Development of a Solar-Powered Closed-Loop Vermicomposting System with Automatic Monitoring and Correction via IoT and Raspberry Pi Module

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***Abstract*—Vermicomposting is a low-cost technology that naturally converts organic wastes into organic fertilizers, commonly called vermicompost, through the combined action of earthworms and mesophilic microorganisms. Vital parameters, such as moisture and temperature, must be considered in the vermicompost production to achieve optimum yield. However, manual monitoring and correction of these said parameters do not give guaranteed results. Also, the traditional process of harvesting vermicompost consumes longer time and requires more human intervention. As a solution, the proponents introduced the development of a system which monitors and corrects these vital parameters, determines the readiness of vermicompost for harvest using digital image processing, and automatically sieves the vermicompost. The system uses Raspberry Pi microcontroller, sensors, and an android phone for monitoring. To measure the system's reliability and efficiency, the proponents conducted two setups of vermicomposting system – one controlled and the other uncontrolled. From the data gathered, the automated system surpassed the latter in terms of production time, yield quality and quantity.**

Keywords*— *vermicompost, African Night Crawlers, Eudrilus eugeniae, sieve, IoT, Raspberry Pi, image processing.

I. Introduction

Vermicompost is a nutrient-rich organic manure that has shown a positive effect on plant growth and development. It contains nutrients such as nitrogen, potassium, phosphorus and calcium which are in ready to uptake form [1]. Intensive studies show that vermicomposting is one of the most important aspects of earthworm technology because it is proven to be an effective mode of waste management, nutrient recycling and sustainable organic farming [2]. It is one of the emerging farming observed in developing countries like the Philippines [3].

Eudrilus eugeniae or commonly known as African night crawler is one of the 400 species of Earthworm that can be found in the Philippines. It is indigenous to Africa but extensively bred in the USA, Canada, Europe and Asia. In tropical country like the Philippines, ANC increases rapidly due to favorable weather condition. It has been identified as a detritus feeder and is capable of decomposing large quantities of organic wastes quickly. Its capability to recover waste protein makes it a potential protein source for animal feeds [3][5]. Earthworms' body work as a biofilter and they have been found to remove pathogens from wastes. Their participation enhances natural biodegradation and decomposition of organic waste from 60 to 80% under optimum conditions of temperature and moisture [6].

Two of the vital parameters that needs consideration in a vermicomposting system are moisture and temperature. The worm bedding must be able to hold enough moisture because they breathe through their skin. A moisture level less than 50% is fatal to worms. Also, maintaining temperature within the worms' tolerance is important to both vermicomposting and vermiculture processes [4]. According to Macabuhay, moisture level must be maintained at around 60-80% in Philippine setting so that microbial activity is high and food matter is easy to feed up. Studies show that Eudrilus euginiae have preferences for high temperature, with maximum biomass production occurring from 25°C – 30° C, while growth rates were very low at 15°C [3].

An automated system of producing organic fertilizer can greatly increase the development of the current agricultural technique [3]. This study aims to develop an automated system that monitors and corrects these vital parameters for vermicompost production.

Fig. 1. African Night Crawler (Eudrilus euginea). A one kilogram of ANC is capable of decomposing 1 kilogram of organic wastes in one day.

II. Methodology

The design and development of the study is primarily concerned with controlling the critical parameters of the vermicomposting system for optimum yield. When undesired range are not met, the correction system initiates. In this study, the vital parameters that were considered are moisture content and temperature.

Two microcontrollers were used. The temperature sensors and relay drivers are connected to the Raspberry Pi. The Arduino UNO reads the analog data from the moisture sensor and transmits it to the Raspberry Pi. The notification system informs the user about the moisture, temperature and pH index of the vermicompost.

The system is divided into two subsystems – the vermicomposting system, where all the sensors and correction occur, and the sieving system, which is mostly mechanical.

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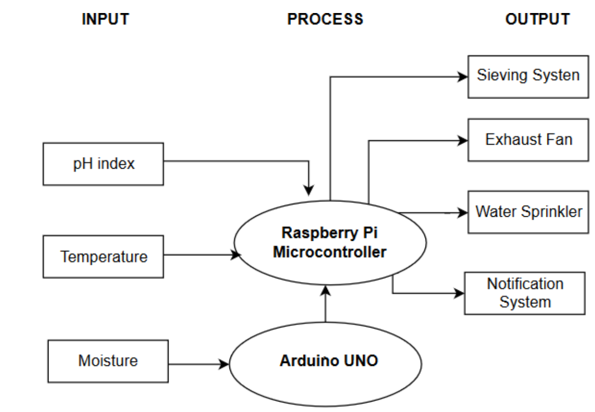

Fig. 2. Conceptual Framework of the Study.

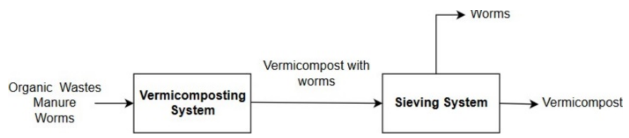

Fig. 3. General Block Diagram.

A. *Composition of Substrates*

The selection for substrate material is based on the organic wastes abundant in the area for deployment. In this study, the substrate is composed of banana stalk and cow manure with a C:N ratio of 7:3. A total of 12 kilograms of substrate was collected and used.

B. *Photovoltaic power system*

To reduce electrical consumption, the entire system is powered by a 260 W solar panel, a 20-Ampere solar charge controller and a 12 V 200Ah Battery bank. All components require only DC power to operate.

C. *Monitoring and Correction System*

To monitor the status of the vermicompost, moisture and temperature sensors are placed inside the worm bin. Three sensors for each parameter were used for precise measurements since vermicompost is not a homogenous mixture. Exhaust fan and water sprinkler was used to optimize the environment of the African Night Crawlers. Values measured from the moisture sensor and temperature sensor are sent to the Raspberry Pi microcontroller. When the measured moisture value is above or below the threshold values, 50% and 80%, the water sprinkler will be activated by the Raspberry Pi. When the measured temperature value is above the threshold value, 32□, the ventilation device and the water sprinkler will also be activated by the Raspberry Pi. Both will be deactivated when the received data becomes within the threshold.

D. *Image Processing*

To detect the health and readiness of the vermicompost for harvest, a digital camera captures the image of the soil. The image will be sent to the Raspberry Pi to be processed. The RGB values will be extracted and analyzed using the equation below:

$$pH\ index = \frac{Red \times Blue}{Green} \tag{1}$$

In a study of Sudha, the pH index ranges from 0.0070-0.0261. In the mentioned study, the image processing followed the diagram below [7]:

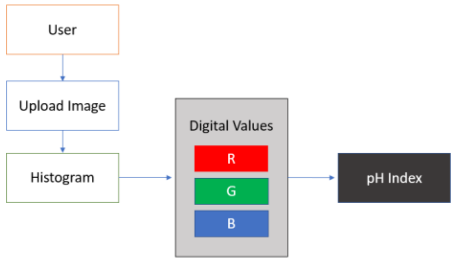

Fig. 4. RGB Extraction Diagram

In this study, the authors performed the same procedures [7-10] in extracting the RGB values of the vermicompost except that the camera used was a Raspberry Pi Camera and that the image is processed to obtain RGB values instantly. The pH index range was recalibrated by extracting RGB values of substrates and vermicompost as shown in Table I and II, respectively.

TABLE I. PH INDEX VALUES OF 30 SAMPLE IMAGES OF SUBSTRATE FOR CALIBRATION

Trial Number	pH index	Trial Number	pH index	Trial Number	pH index
1	0.0158	11	0.0168	21	0.0165
2	0.0152	12	0.0165	22	0.0165
3	0.0155	13	0.0168	23	0.0161
4	0.0152	14	0.0168	24	0.0168
5	0.0155	15	0.0168	25	0.0168
6	0.0158	16	0.0165	26	0.0165
7	0.0160	17	0.0161	27	0.0168
8	0.0163	18	0.0165	28	0.0161
9	0.0159	19	0.0171	29	0.0168
10	0.0172	20	0.0168	30	0.0168

TABLE II. PH INDEX VALUES OF 30 SAMPLE IMAGES OF VERMICOMPOST FOR CALIBRATION

Trial Number	pH index	Trial Number	pH index	Trial Number	pH index
1	0.0455	11	0.0433	21	0.0433
2	0.0436	12	0.0411	22	0.0411
3	0.0432	13	0.0411	23	0.0432
4	0.0432	14	0.0417	24	0.0435
5	0.0432	15	0.0432	25	0.0411
6	0.0432	16	0.0432	26	0.0455
7	0.0432	17	0.0453	27	0.0432
8	0.0390	18	0.0432	28	0.0411
9	0.0432	19	0.0433	29	0.0432
10	0.0432	20	0.0433	30	0.0409

In Table I, the most frequent pH index is 0.0168 with a range of 0.0152-0.0172. Based on the gathered data from Table II, the

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pH index ranges from 0.0390 – 0.0455, with 0.0432 the most frequent. The range of the two is distant with a difference of ranging from 0.0173-0.0389.

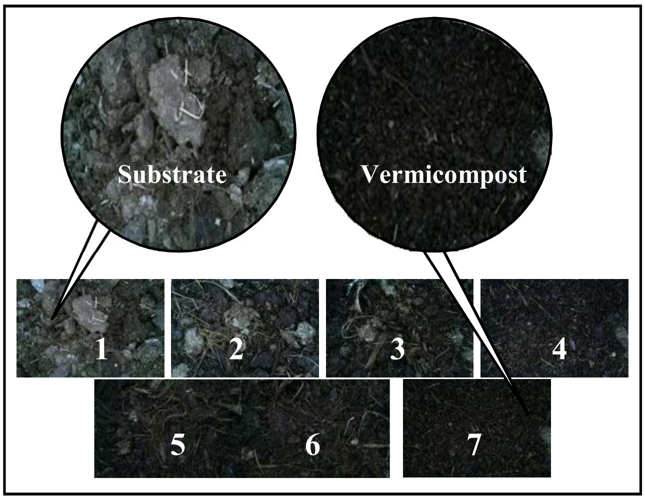

Fig. 5. Sample Images of Vermicompost in a week

The duration of the vermicomposting process in the controlled setup is approximately one week. Shown in the figure above are the images of vermicompost in one whole cycle. The finished product is much darker and finer compared to the initial input. Table III shows the corresponding pH index of the images in Fig. 5.

TABLE III. PH INDEX OF VERMICOMPOST PER DAY

Day	pH Index
1	0.0181
2	0.02
3	0.0243
4	0.0283
5	0.0315
6	0.0349
7	0.0393

E. Sieving System

The developed system is also equipped with a three- layered sieve for the automatic segregation of vermicompost and worms. When the soil pH index is between 0.0390 and 0.0455, the sieving system will initiate for a duration of 15 minutes. DC gear motors are used to operate the three-layered sieve, it will provide the motion of the mesh screens. The motor used for this study has a speed of 282 revolution per minute, 12V rating.

Fig. 6. Motor shafting setup

F. Android App Interface

To monitor the status of the critical parameters and processes in the vermicomposting system. Also, to notify the user if the system needs to restart. Android is developed by the Open Handset Alliance and provides applications that can access the phone hardware (camera), Wi-Fi and cellular networks, user data, and phone settings, through a third-party development with an extensive API.

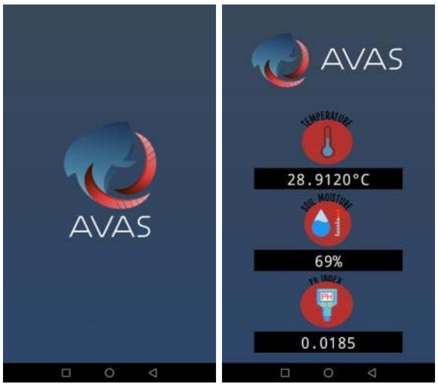

Fig. 7. Android app interface

G. Statistical Analysis

Regression analysis was used for the pH index of the controlled and conventional system to determine the maturity rate of the vermicompost.

The exponential analysis is in the equation form of:

$$y = \alpha e^{\beta x} \quad (2)$$

Where: y = pH index
α = constant
β = growth rate
x = number of days past

III. Results and Discussion

The moisture and temperature of the vermicompost were constantly monitored and controlled to create an ideal environment for the ANCs. The moisture level of the vermicompost was monitored and corrected. It can be observed that when the moisture level reached below the desired range, it is followed by an increasing marker which indicates that the correction system operated. The lowest moisture reading recorded was 55% and the maximum moisture level was 82.50%.

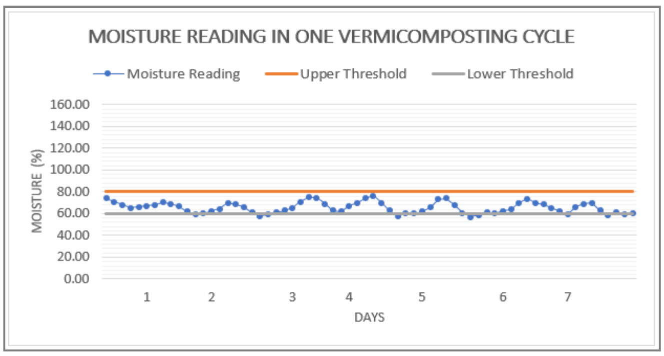

Fig. 8. Moisture reading of the vermicompost in a span of approximately seven days or one week.

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Similarly, the temperature of the vermicompost was monitored and corrected. There are markers indicating the temperature rise in the worm bin. However, it is observable that after sharp increases, the temperature falls back below 32°C implying that the correction system functions. The lowest temperature measured was 23.24°C and the highest temperature recorded was 34.95°C.

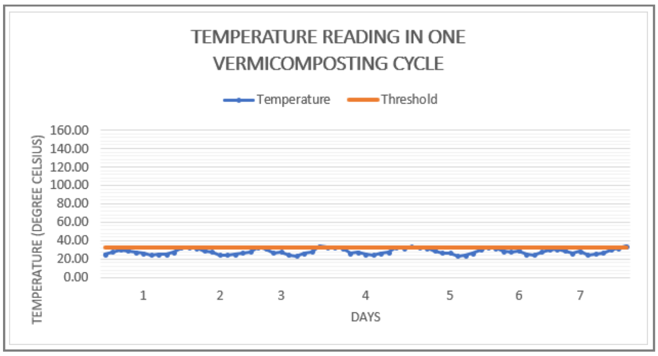

Fig. 9. Temperature reading of the vermicompost in a span of approximately seven days or one week.

The pH index is measured every three hours. The graph reveals that the production time of vermicompost in the controlled setup took only approximately 7 days to finish while the conventional setup lasted about 13 days as shown in Fig. 10.

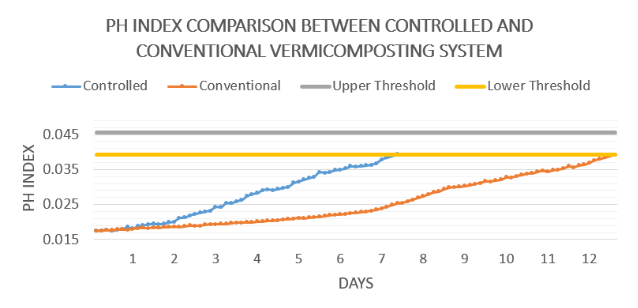

Fig. 10. pH Index Between Controlled and Conventional Vermicomposting Setup. The graph above shows one whole vermicomposting cycle of each setup.

Figs. 11 and 12 shows the scatter plot and the trend line of the controlled and conventional setup's pH index of the vermicomposting system for one cycle. The regression plot shows that the growth rate in the controlled setup is greater compared to the conventional setup and that the monitoring and correction system improved the rate of production time of vermicompost by 75.86%.

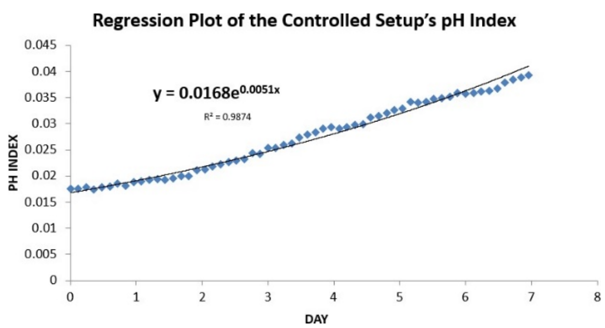

Fig. 11. Regression plot of the Controlled Setup's pH Index

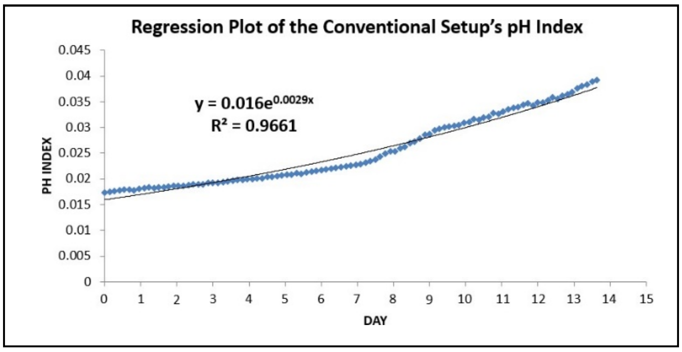

Fig. 12. Regression plot of the Conventional Setup's pH Index

Fig. 13 shows the sieved vermicompost per layer. The sieving process lasted for 10 minutes. For an input of 12 kilograms, the system can produce 4-5 kilograms of vermicompost in one week. The harvested vermicompost was brought to the Philippine Coconut Authority for laboratory test and the results can be found in Table IV.

Fig. 13. Sieved vermicompost per layer

The table below shows the laboratory results of the vermicompost prior to washing. The NPK content of the vermicompost is approximately 4.89%, the moisture content is about 65.536%, the organic matter is around 45.933% and lastly, the C: N ratio is 16.123:1.

TABLE IV. VERMICOMPOST LABORATORY RESULTS

Analysis	Standard value of compost	Vermicompost
$N\text{-}P_2O_5\text{-}K_2O$	2.5-5%	4.89 ± 0.245%
Organic matter	≥20%	45.933 ± 0.507%
C: N	10:1-20:1	16.123:1

IV. CONCLUSION

In this study, the authors optimized the environment of the African Night Crawlers by installing a monitoring and correction system. Furthermore, the system uses image processing to detect the readiness of the vermicompost for harvest. The developed system is also equipped with a three- layered sieve for the automatic segregation of vermicompost and earthworms. DC gear motors are used to operate the three- layered sieve.

The vermicompost's quality and readiness for harvest is indicated by a machine vision technology that captures the image of the soil, extracts the RGB values, processes and communicates with the sieving system whether to initiate or not. The sieving system provides a convenient and effective method of separating the worms from the vermicompost.

The obtained pH index for vermicompost ranges from 0.0390-0.0455. Performing regression analysis and representing

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the data through exponential function reveal that the pH index of the controlled setup increases faster compared to the controlled setup at a rate of 0.0051 with 99% confidence level in a span of approximately one week.

Lastly, implementing a notification system via Android allows the farmers to monitor the status of the critical parameters and processes in the vermicomposting system.

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