Moisture Measurement Growing Media and Automatic Watering Mini Greenhouse Growing Media for Microgreen

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ABSTRACT

Microgreens are a specific type of vegetable that has gained tremendous popularity in industrialized countries due to their higher nutrient and vitamin content compared to commonly grown foods. However, in Indonesia, microgreen plants are not yet widely recognized within the broader community. Agriculture plays a crucial role in an agrarian country like Indonesia. However, in certain regions, farmers have not fully embraced modern technology for land cultivation, irrigation management, and increasing crop yields.his research utilizes Tsukamoto's Fuzzy Logic method and incorporates a stepper motor as a nozzle driver for automatic watering in a mini greenhouse. The study employs sensors such as soil moisture sensors to measure and control soil moisture levels, as well as water flow sensors to monitor water discharge. The use of a soil moisture sensor enables precise control over soil moisture, ensuring optimal conditions for microgreen cultivation. The results of this study indicate an error value of 0.7% in sensor calibration and a 90% success rate in planting microgreens using this tool. The high success rate can be attributed to the ideal humidity levels maintained in the majority of the planting media, ranging from 45% to 65%.

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1. INTRODUCTION

Agriculture holds a significant position in agrarian nations like Indonesia. However, in specific regions, farmers are not leveraging modern technology for land cultivation, irrigation management, and enhancing crop yields [1]. Greenhouses have emerged as a widely adopted technology in agricultural settings, embraced by both contemporary farmers and researchers. In this context, one study aimed to enhance control within greenhouses through engineering approaches focused on air humidity and water irrigation [2].

Thanks to the automatic control system and the ATMega 328 microcontroller, farmers are no longer reliant on manual labor and can save time by avoiding the need for daily manual control of the greenhouse. This allows them to engage in other activities [3]. Furthermore, this study incorporates Tsukamoto's fuzzy logic method, which is a type of logic that utilizes two distinct values: false and true [4].

In the theory of fuzzy logic, a value can be determined as either true or false based on its level of membership in a fuzzy set [5]. There are numerous factors that can influence plant cultivation, including the humidity of the growing medium, air temperature, and more. An increasingly popular example of plant cultivation is microgreens, which are plants harvested within 7-14 days of planting and are also referred to as germination.

The underlying issue addressed in this study pertains to the cultivation of microgreen plants without the utilization of technology, which can result in reduced harvest yields, contrary to the expectations of many farmers [6]. Typically, microgreen farmers face challenges related to the inability to monitor soil moisture and automate irrigation, leading to the death or stunted growth of microgreens in relation to their age [7]. Cultivating microgreens in open land poses several weaknesses, including inadequate air humidity, unsuitable environmental temperatures, susceptibility to wind damage, and vulnerability to floods, which do not align with the optimal requirements for plant growth. Consequently, these factors adversely affect the growth and productivity of microgreen farmers [8].

Various methods, including artificial intelligence techniques such as artificial term networks, fuzzy logic, and genetic algorithms, can be employed as automatic irrigation design methods [9]. Previous studies have explored related research topics, such as the work conducted by [10] titled "Design and Construction of Automatic Planting Device Using NodeMCU Based on Internet of Things." This research aimed to elucidate the operational principles of soil moisture sensors and automatic systems.

Another relevant study in the domain of fuzzy logic is titled "Provision of Micro Credit at Bank Mandiri Bogor with the Fuzzy Tsukamoto Method" [13]. This research focused on obtaining successful solutions, with the outcome heavily reliant on various parameters, including population size, offspring size, and the number of generations utilized.

2. METHODS

2.1. Fuzzyfication Calculation

Fuzzy calculation involves converting specific input values of a system into linguistic variables by utilizing predefined membership functions. It is an effective approach to map an input space to an output space. When dealing with highly complex systems, fuzzy logic provides a viable solution [19]. Fuzzy systems are particularly advantageous for approximate reasoning, especially when addressing problems that are challenging to define using mathematical models. For instance, when the input values and parameters of a system are imprecise or ambiguous, it becomes difficult to establish a precise mathematical model.

2.1.1. Fuzzyfication

In the developed system, fuzzy logic is employed to automatically determine the timing of plant watering based on the input value of soil moisture. The fuzzy calculation consists of three stages: fuzzyfication, inference, and defuzzyfication.

The first stage, fuzzyfication, involves creating fuzzy variables based on the designated parameter values, namely the soil moisture level and watering time. The fuzzy variable for the soil moisture level is categorized into dry, wet, and ideal fuzzy sets [20]. Each set is further divided to obtain specific fuzzy variables. The membership formula for the soil moisture value is as follows:

$$\mu\, dry(x) \begin{cases} 1\,, & x \le 20 \\ \dfrac{50-x}{30}\,, & 20 < x < 50 \\ 0\,, & x \ge 50 \end{cases} \tag{1}$$

$$\mu\, ideal(x) \begin{cases} 0, & x < 27 \\ \dfrac{x-20}{30}, & 20 < x < 50 \\ \dfrac{80-x}{30}, & 50 < x < 80 \\ 0, & x \ge 80 \end{cases} \tag{2}$$

$$\mu\, heat(x) \begin{cases} 1\,, & x \ge 80 \\ \dfrac{x-80}{30}\,, & 50 < x < 80 \\ 0\,, & x \le 50 \end{cases} \tag{3}$$

Based on the membership formula, the soil moisture value is also obtained a graph that will show the relationship of the three linguistic variables that have been arranged as in Fig. 1. In the given graphical image, it is evident that when the predicate value is 1, the value is definitely true or TRUE, indicating that it does not fall within the threshold of uncertainty in Fuzzy calculations. For instance, if the predicate value for the dry set is 20, it means that when the humidity is 20, the set is undoubtedly classified as "dry." However, when the humidity level is 21, fuzzy changes are introduced to determine the predicate value. The time mentioned in this context is measured in milliseconds (ms), which is a common unit used in Arduino programming. In the implemented system, the motor will halt at three specific positions: the starting point, midpoint, and the final point. The duration of each stoppage will be determined by the moisture level detected in the soil.

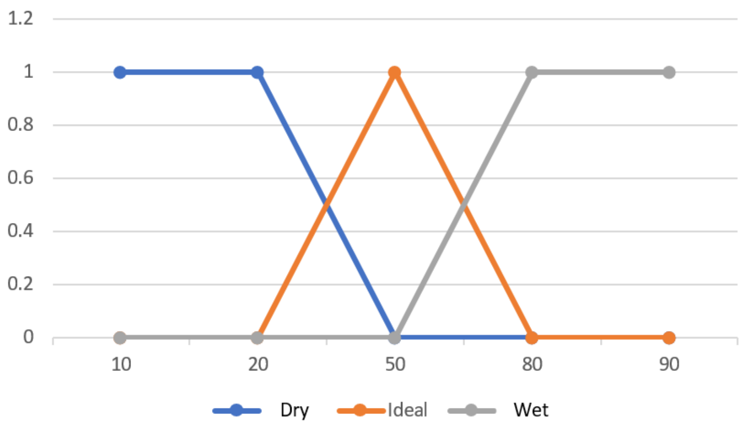

Fig. 1. Graphic fuzzyfikasi

The agglomeration function that has been created is then incorporated into the Arduino IDE program to enable its execution within the system. Additionally, the generation of membership values is available for the watering time. Watering time refers to the duration during which the motor operates in three intervals to water the soil in the greenhouse. The formula for generating the membership value for watering time can be observed in the following equation.

$$\mu\, fast(x) \begin{cases} 1, & x \leq 1000 \\ \dfrac{3000 - x}{2000}, & 1000 < x < 3000 \\ 0, & x \geq 3000 \end{cases}$$

$$\mu\, medium(x) \begin{cases} 0, & x \leq 5000 \\ \dfrac{x - 1000}{2000}, & 1000 < x < 3000 \\ \dfrac{5000 - x}{2000}, & 3000 < x < 5000 \\ 0, & x \geq 5000 \end{cases}$$

$$\mu\, slow(x) \begin{cases} 1, & x \geq 5000 \\ \dfrac{x - 3000}{2000}, & 3000 \leq x \leq 3000 \\ 0, & x \leq 3000 \end{cases}$$

By utilizing the membership formula, the watering time value is obtained, and a graph is generated to illustrate the relationship among the three linguistic variables, as depicted in Fig. 2. This graph portrays the correlation between these variables in a visual manner.

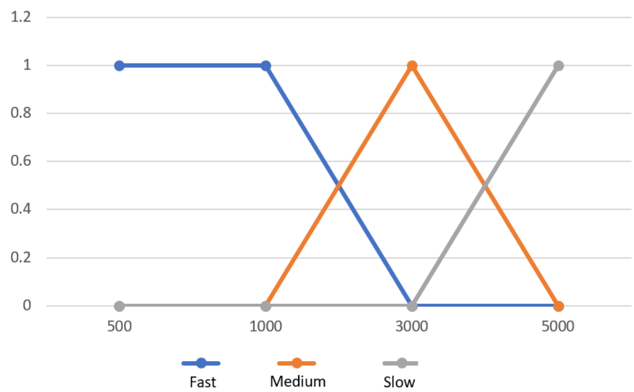

Fig. 2. Stepper motor stopover time fuzzy membership chart

The time reference for motor stops is determined through adjustments made after conducting system experiments. Once the appropriate aggotaan function is created, it is then incorporated into the Arduino IDE program to enable its execution within the system.

2.1.2. Inference

In the subsequent stage, the pre-established rules serve as the knowledge base for the inference process in the inference block. Inference involves evaluating these rules to generate output based on each rule. To obtain output in fuzzy domains, the implication function is applied. In the inference phase, rules are formulated based on the potential predicate values derived within the system.

2.1.3. Defuzzyfikasi

The input obtained from the defuzzification process is a fuzzy set, which is then transformed into a crisp (sharp) value. This crisp value represents the output of the storage time. Using Tsukamoto's fuzzy method, the average value in the defuzzification process is calculated using the following formula:

$$Z = \frac{\sum_i^n \alpha predicate_i \ x \ z_i}{\sum_i^n \alpha predicate_i} \quad (4)$$

The average value is the value obtained from the inference value of each obtained aggotaan function divided by the sum of the predicate values from each category.

2.2. System Design

This research focuses on developing moisture measurement tools and an automatic watering system for microgreen plants. The objective is to minimize both excessive and insufficient moisture levels in the planting media [11], [12]. The study utilizes Tsukamoto's Fuzzy Logic method, which consists of three stages to determine the appropriate amount of water to be irrigated. The delay time during watering is utilized as a key factor in this tool [13].

2.2.1. Mini Greenhouse Specifications

The mini greenhouse in this study has dimensions of 50 cm in height and 60 cm in width. It includes a planting media board for seeding the plants. The frame of the mini greenhouse utilized in this research is constructed with a hole thickness of 1.5mm and employs an impraboard board with a thickness of 2mm. For reference, the framework of the mini greenhouse is depicted in Fig. 3.

Fig. 3. Mini Greenhouse Framework

2.2.2. System Block Diagram

The block diagram illustrates the Arduino receiving input from the soil moisture sensor. The Arduino then provides output to the LCD to display the reading of the soil moisture sensor value. Additionally, it delivers output to the relay, which serves as a signal or command for the water pump and stepper motor. The stepper motor receives power supply from the 12V source [14]. Fig. 4 depicts the block diagram of the system.

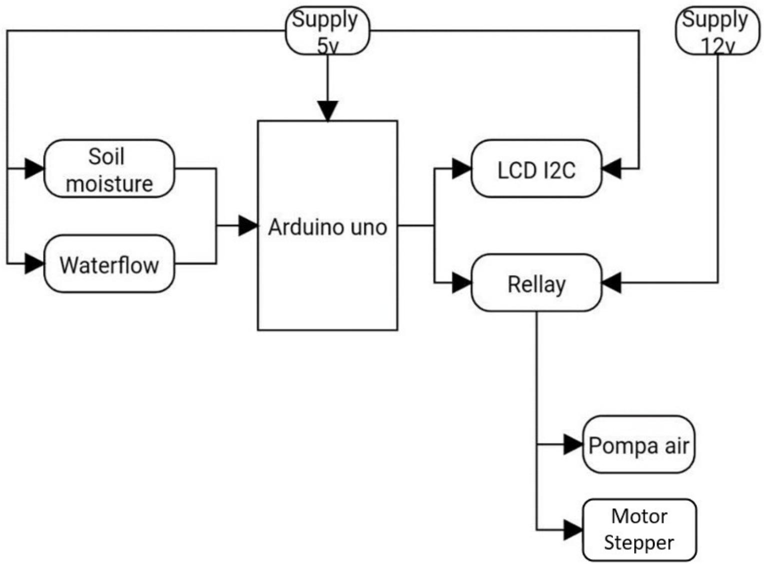

Fig. 4. System Block Diagram

2.2.3. Flowchart

In this flowchart, Arduino Uno receives input from both soil moisture and water flow sensors. The input from the soil moisture sensors is processed by Arduino Uno using Tsukamoto's fuzzy logic method. The flowchart displaying this process can be observed in Fig. 5.

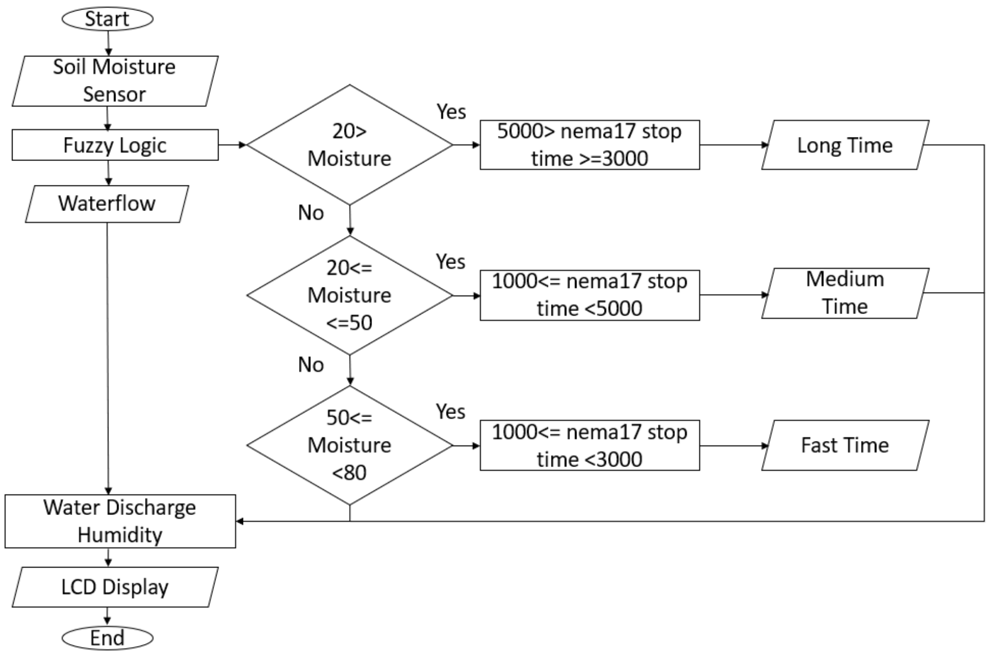

Fig. 5. Flowchart

2.2.4. Wiring Sistem

In this wiring system circuit, a 12V power supply is utilized, regulated by IC 7085. The output from IC 7085 provides a 5V voltage to supply Arduino Uno and other peripherals. A soil moisture sensor is connected to the 5V and ground pins, with the signal pin connected to analog pin 0 on the Arduino. The water flow sensor is connected to the 5V pin and ground, with the signal pin connected to digital pin 2. The Nema 17 stepper motor is connected to the A4988 driver, with pins 2B, 2A, 1A, and 1B connected accordingly. The STEP pin is connected to pin 3 on the Arduino, and the DIR pin is connected to pin 4 [15]. The wiring system configuration is illustrated in Fig. 6. Table of uses of pins on wiring systems is shown in Table 1.

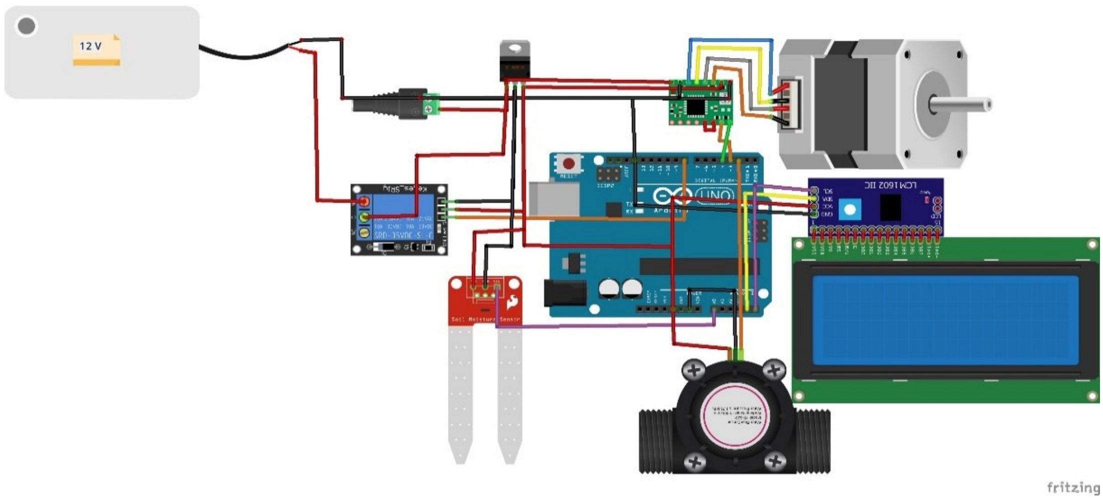

Fig. 6. Wiring Sistem

Table 1. System Wiring Pin

Arduino Uno Pin	Sensor or Component
VCC 5 V	VCC (Soil Moisture Sensor, Water Flow Sensor, Relay, LCD dan Driver A4988)
VCC 12 V	VCC (Driver A4988)
GND	GND (Soil Moisture Sensor, Water Flow Sensor, Relay, LCD, dan Driver A4988)
A0	Soil Moisture Sensor
A5	SCL LCD
A4	SDA LCD
2	Water Flow Sensor
3	Step Pin Driver A4988
4	Dir Pin Driver A4988
8	Pump Relay

3. RESULTS AND DISCUSSION

System testing is conducted to ensure that the developed system operates in alignment with the research objectives. This testing aims to enhance the success rate of microgreen planting and validate the functionality of the created tools.

3.1. Sensor testing and calibration

In this study, a soil moisture sensor is employed for measuring the moisture level in the planting media. To ensure accurate measurement results for each category, sensor calibration was performed. The calibration of the soil moisture sensor was conducted using a measuring instrument called Mediatech Soil Meter 3 in 1 [16]. The error calculation process is determined by comparing the obtained measurement values. The error value is derived from equations (5) and (6).

$$Difference = |Reference\ Value - Sensor\ Value| \tag{5}$$

$$Error\ percentage = \frac{|Difference|}{|Reference\ Value|}\ x\ 100\ \% \tag{6}$$

In order to align the range of the Mediatech soil meter values with the soil moisture sensor used, an adjustment was made by multiplying the meter values by 10. This adjustment ensures that the reading range of both the sensor and the measuring device are consistent. The table depicting the results of the sensor testing can be observed in Table 2.

Table 2 displays the values obtained during the calibration process to determine the sensor error by comparing the measuring instruments used to identify the most effective results. The decimal values represent the meter readings observed with a needle.

Table 2. Tool Test Results

No	Soil Moisture (%)	Mediatek Soil Meter (%)	Difference(%)	Error Value (%)
1	23.17	23	0.17	0.74
2	23.95	23.5	0.45	1.91
3	25.73	25.4	0.33	1.29
4	32.06	31.58	0.48	1.51
5	35.08	34.8	0.28	0.80
6	43.1	43	0.10	0.23
7	45.23	44.8	0.43	0.95
8	47.71	47.5	0.21	0.44
9	48.21	48	0.21	0.43
10	49.98	49.5	0.48	0.96
11	50.09	49.6	0.59	1.86
12	51.28	50.5	0.78	1.54
13	53.81	53.7	0.11	0.20
14	55.33	55	0.33	0.60
15	58.18	58	0.18	0.31
16	62.55	62.5	0.05	0.08
17	63.43	63	0.43	0.68
18	63.73	63.5	0.13	0.20
19	64.87	64.5	0.37	0.57
20	66.02	65.7	0.32	0.48
21	68.32	68	0.32	0.47
22	69.06	68.8	0.26	0.37
		Average error		**0.71%**

3.1. Data Retrieval Process

In this study, data was collected to examine the impact of planting media humidity on the stopping time of the stepper motor and to monitor the water discharge onto the planting media. Data collection was conducted under different humidity conditions, namely dry, ideal, and wet conditions. The test results are presented in Table 3.

Table 3. Tool Test Results

No	Planting Media Moisture	Category	Stepper Motor Stop (ms)	Category	Water discharge
1	23.17%	Dry	4128	Slow	6 L/min
2	23.95%	Dry	3998	Slow	6 L/min
3	25.73%	Dry	3234	Slow	6 L/min
4	32.06%	Dry	2268	Slow	6 L/min
5	35.08%	Dry	2218	Medium	6 L/min
6	43.10%	Dry	1980	Medium	6 L/min
7	45.23%	Ideal	1883	Medium	6 L/min
8	47.71%	Ideal	1631	Medium	5 L/min
9	48.21%	Ideal	1605	Medium	5 L/min
10	49.98%	Ideal	1553	Medium	5 L/min
11	50.09%	Ideal	1488	Medium	5 L/min
12	51.28%	Ideal	1393	Medium	5 L/min
13	53.81%	Ideal	1287	Medium	5 L/min
14	55.33%	Ideal	1255	Medium	4 L/min
15	58.18%	Ideal	1203	Medium	4 L/min
16	62.55%	Ideal	1173	Medium	4 L/min
17	63.43%	Ideal	1141	Medium	4 L/min
18	63.73%	Ideal	1130	Medium	4 L/min
19	64.87%	Ideal	1098	Medium	4 L/min
20	66.02%	Wet	1007	Fast	3 L/min
21	68.32%	Wet	993	Fast	3 L/min
22	69.06%	Wet	986	Fast	3 L/min

Based on Table 3, the humidity of the planting media is categorized into three: dry, ideal, and wet. The percentage of humidity in the growing media is monitored and displayed on the 20×4 LCD screen within the mini greenhouse. Additionally, the watering time is categorized as fast, medium, and slow [17]. The stepper motor used in the system has three stopping points, with a maximum stopping time of 5000 ms or 5 seconds at each point, which is displayed on the serial monitor. The stopping time of the stepper motor is dependent on the humidity of the planting media in the mini greenhouse, controlled by Arduino using the Fuzzy Logic Tsukamoto method [18]. This study also involves monitoring the water discharge, which is displayed on the 20×4 LCD. A graph illustrating the effect of planting media humidity on the stepper motor stopping time is depicted in Fig. 7.

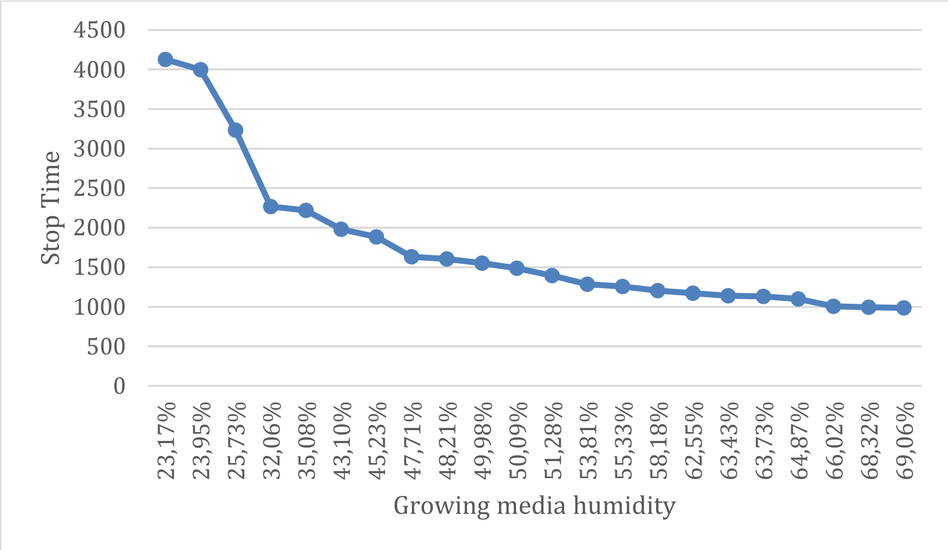

Fig. 7. Graph of the Effect of Planting Media Humidity on Stepper Motors

In the depicted graph, the relationship between planting media humidity and the stopping time of the stepper motor can be observed. It shows that as the humidity of the planting media increases, the stopping time of the stepper motor decreases. In this study, when the humidity of the growing media reaches the ideal condition, it remains relatively stable within the range of 50% to 70% humidity, which is the desired range for microgreen plants.

4. CONCLUSION

Based on the conducted testing of the developed tool, it can be concluded that this study utilizes soil moisture sensors as a means to identify the humidity of the planting media, which in turn serves as an indicator for watering. The research is categorized into three humidity ranges: dry (0-45%), ideal (45-65%), and wet (65-80%). The calibration of the sensors yielded an error value of 0.71%. The stability of the growing media's humidity is considered highly stable, particularly under ideal conditions.

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