Determination of Soil Nutrients and pH level using Image Processing and Artificial Neural Network

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***Abstract*—In this study, image processing and artificial neural network was used to efficiently identify the nutrients and pH level of soil with the use of Soil Test Kit (STK) and Rapid Soil Testing (RST) of the Bureau of Soils and Water Management: (1) *pH*, (2) *Nitrogen*, (3) *Phosphorus,* (4) Potassium, (5) Zinc, (6) Calcium, and (7) Magnesium. The composition of the system is made of five sections namely soil testing, image capturing, image processing, training system for neural network, and result. The use of Artificial Neural Network is to hasten the performance of image processing in giving accurate result. The system will base on captured image data, 70% for training, 15% for testing and 15% for validation as default of neural network tool of MATLAB. Based on the result, the program will show the qualitative level of soil nutrients and pH. Overall, this study identifies the soil nutrient and pH level of the soil and was proven accurate.**

***Index Terms*—Soil, Digital Image Processing, Artificial Neural Network, MATLAB, Nutrients**

I. INTRODUCTION

The Philippines is one of the countries in Southeast Asia that has land of abundant nutrients that can be utilized through farming. Consequently, as the continuous planting of crop occurs, it results to deficiencies in the nutrients of the soil that will also make the yield lower. To resolve this problem, soil preparation is needed before planting crop to make sure that it will be getting the right amount of nutrients from the soil. Thus, ensuring the maximum yield for the crop.

Soil Preparation is a process that is essential before planting. Excessive or lacking fertilizer use has a significant effect to the crop yield. Just like humans, crops also needs well distributed nutrients that is right for them to grow healthily [1]. Applying inorganic fertilizer to the soil for better yield might lead to negative effects as these chemicals change the soil nutrient pattern as time goes by [2].

The Bureau of Soils and Water Management (Philippines), an agency of the government under the Department of Agriculture, spearheaded the distribution of Soil Test Kit to field technicians to evaluate the reliability of the kit and as well as the fertilizer recommendation that it provides [3]. The use of Soil Test Kit was adapted in other countries as well as in over 50 locations in the USA [4].

Soil Test Kit is a method that gives the macronutrient level of the soil in a short period of time. It involves colorimetry that measures qualitative number of primary macronutrients (Nitrogen, Phosphorus and Potassium) and it also includes the pH level of the soil where it determines whether the soil is acidic, neutral or basic. The result of the test will be used as basis in making fertilizer recommendation on the how much fertilizer is needed by the soil to grow a particular crop [5]. BSWM continues to make new soil test kit also known as Rapid Soil Test Kit (RST) that measures the secondary macronutrients (Zinc, Calcium, and Magnesium) that are also essential nutrients for plant growth and gives information on how much specific fertilizer are prescribed [6].

Many farmers are not practicing the conventional method of soil preparation which includes the use of soil test kit. The lack of knowledge of the farmers in the existence and the procedure in using the soil test kit, and as well as on how to interpret the result that it provides, to come up with the necessary fertilizer recommendation are the common factors why the farmers are not using STK and RST. The farmers also have their traditional way on how to prepare their farm that they've acquired through their ancestors without considering that the nutrients of the soil changes from time to time resulting to different crop yield (Suplido, M. E. A., 2015).

Various sensors such as electrochemical, optical and radiometric sensors that can be used in determining various soil physical and chemical information and properties are developed to be used as on-the-go soil sensors but among these sensors, electrical and electromagnetic are widely used [7][8][9]. Another study uses Field Programmable Gate Array (FPGA) together with Photodiodes, LED, and Analog-to-Digital Converter [10]. In a separate study, RF spectroscopy is used in determining the Nitrogen and Potassium level of the soil. A cell was designed to catch up

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the specific frequency spectra of each nutrient [11]. Other than RF spectroscopy, Visible-Near Infrared (Vis-NIR), Near Infrared (NIR) and Mid Infrared (MIR) are also used for determining the performance measurement of soil properties [12][13][14]. In addition, Ion Selective Electrodes (ISEs) were used to determine the macronutrient level of the soil [15]. The sensors convert the chemical information to electrical signal that will be used as an input of a microcontroller in interpreting the data [16]. Also, with the use of electrochemical method and optical diffuse reflectance sensing, soil macronutrients can be detected [17]. Lastly, there are existing studies that uses color detector sensor and in identifying the level of macronutrients and pH of the soil however, they are all limited with pH and primary macronutrients (Nitrogen, Phosphorus and Potassium) detection only [18].

The device is composed of a controlled-light module box where the position and distance of camera to the samples are fixed. Captured image from the module box are going to be the input for image processing to determine the level of macronutrients and pH level of the soil.

In general, this study aims to develop a Soil Nutrient Analyzer using Soil Test Kit and Rapid Soil Testing of the Bureau of Soils and Water Management through color recognition.

Specifically, this study aims to develop a program that will give soil pH and six different nutrient level namely Nitrogen, Phosphorus, Potassium, Zinc, Calcium, and Magnesium using image processing and artificial neural network via MATLAB.

II. METHODOLOGY

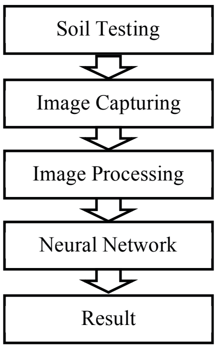


Fig 1. General Framework

The general framework shown the composition of the five different sections of the system namely, soil testing using Soil Test Kit and Rapid Soil Testing of the Bureau of Soils and Water Management, image capturing from the controlled-light module box, image processing and artificial neural network using MATLAB, and the result of the soil testing which is the level of the nutrients and pH of the soil.

A. Soil Testing

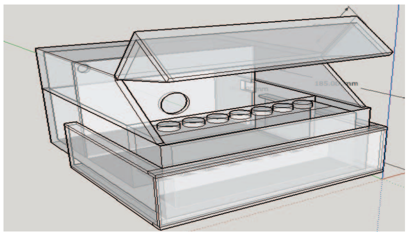
(a)

(b)

Fig 2. (a) Rapid Soil Testing Kit for Zinc, Calcium, and Magnesium (b) Soil Test Kit for pH, Nitrogen, Phosphorus and Potassium

Soil Test Kit (STK) and Rapid Soil Testing (RST) has different set of chemicals that is needed to determine the nutrients and pH level of the soil. The chemicals will be mixed with the soil sample following the procedure indicated in the kit.

B. Image Capturing



(a)

(b)

Fig 3. (a) Design of the controlled-light module box (b) Logitech c920 HD Pro Webcam

The design of the box is 9.5 inches long, 8 inches wide, and 5 inches high. These measurements were based on experiment considering the distance of the lens of the camera to the object being captured with acceptable focus. The height considers the height of the test tube being used as well as the position of the webcam and the width is

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considered for the spaces between the four test tubes that will be used for soil testing. There will be three images to be captured to acquire the final result of the soil testing. One is for initial pH, another is for Nitrogen, Phosphorus, Potassium, and final pH, and last for Zinc, Calcium and Magnesium. There will be an exact spot to insert the test tube with mixture of soil and chemicals for each parameter to be analyzed prior image capturing.

C. *Image Processing*

This section is composed of four different sections which includes, image acquisition, image preprocessing, image segmentation, and feature extraction [19]. Image acquisition was done using the camera inside the controlled-light module box. Sample image that will be used for image processing is shown in Figure 4.

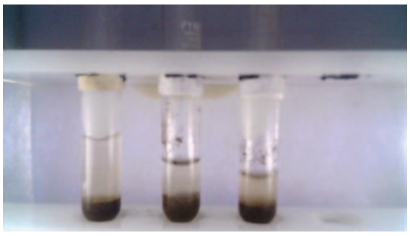

Fig 4. Sample Image acquired from the controlled light module box for Zn, Ca, and Mg respectively

Noise reduction and contrast/brightness adjustment will be done in image preprocessing. Image segmentation includes cropping region, thresholding, and masking. Cropping region includes setting of region of interest (ROI). ROIs are used to focus the processing and analyzing a specific part in an image [20]. For example, in the image above, the area inside the box is the region of interest where in, it is the only part of the image subject for image processing. There will be different ROIs for each soil nutrient parameter and has different location with respect to the image.

Fig 5. Sample cropped image after setting the ROI for Zn

After cropping the image as shown in Figure 5, it will be then undergone thresholding and masking. Thresholding is used to remove the unwanted part of the image by using color thresholder app in MATLAB shown in Figure 6. It sets a threshold value, pixel that is above can be classify as object while pixel that is below the threshold will be classified as background or vice versa [21][22][23].

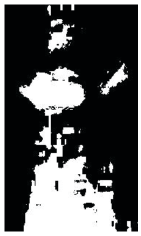

Fig 6. Sample cropped image after thresholding and masking for Zn

And lastly, Feature extraction does the color analysis per se. Mean values for the Hue, Saturation, and Value of the image; and mean value of Lab space are the two features being extracted to come up with the nutrient and pH level of the soil.

D. *Training System*

In this section, the processed images will be used as the training input. The pH and the nutrient level assessment will be based on the standards given by the bureau of soils and water management and this will be served as the database for the system. The processing and training using backpropagation neural network architecture will be used to improve the accuracy of the result of the program by capturing non-linear interactions between various parameters in a complex system [24][25]. There will be different sets of input for each parameter and also has different target since training data have different quantity. The common thing is the input data will have 6 x n matrix where n is the quantity of input and target per parameter. The six values are the mean of HSV and LAB of the image. The target data will have 1 x n matrix that will be set according to acquired result of determining the soil nutrient level through naked eye. There is a specific neural network for each parameter thus, it has several performance plots.

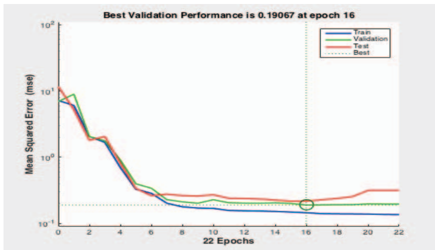

Fig 7. Initial pH (CPR) Level Assessment Performance Plot

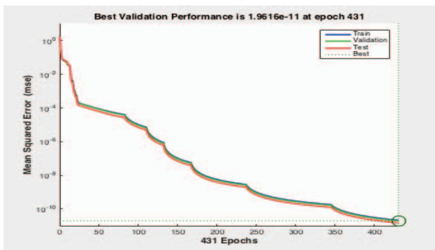

Fig 8. Final pH (BCG) Level Assessment Performance Plot

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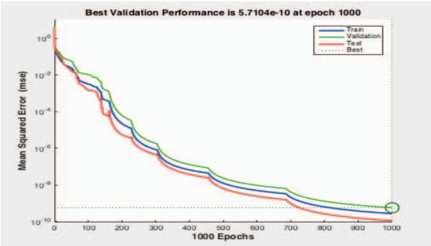

Fig 9. Final pH (BTB) Level Assessment Performance Plot

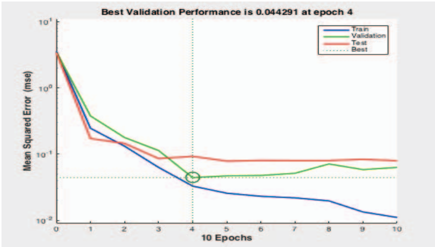

Fig 10. Nitrogen Level Assessment Performance Plot

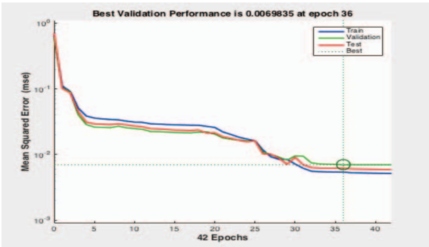

Fig 11. Phosphorus Level Assessment Performance Plot

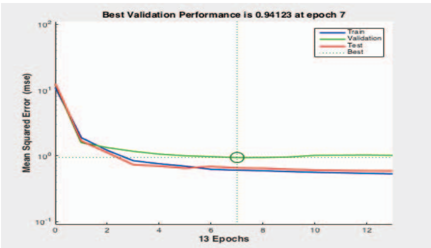

Fig 12. Potassium Level Assessment Performance Plot

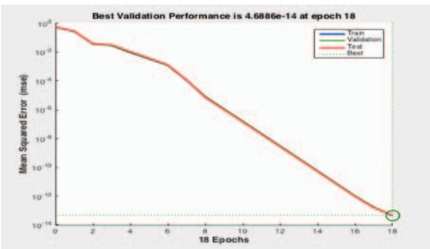

Fig 13. Zinc Level Assessment Performance Plot

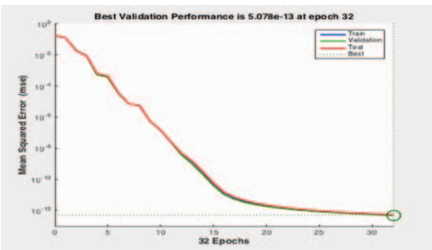

Fig 14. Calcium Level Assessment Performance Plot

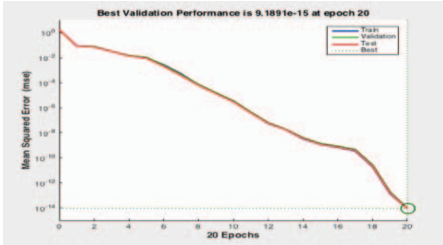

Fig 15. Magnesium Level Assessment Performance Plot

The performance plot of each parameter is presented from figure 7 to figure 15. It shows that the Mean Square Error is less than $1x10^{-10}$ and can be now used for validation. For nutrient and pH level identification, the program uses 670 captured image samples (130 images each for Nitrogen, Phosphorus, Potassium, and pH while 50 images each for Zinc, Calcium, and Magnesium). Training and performance parameters are initialized after creating the neural network. Artificial Neural Network uses iterative learning algorithm, weights and biases are arbitrarily initialized and the images are presented to the network one at a time. At least one of the training parameters must be satisfied for the network to consider the data as correctly classified. From the image sample, 70% was used for training, 15% for testing and 15% for validation. The neural network has 5 hidden layers prior training.

The training process will be repeated until the training number is reached. The learning algorithm allows the network to improve its performance by adjusting the weights so as to predict the next set of data correctly. The training stops once the square error of the network is less than $1x10^{-10}$.

E. *Result*

The outcome will provide the result of the qualitative level of soil pH, Nitrogen, Phosphorus, Potassium, Zinc, Calcium, and Magnesium.

III. DESIGN CONSIDERATIONS

The process of using soil test kit and rapid soil testing will be conducted first by following the procedure provided by the bureau of soils and water management. The changes in the color of the chemical after reacting with the soil will undergo image capturing using the light controlled module box. The captured image will be then processed using MATLAB software. Based on the result, it will generate the nutrients and pH level of the soil sample.

MATLAB serves as an Integrated Development Environment (IDE) for image processing. The process includes four sections namely: image acquisition, image segmentation, feature extraction, and feature comparison. The Backpropagation Neural Network is used as training model. It was used to increase the accuracy of the program in providing the level of nutrients and pH of the soil.

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IV. EXPERIMENTS AND RESULTS

A. Result of Database Collection

Table 1
Number of images or pixel gathered per nutrient and pH level

	Number of image/pixel per parameter																
	Low	Medium	High	Deficient	Sufficient	4	4.4	4.8	5.2	5	5.4	5.8	6	6.4	6.8	7.2	7.6
Nitrogen	100	15	15														
Phosphorus	2000px	3500px	3500px														
Potassium				2	128												
Zinc				30	20												
Calcium				35	15												
Magnesium				32	18												
pH (BCG)						1279px	349px	678px	298px								
pH (CPR)										1566px	3634px	994px	2829px				
pH (BTB)													256px	2973px	1657px	873px	641px

Note: px=Pixel

From the data gathered as shown in Table 1, a database consists of images of different level of pH and nutrients (Nitrogen, Phosphorus, Potassium, Zinc, Calcium, Magnesium) of soil after it undergo soil testing from the laboratory of BSWM. Using the controlled-light module box, the images of 130 Nitrogen (100 pictures equivalent to Low, 15 Medium and 15 High), 9000 pixels for Phosphorus (2000 pixels for Low, 3500 for Medium and 3500 for High), 130 images for Potassium (128 equivalent to sufficient and 2 for deficient), 50 images for Zinc (20 equivalent to sufficient and 30 for deficient), 50 images for Calcium (15 for sufficient and 35 for deficient), 50 images for Magnesium (18 images for sufficient and 32 for deficient), 9023 pixels for pH CPR (1566 for 5.0, 3634 for 5.4, 994 for 5.8 and 2829 for 6.0), 6400 pixels for pH BTB (256 for 6.0, 2973 for 6.4, 1657 for 6.8, 873 for 7.2 and 641 for 7.6) and 2604 pixels for pH BCG (1279 for 4.0, 349 for 4.4, 678 for 4.8 and 298 for 5.2) were captured and fed to the program as input. Variability in numbers of the images per level is due to the availability of soil colorimetric result that matched the STK color chart. Each photo undergoes three image processing techniques: image enhancement, image segmentation and feature extraction. All the features of the processed images are saved as a Matlab Workspace (.mat) and as an excel document (.xlsx) for backup.

Ten (10) soil samples randomly selected with different nutrient content were used for the evaluation of the program. The samples were manually test and compared to the STK color chart. The proponents synchronized the testing between manual interpretation of soil testing and the program. It was observed that the result of program was the same to the conventional visual test. Table 2 shows the result of the simultaneous testing. These data gave an accuracy of 100% as shown in Table 3.

Table 2
Result of Nutrient and pH Level Identification (Nitrogen, Phosphorus, Potassium, Zinc, Calcium, Magnesium, Initial pH, and Final pH)

Sample No.	Conventional Method								Program							
	N	P	K	Zn	Ca	Mg	pH Initial	pH Final	N	P	K	Zn	Ca	Mg	pH Initial	pH Final
1	L	L	S	S	S	S	6.0	6	L	L	S	S	S	S	6	6
2	L	L	S	S	D	S	6.0	6.4	L	L	S	S	D	S	6	6.4
3	L	L	S	S	D	S	6.0	6.4	L	L	S	S	D	S	6	6.4
4	L	M	S	S	D	S	6.0	6.4	L	M	S	S	D	S	6	6.4
5	L	M	S	S	D	S	6.0	6	L	M	S	S	D	S	6	6
6	L	L	S	S	D	S	5.4	5.4	L	L	S	S	D	S	5.4	5.4
7	L	M	S	S	S	S	6.0	6	L	M	S	S	S	S	6	6
8	L	L	S	S	D	S	6.0	6.4	L	L	S	S	D	S	6	6.4
9	L	M	S	S	D	S	6.0	6.8	L	M	S	S	D	S	6	6.8
10	L	H	S	S	S	S	5.4	5.4	L	H	S	S	S	S	5.4	5.4

Note: L=Low, M=Medium, H=High, S=Sufficient, D=Deficient

Table 3
Summary of Results

Nutrients and pH	Accuracy
Nitrogen Level	10 out of 10 - 100%
Phosphorus Level	10 out of 10 - 100%
Potassium Level	10 out of 10 - 100%
Zinc Level	10 out of 10 - 100%
Calcium Level	10 out of 10 - 100%
Magnesium Level	10 out of 10 - 100%
pH Initial Level	10 out of 10 - 100%
pH Final Level	10 out of 10 - 100%

V. CONCLUSION

The program that determines the six nutrients (Nitrogen, Phosphorus, Potassium, Zinc, Calcium, and Magnesium) and pH level of the soil through 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 accurate.

The project was successfully implemented and done; However, the proponents would like to make the following recommendations to further improve the project; (1) Collect more soil samples for the data sets which could yield on more accurate results. (2) Have a fertilizer recommendation for a specific crop that will be based on the result of the soil testing.

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