SoilMATTic: Arduino-Based Automated Soil Nutrient and pH Level Analyzer using Digital Image Processing and Artificial Neural Network

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***Abstract*—In this study, SoilMATTic was developed for faster and accurate soil analysis compared with conventional method to guide farmers on crop suitability and increase farm productivity and crop yield. The Arduino-based prototype automated the whole process of macronutrient and pH analysis of soil from soil testing procedures up to fertilizer recommendation. It includes stepper motors and pumps to fully automate the chemical reaction of soil with chemical reagent during testing and an on board printer to print out fertilizer recommendations. It uses digital image processing technique to efficiently identify (1) Nitrogen, (2) Phosphorus, (3) Potassium and (4) pH level of Philippine farmlands. The system is composed of five stages namely: automated soil testing, image acquisition, image processing, training system, and recommendation. Artificial Neural Network offered fast and accurate performance for the image processing. The system data base stored and manages 356 captured images where 70% is for training, 15% for testing and 15% for validation. Results of this this study showed 96.67 accuracy in identifying soil macronutrient and pH level and gives fertilizer recommendation for Inbred rice plant, Inbred corn, Tobacco, Sugarcane, Pineapple, Mango, Coconut, Abaca, Coffee, Banana through a generated report in printed form.**

Keywords— Soil, Arduino, Digital Image Processing, Artificial Neural Network

I. INTRODUCTION

The Philippines is still predominantly an agricultural country despite many of its agrarian and rural regions are transforming into industrial and urban societies and many croplands are being diverted to other uses. Many Filipinos living in rural areas still support themselves through agriculture. According Nations Encyclopedia, the country is producing and exporting its main agricultural crops such as rice, corn, coconut, sugarcane, banana, pineapple, mango, abaca, coffee and tobacco [1].

The very high dependency of Filipino farmers on cropland and the growing demand for food supply leads to soil exhaustion. This means that ceaseless cultivation of food crops will render the soil deficient in important macro and micronutrients, including nitrogen, phosphorous, potassium, sulphur, zinc, iron, bronze and boron. According the Bureau of Soil and Water Management of the Department of Agriculture, it is advised to get farmland soil analysed every three-years in order to combat any nutrient deficiencies by applying organic or non-organic fertilizers and help maintain a soil ready farm for each planting season.

According to a Soil Facts publication on 26September 2012 entitled Best Management Practices for Agricultural Nutrients [2], About 20 elemental nutrients are essential for plant growth and some of these nutrients are supplied naturally by the air, water, and soil. A wide variety of organic and non-organic fertilizers can be used to supplement the natural supplies for optimum crop growth. Macronutrients such as nitrogen, phosphorus and potassium (N-P-K) on soil should be managed correctly to maximize benefits. Because when these nutrients are applied in the wrong place at the wrong time, they only become pollutants.

Nitrogen, Phosphorus and Potassium are essential to plant growth and are consumed and can be of short supply in soil. To determine these soil primary nutrients, soil analysis or soil test is performed. [3]

Soil Nutrient Testing is usually carried out to determine the nutrient levels and characteristics such as pH level. It consists of four phases: 1) soil sampling; 2) sample analysis; 3) data interpretation and 4) soil management recommendations. Soil testing can help determine soil fertility levels, and identify nutrient deficiencies which are important for monitoring the stages of land degradation. A good first step in defence to this degradation problem is by regularly analysing soil nutrient and characteristics on which to base land management and fertilizer decisions over time. However, soil tests are commonly carried out in laboratories where soil samples are often sent to laboratories. For small farmers in remote rural areas, portable field-testing may be more suitable, but they are not yet widely available and also require training to correctly interpret results.

The Bureau of Soils and Water Management (BSWM) performs manual soil testing using Soil test Kits to determine the NPK and pH level of soils by comparing the color of the soil which reacted to added chemical reagents to a standard color chart. [4]

Automated analysis of the soil test result has been done before. It made use of digital image processing than doing the conventional comparison to the color chart. It has provided more accuracy and has eliminated human

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judgement in coming up with the results. This study aimed to further develop the conventional soil testing by automating the whole process. The chemical testing on the soil is to be done by an automated machine using gear motor and pumps controlled by the Arduino. The analyses of soil nitrogen, phosphorus, potassium and pH can be done digitally using image processing supported by different algorithms through Artificial Neural Network (ANN).

II. METHODOLOGY

The proposed system is made of five stages namely automated soil testing, image acquisition, image processing, training system, and recommendation as shown in Fig. 1 below.

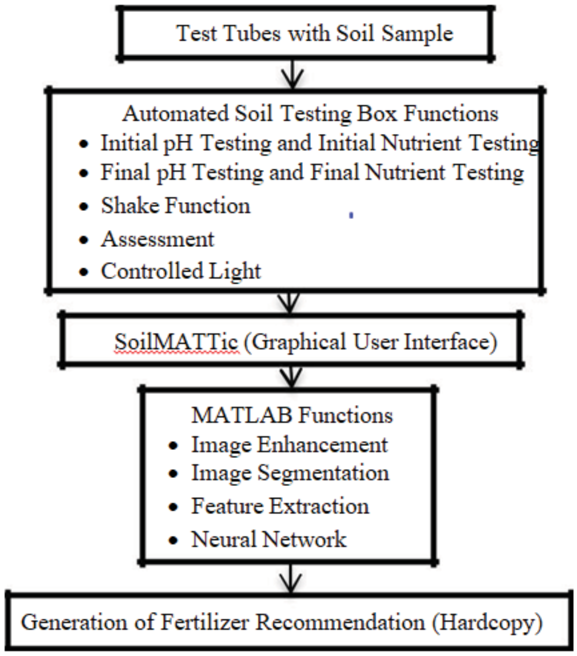

Fig. 1 Main Block Diagram

A. Automated Soil Testing

The main focus of the design is the Automated Soil Testing is responsible for controlling the soil nutrient testing process. It uses Arduino Mega 2560 to control the linear guide stepper motor, pumps, hoses and needles. Proper orientation of the different components will be considered in fabricating the SoilMATTic.

B. Image Acquisition

The image acquisition is responsible for obtaining images using a 1080p Full-HD Webcam with sixteen (16) megapixels, and a controlled-light module included in the automated soil test box.

C. Image Processing

The image processing section comprises of image enhancement, image segmentation and feature extraction. [5] In image enhancement, noise reduction and contrast adjustment will be performed. Thresholding and masking will be included in image segmentation. In feature extraction, color pixel area will be calculated.

D. Training System

Sufficient number of images shall be captured as data samples for the system database. These will be utilized for training, testing and validation. The processed images will be compared with these stored data images where final assessment of the macronutrients level and pH level will be based on the available standards provided by the BSWM. Captured images shall be processed and trained using backpropagation neural network architecture to improve the accuracy of the program. [6]

E. Recommendation

The recommendation section will generate a PDF Format report based on the analysis of the system and will consist the following:

For Macronutrients and pH Level Assessment:

- Qualitative Result of N, P, K and pH level
- Appropriate amount of Fertilizer to be applied per hectare or per plant (for trees)
- Total amount of fertilizer
- When to apply

III. DESIGN CONSIDERATIONS

A. Using Arduino Mega as a Microcontroller for Automated Soil Testing Box

The Arduino Mega will be programmed to fully automate the testing process. It shall control the movement of stepper motor to position the test samples and activate the pumps to apply liquid chemicals on soil samples placed on test tubes. The motor pumps shall be chosen to provide enough pressure to automatically mix the chemical-soil solution. In order for the Arduino to to do these, it shall provide 14 PWM output for the Soil Testing Box where 12 are dedicated for the pumps and 2 are for the stepper motor.

B. Implementation of MATLAB Software for Soil Macronutrient and pH level Assessment using Artificial Neural Network

The actual algorithm in identifying the level of macronutrient and pH of the soil includes the image of the colorimetric chemical result of soil test as the input to the system. These images will be uploaded in Visual Basic data base platform. The images will be processed using MATLAB software and will undergo several stages which include: image acquisition, image enhancement, image segmentation, feature extraction, and feature comparison to achieve accurate result. Based on the result, the program will generate a report in hardcopy format.

The Backpropagation Neural Network serves as a training model. This increases the accuracy of the system and decreases the computation time because it has the ability to implicitly detect complex non-linear relationships between the dependent and independent variables, and to detect all possible interactions between predictor variables.

C. Importing MATLAB functions to Graphical User Interface

The MATLAB functions and the Backpropagation Neural Network will be compiled as C/C++ libraries. The exported libraries can then be imported into Visual Basic.

A GUI as shown in Figure 2 made in Visual Basic will facilitate image capturing. Figure 2(a) allows the user to choose a crop while Figure 2(b) allows the user to view the test result. The compiled MATLAB functions will be called to perform the image analysis. The process ends after a hardcopy report is generated based from fertilizer recommendations provided by BSWM. The user interface of SoilMATTic is shown below:

Fig. 2 (a) GUI for Crop Selection

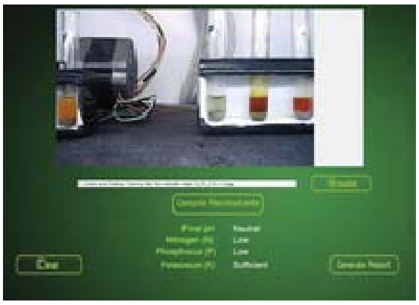

Fig. 2 (b) GUI for viewing results

IV. RESULTS AND DISCUSSION

A. Soil Testing Box Set Up

Fig. 4 Automated Soil Testing Box with Chemical Compartment

The dimensions of the Automated Soil Testing Box as shown in Figure 3 above (16 x 14 x 14 inches) was a convenient dimension to house the essential components and permit motor movement and image capture after effecting adjustments during a series of testing. The dimension (length x width) of the box is sufficient so that the distance of the object under test from the lens shall provide an acceptable focus from the opposite web camera and allows excellent illumination needed for capturing image. Since the subjects under test are placed on test tubes, the height of the soil testing box was approximated based on the size of the tubes [6]. The overall dimension also considered the position and orientation of the web cam, the chemical compartment and the fluid pressure on each needles

Figure 4 below shows the chemical reagent compartment which is composed of 12 containers containing 500ml each. Among the 12 compartments, 11 are dedicated for acid based chemical reagents when combined are responsible for detecting soil macronutrient levels by producing a unique color for different nutrient levels while the 12th container is filled with distilled water to automatically wash the test tube containers after testing.

Fig. 4 Chemical Reagent Compartment

TABLE 1: Chemical Reagents used in Soil Testing

Nitrogen	N – Potassium Dichromate *Hydrochloric Acid can be used instead of heating the solution
Phosphorus	P – Sodium Bicarbonate P1 – Ammonium Molybdate *Stannous Chloride can be used instead of tin foil
Potassium	K– Ammonium Acetate K1–Sodium Tetraphelynboron K2 - Ethanol

pH	BTB (Bromo Thymol Blue) CPR (Chlor Phenol Red) BCG (Bromo Cresol Green)

Table 1 above shows the chemical reagents responsible for testing the respective levels of macronutrient and pH levels by giving distinct color spectra. For testing Nitrogen content, Hydrochloric Acid can be used instead of heating the solution to free the test reliance from the mixing procedure since the acid solution quickly reacts with the soil compounds. The mixing of the chemical-soil solution is done by moving the test tubes via stepper motor as shown below.

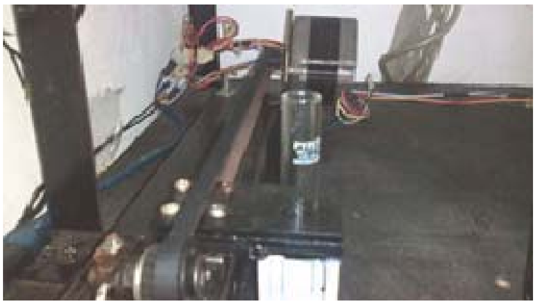

Fig. 5 Stepper-motor set up responsible for the mixing of soil and chemical reagents solution.

B. *Database Development*

Data base development includes collection of different sample images of soil macronutrients and pH at different levels provided by the Bureau of Soil and Water Management laboratory. The system database for macronutrients and pH level identification comprised of 356 captured image samples. A total of 80 sample images for different Soil Macronutrient levels (50, 15 and 15 sample images for Low, Medium and High Nitrogen and Phosphorus content respectively while there are 76 and 4 for Sufficient and Deficient Potassium content respectively.

C. *Result of Macronutrients and pH Level Identification*

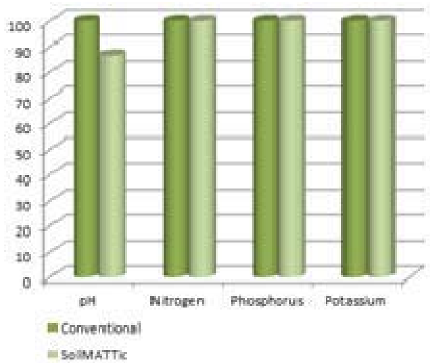

Fig. 6 Test results of fifteen (15) soil samples

Fifteen (15) different soil samples were collected for the evaluation of the prototype. With the supervision of Ms. Agnes Morada, Senior Agriculturist of BSWM, the samples were manually tested and compared to the STK color chart. The results serve as the conventional visual test column on the evaluation sheet given to Ms. Morada. The BSWM representative also witnessed the parallel full automated test conducted by the proponents using the SoilMATTic. The proponents used the same soil samples which allowed the soil expert verify whether the results of SoilMATTic were reliably close to the conventional testing and visual inspection. Figure 11 above shows the results of the SoilMATTic was 100 % consistent with the conventional soil testing procedure on the determination of nitrogen, phosphorus and potassium while 86.67% was achieved on pH level. This means out of 15 samples, the same macronutrient analysis was produced by both methods and 13 out of 15 on pH level.

D. *Fertilizer Recommendations*

Figure 7 below show a sample printout of the SoilMATTic after prototype after a soil test procedure is undertaken. The printout shows a summary of soil assessment showing the levels of N-P-K and pH respectively and the corresponding recommended fertilizer application.

Fig. 7 Sample Print out showing Nutrient levels and Fertilizer recommendation

V. CONCLUSIONS

The development of the Arduino-based prototype that fully automated the soil analysis and fertilizer recommendation was operative and reliable during series of tests conducted. The determination of the Macronutrient and pH level of the soil for 10 major Philippine agricultural crops through automatic soil testing and image processing using artificial neural network was successfully implemented using MATLAB. Based on the results and findings of the research, the project was found to be fully functional and proven to be 96.67% accurate.

To further improve the system, the proponents recommend the following: (1) Consider installing pumps that will produce higher liquid pressure so that mixing of soil samples and chemical reagents would not rely much on shake function, (2) Reconcile the mechanical design and fabrication to improve the manufacturability of the prototype, (3) Consider alternate chemicals that quickly reacts to soil to quickly dissolve soil solution and finally (4) Collect more soil samples for the data sets which could yield more accurate and conclusive results..

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