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Development of Smart Chopper Composting Monitoring System

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ABSTRACT

Overconsumption of food can result in environmental pollution, making it a particularly concerning issue in modern civilization. In Malaysia, food waste is generated at a rate of 16,688 tonnes per day. Despite its biodegradation properties and strong composting potential, about 80% of food waste is still disposed of in landfills. Air, soil and water pollution are risks often associated with food waste disposal. Since two-thirds of total waste is avoidable, preventing the rise of household food waste should be a top priority, among which is through composting. This project aims to build a smart composter that can chop food waste and monitor the mixing of food waste to become mature compost. A DC motor controlled by the Arduino Mega microcontroller was used to spin the chopper blades to shred the food into smaller sizes. Temperature, moisture and pH sensors were used to measure the essential parameters to ensure that the food waste mix can become mature compost. The Liquid-crystal display was used to display the parameter value in real time to facilitate the monitoring process. A fan will be activated if the temperature reaches 60 ^oC to reduce the heat, followed by a solenoid valve to increase the moisture level by supplying water to the compost when the compost is dry. The sensors were also compared with commonly used measuring devices to assess the effectiveness of the sensors used. From the results, all the sensors used were reliable as displayed by a high percentage of accuracy with an average error percentage per sensor of 3.45% for temperature, 2.62% for moisture and 3.52% for pH. Several improvements can be made in the future to achieve smaller amounts of chopped food waste in lesser time, which can be done by reducing the distance between the chopper blade and the container, besides adding more blades.

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1. Introduction

The amount of waste generated in many cities and towns is increasing due to population growth, urbanisation and changing lifestyles. Peninsular Malaysia's daily solid waste production grew from 16,200 tonnes in 2001 to 19,100 tonnes in 2005, or from 0.8 kilogrammes per person per day to 1.2 kilogrammes. On average, 45% of Malaysia's solid waste is made up of food waste, 24% plastic, 7% paper, 6% metal, as well as 3% glass and other materials [1]. It has been reported that the composition of organic waste (food waste) in municipal solid waste is the highest among the solid waste produced (45%) [1-3]. In addition, around 1.3 billion tonnes of food have been reported to be lost in the processes of production, processing, distribution, consumption and disposal [4].

Most food waste is landfilled together with other waste, leading to problems such as odours, drawing parasites, harmful gas emissions, leachate tainting of groundwater and landfill waste [5]. Besides, a lot of Malaysian landfills have reached their capacity, making the process more difficult [6]. Composting is one of many solutions to reduce the amount of solid waste going to landfills, reduce greenhouse gas emissions and improve soil fertility, which in turn would result in improved plant development [7,8]. The Twelfth Malaysia Plan also suggests using food stall waste, which consists mostly of discarded food and tissues, to create compost or biogas [9].

Composting is the process of converting organic waste into a solid, paste or mush-like substance, as well as the controlled aerobic biological decay of organic materials [10]. It is essentially similar to the cycle of spontaneous decomposition with the distinction that organic waste is enhanced and optimised for microbial development [11]. Compost is often found at home or on a forestry farm, where wet waste is composted and used as agricultural manure [12].

Natural decomposition is a slow and time-consuming process. Thus, efforts have been made to find a sustainable alternative method for accelerating the breakdown of food waste to overcome such challenges. A compost machine is a standalone device that speeds up the composting process and produces higher-quality compost. It produces manure after receiving waste as an input. Based on the existing technologies and design of the compost machine, important components should be possessed in the selected compost machine based on material, design of chamber, design of cutting, mixing hand, shaft and motor.

Composting is usually faster when materials are split and chopped into bits with the help of a cutting blade grinder system [13] as smaller particles provide more surface area [14]. Maximised area of decomposition will speed up its breakdown. The distribution of the finished compost in particles is critical to the distribution of gas and water and, especially, the water retention ability [15]. The best cutting blade design maximises the number of processed materials by making the most contact with the feed component [16]. Additionally, compared to other blades, the blade with a linear edge form will need less force (the sharpest one). Different kinds of chopper blades are used, among them are made up of 3 to 20 tiny blades with five-pointed corners and hexagonal spindle holes [17]. Other choppers are made up of a frustum-shaped receptacle that holds all organic waste [18].

Other than making the food waste smaller, the composting machine should be able to turn the compost regularly. Compost, if turned regularly, kept moist and has a good mix of components, is usually ready to be used in three to six months. The composting period can be reduced to less than a month with daily turnings and highly degradable materials [19]. Ready-to-use fertilisers take more than a year to produce if the techniques used require almost little turning [20].

Composting takes place basically at two temperatures mesophilic and thermophilic ranges at 10-40 ^{o}C and over 40 ^{o}C, respectively. Despite successful composting by mesophilic temperatures, experts recommend that temperatures between 43 ^{o}C and 65 ^{o}C be held [21]. Substantial stabilisation occurs through the regulation of air supply, water and temperature [22].

For microorganisms to operate, there must be moisture. The process would be slower if the ingredients are dry. On the other hand, too much water makes the fertiliser heap soggy and dense, impeding the airflow. When fertilising, the soil components should be saturated but not dripping wet. Some studies employed a DS18B20 moisture sensor to monitor the moisture content [11,18].

The pH level is the most important parameter in composting [23]. The best pH values range between 5.5 and 8.0 for composting [24]. Others mentioned pH values between 6.0 to 7.8, which are considered neutral pH, ensuring high quantities of microorganisms for effective decomposition [13]. In general, pH fits a composting pattern; reduced pH levels in the early composting phases and increased pH in later composting phases [23]. Improved pH has induced an improvement in NH_3/NH_4 ratio with the consequence that the volatilisation rate has been improved [25]. Aerobic composting has demonstrated significantly greater pH than anaerobic possibly owing to higher concentrations of potassium [26].

Aeration is a significant composting element [23]. Essentially, composting is an aerobic mechanism that absorbs O_2 and emits gassed H_2O and CO_2 [27]. The composter body should have a pore or hole to ease the air can through in to give aeration to the food waste. The purpose of the aeration is to accelerate the composting process. Meanwhile, a high temperature above 72 ^oC may kill the bacteria and will distract the composting process [28]. The aeration flow is needed to flow out the heat insides to reduce the high temperature.

Current automated composters, on the other hand, are disadvantageous in terms of blocking odours, reducing outgassing and determining the compost maturity index [29]. Composting is a tightly regulated process that includes measured inputs of water, air, carbon and nitrogen-rich materials. A monitoring and control system can help users by establishing the maturity of the compost with proper monitoring and determining should there is a problem. The chopper composting machines must perform ideally to their tasks and requirements, must be simple to use and safe to run [29].

This study presents the mechanical architecture of a composting system that includes an automated chopper, temperature, moisture and pH monitoring, as well as a mechanism for controlling temperature and moisture. A high-torque motor was used to power the proposed smart chopper composting monitoring system, which is controlled by an Arduino Mega and L298N motor driver. Temperature, moisture, and pH were three variables tracked to determine the compost's maturity before it could be used. Also, this study provides and explains the monitoring and control of the system's efficacy.

2. Methodology

Figure 1 depicts the block diagram of the electrical circuit connections as well as the parts needed to construct an automated composter with an upgraded function that can monitor temperature, moisture and pH levels, as well as manage temperature and moisture levels. Each component serves a distinct function in the overall system's effectiveness.

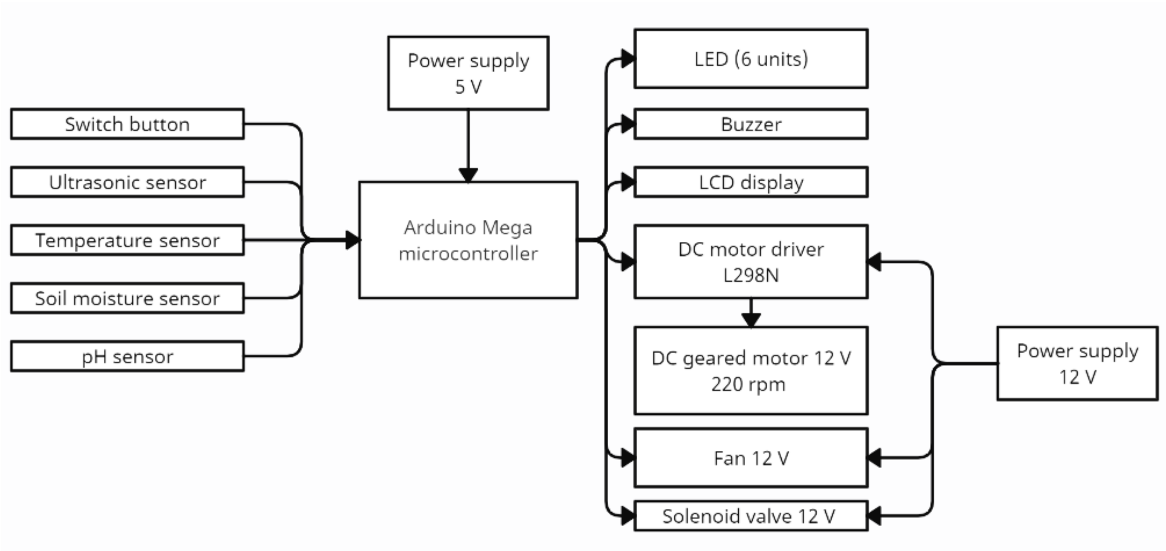


Fig. 1. Circuit block diagram

Figure 2 shows the design of the developed composter machine where handcrafted compost tanks were used. Strong iron was utilised to withstand the cutting power generated by the chopper blades in Tank 1 when it is operating and avoid leaks while the compost was being preserved in Tank 2. In Tank 2, three sensors, namely temperature, moisture and pH, were placed to monitor the compost's maturity. An Arduino Mega microcontroller contained in the electronic box was used to gather and process the sensor data. In addition, an LCD was used to display the sensor readings.

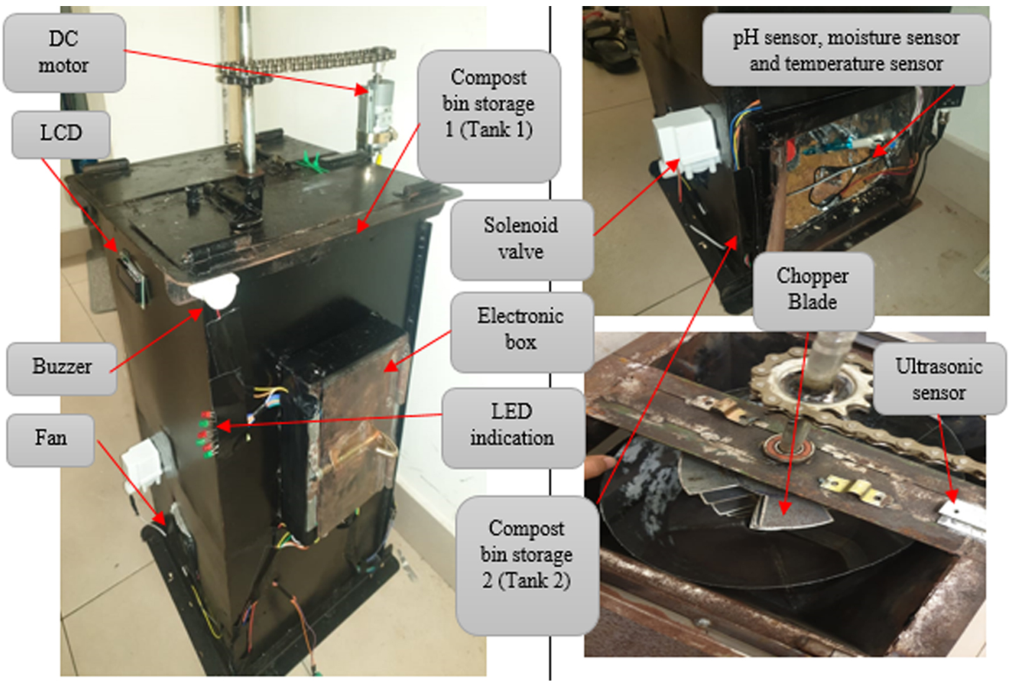


Fig. 2. Composter prototype

First, food waste, specifically cabbage combined with soil, was manually fed into Tank 1. The soil used for this study was normal soil with low moisture content since the mixture can produce better compost when mixed with compost material. An ultrasonic sensor was placed in Tank 1. When the ultrasonic sensor detects an object at a distance of 5 cm or less, that is, there is an opening movement of the compost Tank 1 enclosure, it sends a signal to the microcontroller instructs a DC-geared motor

(12 V, 220 rpm, 10 kgf.cm) to run for 4 minutes. The blades are mounted on a DC-geared motor. As the DC motor rotates, the blades mix and chop cabbage and soil. A high torque DC gear motor is required to prevent the blades from jamming when the kitchen waste and soil mixture are placed on them. After the shredding was completed in the first part of the tank, the compost was manually added to Tank 2. In the second tank, temperature, moisture and pH sensors were placed to monitor the condition of the floor. The readings received from the sensors were displayed on the LCD at each preset time.

According to our definition, the best conditions for accelerating composting are temperatures between 40 °C and 60 °C, moisture levels between 40% and 60%, and a pH between 6.0 and 7.8. The red LED will turn on if the mixture's condition in Tank 2 is out of range; otherwise, the green LED will turn on. The solenoid valve was used to supply water to the compost mix to control the moisture level. The fan will activate when the temperature is above 60 °C to reduce the temperature to the ideal threshold.

When measuring during an analytical process, the absolute percentage of error was used to identify the efficiency of the sensor measurements. The value is closer to the acceptable or original when the percentage of error is low. A 1% error, for example, implies an extreme closeness to the acceptable number, but a 48% error shows results far from the genuine value. Since sensors can be inaccurate or do not have the potential to estimate precisely, measurement mistakes are often unavoidable. The percentage error was defined by Eq. (1).

$$\%\, Error = \left|\frac{A_i - F_i}{A_i}\right| (100) \tag{1}$$

Where;
A_i= Actual value
F_i= Forecast value

The forecast value was derived from the sensor readings taken from the LM35 temperature sensor, soil moisture module and analogue pH sensors, while the actual value was taken from the meters HI99121 Direct Soil Measurement pH Portable Meter and ECOWITT WH0291 Soil Moisture Tester Plant Soil Moisture Sensor Meter.

Each temperature, moisture and pH measurement readings were collected three times with each data collection being conducted for 1 minute. The computation using Eq. (2) was performed to determine the mean percentage error at each trial taken from 14 observations. Eq. (3) was used to determine the average value of the mean percentage error from a total of 3 trials.

$$Mean\,\%\, error = \left(\frac{1}{n}\right)\left(\sum_{i=1}^{n} \frac{|A_i - F_i|}{A_i}\right)(100) \tag{2}$$

Where;
n= total number of observations

$$Average\ of\ mean\,\%\, error = \frac{mean\,\%\,error\ trial\ 1 + mean\,\%\,error\ trial\ 2 + mean\,\%\,error\ trial\ 3}{3} \tag{3}$$

3. Results

3.1 Efficiency of Chopping Mechanism

The cutting efficiency of the developed blade has been tested to see if the cutting mechanism is effective. The length of the vegetable was measured both before and after it has been cut by the blades in a predefined amount of time. Figure 3 depicts the size of the cabbage before being chopped. Three samples were chosen at random.

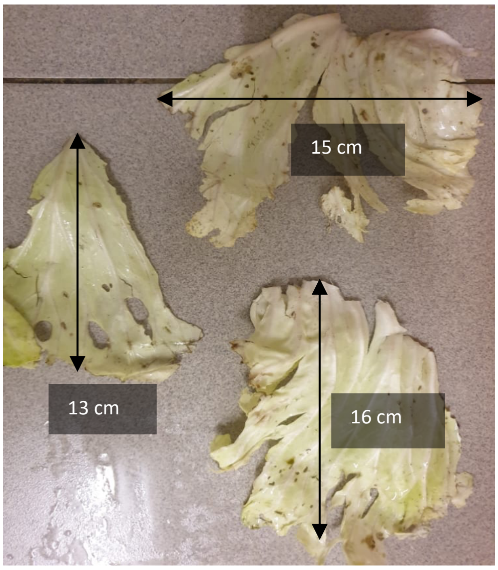


Fig. 3. Cabbage size before being chopped

Table 1 displays the length of the vegetable sample after 1 to 4 minutes. After 4 minutes of chopping, the vegetables for samples 1, 2 and 3 were able to shrink to lengths of 4 cm, 3.5 cm and 3 cm, respectively.

Table 1
Cabbage size after being chopped

	Length Sample (cm)		
Duration (min)	Sample 1	Sample 2	Sample 3
0	16	15	13
1	10	8.5	8
2	7.5	7	6
3	5	6.5	5.5
4	4	3.5	3

3.2 Efficiency of Temperature, Moisture and pH Measurements

Using the temperature, soil moisture and pH meter, the accuracy of the temperature, moisture, and pH sensor values was confirmed. Coexisting the sensors with the metering device is necessary to obtain a value that is roughly the same and get a lesser proportion of error. To observe the condition of the disparities, the differences are presented in graphs shown in Figures 4 to 6. Figures 4 (a) to (c) present the measurement plot of the temperature sensor and the temperature meter.

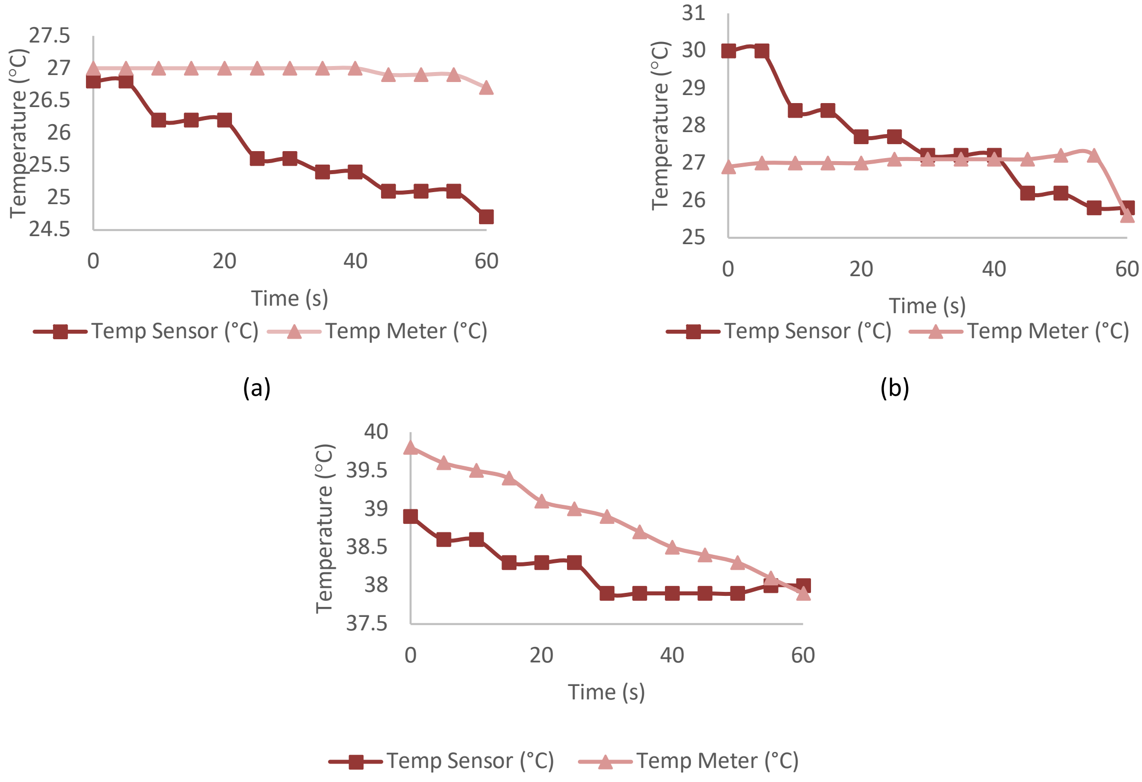


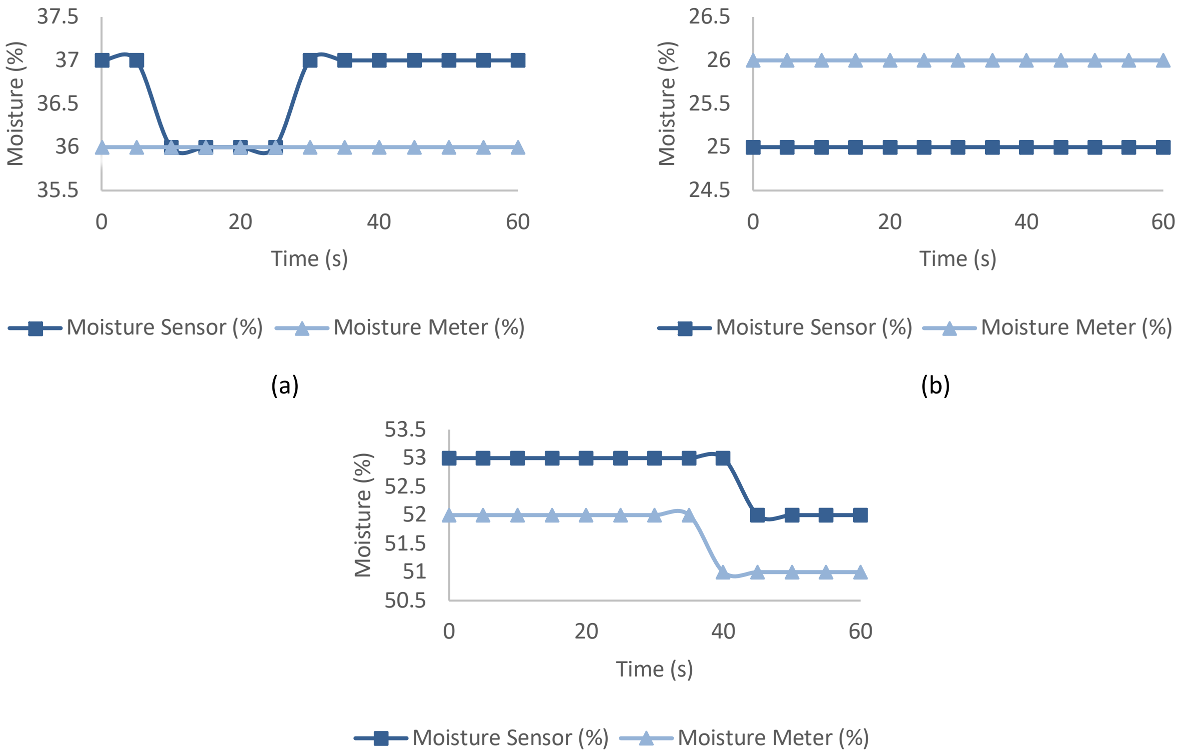
Fig. 4. Temperature readings from the (a) first trial; (b) second trial; (c) third trial

The average mean percentage error for the first, second, and third temperature measurement trials, as shown in Table 2, was 3.45%, with individual values of 4.63%, 3.99% and 1.75%.

Table 2
Absolute percentage of error and mean percentage error for temperature measurements

	Trial 1			Trial 2			Trial 3		
Time (s)	**Sensor (°C)**	**Meter (°C)**	**Error (%)**	**Sensor (°C)**	**Meter (°C)**	**Error (%)**	**Sensor (°C)**	**Meter (°C)**	**Error (%)**
0	26.8	27	0.74	38.9	39.8	11.52	38.9	39.8	2.26
5	26.8	27	0.74	38.6	39.6	11.11	38.6	39.6	2.53
10	26.2	27	2.96	38.6	39.5	5.19	38.6	39.5	2.28
15	26.2	27	2.96	38.3	39.4	5.19	38.3	39.4	2.79
20	26.2	27	2.96	38.3	39.1	2.59	38.3	39.1	2.05
25	25.6	27	5.19	38.3	39	2.21	38.3	39	1.79
30	25.6	27	5.19	37.9	38.9	0.37	37.9	38.9	2.57
35	25.4	27	5.93	37.9	38.7	0.37	37.9	38.7	2.07
40	25.4	27	5.93	37.9	38.5	0.37	37.9	38.5	1.56
45	25.1	26.9	6.69	37.9	38.4	3.32	37.9	38.4	1.3
50	25.1	26.9	6.69	37.9	38.3	3.68	37.9	38.3	1.04
55	25.1	26.9	6.69	38	38.1	5.15	38	38.1	0.26
60	24.7	26.7	7.49	38	37.9	0.78	38	37.9	0.26
Mean Percentage Error			**4.63%**			**3.99%**			**1.75%**

Figures 5 (a) to (c) display the measurement plot of the moisture sensor and the moisture meter.



(c)

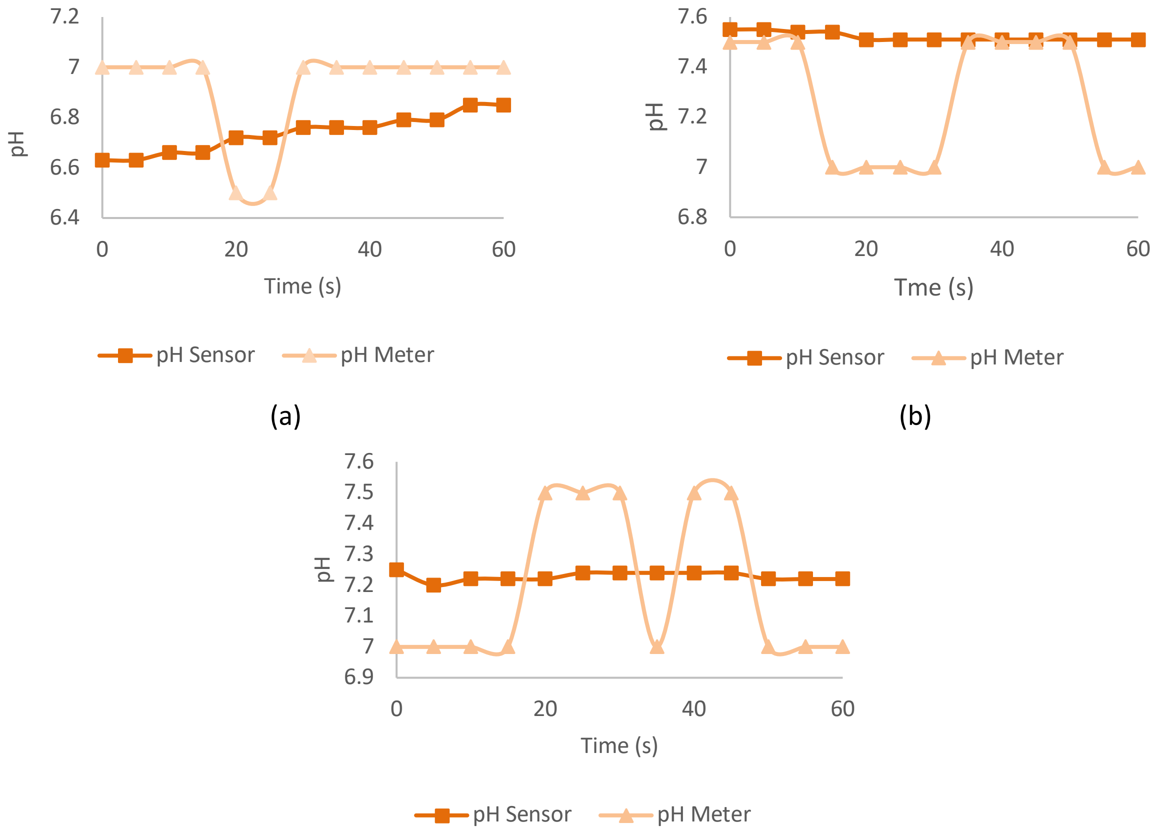
Fig. 5. Moisture readings from the (a) first trial; (b) second trial; (c) third trial

According to Table 3, the mean percentage error for the first, second and third moisture measurement trials was 1.92%, 3.85%, and 2.09%, respectively, resulting in an average value of 2.62%.

Table 3
Absolute percentage of error and mean percentage error for percentage of moisture measurements

	Trial 1			Trial 2			Trial 3		
Time (s)	**Sensor (%)**	**Meter (%)**	**Error (%)**	**Sensor (%)**	**Meter (%)**	**Error (%)**	**Sensor (%)**	**Meter (%)**	**Error (%)**
0	37	36	2.78	25	26	3.85	53	52	1.92
5	37	36	2.78	25	26	3.85	53	52	1.92
10	36	36	0	25	26	3.85	53	52	1.92
15	36	36	0	25	26	3.85	53	52	1.92
20	36	36	0	25	26	3.85	53	52	1.92
25	36	36	0	25	26	3.85	53	52	1.92
30	37	36	2.78	25	26	3.85	53	52	1.92
35	37	36	2.78	25	26	3.85	53	52	1.92
40	37	36	2.78	25	26	3.85	53	51	3.92
45	37	36	2.78	25	26	3.85	52	51	1.96
50	37	36	2.78	25	26	3.85	52	51	1.96
55	37	36	2.78	25	26	3.85	52	51	1.96
60	37	36	2.78	25	26	3.85	52	51	1.96
Mean Percentage Error			**1.92%**			**3.85%**			**2.09%**

Whereas Figures 6 (a) to (c) display the measurement plot of the pH sensor and the pH meter.



(a) (b)

(c)

Fig. 6. pH readings from the (a) first trial; (b) second trial; (c) third trial

According to Table 4, the mean percentage error of the first, second and third pH measurements was 3.66%, 3.58% and 3.32%, respectively, yielding a mean value of 3.52%.

Table 4
Absolute percentage of error and mean percentage error for pH measurements

	Trial 1			Trial 2			Trial 3		
Time (s)	**Sensor**	**Meter**	**Error (%)**	**Sensor**	**Meter**	**Error (%)**	**Sensor**	**Meter**	**Error (%)**
0	6.63	7	5.29	7.55	7.5	0.67	7.25	7	3.57
5	6.63	7	5.29	7.55	7.5	0.67	7.2	7	2.86
10	6.66	7	4.86	7.54	7.5	0.53	7.22	7	3.14
15	6.66	7	4.86	7.54	7	7.71	7.22	7	3.14
20	6.72	6.5	3.38	7.51	7	7.29	7.22	7.5	3.73
25	6.72	6.5	3.38	7.51	7	7.29	7.24	7.5	3.47
30	6.76	7	3.43	7.51	7	7.29	7.24	7.5	3.47
35	6.76	7	3.43	7.51	7.5	0.13	7.24	7	3.43
40	6.76	7	3.43	7.51	7.5	0.13	7.24	7.5	3.47
45	6.79	7	3	7.51	7.5	0.13	7.24	7.5	3.47
50	6.79	7	3	7.51	7.5	0.13	7.22	7	3.14
55	6.85	7	2.14	7.51	7	7.29	7.22	7	3.14
60	6.85	7	2.14	7.51	7	7.29	7.22	7	3.14
Mean Percentage Error			**3.66%**			**3.58%**			**3.32%**

3.3 Efficiency of Temperature and Moisture Control

This section attempts to discuss the technique used to prevent compost bin storage from becoming too hot. The purpose of this system is to maintain the compost's microorganisms as they contribute to soil fertility. Temperature is a key indicator of the compost's health. Figure 7 illustrates a controlled temperature shift that occurs when a temperature rises too high and heat is emitted by a fan that is automatically turned on and off depending on predetermined conditions.

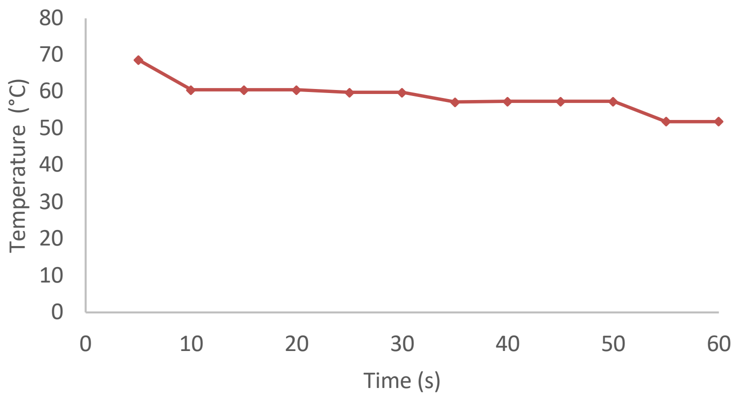


Fig. 7. Temperature changes when the heat reached 60 °C

Figure 8 depicts the compost's condition both before and after the water has been introduced. A solenoid valve was installed to control the water flow to maintain the correct amount of soil moisture at all times. The graph demonstrated that the solenoid valve was operating as intended since there was a quick increase to 50% when the moisture content was below 40%. The soil's microbes depend on this moisture to survive and grow. Worm-infested, wet soil might improve the soil.

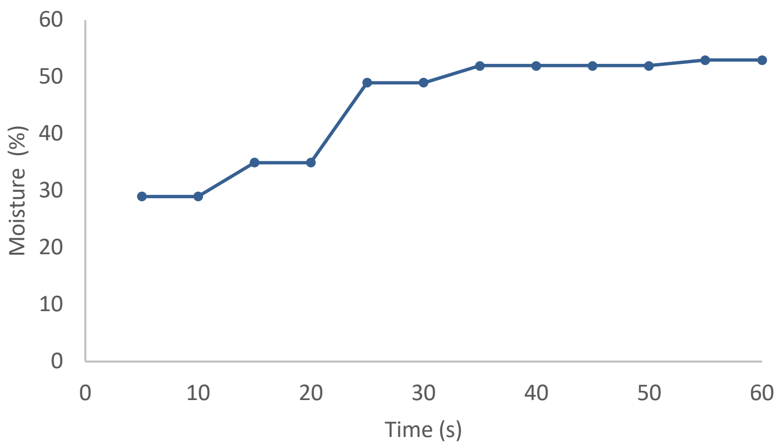


Fig. 8. Moisture changes when a dry condition is detected

4. Conclusions

A smart composting monitoring system with temperature and moisture control has been successfully developed in this study. Soil temperature, moisture and pH sensors were the three main sensors in the system by which the effectiveness of the sensors used has been evaluated. The system demonstrated good measurement accuracy with an error range of 1.75% to 4.63% for the temperature sensor, 1.92% to 3.85% for the moisture sensor and 3.32% to 3.66% for pH sensors. The fan worked as intended to cool down the heat inside the chamber when the temperature rose above 60 ^{o}C. Meanwhile, the solenoid valve also played its role as the moisture content increases when the food waste mixture dropped below 40%. The chopping mechanism gave acceptable results; however, some improvements can be made to optimise the chopping efficiency. For instance, the first tank area should be lowered again to place it closer to the blade, as most composting materials cannot be properly shredded when the gap is too wide. Moreover, the spacing between the blades should also be tightened so that the compost material does not get trapped in the gaps between the blades.

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