Probe Sensors, pH, NPK, Moisture, Soil*

CHAPTER 1

INTRODUCTION

Background of the Study

A vital yet frequently overlooked component of the natural system is soil. It is a complex mixture comprising various elements such as minerals, organic matter, water, and air. Each of these components plays a crucial role in plant growth. Plants rely on the soil as a source of essential nutrients such as Nitrogen (N), Phosphorus (P), and Potassium (K), which are essential for their growth and development (Harvesto Group, 2022). Among other things, soil supports food provision and water purification, which helps to meet fundamental human needs (Singh, 2022). The problem in food supply increases due to the increase in population and soil can be of help since it is imperative for crop production that could supply food for all. According to the United Nations (2019), the expected global population in the year 2050 is 9.7 Billion. Agriculture needs higher yields to produce food products that can keep up with the demand for food driven by our growing population (Silver et al., 2021).

Agriculture and environmental management are anticipated to form the core of sustainable food systems and worldwide developmental goals (World Bank, 2024). These comprise an activity called soil health monitoring. Singh (2022) states that monitoring soil health is essential for maintaining food security and reducing carbon emissions because of the interaction between soil and climate change. Under the influence of both agricultural and non-agricultural human activities, surveillance enables tracking of changes in the features and properties of soil over time. It also aids in assessing the state of soil functions and the environmental hazards related to industrial methods. Here, the identification of soil status is provided as a means of noticing anomalies or improving farming techniques. However, soil quality assessment has several areas for improvement. According to Wang et al. (2023), assessing soil conditions can be time-consuming and costly due to its complexity and diversity. The traditional methods of health monitoring in crops are tedious, labor-intensive, and prone to human error so it is not ideal (OnSpace, 2023). Due to the limitations, modern technology and automation in agriculture are fast becoming increasingly important. Embracing these evolutions, this study will be innovating a portable soil monitoring device aimed to supply factual, accurate, and precise information about soil characteristics that utilize improvements made by sensor technology.

According to Tolentino et al. (2020), the agricultural industry is gradually becoming more receptive to numerous technological changes. Soil sensors enable real-time tracking of soil nutrients with fair accuracy, making them a very useful resource for farmers (Xie et al., 2024). However, static situations may be challenging to assess due to soil variability, which is influenced by several factors.

This research aimed to develop a portable device that measures NPK levels, pH, and moisture levels to overcome the aforementioned limitations and challenges. It will empower farmers to optimize their agricultural activities so that they enhance crop production. On the other hand, it will help in sustainable agriculture by diminishing excess utilization of water, fertilizers, and pesticides. The portable soil monitoring device shall provide information in real-time, hence enabling intervention at the right moment to have healthier crops as well as improve overall agricultural productivity (Choubey et al., 2024).

Statement of the Problem

With the application of this study, productivity and crop quality will be further enhanced by offering timely and accurate information regarding soil conditions. The study explored the functionality, accuracy, and efficiency of the soil monitoring device by answering the following questions:

1. Is there a significant association in the observed and expected functionality of the device in terms of:
    A. Liquid Crystal Display (LCD) Screen
    B. NPK, pH, and Moisture Sensor Probes
    C. Soil Monitoring Device Circuit
2. Is there a significant difference between the observed and expected accuracy of the soil monitoring device in terms of:
    A. pH Level
    B. Nitrogen Content
    C. Phosphorus Content
    D. Potassium Content
    E. Moisture Level
3. Is there a significant difference in the time it takes for the soil monitoring device to display expected soil level results compared to manual testing?

Scope and Limitations

The study created a portable soil monitoring device that scans the properties of soil being tested in real-time. The device will only scan for the following properties: pH, Nitrogen, Phosphorus, Potassium, and Moisture. The said device will not scan other properties of the soil such as silt, clay, fertilizer, color, texture, smell, and other properties that were not mentioned. Other than Loam Soil, Potting Mix Soil, and Aroid Mix Soil, no other types of soil were tested.

The researchers only utilized Arduino UNO R3 compatible parts for the device's components. The device will not exhibit Wireless Fidelity (Wi-Fi) nor Bluetooth capabilities to transmit data to other devices, as the data will only be shown through the device's LCD screen. The study took five months to complete, starting from September 2024 to January 2025.

Significance of the Study

With the creating and testing a portable soil monitoring device by measuring the NPK (Nitrogen, Phosphorus, Potassium), pH, and moisture levels of soil, including an interpretation based on the data collected. This device aims to change the agriculture industry. It would enhance the productivity and quality of crops by offering timely and accurate information regarding the soil condition. This would shorten soil analysis time, allowing farmers and government officials to act faster to maximize the short window of time for excellent soil quality.

Agricultural Communities. The time between planning and taking action will be reduced due to the quick info gathered by the device, maximizing the time they grow crops. Communities that rely on their agriculture to strive economically will greatly benefit from the creation of a Portable Soil Monitoring Device.

Farmers. May use this device to get information about the soil and provide it with proper treatment for their respective plants/crops for better results and quality. Makes soil testing more accessible and cheap.

Geodetic Engineers. Geodetic engineers could make quick price assessments of land areas using this technology, accelerating the process of buying land and helping other related businesses in terms of land.

Indoor Gardeners. May use this device to track the conditions of the soil their plants are growing on, which affects the way a plant grows.

Future Researchers. This research may be used as a basis for future innovations regarding agricultural technologies. It may also help future researchers by providing them an alternative way of testing soil qualities making the process more efficient and easier.

Definition of Terms

Arduino. An open-source electronics platform with easy hardware and software capabilities (Arduino, 2018). Arduino boards refer to the hardware component and Arduino Programming Language refers to the Integrated Development Environment (IDE) software component. Both components are used to build and program the Portable Soil Monitoring Device.

Moisture. A very small drop form of liquid, usually water, is commonly found in air, substances, or on the surface (Cambridge University, n.d.). This is one of the properties that will be scanned by the Portable Soil Monitoring Device.

Nitrogen. A Macronutrient that is essential for ensured energy for the functions of the plant and amino acids (Koch Agronomic Services, 2023). This is one of the properties that will be scanned by the Portable Soil Monitoring Device.

pH. Measure of hydrogen ion concentration to classify the acidity or alkalinity of the soil (Queensland, 2013). This is one of the properties that will be scanned by the Portable Soil Monitoring Device.

Phosphorus. A vital plant nutrient especially for seedlings is part of plant cells (NSW Government, n.d.). This is one of the properties that will be scanned by the Portable Soil Monitoring Device.

Potassium. A Macronutrient that is essential to move water and nourishment of plant tissues (University of Minnesota Extension, 2018). This is one of the properties that will be scanned by the Portable Soil Monitoring Device.

Portable. Refers to a lightweight machine that is capable of being easily carried or moved (Cambridge University, n.d.). This was one component of the goal of the study; to create a portable soil monitoring device that can be easily carried.

Sensors. A device that recognizes and reacts to any physical input such as light, heat, motion, moisture, and other environmental phenomena (Sheldon, 2022). This component was used in making the Portable Soil Monitoring Device.

Soil. A natural material that contains minerals and organic matter where micro and macronutrients such as pH, NPK, and Moisture have a direct effect on the growth and development of plants (*What Are Soils? | Learn Science at Scitable*, n.d.). The study utilized soil that contains specific pH, NPK, and Moisture levels as a way to test the accuracy and efficiency of the soil monitoring device.

Soil Monitoring Device. This is the final product of the study.

CHAPTER 2

REVIEW OF LITERATURE AND CONCEPTUAL FRAMEWORK

This chapter provides an overview of related literature about the soil sensors to be used in the study. This section also presents the application of these sensors in different studies where the findings and recommendations further support the goals and methodologies reflected in the study. Furthermore, the research gaps present in the studies in this section became the basis for narrowing down the fields and characteristics the researchers will study. Four themes were discussed in this section, Problems in Soil Monitoring, Soil Monitoring Advances, Challenges Faced by Soil Monitoring Technologies, and Methodology of Related Studies. This chapter also covers two frameworks, the conceptual framework and architectural framework, illustrating the input, process, and output (IPO) of the monitoring device, and how it operates to reflect the output respectively.

Problems in Soil Monitoring

The analysis of soil components and concentration levels is known as soil monitoring in which soil tests and field observations are applied to determine the condition and quality of soil for agricultural or recreational use. Through this, a comparative analysis of soil may be applied to evaluate soil quality from year to year, identifying aspects to improve, and completely utilizing the soil's potential for agricultural use. When soil is unregulated in physical, chemical, and biological aspects, it leads to poor soil quality. Poor soil quality may lead to soil degradation affecting plant growth and crop yield negatively, thus needing high cost and time to resolve. Soil degradation may also be an effect, causing landslides and floods – factors in intensifying pollution (*Soil Monitoring - Know Your Soil | Infonet*

Biovision Home., n.d.). The Department of Environment and Natural Resources (DENR) reported that 75% of the total cropland in the Philippines is vulnerable to erosion of various degrees losing about 457 million tons of soil annually. The loss of at least 47,000 hectares of forest cover was said to contribute to soil degradation since around 11 to 13 million hectares are considered degraded (Department of Agriculture, 2019). As soil is a non-renewable resource that supports different sectors in society, especially in agriculture, the demand for quick, reliable, and advanced technology in soil monitoring is heavily needed in society to reduce the amount of soil lost to degradation (*Soil Degradation: The Problems and How to Fix Them*, 2021).

The sector of agriculture faces challenges that hinder farmers from easily accessing soil monitoring technology. Soil testing requires costs to conduct and operate. About $75 is the expected average price for soil tests which will further depend on the specific elements one aims to measure given that there are different types of testing for a specific soil content level. Prices may cost $1,000 or more which is unpractical for farmers as part of their profit from agriculture will be allocated to the expense for monitoring the soil content levels (Gerhardt, 2024).

The manual testing process of NPK, pH, and moisture levels is measured with the use of a soil testing kit or equipment. The principle of photoelectric colorimetry is applied to a soil sample mixed with a testing solution. The solution then reacts to generate colored substances, modifying its appearance. The reflected color in the solution is then compared to a chart with different color shades that have specific interpretations regarding the content levels of soil. Additionally, soil meters can be an alternative where its prongs are inserted into the soil which will then reflect on its scalar component the concentration levels of soil (*How Can I Soil Fertility, NPK, PH and Moisture Content?*, 2024).

In terms of manual testing, results are often inaccurate and time-consuming compared to real-time data, making the gathered results difficult to validate (Ouyang, 2022). Manual testing can often be slower in terms of time before displaying specific values since each step needs to undergo verification, hindering efficiency and, hence, making it time-consuming. Furthermore, manual testing is highly prone to human error as it requires human intervention. When a larger sample size is needed to be tested, specific details of the testing process may be overlooked. This may lead to inconsistency and inaccuracy of test results. To reduce the chances of invalid data, large-scale projects require human resources with above-average skills to increase the accuracy of testing as lower-level performing staff can lead to bottleneck effects, causing higher margin of errors as the human ability has limitations and can not ensure full and equal replication of the process (*Advantages and Disadvantages of Manual Testing*, 2024).

Soil Monitoring Advancements

The pH Level of soil plays an important role in determining the condition of the soil for plant growth. Acidity does not restrict plant growth directly but the contents of the soil that plays a crucial role in plant growth can be negatively affected. It degrades the favorable environment for bacteria, earthworms, and other soil organisms making the soil vulnerable to leaching and decreasing valuable plant nutrients such as Phosphorus and Molybdenum (Agriculture Victoria, 2024).

In determining the pH level of the soil, a soil pH sensor is used where electrodes are inserted into the soil to detect the concentration of hydrogen ions contained in the soil (NiuBoL, 2023). This device is usually used for the agricultural sector, more specifically, farmers to be able to read and adjust the acidity or alkalinity of the soil to improve crop growth and yield (NiuBoL, 2023). An example of an Arduino-compatible pH Sensor is called a Gravity Analog pH Sensor which has a Signal Conversion Module and pH Electrode (Parida, 2020). The Signal Conversion Module has an onboard voltage regulator chip that is rated for 3.3-5.0V and is widely compatible with Arduino boards. It features a BNC Probe Connector where the pH Electrode is connected. The accuracy rate of the module is ±0.1@25°C and the detection range is 0~14 pH Scale (Parida, 2020). For the pH Electrode, the operating temperature range is 5~60°C. The Zero (Neutral) Point is 7±0.5. This electrode features easy calibration and an internal resistance of <250MΩ.

To calibrate and test the accuracy rate of the Arduino-compatible pH Sensor, it will be subjected to a known pH buffer solution (Circuit Schools, 2021). If your buffer solution has a pH Level of 7, then the output data of the sensors should be equal or decimals near 7 (Circuit Schools, 2021). It is recommended by Thomas (2024) to subject the sensors to standard pH Solutions which are pH 4, 7, and 10 to guarantee the accuracy of the sensors when subjected to various samples.

Nitrogen, Phosphorus, and Potassium (NPK) are macronutrients found in soil that are required by plants for healthy growth and development. Nitrogen (N) is a vital component for plants as it is absorbed during photosynthesis. This makes it responsible for the growth of the plant's leaf and stem. Phosphorus (P) allows plants to commence various internal and external processes such as energy transfer, root development, and production of flowers or other reproductive components. Potassium (K) regulates water uptake and retention which promotes the transport of sugars and nutrients within the plant's structure. This further enhances the health of the plant in terms of development and resistance to disease. With insufficient NPK levels in soil, plants are susceptible to poor health and diseases caused by nutrient deficiency, affecting agriculture as crop yield is reduced. Additionally, chances of soil degradation might increase given that the soil may experience nutrient imbalance with other nutrients having greater percentages than usual (Botha, 2023). According to Agrocares (2023), NPK is the primary nutrient that plants need in the greatest quantities. Therefore, they are often seen as the most essential elements for crop growth. Due to NPK being vital to plant growth, it is important to apply the right amount of nutrients based on the plant's needs and soil condition. In this case, farmers and gardeners can use the NPK sensor to assess the nutrient content of the soil, enabling them to apply the appropriate amount of fertilizer to maximize crop yield per Last Minute Engineers (n.d.).

In Arduino under the field of Robotics, sensors play a crucial role in identifying the condition of the soil and its nutrient requirements. The soil NPK sensor is suitable for detecting the content of nitrogen, phosphorus, and potassium in the soil. It helps in determining the fertility of the soil thereby facilitating the systematic assessment of the soil condition. The sensor can be buried in the soil for a long time as it has a high-quality probe capable of electrolytic, and salt and alkali corrosion resistance, ensuring long-term operation and being suitable for all kinds of soil. In terms of manual testing, NPK levels of soil are generally measured with the use of NPK test strips where specific colors correspond to the numerical value or interval of NPK levels in the soil. (LME Editorial Staff, n.d.).

One type of this sensor utilized in the study is the JXCT Soil NPK. This type of NPK sensor will not require chemical reagent as it has probes that will be inserted in soil to measure its NPK levels, making it have high accuracy, response speed, and interchangeability. Operating on a 9-24V, measuring NPK levels up to 1mg/kg (mg/l). The sensor is then connected to the RS485 or MAX485 Modus Interface Module as this component allows long-distance serial communication through signaling up to 1200 meters, supporting up to 2.5MBit/Sec data rates (*Measure Soil Nutrient Using Arduino & Soil NPK Sensor*, 2023).

In the Digital Age, where technology continues to develop, integrating traditional and modern practices in agriculture is now common to improve current systems and eradicate possible inaccuracies. These developments include a soil moisture level sensor, an appliance used to monitor the moisture level present in soil (Cherlinka, 2023). These tools aid in improving irrigation systems and managing water resources because of their ability to supply information about soil moisture at different depths (NiuBoL, 2024). This device has been used in several recent innovations and research.

It is important to keep track of soil moisture because enhanced soil moisture improves plant growth by improving root growth, uptake of water, and use of substrates, particularly in dry conditions. The high availability of moisture in the soil also results in the plant's increased biomass and dry matter yield, thus enhancing the overall productivity of the plant. Sufficient moisture allows plants to carry out necessary life processes, which are crucial for their growth (Chen et al., 2007, Yavkacheva, 2023). The moisture values of the soil depend on various things like rainfall, soil texture, or the presence of plants, which affect how much moisture is absorbed or retained. In dry soils, cracks allow the soil to absorb more moisture while moisture changes are further affected by the cycle of evaporating and transpiring water from the ground and then releasing it into the air. How quickly and up to what extent are these changes monitored usually depends upon the climatic elements like the amount of rainfall or type of plant cover (Seviratne et al., 2010). Existing techniques of measuring soil moisture content include the use of the gravimetric soil moisture content method, tensiometers, and neutron probes, as well as practical, labor-intensive harvesting wherein all the other methods require rather costly apparatus or time to get meaningful outcomes (Berg & Sheffield, 2018).

Challenges Faced by Soil Monitoring Technologies

To further evaluate the accuracy of the NPK sensor, a study entitled “Design and Build a Soil Nutrient Measurement Tool for Citrus Plants Using NPK Soil Sensors Based on the Internet of Things” aimed to send the results to Thingspeak Web from data collected through NPK sensors. After the experimentation process, it was concluded that nutrient content was higher in wet soil than in dry soil, inferring an accuracy rate of 90%. With the application of external software, it was easier to calculate data. However, the gap in this setup is that it sacrifices its potential to be portable and compact (Pratama et al., 2021).

A study conducted in February 2024 entitled “Monitoring of Soil Nutrients Using Soil NPK Sensor and Arduino” aimed to assess the feasibility and accuracy of the sensor approach in monitoring soil nutrient levels specifically, NPK. After conducting the experiments to test the accuracy and efficiency of the NPK sensor, it can be concluded that this Arduino technology presents a significant advancement in soil nutrient monitoring for agricultural purposes. Recommendations and gaps were identified where there is more research needed to be conducted in exploring other soil types to further test the automation when exposed to diverse types of soil. Additionally, the proper physical aesthetics of the NPK sensing device must be improved given that the study’s sensor does not have an outer shell that will keep the wires and components intact. Portability is also its weakness as the study’s device is dependent on a computer for its power source (Kumar et al., 2024).

Based on the study entitled “Conventional to Modern Methods of Soil NPKSensing: A Review,” soil NPK monitoring sensor provides advantages such as efficiency where it enables accurate monitoring of soil conditions. However, implementation of these technologies experiences human-related issues or margin of error where extraneous variables may affect the expected results. More studies need to be explored in terms of the number of soil samples and device set-up to have advancements in terms of gathering data (Dattatreya et al., 2024).

One of the recent studies gathered includes a study by Tolentino, et al. (2020), which aimed to create a plant monitoring device. They utilized several sensors, including a moisture level sensor. The research also used Arduino for the processing and display of data through LCD screen and Raspberry Pi for mobile access display. This study experimented with and compared the information from a standard soil test kit and the plant monitoring device they created. Through the experimentation and data acquired, they concluded that the sensor was able to provide precise data to aid in the development of a device with a percentage error of 12%.

A study conducted in June 2020, titled “Soil moisture sensing with RFID commodity systems,” aimed to innovate and replace the existing soil moisture sensors which appear to be expensive and complicated. This study utilized RFID tags which are attached to a plant’s container to monitor the soil moisture content to be reflected by their Differential Minimum Response Threshold (DMRT) metric. The prototype, named “GreenTag,” showed creditable data which achieved a 90-percentile moisture estimation error of 5%. This can be comparable to the expensive soil moisture with a percentage error of 4% (Wang, et al, 2020).

Despite the innovations, there is an observed lack of available NPK, pH, and Moisture level sensors that can be portable and user-friendly. This technology will be utilized in this study to produce a soil monitoring device with accurate data on these soil content levels. This research aims to remove the expensive apparatus and manual work while trying to reduce the time to yield accurate and timely soil moisture readings to farmers.

Methodology of Related Studies

A true experimental research design that evaluates the cause-and-effect relationship between two variables. This type of research design focuses on the difference between the change in one variable and another variable (Voxco, 2021). A true experimental research design was applied in the study “Arduino-Based Experiments: Leveraging Engineering Design and Scientific Inquiry in STEM Lessons” to develop Arduino-based experiments to facilitate the implementation of STEM lessons following scientific inquiry and engineering design processes. The study conducted three experiments where it assessed the cause and effect of the relationship between the efficiency and effectiveness of the implementation of STEM lessons towards practical applications (Nguyen et al., 2024). Another Robotics study applied this research design which is entitled “Experimental verification of design automation methods for robotic finger” where it has an objective to validate the methods of Generic Automated Finger Design (GAFD), Manually Designed Fingers (MDF), and the eGrip tool. The strengths and weaknesses of the experimental results were compared (Honarpardaz et al., 2017).

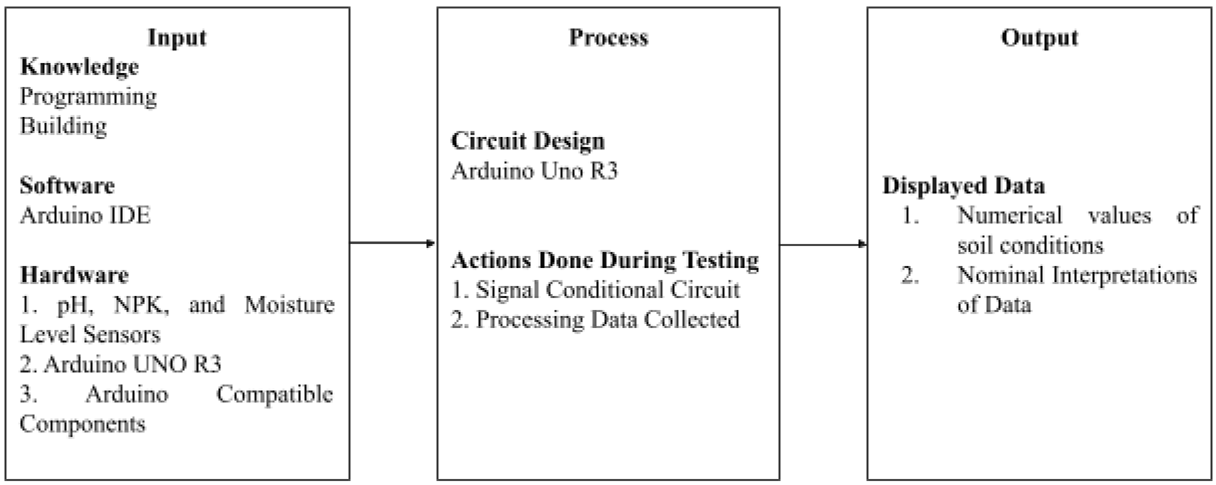
One type of statistical analysis is a Chi-square test which tests the frequencies of observed frequencies in one or more categories, analyzing if the recorded data matches the expected frequencies (*The Chi-Square Test*, n.d.). The Pearson Chi-square statistical test was used in the study “Construction Robotics and Human-Robot Teams Research Methods” to compare the observed results with the expected results to test if there was a significant difference. It revealed that there is a significant association between the observed and expected results, hence supporting the hypothesis that there is an association between variables (Onososen et al., 2022). In another related literature “The Effects of User Adaptability to Automation for a Robotic Art Box”, the statistical test was used to determine if two incidents have significant differences to conclude that the application of new learning modalities with the integration of robots had a significant impact on performance for certain tasks (Morales et al., 2017).

In the study’s statement of the problem, specific questions were identified which mainly focused on Functionality, Accuracy, Efficiency, and Portability. Functionality refers to the ability of a component to perform according to its intended goal, meeting its standards and purpose. In testing a system’s or component’s functionality, the prototype is tested under a predetermined set of specifications and performance. One type of testing is the Black Box Test which assess whether the given input results in the desired output. The external specifications are only measured without peering into its internal structure or workings (Shain, 2022). Accuracy is the closeness of a calculated measure to an actual value by measuring its difference. For accuracy, the average value of multiple measurements is calculated, supported by precision to identify how close the measurements are to the expected and observed values (Indeed Editorial Team, 2024). Efficiency focuses on completing tasks and activities in the shortest time possible with the least waste in a given timeframe. Time efficiency is measured by input divided by output times 100 (Nekvinda, 2024). Lastly. portability refers to the characteristic of being easily transferred from one location to another. A portable device can be easily carried designed to be held and used in the hands and operate on battery capacity (Sierra Software Ltd, 2020).

Conceptual Framework

Figure 1

Conceptual Framework



Functionality, efficiency, accuracy, and portability will be evaluated through the application of the input, process, and output framework. The input consists of three parts: knowledge, software, and hardware. Knowledge involves background experience and understanding of Arduino in terms of programming and building. The software utilized to program the soil monitoring device is the Arduino Integrated Development Environment (IDE). The Hardware consists of pH, NPK, and Moisture Level Sensors, Arduino UNO R3, and Arduino-compatible components. The processing of data started with the circuit design of Arduino UNO R3. Data came from values collected from the prongs of NPK, pH, and Moisture sensors; which signals a conditional circuit to start. Data collection proceeds to the Arduino program for it to be processed with the application of Arduino codes and software. The numerical value equivalence of the data from the monitoring device is reflected on the LCD screen as well as the nominal interpretation of each respective numerical value, depending on the verdict of the architectural process of the soil monitoring device.

Architectural Framework

Figure 2

Architectural Framework

To further discuss the process of the portable soil monitoring device, the figure above shows the mechanism of the device. The device starts when the NPK, pH, and Moisture sensors are inserted into the soil. Step 1, the sensors will then start scanning for the following properties of the soil: Nitrogen, Phosphorus, Potassium, pH, and Moisture. Step 2, the sensors will send the data they have gathered to the Arduino UNO R3 to get properly interpreted. Step 3, once the Arduino UNO R3 finishes its interpretation, it will display one of two situational results: If the data was interpreted properly, it will display the interpreted data and the whole process of the device will end. If not, "Err" will be displayed on the properties it was not able to interpret its data. It will then prompt the device to restart its whole process from Step 1 which is labeled as "A".

Hypotheses

Research Hypothesis

The researchers hypothesized that creating a Portable Soil Monitoring Device using Arduino UNO R3 and its compatible components such as the RS485 5 Pin, pH, NPK, and Humidity Sensor can improve the time efficiency in gathering data about the different macronutrients (Nitrogen, Phosphorus, Potassium), pH level, and moisture content while being consistent compared to its manual counterpart.

Statistical Hypothesis

HA_1:

There is a significant difference between the manual and automated testing data in terms of time efficiency.

$H0_1$:

There is no significant difference between the manual and automated testing data in terms of time efficiency.

HA_2:

There is a significant difference between the manual and automated testing data in terms in terms of:

a. Functionality

b. Accuracy

$H0_2$:

There is no significant difference between the manual and automated testing data in terms in terms of:

c. Functionality

d. Accuracy

CHAPTER 3

METHODOLOGY

Research Design

To innovate a portable soil monitoring device that supplies accurate and precise information to measure improvement in the health of the soil to capacitate it, the study covers a quantitative research design, specifically, the Quasi-Experimental or the Causal-Comparative approach. According to Costello (2023), this research methodology is employed to assess how a certain modification may affect generally accepted norms and hypotheses. As defined by Çobanoğlu (2023), it is an approach used by researchers to identify the presence of causal effect relationship between variables. This will analyze the present differences between or among groups without randomizing, manipulating, or controlling variables.

A prototype soil monitoring device was created by using Arduino and sensors. The result from this device was compared to the manual monitoring of the soil levels as mentioned earlier to determine if the data from the prototype is similar to that of manual testing. Thus, it will also help to determine the soil's health condition to help farmers better their crops and industry. The researchers have determined that this is the best approach to employ in the study based on their gathered data.

Materials and Methods

This section will discuss the possible materials and methods that was utilized in creating and testing a Portable Soil Nutrient, pH, and Moisture Monitoring Device. This section will also explain why certain components were chosen to create the Soil Monitoring Device and explain our methods for gathering and analyzing data. The Materials and Methods will serve as the framework for how the research will commence throughout its multiple phases.

Materials

The materials used in this study were chosen by the researchers based on related literature and knowledge obtained from past experiences. The researchers decided to use an Arduino UNO R3 and RS485 5 Pin, pH, NPK, and Humidity Sensor as the main components of our device because the goal of this research is to create a portable and accurate soil monitoring device. The rest of the materials include a MAX485 Modbus Module, ½ Breadboards, Jumper Wires, LCD screen, I2C LCD Adapter, 9V battery, and a Custom Foam Board Casing to make the device serve its purpose of providing quick and reliable information on the soil.

Arduino UNO R3. The researchers chose this because of its versatility, ease of programming, and compatibility with the sensors. It facilitates the communication and control of all other components in the system and can sustain 6 to 20 volts of energy to provide function to the components.

RS485 5 Pin, pH, NPK, Humidity Sensor. The researchers chose a 5-pin sensor as it was the most practical product available. The RS485 protocol allows reliable data communication between the microcontroller and the sensors. The All-in-one 5-pin sensor provides real-time data on key soil parameters. The **pH sensor** tracks acidity, the **NPK sensor** monitors nitrogen, phosphorus, and potassium levels, and the **humidity sensor**

measures soil moisture. It is compatible with an Arduino and 5-30 volts of energy.

MAX485 Modbus Module. The MAX485 Modbus Module converts the Time-To-Live (TTL) Level Signals to RS485 communication protocol. This module is used as the communication bridge of the sensors and Arduino UNO R3 board.

½ Breadboards. The ½ Breadboards serve as the connectivity point of all the components. The researchers opted for this instead of a Printed Circuit Board (PCB) to have the flexibility of changing components with ease.

Jumper Wires. The Jumper wires connect every component of the device to the breadboard. This type of wiring allows the researchers to easily modify the connection of the components if deemed necessary.

LCD screen. The LCD provides visualization of the sensor data in real time. The researchers chose LCD for its good energy consumption rating, bigger size, long lifespan, and cost efficiency.

I2C LCD Adapter. The I2C LCD Adapter recognizes multiple addresses which allows a seamless send and receive data system with other chips with only a couple of wires needed. This helped lessen the use of jumper wires for only two chips.

9V Battery. A 9V battery will provide ample electrical power to the device. It ensures that the Arduino gets enough energy to power the rest of the device.

Custom Foam Board Casing. The custom foam board casing provides housing and storage for the final product. The foam board structure ensures that the system is compact with it due to its customizable features.

Soil. The study used three different types of soil samples namely loam soil, aroid mix, and potting mix soil for further evaluation if the data from the created soil monitoring device is not affected by the external variables present in each soil type.

Soil Pots. The plastic soil pots provide storage for the soil samples, making testing easier using the created portable soil monitoring device.

Manual Soil Testing Kit. The manual soil testing kit is used to manually determine and monitor the levels of nitrogen, phosphorus, and potassium in each soil sample, where the results will then be used as a basis to test the accuracy of the soil monitoring device.

3 in 1 Soil Humidity, pH, and Light Tester. The 3 in 1 Soil Humidity, pH, and Light Tester is used to determine the pH and moisture levels of the soil samples where the results will then be used as a basis to test the accuracy of the soil monitoring device.

Methods

This study prepares soil samples with specific pH and nutrient levels. This is possible by adding natural or chemical fertilizers to these soils. The soil samples were transferred into respective pots, labeling them based on their soil type. All these soil samples were used to verify the accuracy of the sensors and assess the functionality of the system.

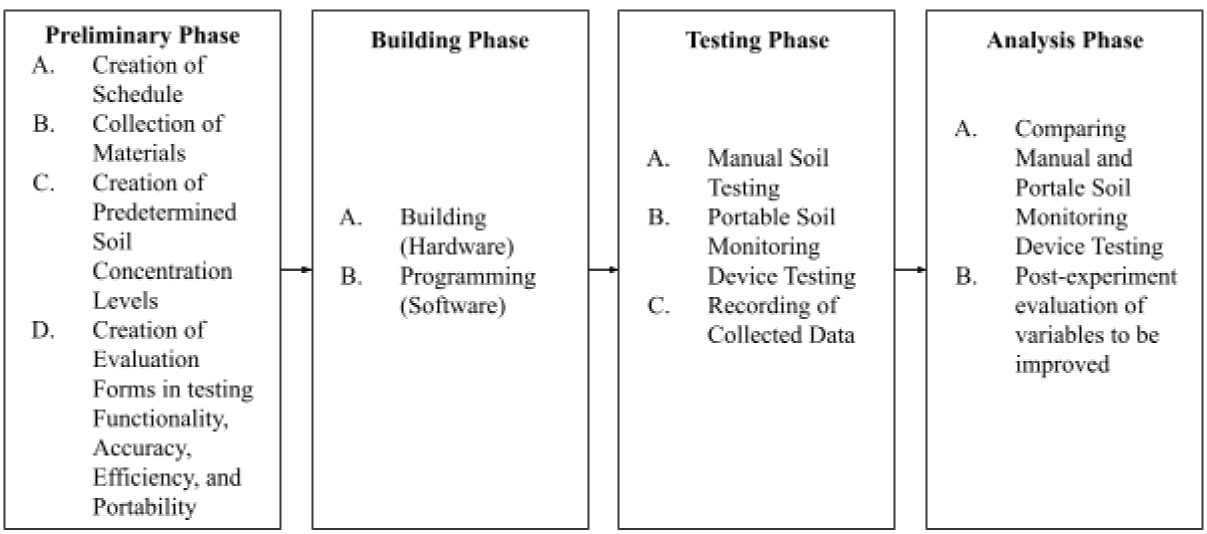
Next, the soil monitoring device was built by connecting the Arduino UNO R3 to the RS485 pH, NPK, and humidity sensor. The MAX485 Modbus module makes the connection between the sensors and Arduino, and the data is displayed on an LCD screen for real-time monitoring. The system is powered by a 9V power supply, and connected wires ensure reliable signal transmission. For the initial prototype, a breadboard will be used for easy modifications. The device will be stored in a custom foam board casing for protection in the final version of the product. A program was written in the Arduino IDE to get and process sensor data, converting it into readable soil nutrients, pH, and moisture content.

Sensor readings are recorded and stored locally at regular time intervals to log and analyze the data. This data comprises NPK concentration, pH concentration, and moisture content levels.

Process

Figure 3

Flowchart of Phases and Processes



The study is divided into 4 phases, which started with the Preliminary phase. A schedule is created to ensure the efficiency of the development. It also outlines timelines for building, testing, and data analysis. Next, The researchers gathered necessary materials, including sensors, and other components necessary to develop the project. After that, natural or chemical fertilizers are mixed into these soils to have predetermined concentration levels of pH and nutrients. The evaluation forms were drafted based on the functionality, accuracy, efficiency, and portability of the soil monitoring device so that its performance guarantees the achievement of the set objectives during testing.

After the preliminary stage, The study moved on to the building phase which consists of both the construction and programming of the device. As we build and code, The research slowly transitions into the Testing phase as preliminary tests are done during building and programming to ensure sensors and the code are working properly.

After the data was collected from the device, The study moved on to the Analysis Phase. A conveniently portable device for monitoring soil is placed against comparable manual methods using NPK, pH, and moisture content in similar conditions. The level of accuracy, efficiency, and ease of use of both approaches sought to contrast in terms of data collection time and consistency in achieving real-field situation use. After the experiment's evaluation will decide whether it should be improved in sensor calibration, data transmission, or the portability of the device.

Patent Table

Table 1

Patent Table to emphasize the difference between the current study and previous studies

Criteria	Current Study	Patent 1	Patent 2	Patent 3
NPK Level Monitoring	RS485 5 Pin, pH, NPK, and Humidity Sensor	N/A	Single probe sensor with a percentage error of 12%	N/A
pH Level Monitoring	RS485 5 Pin, pH, NPK, and Humidity Sensor	N/A	Single probe sensor with a percentage error of 12%	Voltage-based sensor that can be heavily affected by the Temperature and Impedance of the pH Electrode
Moisture Level Monitoring	RS485 5 Pin, pH, NPK, and Humidity Sensor	Uses an unknown sensor	Single probe sensor with a percentage error of 12%	2 probes type of sensor that gathers data using Analog Output

				variations
Power Supply Unit (PSU)	9V Battery	A charger powers the whole system	The device utilizes a rechargeable battery with a charging port	The device is powered by a 5V DC Battery
Display	16x2 LCD screen	Android Application	- LCD screen - Wifi Access with Raspberry pi Wifi module	16x2 LCD screen
Enclosure	Custom Foam Board Casing	N/A	Enclosed but not discussed	N/A

This patent table showcases the difference in features and functionality of the current study compared to other patents created locally and in other countries. The gaps in previous studies and the advantages of the current study can be determined through the data presented in this table. By comparing the data presented, the advantage of the current study is its accuracy and portability. The study will utilize the RS485 5 Pin, pH, NPK, and Humidity Sensor; Each probe will scan only one property to determine their levels accurately.

Additionally, the device will be powered by a 9V Battery and enclosed in a Custom Foam Board Case. Patent 1 is a study entitled "Soil moisture monitoring using IoT enabled Arduino sensors with neural networks for improving soil management for farmers and predict seasonal rainfall for planning future harvest in North Karnataka — India" that aimed to identify soil moisture levels with the application of input sensors using neural networks algorithm and correction factors for monitoring. The study did not measure soil pH and NPK levels where it does not have an outer enclosure, lacking protection and portability. It is also dependent on a direct charger and external software to operate and display data (Athani et al., 2017). Patent 2 "Development of wireless data acquisition system for soil monitoring" focuses on a digital probe sensor to monitor NPK levels, temperature, moisture, and pH levels of soil. The gap in this study is accuracy as the sensor used only has 1 probe which may affect the collection of data from the soil (Tolentino et al., 2020). Lastly, Patent 3 entitled "Automatic testing of Soil Moisture, pH using Arduino and Selection of Specific Crop" has an objective to measure soil moisture and pH to determine and recommend crops suitable for growth in specific soil conditions with the application of Arduino and an external software. The study did not dive into measuring the NPK levels of soil as well as a proper outer enclosure to protect the circuit of the device (Balakrishna et al., 2018).

Data Analysis

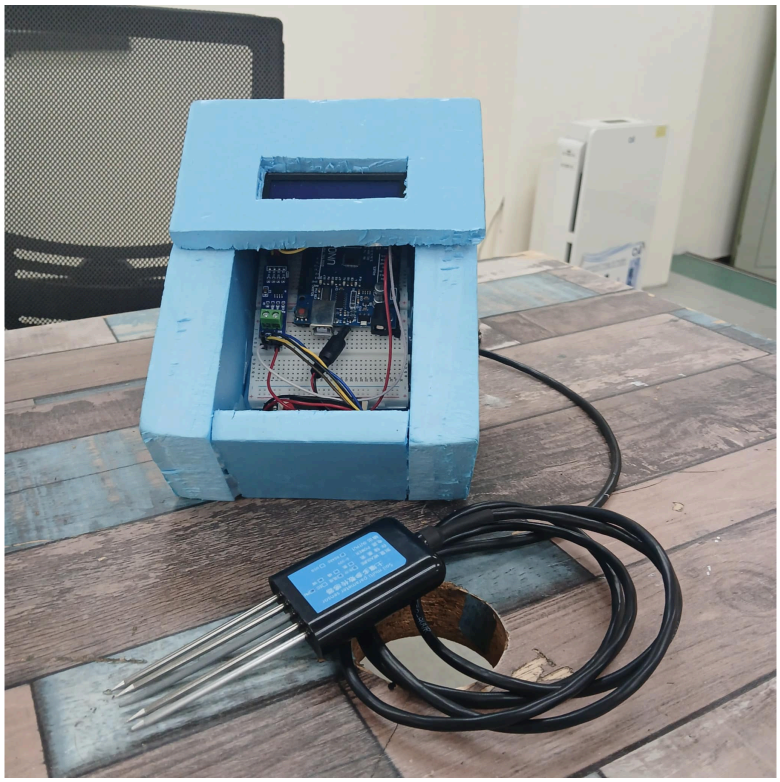
The statistical test utilized in this study is Pearson's Chi-square Test, specifically the Chi-square Goodness of Fit Test and Paired T-Test. According to Turney (2022), the purpose of a Chi-square Test is to determine if the collected data significantly deviates from the expected values. The Chi-square Goodness of Fit Test is employed to examine whether the distribution of frequencies for a categorical variable differs from what the researchers anticipated. According to Bevans (2020), the Paired T-test is used to determine if there is a statistically significant difference between two groups. The researchers tested the performance and data collected from the Soil Monitoring Device compared to manual testing. The data collected were plotted in the Bland-Altman Plot to identify the similarities between the measurements of the two measuring techniques. It is frequently employed for evaluating the similarity of a new instrument or technique in measuring something to the current instrument or technique in use (Bobbitt, 2021). By doing so, the researchers were able to identify if the device is well-matched with the current instruments being used to test the soil's condition.

CHAPTER 4

RESULTS AND DISCUSSION.

Figure 4

Actual image of the Portable Soil Monitoring Device Prototype



Note. The device's dimensions are: Length - 14.5cm, Width - 7.5cm, and Height - 8.8cm

The figure above exhibits the actual image of the Portable Soil Monitoring Device. Before getting the data for the automated testing, the researchers made sure the device consistently obtained the correct value for the required soil nutrients by fixing the Modbus RTU Data Frame in our program. After that, the researchers proceeded with the testing phase where the data were gathered through manual and automated testing on 3 different types of soil (Loam, Potting Mix, and Aroid Mix soils). The researchers used Chi-Square Goodness of Fit Test, Individual T-Test, and Bland-Altman Plot for data analysis to interpret raw data gathered and evaluate the functionality, accuracy, and time-efficiency of the prototype.

Functionality of the Soil Monitoring Device

Table 2

Comparison of the Observed and Expected Functionality of the Soil Monitoring Device

Component	Observed	Expected	Difference	Difference²	Difference² / Exp Fr.
Liquid Crystal Display (LCD) screen	50.00	50.00	0.00	0.00	0.00
NPK, pH, and Moisture Sensor Probes	50.00	50.00	0.00	0.00	0.00
Soil Monitoring Device Circuit	50.00	50.00	0.00	0.00	0.00
					0.00

Note. The Chi² value is 0. The p-value is 1. The results are closely associated with each other at $p < .05$.

The table above shows the connection of the expected and observed outcomes of the portable soil monitoring device in terms of the functionality of each component; namely the Liquid Crystal Display (LCD) screen, NPK, pH, and Moisture Sensor Probes, and Soil Monitoring Device Circuit. The statistical test used to determine if there is a significant association between the expected and observed values to answer the first statement of the problem was the Chi-Square Goodness of Fit test. Each component is expected to operate successfully within a total of 9 trials where the observed successful trials will decrease whenever a trial fails to function by displaying an error in the LCD. From the statistical analysis results, the Chi-Square value is calculated to be 0 where the p-value is 1, being greater than 0.05. It shows that the device had shown the expected results, implying that all said components are fully functional within 50 trials.

Accuracy of the Soil Monitoring Device

In evaluating the accuracy of the soil monitoring device, the researchers measured data from manual soil testing and automated soil testing in three different soil samples namely loam, potting mix, and aroid mix soil. This method was applied to ensure that the portable soil monitoring device reading is not influenced or affected by any extraneous variables found in a specific soil type. Through this, the accuracy of the values collected will be identified through the consistency of the device to measure each respective micronutrient in each soil type.

After collecting data, an independent t-test was used to determine whether there was a significant difference between the means in two unrelated groups, manual and automated testing. With the collected data from manual and automated testing, the results shown in Tables 3, 4, and 5 present the results of an independent t-test comparing the Portable Soil Monitoring Device and Manual Testing Method’s measurements for the five parameters: Nitrogen, Phosphorus, Potassium, pH, and Moisture in the Loam Soil in terms of mean difference, standard deviation of difference, t, df, and p-value.

Table 3

Comparison of Acquired Data from Manual Testing and Automated Testing on Loam Soil

Parameter	N	Mean Diff.	SD of Diff.	t	df	p-value
Nitrogen	3	0.3333	2.333	0.1429	4	0.8933
Phosphorus	3	13.6667	3.480	3.9271	4	*0.0171
Potassium	3	1.3333	2.028	0.6576	4	0.5467
pH	3	0.6667	2.000	2.0000	4	0.1161
Moisture	3	0.0267	0.015	1.8353	4	0.1404

Note. Loam Soil. The result is not significant at $p < .05$.

Table 3 presents the results of an independent t-test comparing the Portable Soil Monitoring Device and Manual Testing Method's measurements for the five parameters: Nitrogen, Phosphorus, Potassium, pH, and Moisture in Loam Soil.

The t-value for Nitrogen in loam soil displayed the smallest value of 0.1429 followed by Potassium, Moisture, and pH with values of 0.6576, 1.8353, and 2.000 respectively. The smaller the t-value the smaller difference that exists between the two techniques. The p-values of each parameter for Nitrogen, Potassium, pH, and moisture were 0.8933, 0.5467, 0.1161, and 0.1404 which is higher than 0.05. This shows that there is no significant difference statistically. This implies that the collected data from both manual and automated testing for Nitrogen, Potassium, pH, and moisture in loam soil were identical to each other.

However, for Phosphorus, it reflected a relatively large mean difference of 13.6667 with a t-value of 3.9271, resulting in a p-value of 0.0171 which is less than 0.05 thus implying that there is a significant difference between the collected data in both testing techniques as phosphorus values from manual testing and automated testing are not equal or similar to each other, having a margin of error. This error may be due to the variables present in loam soil such as other micronutrient values aside from the five parameters measured interfering with the reading of the phosphorus value. The result suggests that the Portable Soil Monitoring device generally provides comparable or similar results as to the Manual Testing Method for four out of five parameters present in the Loam Soil, with Phosphorus only being the outlier in collecting accurate or similar data in loam soil.

Table 4

Comparison of Acquired Data from Manual Testing and Automated Testing on Potting Mix Soil

Parameter	N	Mean Diff.	SD of Diff.	t	df	p-value
Nitrogen	3	2.6667	3.712	0.7184	4	0.5122
Phosphorus	3	10.6667	3.333	3.2000	4	*0.0329
Potassium	3	2.6667	3.333	0.8000	4	0.4685
pH	3	0.3333	0.667	0.5000	4	0.6433
Moisture	3	0.0133	0.032	0.4193	4	0.6965

Note. Potting Mix Soil. The result is not significant at $p < .05$.

Table 4 presents the results of an independent t-test comparing the Portable Soil Monitoring Device and Manual Testing Method's measurements for the five parameters: Nitrogen, Phosphorus, Potassium, pH, and Moisture in Potting Mix Soil.

The t-value for Moisture in Potting Mix soil displayed the smallest value of 0.4193 followed by pH, Nitrogen, and Potassium with values of 0.5000, 0.7184, and 0.8000 respectively. The smaller the t-value the smaller difference that exists between the two techniques. The p-values of each parameter for Nitrogen, Potassium, pH, and moisture were 0.5122, 0.4685, 0.6433, and 0.6965 which is higher than 0.05. This shows that there is no significant difference statistically. This implies that the collected data from both manual and automated testing for Nitrogen, Potassium, pH, and moisture in loam soil were identical to each other.

However, for Phosphorus, it reflected a relatively large mean difference of 10.6667 with a t-value of 3.2000, resulting in a p-value of 0.0329 which is less than 0.05 thus implying that there is a significant difference between the collected data in both testing techniques as phosphorus values from manual testing and automated testing are not equal or similar to each other, having a margin of error. This error may be due to the variables present in potting mix soil such as other micronutrient values aside from the five parameters measured interfering with the reading of the phosphorus value.

The result suggests that the Portable Soil Monitoring device generally provides comparable or similar results as to the Manual Testing Method for four out of five parameters present in the Potting Mix Soil, with Phosphorus only being the outlier in collecting accurate or similar data in loam soil.

Table 5

Comparison of Acquired Data from Manual Testing and Automated Testing on Aroid Mix Soil

Parameter	N	Mean Diff.	SD of Diff.	t	df	p-value
Nitrogen	3	1.3333	1.764	0.7559	4	0.4918
Phosphorus	3	2.3333	2.186	1.0675	4	0.3459
Potassium	3	3.3333	7.333	0.4545	4	0.6730
pH	3	0.3333	0.667	0.5000	4	0.6433
Moisture	3	0.0367	0.009	4.1576	4	*0.0142

Note. Aroid Mix Soil. The result is not significant at $p < .05$.

Table 5 presents the results of an independent t-test comparing the Portable Soil Monitoring Device and Manual Testing Method's measurements for the five parameters: Nitrogen, Phosphorus, Potassium, pH, and Moisture in Aroid Mix Soil.

The t-value for Potassium in Aroid Mix soil displayed the smallest value of 0.4545 followed by pH, Nitrogen, and Phosphorus with values of 0.5000, 0.7559, and 1.0675 respectively. The smaller the t-value the smaller difference that exists between the two techniques. The p-values of each parameter for Nitrogen, Phosphorus, Potassium, and pH were 0.4918, 0.3459, 0.6730, and 0.6433 which is higher than 0.05. This shows that there is no significant difference statistically. This implies that the collected data from both manual and automated testing for Nitrogen, Phosphorus, Potassium, and pH in aroid mix soil were identical to each other.

However, for Moisture, it reflected a relatively large t-value of 4.1576, resulting in a p-value of 0.0142 which is less than 0.05 thus implying that there is a significant difference between the collected data in both testing techniques as moisture values from manual testing and automated testing are not equal or similar to each other, having a margin of error. This error may be due to the variables present in aroid mix soil such as other micronutrient values aside from the five parameters measured interfering with the reading of the moisture content.

The result suggests that the Portable Soil Monitoring device generally provides comparable or similar results as to the Manual Testing Method for four out of five parameters present in the Aroid Mix Soil, with Moisture only being the outlier in collecting accurate or similar data in loam soil.

From the results of the statistical test from the data collected in assessing the accuracy of the portable soil monitoring device in terms of measuring five soil parameters: Nitrogen, Phosphorus, Potassium, pH, and Moisture content, the results suggest that the Portable Soil Monitoring device generally provides comparable or similar results as to the Manual Testing Method. In each soil sample, four out of five parameters were measured to have no significant difference between values collected in both testing techniques. Subsequently, each soil sample had one outlier namely phosphorus and moisture content, with phosphorous being the most frequent. These outliers may originate from the inaccurate reading brought by extraneous variables present in each soil type, affecting the interpretation of the Arduino probe sensors. Additionally, it may also come from an error in the interpretation of the device internally, hence having one out of five micronutrients have a relatively different value from the expected data.

In summary, the automated device was able to accurately measure the majority of the five parameters in each soil type. For Nitrogen, Potassium, and pH, the null hypothesis ($H0_2$) failed to be rejected given that each soil type had no significant difference between the values of both data collection techniques, hence making the automation reliable in measuring these soil content. In terms of Moisture, two out of three soil types had no significant difference in terms of data from both techniques hence failing to reject the null hypothesis ($H0_2$), signifying that there is no significant difference between the expected and observed soil content values. However, for phosphorus, two out of three soil types had a significant difference in data from both testing techniques thus accepting the alternative hypothesis ($H0_2$) that there is a significant difference between the manual and automated testing. This implies that the automation needs to improve its phosphorus reading as it may not be fully accurate.

Time Efficiency of the Soil Monitoring Device

Table 6

Comparison of time efficiency between Manual Testing and Automated Testing on Loam Soil

Parameter	N	Mean Diff.	SD of Diff.	t	df	p-value
Nitrogen	3	44.8333	0.042	1068.9032	4	*0.0001
Phosphorus	3	30.3333	0.042	723.1985	4	*0.0001
Potassium	3	30.2889	0.044	681.5170	4	*0.0001
pH	3	30.2889	0.044	681.5170	4	*0.0001
Moisture	3	0.73889	0.044	16.6254	4	*0.0001

Note. The result indicates there is a large significant difference in the time efficiency between the Manual Testing and Automated Testing on Loam Soil.

The table above provides a detailed comparison between manual testing and automated testing, specifically focusing on their ability to display data quickly for loam soil. Five critical parameters were assessed in this analysis: nitrogen content, phosphorus content, potassium content, pH level, and moisture content. By evaluating the differences in data presentation between the two methods, the study aimed to determine whether automated testing offered any significant improvements in time efficiency compared to traditional manual testing by using individual t-tests for statistical analysis.

Nitrogen displayed the highest mean difference of 44.8333, with a t-value of

1068.9032 and a p-value of 0.0001, indicating a highly significant variation. Similarly, phosphorus had a mean difference of 30.3333, accompanied by a t-value of 723.1985 and a p-value of 0.0001. Both potassium and pH exhibited mean differences of 30.2889, with identical t-values of 681.5170 and p-values of 0.0001, further confirming their statistical significance. Moisture, while showing a smaller mean difference of 0.73889, still yielded a significant t-value of 16.6254 and a p-value of 0.0001. The 0.0001 p-value across all parameters are extremely low compared to the conventional threshold of 0.05 (0.0000001327 to 0.0000004362) which indicates that the differences are highly significant and unlikely to be attributed to random variation, further supporting the conclusion that automated testing yields distinct results faster from those obtained manually. reject the H0 (subscript 1/2)

Table 7

Comparison of time efficiency between Manual Testing and Automated Testing on Potting Mix Soil

Parameter	N	Mean Diff.	SD of Diff.	t	df	p-value
Nitrogen	3	40.3444	0.015	2744.8174	4	*0.0001
Phosphorus	3	30.3444	0.015	2064.4716	4	*0.0001
Potassium	3	30.3056	0.020	1513.0612	4	*0.0001
pH	3	30.3056	0.020	1513.0612	4	*0.0001
Moisture	3	0.76667	0.017	45.9998	4	*0.0001

Note. The result indicates there is a large significant difference in the time efficiency between the Manual Testing and Automated Testing on Potting Mix Soil.

Similarly to Table 6, the table above compares the time efficiency between manual testing and automated testing, this time focusing on potting mix soil. The statistical analysis employed independent t-test to determine significant differences across five critical parameters: nitrogen, phosphorus, potassium, pH level, and moisture content.

Nitrogen displayed the highest mean difference of 40.3444, with a t-value of 2744.8174 and a p-value of 0.0001, indicating a highly significant variation. Similarly, phosphorus had a mean difference of 30.3444, accompanied by a t-value of 2064.4716 and a p-value of 0.0001. Both potassium and pH exhibited mean differences of 30.3056, with identical t-values of 1513.0612 and p-values of 0.0001, further confirming their statistical significance. Moisture, while showing a smaller mean difference of 0.76667, still yielded a significant t-value of 45.9998 and a p-value of 0.0001. The 0.0001 p-value across all parameters are extremely low compared to the conventional threshold of 0.05 (0.0000001327 to 0.0000004362) This analysis highlights a large significant difference between manual testing and automated testing. This result implies that automated testing through the prototype is comparable to that of manual testing on displaying accurate data quickly.

Table 8

Comparison of Time Efficiency between Manual Testing and Automated Testing on Aroid Mix Soil

Parameter	N	Mean Diff.	SD of Diff.	t	df	p-value
Nitrogen	3	40.3167	0.042	961.1727	4	*0.0001
Phosphorus	3	30.3167	0.042	722.7669	4	*0.0001
Potassium	3	30.2833	0.042	722.0064	4	*0.0001
pH	3	30.2833	0.042	722.0064	4	*0.0001
Moisture	3	0.7500	0.042	17.8818	4	*0.0001

Note. The result indicates there is a large significant difference in the time efficiency between the Manual Testing and Automated Testing on Aroid Mix Soil.

To further validate the prototype's accuracy, the researchers extended their testing to include aroid soil mix, comparing manual and automated testing. The table above presents the statistical results for five key parameters: nitrogen, phosphorus, potassium, pH, and moisture content. Using a Individual T-test for analysis, the results reveal significant differences between the two testing methods across all parameters.

Nitrogen displayed the highest mean difference of 40.3167, with a t-value of 961.1727 and a p-value of 0.0001, indicating a highly significant variation. Similarly, phosphorus had a mean difference of 30.3167, accompanied by a t-value of 722.7669 and a p-value of 0.0001. Both potassium and pH exhibited mean differences of 30.2833, with identical t-values of 722.0064 and p-values of 0.0001, further confirming their statistical significance. Moisture, while showing a smaller mean difference of 0.75, still yielded a significant t-value of 17.8818 and a p-value of 0.0001.

These findings highlight the time efficiency provided by automated testing compared to manual methods. The extremely low p-values across all parameters indicate that the observed differences are unlikely to be due to random variation. This highlights the reliability and benefits of automated testing for precise soil analysis, reinforcing its value in agriculture and environmental management.

In summary, the Portable Soil Monitoring Device demonstrated exceptional efficiency in reducing the time required for soil analysis, specifically in measuring macronutrient levels (nitrogen, phosphorus, and potassium), pH levels, and moisture content after acquiring an extremely low p-value of 0.0001 on each parameter. This low p-value indicates that there is a significant difference between manual and automated testing in terms of time efficiency, therefore failing to reject the null hypothesis ($H0_1$). Traditional manual testing methods, which typically require approximately three hours to complete, were significantly accelerated by the prototype. Based on Dattatreya et al. (2024) study and the results for time efficiency, it is proven that through its automated processes and integrated sensor technology, the device was capable of gathering and displaying accurate data within a timeframe of 50 seconds to one minute. This result was accurate to a study conducted by this substantial reduction in testing duration not only enhances operational efficiency but also facilitates real-time decision-making in agricultural and environmental management. The device's ability to provide rapid and reliable data underscores its potential as a practical and scalable solution for soil monitoring in both research and field applications.

Portability of the Soil Monitoring Device

Portability is the ability to transfer one object from one location to another. It can also be carried. A portable device can be easily carried designed to be held and used in the hands and operate on battery capacity (Sierra Software Ltd, 2020). The device with the dimensions: Length - 14.5cm, Width - 7.5cm, and Height - 8.8cm, is portable in the terms mentioned as it is small enough to become a handheld device. The created casing for the said device makes it easier for the product to be transported to different locations.

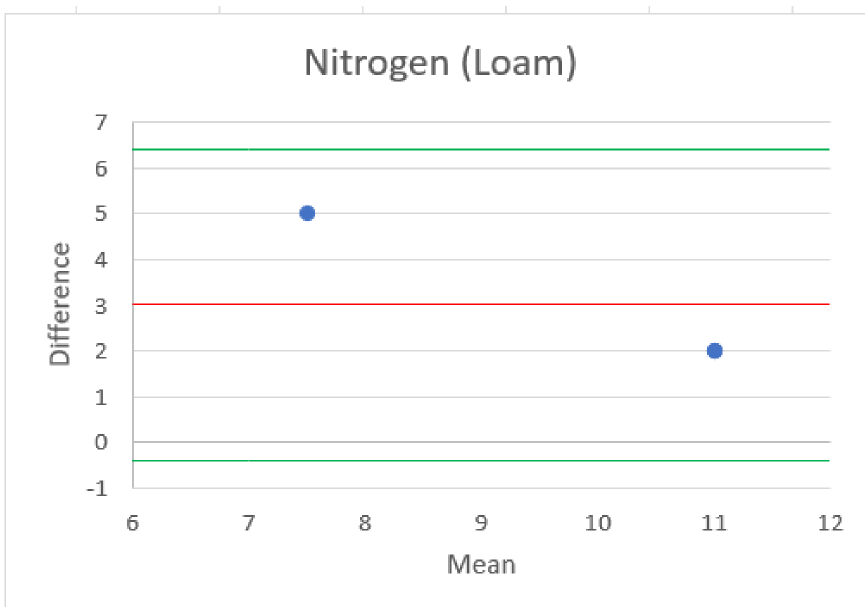
Another aspect of portability is its reliance on other devices for it to function like computers and Electric Outlets. A similar study was conducted by Kumar Et al (2024) that assessed the accuracy and feasibility of the Soil Monitoring Sensors and Arduino, indicating that due to its reliance on computers for their power source, Portability is one of the weaknesses they had identified in their product. This research solved the problem by using a 9V battery to power the system. Additionally, an LCD screen was integrated into the device to show the values detected by the Soil Monitoring Sensors to eliminate the need for computers to display the data from the soil.

In terms of comparison to patents 1, 2, and 3, the portable soil monitoring device was able to function and work based on its expected and observed functionality. It exhibited generally accurate results for each soil parameter: Nitrogen, Phosphorus, Potassium, pH, and Moisture content which each patent lacked as they only monitored one soil parameter. For its characteristics, it was able to apply an LCD alongside an enclosure which the majority of the patents lacked to keep its components from being easily damaged while it is used to monitor soil content without the interference of any external aid for power, display, and safety.

Difference of the two Measuring Techniques

Figure 5

Comparison of the Nitrogen data obtained from manual and automated testing methods across loam soil in three trials.

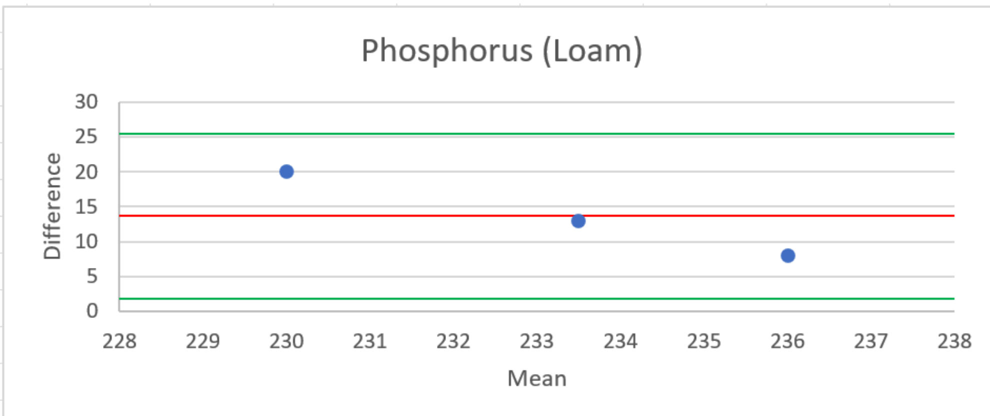


Note. The plot indicates that the data for Nitrogen in Loam soil are similar in both Manual and Automated testing.

The Bland-Altman Plots above provide a visual representation of how the data obtained in the loam soil using manual and automated testing is similar. The red line represents the mean line or bias analysis, which is close to 0, indicating that the manual and automated testing results in nitrogen have similarities when it comes to the data obtained. The data points for nitrogen testing are close to the mean line which signifies that the data obtained from the two measuring techniques is very similar. The green line on the other hand represents the limits of agreement in which it presents the range of how the parameters are likely to fall in the confidence interval of 95%. The limits of agreement have been relatively narrow, and most of the differences in data collected fall in the acceptable range. This indicates that the automated device is generally consistent with the manual testing method in measuring nitrogen present in loam soil.

Figure 6

Comparison of the Phosphorus data obtained from manual and automated testing methods across loam soil in three trials.

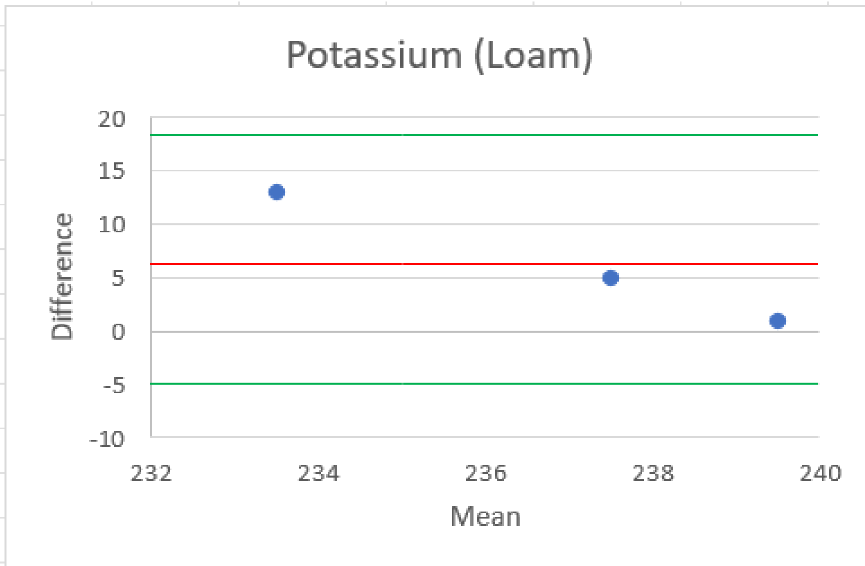


Note. The plot indicates that the data for Phosphorus in Loam soil are similar in both Manual and Automated testing.

Similar with Figure 5, The data points for phosphorus testing are close to the mean line which signifies that the data obtained from the two measuring techniques is very similar. All data points fall within the 95% confidence interval which indicates that the automated device is generally consistent with the manual testing method in measuring nitrogen present in loam soil.

Figure 7

Comparison of the Potassium data obtained from manual and automated testing methods across loam soil in three trials.

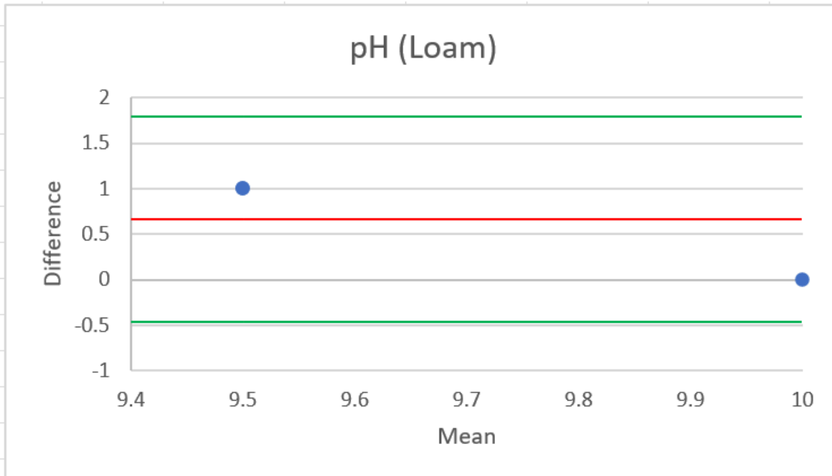


Note. The plot indicates that the data for Potassium in Loam soil are similar in both Manual and Automated testing.

Similar with Figure 6, the data points for potassium testing are close to the mean line which signifies that the data obtained from the two measuring techniques is very similar. All data points fall within the 95% confidence interval which indicates that the automated device is generally consistent with the manual testing method in measuring nitrogen present in loam soil.

Figure 8

Comparison of the pH data obtained from manual and automated testing methods across loam soil in three trials.

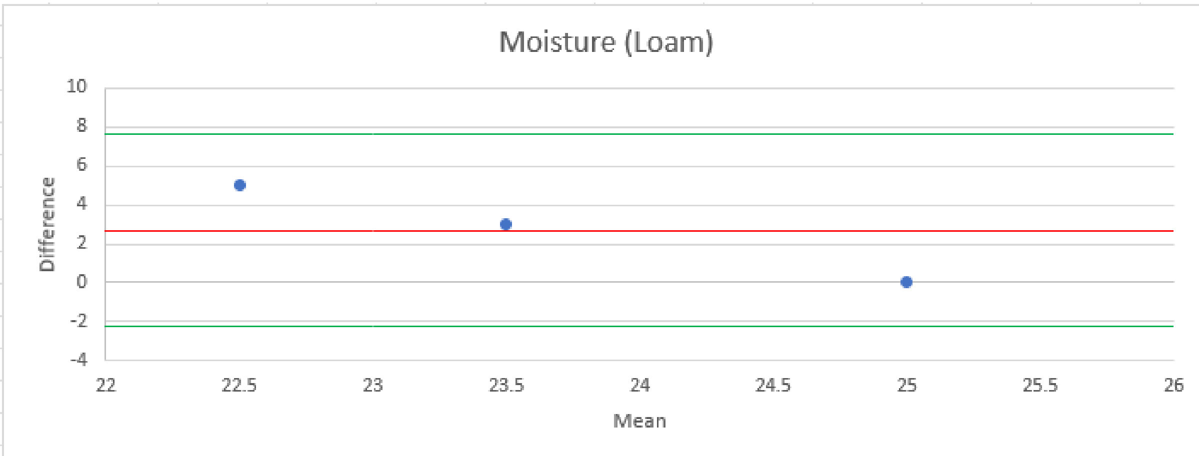


Note. The plot indicates that the data for pH level in Loam soil are similar in both Manual and Automated testing.

Similar with Figure 7, The data points for pH level testing are close to the mean line which signifies that the data obtained from the two measuring techniques is very similar. All data points fall within the 95% confidence interval which indicates that the automated device is generally consistent with the manual testing method in measuring nitrogen present in loam soil.

Figure 9

Comparison of the Moisture data obtained from manual and automated testing methods across loam soil in three trials.



Note. The plot indicates that the data for Moisture content in Loam soil are similar in both Manual and Automated testing.

Similar with Figure 8, The data points for moisture content testing are close to the mean line which signifies that the data obtained from the two measuring techniques is very similar. All data points fall within the 95% confidence interval which indicates that the automated device is generally consistent with the manual testing method in measuring nitrogen present in loam soil.

In summary, the data points of manual and automated testing proves that they were consistent and accurate. With this, the null hypothesis ($H0_2$) was failed to reject due to data points exhibiting similarities between two types of measurement, indicating that the automated device is generally consistent with the manual testing method in measuring the soil nutrients present in loam soil. To further understand the consistency of the automated testing setup, you may visit Appendix B to understand the graphs for Potting mix and Aroid mix soil.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

The experimentation conducted on the Portable Soil Monitoring Device led to a comprehensive conclusion emphasizing its functionality, accuracy, efficiency, and portability. In terms of functionality, the device operated as expected across all 50 trials, with each component—including the LCD screen, NPK sensor, pH sensor, moisture sensor probes, and the device circuit—working consistently and reliably. This confirmed that the system was well-integrated and capable of providing real-time soil analysis without any technical failure throughout the testing phase.

Regarding accuracy, the data gathered by the device was consistent and aligned with results obtained through manual testing methods. Measurements for nitrogen (N), phosphorus (P), potassium (K), pH levels, and soil moisture content showed no significant deviations, with all results falling within or overlapping the 95% confidence interval of the manually collected data. This high level of agreement confirmed that the device could reliably replicate the precision of standard laboratory testing methods.

In terms of efficiency, the Portable Soil Monitoring Device dramatically reduced the time required to test and obtain soil data. While manual testing could take up to three hours to complete, the device delivered accurate readings in just 50 seconds to one minute. This substantial reduction in testing time highlights its potential to streamline soil analysis processes in both research and fieldwork settings.

As for portability, the device was successfully designed to meet the criteria of being lightweight, handheld, and easy to transport. It operated independently without needing external power sources or support systems, making it suitable for use in remote or off-grid locations. Its compact design and ease of mobility enhance its usability, especially for agricultural workers, researchers, and field technicians who require on-the-go soil diagnostics.

The experimentation yielded significant findings regarding the performance of the Portable Soil Monitoring Device. In terms of functionality, the device demonstrated reliable operation, with all components—including the LCD screen, NPK, pH, and moisture sensor probes, as well as the device circuit—performing as intended. Regarding accuracy, the data obtained from the device showed strong consistency with results from manual testing methods for nitrogen, phosphorus, potassium, pH, and moisture levels. Additionally, the device exhibited notable efficiency, significantly reducing the time required for testing and data collection compared to traditional methods. To sum up, the device proved to be a reliable and efficient tool for soil analysis.

Recommendation

Based on the observations and conclusions obtained throughout the experimentation, the following recommendations are humbly recommended:

1. Share the knowledge and encourage the utilization of this device to the following beneficiaries:
    1.1. Agricultural Communities, to help in the planning and implementation stage of their plantation and harvestry to maximize their time efficiency.
    1.2. Farmers, aid in providing proper treatment to their crops' soils to ensure their great quality and growth.
    1.3. Geodetic Engineers, to assist in quicker price assessments of land properties.
    1.4. Indoor Gardeners, keep track of the conditions of their plant's soil, ensuring its healthy growth.
2. Adopt a different Microcontroller board such as Arduino Nano and ESP32 to allow a more compact casing design and additional features such as Wi-Fi and Bluetooth connectivity.
3. Utilize a different sensor that would exhibit additional useful properties such as Temperature and Electrical conductivity and allow a more compact casing design.
4. Swap out ½ Breadboards for a custom-made PCB to create a permanent and reliable connection for all the components to ensure a robust structure that can help withstand any conditions that may wear the device.

5. Create an alternative source of power for all the components for the following reasons:
    5.1. To not easily wear off the power pins of the microcontroller board
    5.2. Supply a higher amount of power throughout the whole device.
    5.3. Enable rechargeability and remove the device's dependency on disposable batteries
6. Take advantage of the advanced features that other types of display technology have to offer like an Organic Light-Emitting Diode (OLED) screen which provides a better viewing angle, color vibrancy, color contrast, and energy efficiency with darker images for a better User Interface.
7. To accurately determine the functionality of the device, meet the minimum 50 trials or sample size for Chi Square Goodness of Fit Test.

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APPENDICES

APPENDIX A

Tables for Raw Data

Table 9

Manual and Automated Testing Raw Data Table for Loam soil

Loam Soil								
Manual Testing				**Automated Testing**				
Trials	**Nutrient**	**Data**	**Time**	**Trials**	**Functioning**	**Nutrient**	**Data**	**Time**
Trial 1	Nitrogen	10 mg/L	45 mins	**Trial 1**	Yes	Nitrogen	12 mg/L	15 secs
	Phosphorus	240 mg/L	30 mins and 30 secs			Phosphorous	232 mg/L	15 secs
	Potassium	240 mg/L	30 mins and 30 secs			Potassium	235 mg/L	18 secs
	pH	10	30 mins and 30 secs			pH	9	18 secs
	Moisture	25%	1 min			Moisture	22%	21 secs
Trial 2	Nitrogen	10 mg/L	45 mins	**Trial 2**	Yes	Nitrogen	5 mg/L	7 secs

	Phosphorus	240 mg/L	30 mins and 30 secs			Phosphorous	227 mg/L	7 secs
	Potassium	240 mg/L	30 mins and 30 secs			Potassium	242 mg/L	10 secs
	pH	10	30 mins and 30 secs			pH	9	10 secs
	Moisture	25%	1 min			Moisture	25%	13 secs
Trial 3	Nitrogen	10 mg/L	45 mins	**Trial 3**	Yes	Nitrogen	12 mg/L	8 secs
	Phosphorus	240 mg/L	30 mins and 30 secs			Phosphorous	220 mg/L	8 secs
	Potassium	240 mg/L	30 mins and 30 secs			Potassium	239 mg/L	10 secs
	pH	10	30 mins and 30 secs			pH	10	10 secs
	Moisture	25%	1 min			Moisture	20%	13 secs

Table 10

Manual and Automated Testing Raw Data Table for Potting Mix soil

Potting Mix Soil								
Manual Testing				**Automated Testing**				
Trials	**Nutrient**	**Data**	**Time**	**Trials**	**Functioning**	**Nutrient**	**Data**	**Time**
Trial 1	Nitrogen	10 mg/L	40 mins and 30 secs	**Trial 1**	Yes	Nitrogen	8 mg/L	11 secs
	Phosphorus	59 mg/L	30 mins and 30 secs			Phosphorous	45 mg/L	11 secs
	Potassium	240 mg/L	30 mins and 30 secs			Potassium	246 mg/L	14 secs
	pH	9	30 mins and 30 secs			pH	10	14 secs
	Moisture	40%	1 min			Moisture	45%	16 secs
Trial 2	Nitrogen	10 mg/L	40 mins	**Trial 2**	Yes	Nitrogen	10 mg/L	8 secs

			and 30 secs					
	Phosphorus	59 mg/L	30 mins and 30 secs			Phosphorous	45 mg/L	8 secs
	Potassium	240 mg/L	30 mins and 30 secs			Potassium	246 mg/L	10 secs
	pH	9	30 mins and 30 secs			pH	8	10 secs
	Moisture	40%	1 min			Moisture	44%	13 secs
Trial 3	Nitrogen	10 mg/L	40 mins and 30 secs	**Trial 3**	Yes	Nitrogen	20 mg/L	9 secs
	Phosphorus	59 mg/L	30 mins and 30 secs			Phosphorous	55 mg/L	9 secs
	Potassium	240 mg/L	30 mins and 30 secs			Potassium	236 mg/L	11 secs

	pH	9	30 mins and 30 secs			pH	10	11 secs
	Moisture	40%	1 min			Moisture	35%	13 secs

Table 11

Manual and Automated Testing Raw Data Table for Aroid Mix soil

Aroid Mix Soil								
Manual Testing				**Automated Testing**				
Trials	**Nutrient**	**Data**	**Time**	**Trials**	**Functioning**	**Nutrient**	**Data**	**Time**
Trial 1	Nitrogen	10 mg/L	40 mins and 30 secs	**Trial 1**	Yes	Nitrogen	8 mg/L	16 secs
	Phosphorus	20 mg/L	30 mins and 30 secs			Phosphorous	18 mg/L	16 secs
	Potassium	240 mg/L	30 mins and 30 secs			Potassium	244 mg/L	18 secs
	pH	9	30 mins			pH	10	18 secs

			and 30 secs					
	Moisture	20%	1 min			Moisture	22%	20 secs
Trial 2	Nitrogen	10 mg/L	40 mins and 30 secs	**Trial 2**	Yes	Nitrogen	14 mg/L	8 secs
	Phosphor us	20 mg/L	30 mins and 30 secs			Phosphor ous	24 mg/L	8 secs
	Potassiu m	240 mg/L	30 mins and 30 secs			Potassiu m	222 mg/L	10 secs
	pH	9	30 mins and 30 secs			pH	8	10 secs
	Moisture	20%	1 min			Moisture	25%	12 secs
Trial 3	Nitrogen	10 mg/L	40 mins and 30 secs	**Trial 3**	Yes	Nitrogen	12 mg/L	9 secs
	Phosphor us	20 mg/L	30 mins and 30			Phosphor ous	25 mg/L	9 secs

			secs					
	Potassium	240 mg/L	30 mins and 30 secs			Potassium	244 mg/L	11 secs
	pH	9	30 mins and 30 secs			pH	8	11 secs
	Moisture	20%	1 min			Moisture	24%	13 secs

APPENDIX B

Bland-Altman Plot for Potting mix and Aroid mix Soils

Figure 10

Comparison of the Nitrogen data obtained from manual and automated testing methods across Potting Mix soil in three trials.

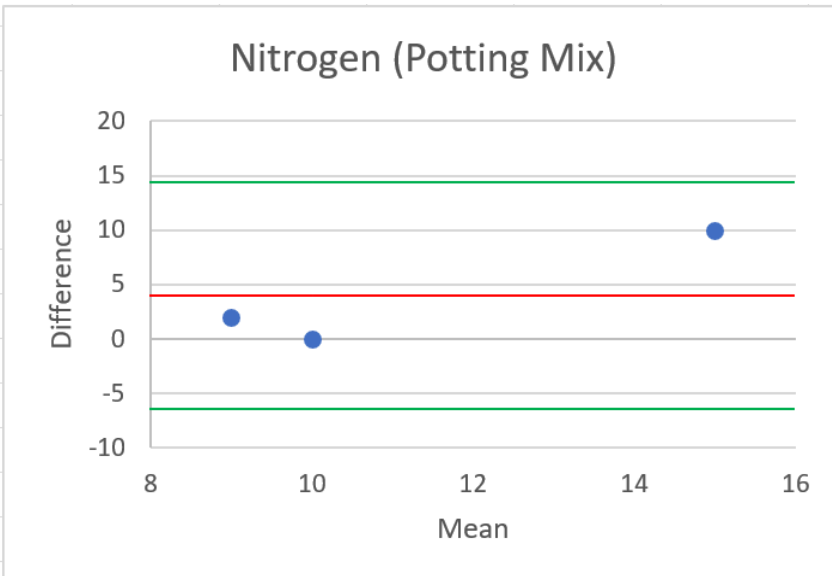


Figure 11

Comparison of the Phosphorus data obtained from manual and automated testing methods across Potting Mix soil in three trials.

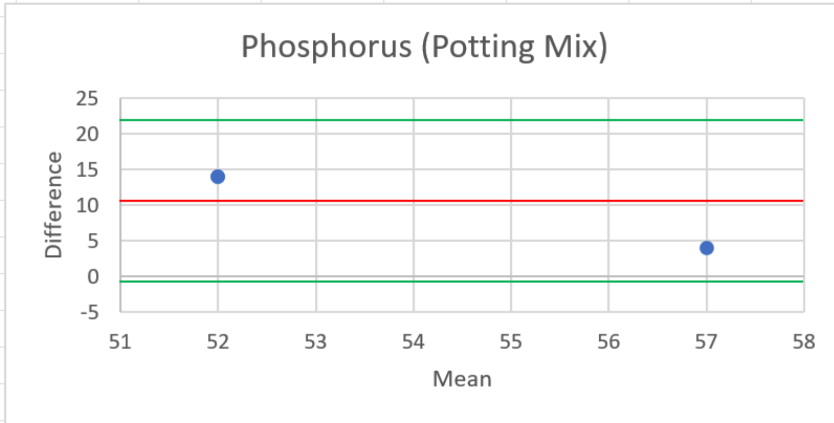


Figure 12

Comparison of the Potassium data obtained from manual and automated testing methods across Potting Mix soil in three trials.

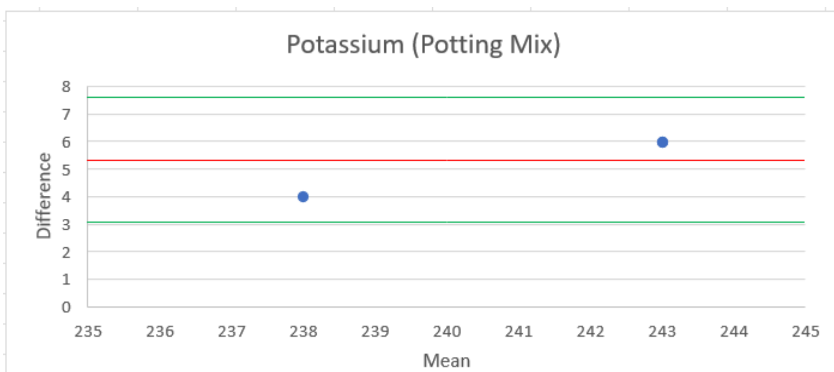


Figure 13

Comparison of the pH data obtained from manual and automated testing methods across Potting Mix soil in three trials.

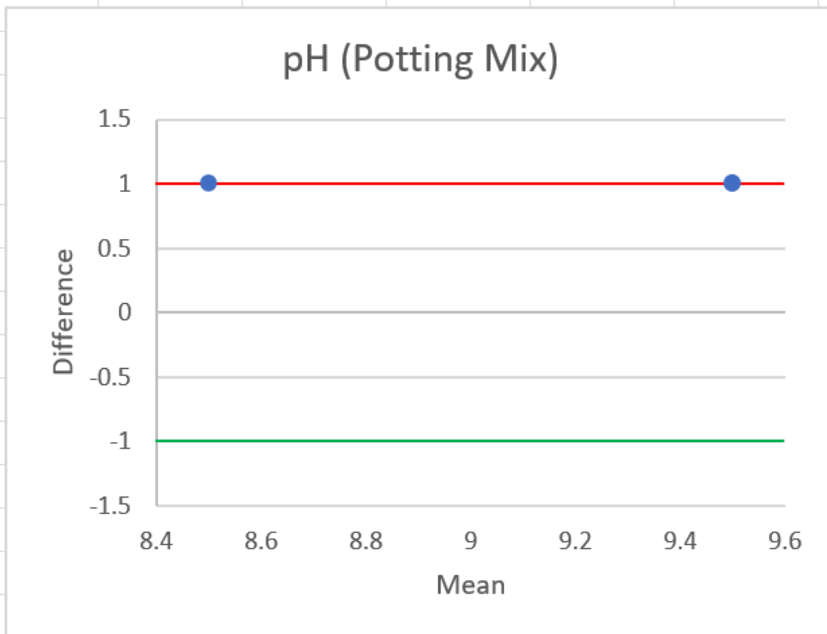


Figure 14

Comparison of the Moisture data obtained from manual and automated testing methods across Potting Mix soil in three trials.

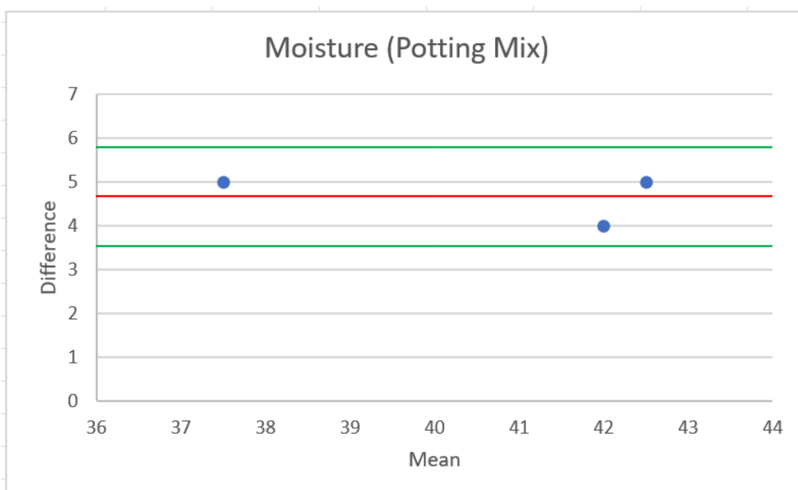


Figure 15

Comparison of the Nitrogen data obtained from manual and automated testing methods across Aroid soil in three trials.

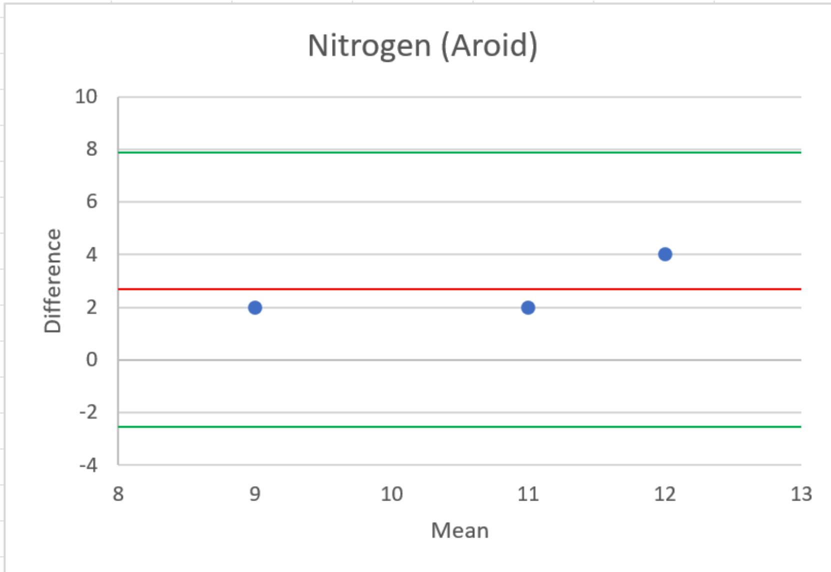


Figure 16

Comparison of the Nitrogen data obtained from manual and automated testing methods across Aroid soil in three trials.

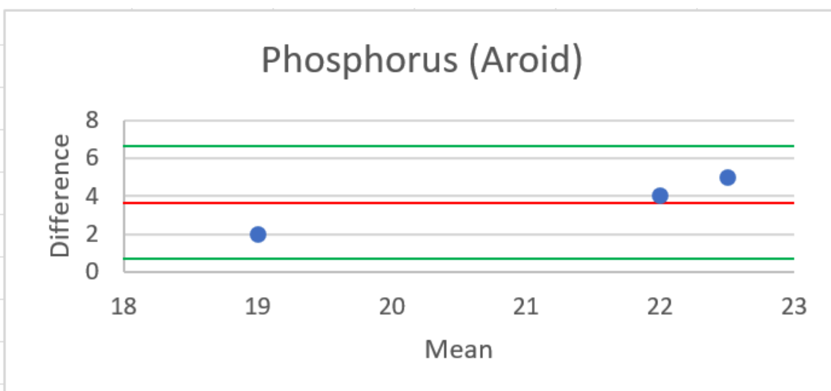


Figure 17

Comparison of the Potassium data obtained from manual and automated testing methods across Aroid soil in three trials.

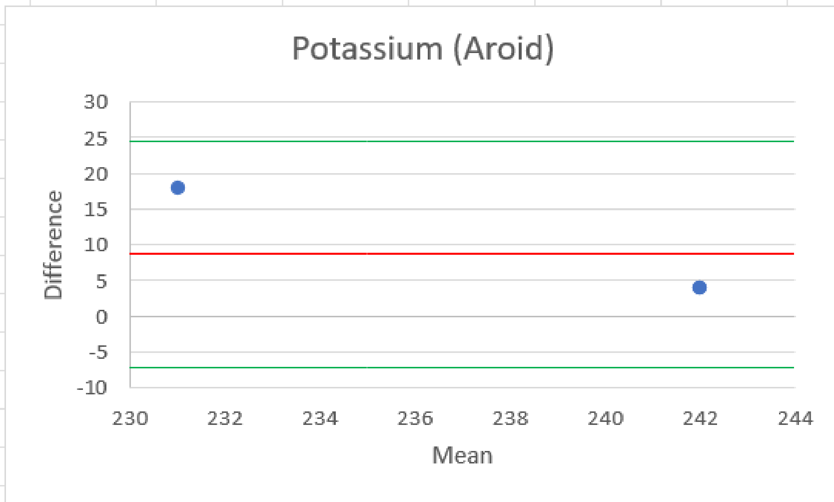


Figure 18

Comparison of the pH data obtained from manual and automated testing methods across Aroid soil in three trials.

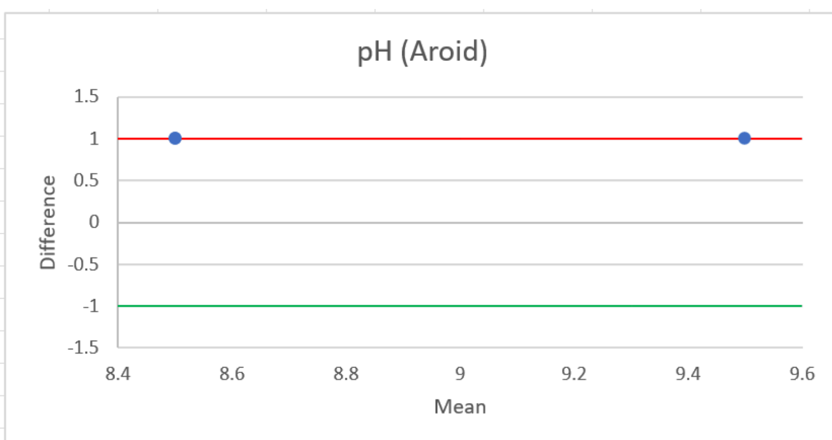
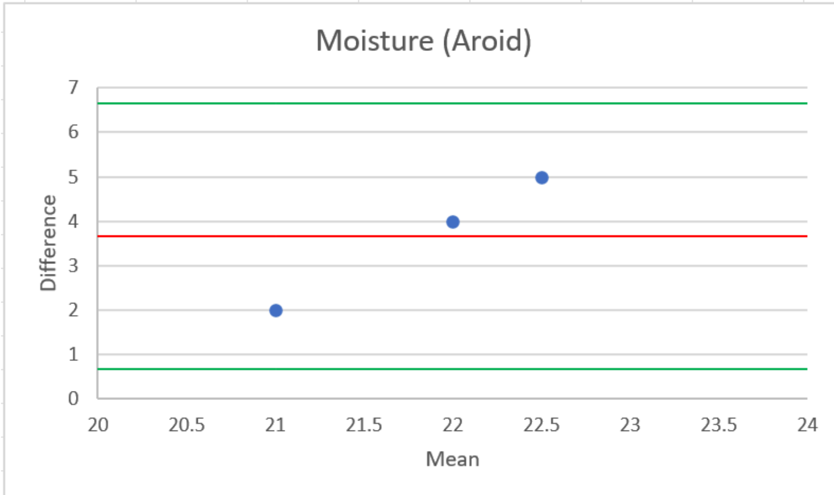


Figure 19

Comparison of the Moisture data obtained from manual and automated testing methods across Aroid soil in three trials.


Moisture (Aroid)
Difference
0
1
2
3
4
5
6
7
20
20.5
21
21.5
22
22.5
23
23.5
24
Mean

APPENDIX C

Budget Plan

Table 12

Budget Plan

Materials	Quantity	Price
RS485 Sensor	1	PHP 3,000
MAX485 Modbus Module	1	PHP 85
Soil	3	PHP 114
Soil Testing Kit	1	PHP 340
Arduino Nano	1	PHP 400
Foam Board	1	PHP 420
½ Breadboard	2	PHP 190
9v Battery	1	PHP 50
		PHP 4,599

APPENDIX D

Gantt Chart

Figure 20

Gantt Chart

Months	**Aug**	**Sep**				**Oct**				**Nov**				**Dec**				**Jan**			
Weeks	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Topic 1																					
Topic 2																					
Topic 3																					
Last Topic																					
Topic Proposal																					
Chapter 1-3																					
Revision for																					

Chapter 1-3																					
Topic Defense																					
Revision based on comments																					
Material Collection																					
Approval Forms																					
Creation of Prototype																					
Coding																					
Testing																					
Chapter 4-5																					
Revision																					

for Chapter 4-5																					
Final Defense																					
Final Revision																					

APPENDIX E

Approval Forms for Laboratory

Appendix C - MSHS Form A

Application of MSHS students to conduct experiments at MSHS Laboratory.

Name of Students: Besas, Luke Andrei M. Gener, Sean Lugene R. Kawamura, Takayuki V. Luzano, Jun P. Tabian, Kassandra Andrea P.	Grade Level and Section: 12 - Del Mundo Contact Numbers: 09464138400 09169381145 09167428007 09612110980 09051683290
Purpose: Research Experimentation	Class Time: 1:40 PM - 4:00 PM
Name of Research Adviser: Ma. Cecilia D. Rollon	Contact Number: 09173006062

<table>
<tr><td colspan="2">Student/s Responsibilities:

1. I/We will strictly observe the laboratory rules and guidelines.
2. I/We will conduct our school experiment at MSHS Laboratory only in the presence and supervision of my/our teacher.
3. I/We accept the responsibility for any loss or damage of equipment that we are permitted to handle during the conduct of the experiments and/or related activities.
4. I/We are liable for payment/replacement of the said damages and pay other charges that are deemed necessary to restore the working condition of the equipment.
5. I/We accept the responsibility for proper treatment and disposal of wastes generated during the conduct of my/our experiment at MSHS Research Center.</td></tr>
<tr><td colspan="2">CONFORME: Ma. Cecilia D. Rollon</td></tr>
<tr><td>Student(s):</td><td>Research Adviser or Representative:</td></tr>
<tr><td>(1) Besas, Luke Andrei M.

(2) Gener, Sean Lugene R.

(3) Kawamura, Takayuki V.

(4) Luzano, Jun P.

(5) Tabian, Kassandra Andrea P.</td><td>Ma. Cecilia D. Rollon</td></tr>
<tr><td>APPROVED:</td><td>NOTED:</td></tr>
</table>

<table>
<tr><td>Maria Milabelle A. Dela Masa

Laboratory In-Charge</td><td rowspan="2">OWEN B. OMBID, PhD

Officer In-Charge, Principal</td></tr>
<tr><td>Michelle Z. Yakit,

Science Department Head</td></tr>
</table>

Appendix D

Makati Science High School Research Center

Form B. SAFETY IN THE SCIENCE LABORATORY

To the Students:

Read, understand, and follow these safety precautions. Your signature on this sheet indicates your absolute willingness to conform with these rules:

1. Unauthorized and unsupervised work in the laboratory is NOT allowed.
2. Wear laboratory gown and safety goggles AT ALL TIMES. Contact lenses should NOT be worn. (Spectacles could be worn in place of contact lenses).
3. Know the emergency procedures and the locations of ALL nearby eye wash stations, safety shower, medicine cabinet, and fire extinguisher.
4. ALL chemicals spilled on the body should be washed immediately with

cold running water. Contaminated clothing should be removed at once.

5. Read and study each experiment and carefully plan your work before starting your experiment.
6. NO open toe shoes are allowed in the laboratory. Long hair must be tied.
7. Carefully READ labels on chemical bottles. NEVER return excess chemicals to the stock bottles.
8. DO NOT pipette chemicals directly into a reagent bottle. Instead, pour aliquot of the reagent from the stock bottle into a beaker/flask. NEVER pipette by mouth but use a pipette bulb instead.
9. Bringing of food and drinks, laptops, tablets, and bags are NOT ALLOWED inside the laboratory. Bags should be placed in a designated area outside the laboratory. The items ALLOWED inside the laboratory are LIMITED to pen, notebook, and logbook ONLY.
10. NEVER taste chemicals. Smell chemicals cautiously by wafting the vapors towards you.
11. AVOID using an open flame in the vicinity of flammable liquids.
12. Always ADD acid to water, and NOT vice-versa.
13. Cover CHEMICAL SPILL with the following appropriate clean-up material:
    a. For ACID spills - use SODIUM BICARBONATE
    b. For BASE spills - use CITRIC ACID
    c. For mercury spill - use SULFUR POWDER
14. Dispose all chemicals as directed by your
15. adviser/teacher consistent with accepted waste disposal regulations.
16. Report ALL breakages, malfunction of equipment, accidents and hazardous

conditions. IMMEDIATELY to the laboratory In-charge.

I/We have read carefully and understood all the safety rules contained on this sheet. I/We will abide fully by all the above-mentioned rules.

AFFIX YOUR SIGNATURE and the date. Retain a copy in your logbook.

Besas, Luke Andrei M. Gener, Sean Lugene R. Kawamura, Takayuki V.

Luzano, Jun P. Tabian, Kassandra Andrea P.

Date:

MA. CECILIA D. ROLLON

Name & Signature of Research Adviser

Date:

Appendix E

Date:

Dear Teachers,

Warm Greetings!

We are Grade 12 students from Del Mundo. We are now in the data collection phase of our Research and we have a scheduled laboratory experiment on December 12-13, December 19-20, 2024.

Reason for request to be excused, please

☐ check one. Our procedures are time-bound.

☐ Our samples and/or materials were only available at this date.

☐ This is the only time a teacher is available to supervise our group.

☐ Others, please specify.

____

In this regard, may we request to be excused from our classes on the said date(s).

Rest assured that we will comply with whatever requirements we might miss from this activity.

Thank you for your support.

Besas, Luke Andrei M. Gener, Sean Lugene R. Kawamura, Takayuki V.

Luzano, Jun P. Tabian, Kassandra Andrea P.

Recommending Approval:

MA. CECILIA D. ROLLON

MICHELLE Z. YAKIT

Research Adviser/Representative Head Teacher III, Science Department

Approved by:

OWEN B. OMBID, PhD

Officer In- Charge, Principal

Appendix F

Parent's Consent

In signing this form, I am allowing my child to stay at Makati Science High School to perform necessary experiments for their Research on <u>December 12-13, December 19-20, 2024</u>, from <u>1:40</u> PM to <u>4:00</u> PM under the supervision of Ms. Ma. Cecilia D. Rollon

Parent's Name: ____________________

Parent's Contact Number: ______________________

Parent's Signature: ______________________

Child's Name: ______________________

Child's Contact Number: ______________________

Child's Grade Level and Section: ______________________

Date: ______________________

APPENDIX F

Arduino Code

```
#include "SoftwareSerial.h"
#include "Wire.h"
#include <LiquidCrystal_I2C.h>

#define RE 8
#define DE 7

// Add timeouts and error flag checks
#define TIMEOUT 2000 // Timeout for sensor response in milliseconds
#define INVALID_VALUE 255 // A value that indicates an invalid reading

int getNitro();
int getPhos();
int getPota();
int getPh();
int getMo();
int values[4]; // Array to store the received values
SoftwareSerial mod(2, 3); // SoftwareSerial RX, TX pins

LiquidCrystal_I2C lcd(0x3F, 16, 2);

// General function to handle sensor reading with timeout and value range check
byte getSensorValue(byte cmd[]) {
  unsigned long startTime = millis();
  byte tempValue = INVALID_VALUE; // Default value if no valid data is read

  digitalWrite(DE, HIGH);
  digitalWrite(RE, HIGH);
  delay(10);
```

```
    if (mod.write(cmd, sizeof(cmd)) == sizeof(cmd)) {
      digitalWrite(DE, LOW);
      digitalWrite(RE, LOW);

      while (millis() - startTime < TIMEOUT) {
        if (mod.available()) {
          tempValue = mod.read();
          if (tempValue != INVALID_VALUE) {
            // Add validation to ensure the value is in a reasonable range
            if (tempValue > 0 && tempValue < 200) {  // Assume valid range
              return tempValue;
            } else {
              return INVALID_VALUE;  // Return error value if invalid range
            }
          }
        }
      }
    }

    return INVALID_VALUE;  // Return error if no valid data within timeout period
}

void setup() {
  Serial.begin(9600);
  mod.begin(9600);
  pinMode(RE, OUTPUT);
  pinMode(DE, OUTPUT);

  // Start I2C communication
  Wire.begin();

  // Initialize the LCD
  lcd.begin(16, 2);
  lcd.backlight();
  lcd.clear();

  lcd.setCursor(0, 0);
  lcd.print("Portable Soil");
```

```
  lcd.setCursor(0, 1);
  lcd.print("Monitor Device");
  delay(2500);
  lcd.clear();
}

void loop() {
  lcd.setCursor(0, 0);
  lcd.print("Calibrating.");
  delay(500);
  lcd.clear();
  lcd.print("Calibrating..");
  delay(500);
  lcd.clear();
  lcd.print("Calibrating...");
  delay(500);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Calibrating.");
  delay(500);
  lcd.clear();
  lcd.print("Calibrating..");
  delay(500);
  lcd.clear();
  lcd.print("Calibrating...");
  delay(500);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Calibrating.");
  delay(500);
  lcd.clear();
  lcd.print("Calibrating..");
  delay(500);
  lcd.clear();
  lcd.print("Calibrating...");
  delay(500);
  lcd.clear();

  int val1, val2, val3, val4, val5;
  val1 = getNitro();
  val2 = getPhos();
  val3 = getPota();
  val4 = getPh();
  val5 = getMo();
  delay(250);
```

```
lcd.setCursor(0, 0);
lcd.print("Reading Data.");
delay(500);
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Reading Data..");
delay(500);
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Reading Data...");
delay(500);
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Reading Data.");
delay(500);
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Reading Data..");
delay(500);
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Reading Data...");
delay(500);
lcd.clear();

// Print to Serial Monitor (debugging)
Serial.print("Nitrogen: ");
Serial.println(val1 == INVALID_VALUE ? "Invalid" : String(val1));
Serial.print("Phosphorous: ");
Serial.println(val2 == INVALID_VALUE ? "Invalid" : String(val2));
Serial.print("Potassium: ");
Serial.println(val3 == INVALID_VALUE ? "Invalid" : String(val3));
Serial.print("pH Level: ");
Serial.println(val4 == INVALID_VALUE ? "Invalid" : String(val4));
Serial.print("Moisture: ");
Serial.println(val5 == INVALID_VALUE ? "Invalid" : String(val5));
```

```
  delay(2000);

  lcd.clear();

  // Display on LCD
  lcd.setCursor(0, 0);
  lcd.print("N: ");
  lcd.print(val1 == INVALID_VALUE ?
"Err" : String(val1));
  lcd.print(" mg/kg");

  lcd.setCursor(0, 1);
  lcd.print("P: ");
  lcd.print(val2 == INVALID_VALUE ?
"Err" : String(val2));
  lcd.print(" mg/kg");
  delay(2500);

  lcd.clear();

  lcd.setCursor(0, 0);
  lcd.print("K: ");
  lcd.print(val3 == INVALID_VALUE ?
"Err" : String(val3));
  lcd.print(" mg/kg");

  lcd.setCursor(0, 1);
  lcd.print("pH: ");
  lcd.print(val4 == INVALID_VALUE ?
"Err" : String(val4));
  delay(2500);

  lcd.clear();

  lcd.setCursor(0, 0);
  lcd.print("Moist: ");
  lcd.print(val5 == INVALID_VALUE ?
"Err" : String(val5));
  delay(2500);

  lcd.clear();
}

int getNitro() {
  byte nitroCmd[] = { 0x01, 0x03, 0x00,
0x00, 0x00, 0x02, 0xC4, 0x0B };
```

```
  return getSensorValue(nitroCmd);
}

int getPhos() {
  byte phosCmd[] = { 0x01, 0x03, 0x00, 0x02, 0x00, 0x02, 0xC4, 0x0B };
  return getSensorValue(phosCmd);
}

int getPota() {
  byte potaCmd[] = { 0x01, 0x03, 0x00, 0x04, 0x00, 0x02, 0xC4, 0x0B };
  return getSensorValue(potaCmd);
}

int getPh() {
  byte phCmd[] = { 0x01, 0x03, 0x00, 0x06, 0x00, 0x02, 0xC4, 0x0B };
  byte phValue = getSensorValue(phCmd);

  // Check if the pH value is within the valid range of 0 to 14
  if (phValue < 0 || phValue > 14) {
    return INVALID_VALUE;
  }
  return phValue;
}

int getMo() {
  byte moCmd[] = { 0x01, 0x03, 0x00, 0x08, 0x00, 0x02, 0xC4, 0x0B };
  return getSensorValue(moCmd);
}
```

APPENDIX G

Curriculum Vitae

CURRICULUM VITAE

NAME OF RESEARCHER: Luke Andrei M. Besas

BIRTHDAY: November 9 2007

ADDRESS: 2441 Rubi St. San Andres Bukid, Manila

CONTACT NUMBER: 09166585404

EMAIL ADDRESS: luke.besamoodle@makatiscience.edu.ph

EDUCATIONAL ATTAINMENT

School Year	Institution	Level	Awards and Achievements
2019 - Present	Makati Science High School	Grade 7 - Present	With Honors
2012 - 2019	La Paz Elementary School	Grade 1 - Grade 6	With Honors

PREVIOUS RESEARCHES

- Like And Yikes: The Perspective of Private Convetional Fuel Vehicle Drivers on E-Trikes (Grade 11)
- Innovating a Thermos Comparable With Commercial Flasks in Thermal Longevity (Grade 10)

INSIGHTS

In my experience, The first of many struggles in this research is our budget. Since we arw students, it was advised to keep a budget under 5000. Even with the budget under 5000, its still hard to follow up because not all times we have the budget to pay it. Another thing is the limit is limiting. even if we did have the budget, some of our initial equipment are already expensive, limiting our options to only a few changes on our final product to avoid going over the proposed budget. After that is the creation and programming of the device itself. For me, Its hard because i was not familliar with the programming language and building an arduino product itself thats why im very thankful to Sean. Last struggle I faced, Is managing my time. I sometimes forget to give some time for the creation of research paper and other activities, i try my best to comply after our training.

CURRICULUM VITAE

NAME OF RESEARCHER: Sean Lugene R. Gener

BIRTHDAY: December 18, 2006

ADDRESS: 2460 B Camachili St. Arellano Ave. Sta. Ana, Manila

CONTACT NUMBER: 09169381145

EMAIL ADDRESS: sean.genemoodle@makatiscience.edu.ph

EDUCATIONAL ATTAINMENT

School Year	Institution	Level	Awards and Achievements
2019 - Present	Makati Science High School	Grade 7 - Present	With Honors
2012 - 2019	Palanan Elementary School	Kindergarten - Grade 6	With Honors

PREVIOUS RESEARCHES

- Lemon Peel (Citrus limon) Pectin and Cornstarch as Citrus-Infused Bioplastic
- FriYAY or NAY? Perception of MSHS on the National Reading Program being Catch-Up Fridays

INSIGHTS

Quantitative research back in my junior high school years has been the hardest one I've dealt with until the day I met Qualitative research. To make it a bit more challenging, I was granted to lead a group. I haven't seen myself to be a leader material let alone being a research co-leader. That POV of mine changed after fulfilling my duty. This type of research is harder than the one I've dealt with before, however, I had good groupmates who always had my back when I needed to. Being a leader doesn't mean you need to do everything, it's you leading the group to success with everyone's help. Our research turned out to be successful thanks to the power of friendship.

CURRICULUM VITAE

NAME OF RESEARCHER: Takayuki V. Kawamura

BIRTHDAY: August 18, 2006

ADDRESS: The Beacon Roces Tower, Don Chino Roces, Makati City

CONTACT NUMBER: 09167428007

EMAIL ADDRESS: taka.kawamoodle@makatiscience.edu.ph

EDUCATIONAL ATTAINMENT

School Year	Institution	Level	Awards and Achievements
2023 - Present	Makati Science High School	Grade 11	With High Honors
2022 - 2023	Makati Science High School	Grade 10	With Honors
2021 - 2022	Makati Science High School	Grade 9	With High Honors
2019 - 2021	Makati Science High School	Grades 7 - 8	With Honors
2013 - 2019	Light of the World Christian Academy of Makati	Grades 1 - 6	Top 3, With High Honors

PREVIOUS RESEARCHES

- RoboTeach: Documenting the Experience and Challenges of Robotics Teachers in Maksci (Grade 11)
- Phytoremediation of Acidic Loam Soil Using Bok Choy (*Brassica rapa subsp. chinensis*) (Grade 10)
- Mangosteen Ethanolic Extract (Garcinia mangostana) and Polymerized Linseed (Linum usitatissimum) oil as an Anticorrosive Coating on Mild Steel (Grade 9)
- Extracted Ethanol from Water Lilies (Nymphaeaceae) as a Disinfectant (Grade 8)
- Garden Soil in Sandy Soil in the Growth of Eggplant (*Solanum melongena*) (Grade 7)

INSIGHTS

For my last research in MakSci, I did not expect that the field that would be given to me would still be the field of Robotics as this is where I'm least knowledgeable. This was one of the challenges that I encountered as this was my first quantitative Robotics research given that I only had experience with the category under qualitative research. This was also my most expensive study compared to my research in the past four to five years. However, I enjoyed the study from start to finish since I had group members with experience in the field alongside advisers and panelists, hence making it easier for me to lead the group. Even though I was stressed when I first saw my category, I was thankful for it since it can add to the credentials and experience that I need if ever I pursue a career in the field. My last research became memorable as it is my first and last under the category in my high school research.

CURRICULUM VITAE

NAME OF RESEARCHER: Jun P. Luzano

BIRTHDAY: September 17, 2007

ADDRESS: 167 Molave St., Cembo, Taguig City

CONTACT NUMBER: 09934299847

EMAIL ADDRESS: jun.luzamoodle@makatiscience.edu.ph

EDUCATIONAL ATTAINMENT

School Year	Institution	Level	Awards and Achievements
2019 - Present	Makati Science High School	Grade 7 - Present	With Honors
2012 - 2019	San Jose Elementary School	Grade 1 - Grade 6	With Honors

PREVIOUS RESEARCHES

- The Effects of Barangay Health Center Closures: Narratives and Perceptions of CEMBO Zone and Group Leaders (Grade 11)
- Regulating the Ripening of Carabao Mango (*Mangifera indica var. Carabao*) with Nitrogen-Doped Carbon Quantum Dots (Grade 10)

INSIGHTS

In my junior years, we conducted numerous research that is why research is not really new to me. However, I find it hard to conduct this new type of research since normally I am more suited and knowledgeable in Life Sciences or Chemistry kind of research and robotics isn't really my strong suit. The intricacies of programming, mechanical design, and electronic components are areas where I have limited experience and only the lessons from our ICT subject from grade 10 gave us a little background about programming and nothing else. Despite these challenges, our group managed to successfully conduct and complete our research project This is due to the cooperation of each member in our research.

CURRICULUM VITAE

NAME OF RESEARCHER: Kassandra Andrea P. Tabian

BIRTHDAY: January 20, 2007

ADDRESS: 457a JP Rizal St., Vergara, Mandaluyong City

CONTACT NUMBER: 09051683290

EMAIL ADDRESS: kass.tabimoodle@makatiscience.edu.ph

EDUCATIONAL ATTAINMENT

School Year	Institution	Level	Awards and Achievements
2019 - Present	Makati Science High School	Grade 7 - Present	With Honors
2013 - 2019	Francisco Benitez Elementary School - Main	Grade 1 - Grade 6	With Honors

PREVIOUS RESEARCHES

- Growth of Okra Plants using Vermiculture
- FAST: The Utilization of Arduino UNO as a Flood Alert System
- FriYAY or NAY? Perception of MSHS on the National Reading Program being Catch-Up Fridays

INSIGHTS

Conducting research, in general, has always been something I find difficult. I find the process to be time-consuming yet, fast-paced hence, I find it hard. Throughout my junior years, I've explored and conducted quantitative research therefore, I've gained enough knowledge and expertise. This year, I, along with my groupmates were given a chance to do something we hadn't done, quantitative research thus, the challenges we encountered. As we went through the process of writing and gathering data, I learned a lot and enjoyed what I was doing, a contrast to the past years of researching. Although I've always known the importance of research, this year definitely highlighted its significance and made such impact to me.