

Soil parameter detection of soil test kit-treated soil samples through image processing with crop and fertilizer recommendation

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ABSTRACT

Standard laboratory soil testing is deemed to be expensive and time-consuming. Utilizing a soil test kit is considered to be a cost-efficient and time-saving way of soil testing. This project study aims to develop a prototype that detects soil parameters (i.e., soil pH, nitrogen, phosphorus, and potassium) and gives crop and fertilizer recommendations after the soil sample has undergone a soil treatment test kit and its acceptability for possible users. The prototype development primarily used image processing to detect the needed parameters that lead to crop and fertilizer recommendations. In the evaluation of the effectiveness of the prototype, 50 trials were conducted per parameter. All of the said parameters were recorded as highly effective except for nitrogen Low, which is interpreted as effective only. There were 30 possible users invited to assess the acceptability of the prototype. A survey based on the technology acceptance model was administered to the 30 respondents garnering a 4.85 weighted mean interpreted as excellent. The prototype was proven effective and accepted as a device that can detect soil pH and primary macronutrient levels. It gives the appropriate crop and fertilizer recommendations based on the gathered data.

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1. INTRODUCTION

With 30 million hectares of land area covering the distinct archipelago, the Philippines is considered one of Asia's leading agricultural countries. The United Nations Development Program described the Philippines as a country with 'mega biodiversity'. This condition is evident in the country's vast topography, ranging from mountainous terrains, dense forests, and plains suitable for sustainable agriculture [1]. The increase in crop production is mainly dependent on soil fertility and productivity. Soil fertility primarily refers to the soil's ability to provide nutrients in a sufficient amount and appropriate quantity. In contrast, soil productivity refers to the capacity of soil to yield crops.

Hence, the correct amount of fertilizer must significantly increase farmers' yields regarding the crop they prefer. Knowing the current soil nutrient status is a prerequisite in applying the fertilizer since it dictates the correct amount of fertilizer to be applied or a need to apply fertilizer. Testing the soil is a procedure that

gathers data about the nutrient content, composition, and acidity of a particular soil sample. Furthermore, testing of the soil can assure soil fertility and soil productivity [2], [3].

There are various methods of testing the soil. One of these ways is through utilizing soil test kit (STK). It is a qualitative method of determining soil pH and primary macronutrients: nitrogen, phosphorus, and potassium (NPK). STK uses color matching to determine the acidity and nutrient contents of the soil. Thus, this type of method is mainly dependent on the color matching ability of the user [4]-[6]. The most accurate process of testing is through laboratory tests. However, soil laboratories can be done with proper equipment and facilities and takes too long to perform. The process usually takes ten days to complete the soil sample's complete analysis [7], [8].

Nevertheless, there is no straightforward, cost-efficient, and dependable technology obtainable to establish the macronutrient contents and acidity of soil that ordinary farmers can utilize on a timely basis [9]. For these reasons, this project study aims to develop a prototype that can solve these existing problems through image processing. Moreover, the prototype recommends the correct proportion of fertilizer upon completing the STK procedures.

- Detection of soil pH level and soil macronutrient

This section discusses the importance of detecting the soil pH level and soil macronutrients, namely NPK. Several studies [10]-[12] stated that it is necessary for the correct amount of fertilizer needed by the soil for crop production. There are several processes and ways for soil pH level and soil macronutrient detection, like optical sensing, electrochemical sensing, and soil test kits.

Optical sensing is a process of detecting the soil macronutrients by observing the energy level being absorbed by the soil. The energy level of the soil pertains to the number of soil nutrients. Optical sensing primarily uses reflectance spectroscopy. There are several types of spectroscopy used for soil nutrient detection. Near-infrared spectroscopy (NIRS) and diffuse reflectance spectroscopy were used to detect the nitrogen and pH levels. Attenuated total reflectance spectroscopy (ATR) is being used for phosphorus detection [13]-[15]. In contrast, electrochemical sensing is another process of detecting soil macronutrients by introducing voltage or current to the soil sample and observing the response of the selected ions. The reaction of the selected ions will serve as a detectable electrical signal through sensors like ion selective field effect transistor (ISFET) and ion-selective electrode (ISE). Electrochemical sensing implores the concept of pretreatment and chemical analysis [16]-[18].

Sharma and Chatterjee [19] stated that using a soil test kit is also a common and more cost-efficient way of detecting the soil macronutrients, soil pH level, and other significant soil parameters like soil salinity. The soil macronutrient and soil pH level determination under the laboratory standard process undergoes weeks to almost a month, depending on the laboratory's workload. Consequently, the farmers are hesitant to give soil samples to laboratories because of time constraints, not to mention the laboratories' fees. Therefore, farmers resort to methods that save them time and measures to cut some costs. Farmers choose STKs for their determination of soil macronutrients and soil pH levels.

In the development of the prototype, it will primarily use an STK that is readily available. The use of STKs is an efficient way to determine the soil macronutrients and soil pH levels than the complex processes offered by optical sensing methods and electrochemical sensing methods. Furthermore, the said methods use bulky apparatuses, making it a lesser option for farmers and not giving in-situ results.

- Image processing and OpenCV

This section showcases several related studies that utilized image processing and OpenCV. Image processing gives technological advances in several science disciplines like medical sciences, geological sciences, and especially in agricultural sciences. Image processing serves as a tool for objective visual interpretation of a given image. Several applications include color recognition, digital photography, automatic character recognition, remote sensing, and reconnaissance [20], [21].

Khan *et al.* [22] utilizes an Image processing technique known as Image Segmentation. The primary input in this study is the tuberculosis (TB) images. It underwent block-based and layer-based segmentation that enhances images and becomes ready for interpretation. It utilizes OpenCV, an image processing software. Chest X-ray will capture the image of the patients' lungs. Upon image processing, hospital personnel can diagnose symptoms and determine the patient's Tuberculosis.

Moreover, Liu *et al.* [23] stated that color recognition could easily be detected by using a recognition algorithm programmed in OpenCV. This study uses color recognition to identify real-time reagents realizing the central tube positioning, color extraction, and classification in a biochemical reaction. Paliwal *et al.* [24] emphasized that image processing methods could be used to calculate the infected percentage in crops and develop elementary machine learning algorithms for classifying the agricultural fields incorporated in the robotic system. The studies included maize, bell pepper, and tomato for image experimentation, leading to the development of algorithms to increase the yield of crops.

Several recent studies [25]-[27] developed prototypes to determine the disarrays through visual observation through internet-of-things (IoT), cloud computing, and image processing of tomato (*Solanum lycopersicum*) plant. The leaf of the tomato plant is captured and underwent a training model. The image processing techniques used and were carried out by the OpenCV library in Python were resizing, noise removal, and segmenting.

Also, Hamuda [28] stated that the identification of plants from a particular soil background and other filtrates could be achieved through image-based plant segmentation techniques. Color index-based segmentation, threshold-based segmentation, and learning-based segmentation are the primary image processing techniques used for color features and shape analysis for cauliflower under different weather conditions. Furthermore, it used signal processing and computer vision techniques leading towards innovative agricultural applications.

For the development of the prototype, image processing is the primary process to determine soil pH and primary macronutrient levels from the STK. Moreover, the use of OpenCV is the primary image processing software. The use of Raspberry Pi as the central processing unit of the prototype is relatively new, thus getting some significant attention from researchers, especially in the image processing field. The image processing capabilities of OpenCV were applied in various real applications, mainly in the agricultural field. OpenCV is essential in the various characteristics of any agricultural undertakings [29], [30].

2. RESEARCH METHOD

The research designs used in the study are developmental research and descriptive-evaluative research. Developmental research was used since the output of the study is a prototype. Also, the prototype follows the concepts of descriptive-evaluative research. The developed prototype was described and was adequately assessed in terms of effectiveness and acceptability.

2.1. System's architecture

Figure 1 illustrates the system's architecture of the prototype. The soil samples to be tested came from the Regional Soil Laboratory. The said soil samples were already prepared for testing. Proper soil collection is not anymore covered in this study. Following the STK's procedure is the next process. Four types of tests are included in the STK: pH test, nitrogen test, phosphorus test, and potassium test. The Raspberry Pi camera captures the images of the STK-treated soil samples. The STK instructions set the proper way on how to capture the images. It should be followed to obtain correct readings. After the images were captured, it undergoes image processing.

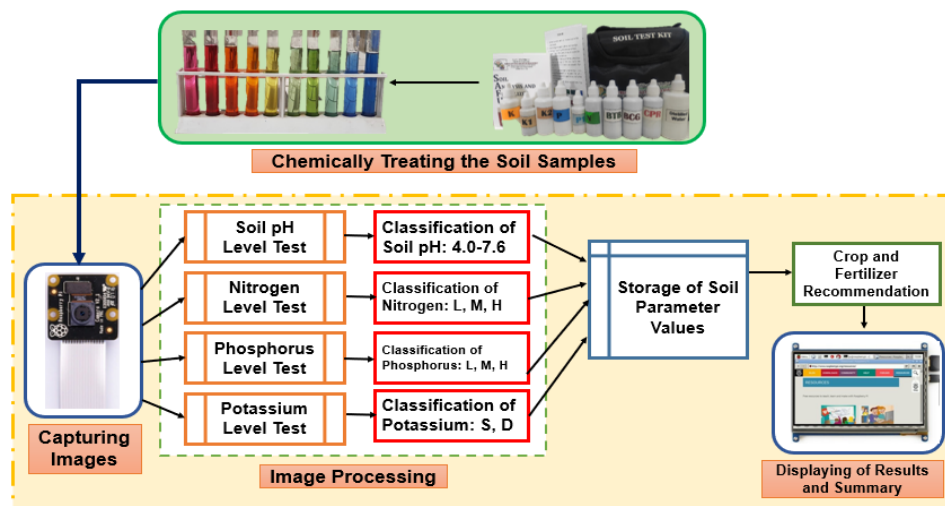


Figure 1. System's architecture of the prototype

2.2. Image processing techniques

Image processing techniques include image segmentation and image filtering. Through image segmentation, the desired portion of the original images is identified and extracted. Following the process,

the extracted image will be filtered out, removing unwanted embedded noise (part of the image which is degraded). These processes will be able to detect the color of the images accurately. Once the camera has captured the image, the raspberry pi will initiate the region of interest from the captured image. The region of interest pertains to the portion of the captured image that will be analyzed. The red, green, blue (RGB) value of the region of interest will be extracted. Furthermore, it will be converted to its binary form counterpart for analysis. The binary form of the image will be compared to the predetermined set of values for soil pH and primary macronutrients.

Another image processing technique used is point feature matching, the features of the captured image of chemically-treated soil sample will be matched through the features of the soil pH and primary macronutrient as reflected in the attached manual of the STK. The RGB value of the image from the manual of the STK will serve as the basis of the prototype's processes in terms of image processing and classification of the soil parameters. After image processing, a recommendation can be derived on what crop can be planted and its fertilizer requirements. The soil pH level is the basis for the crop recommendation since the proper amount of the pH relates to the necessary fertilizer recommendation's absorptive capacity. The systems map the crop that matches the pH level given. After mapping, the systems retrieve the fertilizer recommendation for the combination of nitrogen, phosphorus, and potassium. Nitrogen and phosphorus observe three-level, which are high (H), medium (M), and low (L), while potassium notes only two-level which are sufficient (S) and deficient (D). There will be 18 combinations of levels among the nitrogen, phosphorus, and potassium. These combinations are present among all crops present in the system.

2.3. Hardware specification

In this part, the hardware specification of the prototype showcases the physical appearance of the prototype itself. It describes the parts of the prototypes and how it relates to the overall function of the prototype. Figure 2 presents the actual design of the prototype of the study.

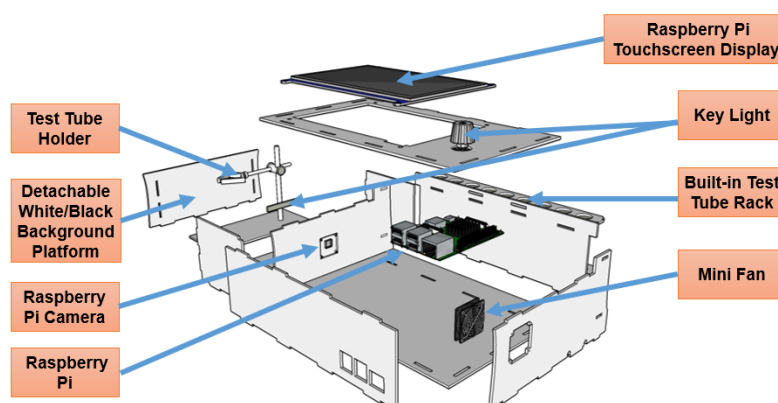


Figure 2. Hardware specification of the prototype

The Raspberry Pi serves as the central processing unit of the system. Raspberry Pi 4 Model B was the model used in the prototype. The said model is the latest model that has Quad core 64-bit ARM-Cortex A72 running at 1.5 GHz. These specifications are suitable for the maximum processing of data from the images captured. The Raspberry Pi Touchscreen display guides the user of the prototype in utilizing the prototype. It allows users to click buttons with a pre-defined process incorporated in the system's graphical user interface. Raspberry Pi touchscreen display has a dimension of seven inches by seven inches. The Raspberry Pi Camera captures the test tubes' images where the soil samples were tested in accordance with soil test kit procedures. It is connected to the Raspberry Pi for processing. Raspberry Pi NoIR infrared camera board V2 is the model used in the prototype. It has a capturing resolution of 1080 p and 8 Megapixels.

The built-in test tube rack is a feature of the prototype that lets the users place the test tubes in an upright position at the same time. It provides temporary storage of test tubes with or without chemicals for safety reasons and safe storage. During the capturing process of images of the STK-treated soil sample, the test tube must be positioned in a pre-defined way to capture the image. For the soil pH level, nitrogen and phosphorus, it is advisable to tilt the test tube. At the same time, for potassium, the test tube must be upright in capturing the image of the STK-treated soil sample. Test tube holder can hold the test tube in the desired

position for the optimal capturing process of the images needed. It is strategically placed in front of the Raspberry Pi Camera to avoid blurriness.

To have untainted images for the STK-treated soil sample, it is necessary to have a correct background color. The white-colored background is needed when capturing the images from pH level, nitrogen, and phosphorus, while a black-colored background is required for potassium. The white/black background platform is detachable so as not to consume space in the prototype.

The key light provides proper lighting for the test tube before being capture for optimized image quality. It is useful for a situation like dim environment lighting. The key light is composed of light emitting diodes (LEDs) and a potentiometer. The critical light intensity can be adjusted so that proper lighting can be adjusted using the potentiometer. Furthermore, the key light being adjustable avoids glare in the test tube since test tubes are made of glass and prone to glare when light is struck upon it.

2.4. Statistical treatment of data

Statistically treating the data is a prerequisite to the establishment of conclusions. Furthermore, the treatment of data with statistics measures whether the objectives of the study are achieved. Percentage remarks and arithmetic mean were used to treat data statistically. Percentage remarks was used to determine the prototype's effectiveness, and the arithmetic mean is used to determine the acceptability of the prototype among possible users.

$$\text{Percentage Remarks} = \frac{\sum X_n}{n} \times 100 \quad (1)$$

where X_n is correct actual readings and n is the number of readings.

Table 1 is used to determine the description of the prototype in terms of its effectiveness. It exhibits the list of the range of percentages, each having a corresponding level of productivity. Furthermore, the formula below serves as the basis of the results that have been calculated for several trials to be conducted.

$$\text{Weighted Mean} = \frac{\sum(X_n s)}{n} \times 100 \quad (2)$$

Where X_n is the correct actual reading, n is the number of respondents, and s is the score of response where scores can be classified numerically: five as excellent, four as very satisfactory, three as satisfactory, two as fair, and one as poor.

Table 1. Equivalent interpretation of data remarks on effectively testing

Percentage	Description
100.00-90.00	Highly effective
89.99-80.00	Effective
79.99-70.00	Partially effective
69.99-60.00	Less effective
59.99-0.00	Not effective at all

Table 2 is used to determine the description of the prototype in terms of its acceptability. It shows the list of the range of points, each having a corresponding level of being accepted. The acceptability was determined using a survey questionnaire administered to possible users of the prototype.

Table 2. Equivalent interpretation of data remarks on acceptability

Range	Description
5.00-4.00	Excellent
3.99-3.00	Very Satisfactory
2.99-2.00	Satisfactory
1.99-1.00	Fair
0.99-0.00	Poor

3. RESULTS AND DISCUSSION

3.1. Final prototype

Figure 3 presents the actual prototype of the project study. The said prototype incorporated all possible design considerations. The final prototype was made out of black opaque acrylic. The design of the prototype was observed and appropriately incorporated.

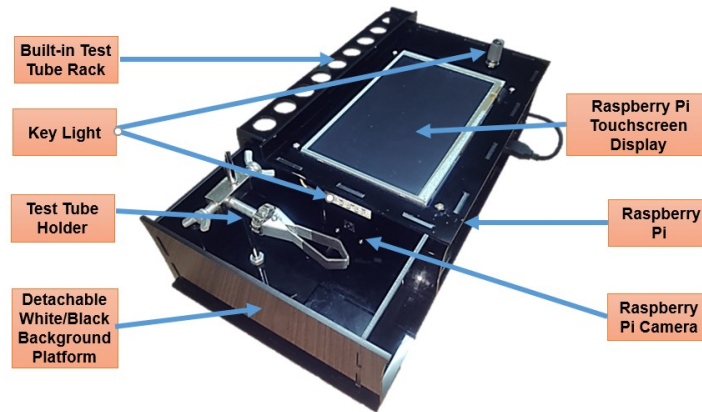


Figure 3. Final prototype

3.2. Evaluation of effectiveness of the prototype

The effectiveness pertains to the percentage of the correct actual task performed compared to the prototype's expected task. Five parameters are being monitored; i) nitrogen level, ii) phosphorus level, iii) potassium level, iv) soil pH level, and v) correct crop and fertilizer recommendation.

3.2.1. Soil primary macronutrients

The number of testing per soil parameter per level is 50. One of the objectives of this study is to test the prototype's effectiveness, especially the function of the prototype, to accurately detect the correct level of soil pH and primary macronutrients of the STK-treated soil sample. Using (1), the number of trials that correctly determined level was recorded and added and divided by the number of trials (i.e., 50 trials).

Figure 4 exhibits the effectiveness of nitrogen, phosphorus, and potassium in terms of percentage. For nitrogen, the high and medium levels both have a rating of 92%, while the Low level has a 90% rating. All of the levels of nitrogen were interpreted as highly effective. For phosphorus, the levels of high and medium have a mark of 92% and 96%, respectively, interpreted as high effective while the low level has a mark of 88% and read as effective. For potassium, the sufficient and deficient levels are interpreted as highly effective, with a rating of 92% and 96%, respectively.

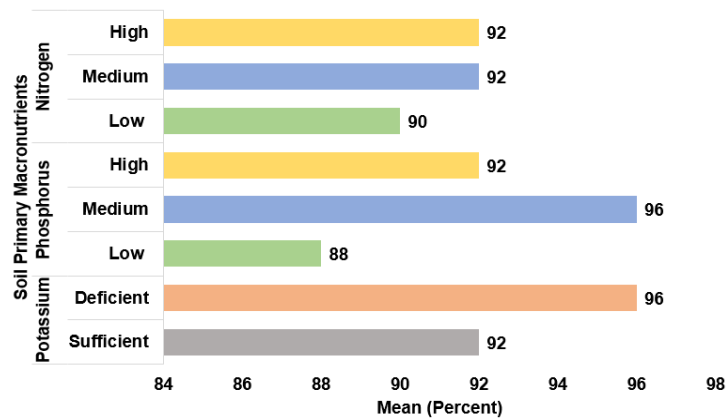


Figure 4. Effectiveness of NPK per level in percentage

3.2.2. Soil pH level

Figure 5 showcases the effectiveness of the Soil pH level in terms of percentage. The soil pH levels 5.4, 6.0, and 7.2 have garnered a 98% rating, which is considered the highest rating among all computed ratings. The soil pH levels of 4.0, 4.4, 5.2, 6.4, and 7.6 have a rating of 96%. A rating of 94% for soil pH levels of 4.8 and 5.0 was noted. The lowest rating, 92%, among all the levels were illustrated by the soil pH levels of 5.8 and 6.8. Using Table 1, all of the soil pH level ratings have been interpreted as highly effective.

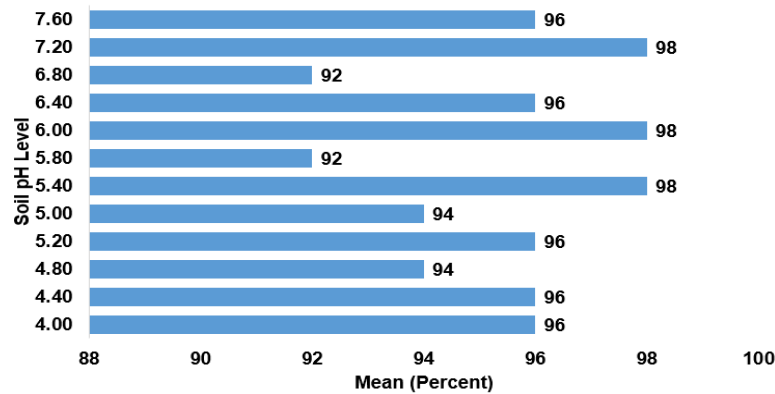


Figure 5. Effectiveness of Soil pH per level in percentage

3.2.3. Crop and fertilizer recommendation

The evaluation of the crop and fertilizer recommendation capability of the prototype was done through manual checking. The evaluation observed 50 trials. After the prototype had given its crop and fertilizer recommendation through mapping, this will be manually cross-referenced to the given crop and fertilizer recommendation of the Regional Soils Laboratory, Department of Agriculture. Utilizing (1), the number of correctly suggested crop and fertilizer recommendations by the prototype was recorded and added and divided by the number of trials. A 96% rating was calculated for the prototype's effectiveness in recommending crops and fertilizer suited for the given soil sample. This is also interpreted as highly effective.

3.3. Validation of the data gathered

The gathered data from the prototype were compared to the data present at the Regional Soils Laboratory. Standard laboratory tests were administered to the sample soil samples used in the study. The validation includes all the soil pH and NPK levels. It further includes the crop and fertilizer recommendation by cross-referencing the prototype's recommendation and recommendation at the Regional Soils Laboratory. In this manner, the prototypes give the correct level; it also gives the right crop and fertilizer recommendation.

3.4. Acceptability of the prototype

Another part of the study's objective pertains to the prototype's acceptability to possible users like farmers, researchers, and personnel from the Regional Soils Laboratory and Department of Agriculture. The sample population is 30, composed of 15 farmers, five Regional Soils Laboratory personnel, five personnel of the Department of Agriculture Region 5, and five researchers. The research instrument used in determining the prototype's acceptability is a survey questionnaire based on the technology acceptance model. The technology acceptance model determines the user's perception of the utilization of new technology in job performance or goal achievement, thereby leading towards the acceptance of the latest technology, i.e., prototype. As reflected in Table 3, the highest response among all seven-question is "excellent." This response primarily demonstrates the acceptance of the possible use of the said prototype

Table 3. Summary of survey result for the acceptability of the prototype

Particulars	Excellent	Very Satisfactory	Satisfactory	Fair	Poor	Mean
Q1: Learning to operate this prototype was easy for me	23	7	0	0	0	4.77
Q2: I found it easy to get this prototype to do what I want to do	25	5	0	0	0	4.83
Q3: My interaction with this prototype has been clear and understandable	26	4	0	0	0	4.87
Q4: I found this prototype to be flexible to interact with	24	6	0	0	0	4.80
Q5: It was easy for me to become skillful at using this prototype	27	3	0	0	0	4.90
Q6: I found this prototype easy to use	28	2	0	0	0	4.93
Q7: I have found this prototype useful in my job	26	4	0	0	0	4.87
					Weighted Mean	4.85
					Adjectival Description: Excellent	

Question number six garnered the highest percentage. In comparison, the second to highest percentage collected are question number five. The lowest garnered rate in terms of answers in the “excellent” option is question number one. It is therefore concluded based on the result of the survey that the prototype is easy to use and can be useful in their job.

4. CONCLUSION

Given the findings, the following conclusions were drawn; i) The image processing function of the prototype, as the primary process for detection of the level of soil pH and primary macronutrients, is highly effective; ii) The crop and fertilizer recommendation capabilities of the prototype is also rated highly effective; iii) The acceptability of the prototype, based from the 30 respondents of possible users of the prototype, showed a high percentage in terms of parameters using the Technology Acceptance Model in terms of easiness to use the prototype and had an overall weighted mean of 4.85 with an adjectival description of excellent. The result of the study leads to the following recommendations: (a) Since the current prototype is dependent on the commercial power source, the prototype has built-in independent power supplies like power banks, making it portable; and (b) Usage of the up-to-date or latest model of Raspberry Pi so that it will not cause any lag or delays in the processing capabilities of the prototype.

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