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Characterization of Stepper Motor Rotation for Automatic Self-Cleaning Litter Box Using IOT Technology

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Abstract

A project of the Internet of Things (IoT) concept that controls a system using an internet platform and an Android smartphone. Users can control the system remotely if they have internet data. The product requires a WIFI connection and power supply to turn on the system. This automated system uses several electronic components such as the NODEMCU ESP8266 microcontroller, stepper motor and motion sensor. The project includes a method to filter and separate pet feces automatically without the pet owner doing manual cleaning daily. At the same time, the system has a unique function to make it easier for users to add new sand to their pet litter box. This project studies and analyses the components involved in manufacturing automatic IoT litter box products, namely the stepper motor and servo motor by characterizing the accuracy of the rotation angle of continuous servo motor and stepper motor. The motor with the least angular accuracy error will be selected to improve performance using microstepping techniques and reduce the heating temperature by decreasing the current value. Using the proper type of motor will result in a high-quality product, and issues often experienced in industrial motor usage may be avoided.

Keywords: Stepper Motor, Servo Motor, Microstepping, Iot Litter Box, Nodemcu ESP8266

Introduction

The Internet of Things (IoT) is a network of interrelated computing devices, machines, products, animals, and people that can send data and allow direct contact between everything (Yu et al., 2021). The product developed is related to pet care, namely an Automatic Self-Cleaning Litter Box. This Automatic Self-Cleaning Litter Box utilizes a smartphone to regulate the litter box's sand container and gets notifications for user alerts and monitoring through a product-specific app. Overall, this product needs a Wi-Fi and data connection for users to interact with it. Two kinds of motors, including continuous servo motors and stepper motors, were tested for their potential for use in this product. In addition, the characterization of each of these motors may be employed in the future since the motor's attributes are evaluated several times, and a reference graph is generated. Each tested motor is meant to enhance the performance and precision of applications using continuous-servo motors and stepper motors. Using the proper type of motor will result in a high-quality product, and issues often experienced in industrial motor usage may be avoided. The features of each kind of motor vary based on the application produced.

Research Background and Motivation

Nowadays, many products that use IoT Technology have been produced to facilitate users' daily work because technology will follow the passage of time to become more sophisticated. The Internet of Things has also shown its significance and possibility in a growing area's economic and industrial development. In addition, the trade and stock exchange markets see this as a revolutionary move (Kumar et al, 2019).

The Need for Stepper Motor and Issues

Each technology has its specialty, and since the choice of a stepper or servo technology influences the chance of success, the machine designer must analyze the technical benefits and drawbacks to pick the optimal motor-drive system for a given application (Ufa, 2020). Stepper motors are used extensively in numerical control, servo control systems, robot terminal placement, and computer peripherals. However, stepper motors have their unique issues: dynamically unstable total produced torque as measured on the motor shaft, low-frequency oscillations around synchronism at high speeds, and resonance at low speeds. To overcome the issue, the microstepping system divides the step angle of the motor, which is usually 1.8 degrees, into the number of steps determined by the microstepping ratio (MSR) and minimizes the influence of mid-frequency resonance as MSR grows (Zhao et al, 2018).

Theoretical Underpinnings and Literature Review

Theoretically, microstepping is relatively straightforward, and the technology eliminates all resonance, vibration, and noise issues in a stepper motor system. There are several phenomena that restrict the system's functionality. Some relate to the driver, while others pertain to the engine. Using a combination of high-precision controllers or drivers, such as PBM 3960 and PBL 3771, or an equivalent, the inaccuracies associated with the driver are minimal compared to those associated with most available motors. Figure 1 demonstrates that by adjusting the angle of each step, the resolution and smoothness of the rotor's revolution may be altered (Vyas et. al, 2019).

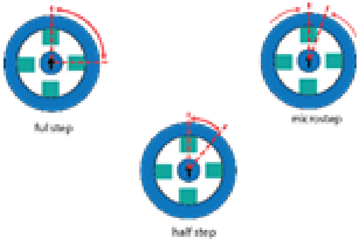


Figure 1: Excitation or energizing modes of a stepper motor.

Several studies have focused on the development of custom-designed wireless systems for stepper motor control (Vyas et al., 2018), demonstrating the benefits of IoT in enhancing the flexibility and scalability of motor-based systems.

In Industry 4.0 environments, stepper motors play a crucial role, particularly in precision control applications and improving energy efficiency (Harrouz et al., 2022). Zhao et al. (2018) introduced a Sinusoidal Pulse Width Modulation (SPWM) controller for micro-stepping, which optimizes current control in each motor phase to achieve higher precision. Micro-stepping is a technique used to enhance the precision and smoothness of stepper motor movements by dividing each full step into smaller steps. By adjusting the phase currents sinusoidally, micro-stepping minimizes vibrations and improves motor efficiency, particularly in applications requiring fine movement control.

Vyas et al (2018), further analyzed the sources of error in micro-stepping systems, identifying factors such as phase current distortion, nonlinearity in driver circuits, and motor inductance. They emphasized the importance of accurate control algorithms and driver design in mitigating these errors. As a result, micro-stepping improves resolution and reduces mechanical stress in stepper motors.

Research Motivation

IoT-driven innovations in automation have also been applied to pet care, where smart sensing and data analytics are used to improve waste management processes (Deeraj et al. 2024, Singh et al., 2024) . This research aims to extend the application of IoT-enabled stepper motor systems by exploring their role in automating pet waste cleaning. By focusing on the optimization of motor performance, system reliability, and energy efficiency, this study seeks to contribute to the development of more intelligent and autonomous pet care solutions.

Step Angle of the Stepper Motor

The angle through which the motor shaft rotates in response to each instruction signal is known as the step angle (β). Reducing the step angle, increasing the number of steps per rotation, and improving the positioning resolution or precision. The step angles may range from 0.72 degrees to 90 degrees. However, the most common step sizes are 1.8º, 2.5º, 7.5º, and 15º.

The value of the step angle may be stated in terms of the rotor and stator poles (teeth) Nr and Ns, respectively, as shown in Equation (1), or terms of the number of stator phases (m) and the number of rotor teeth, as shown in Equation (2).

$$\beta = \frac{N_s - N_r}{N_s . N_r} \times 360° \quad \text{……… (1)}$$

$$\beta = \frac{360°}{m \times N_r} \quad \text{……………………(2)}$$

Resolution is determined by the number of steps required to complete one rotation of the rotor shaft, as shown by equation (3). The greater the resolution, the more precisely the motor can place items (Al-Naib et al., 2019).

$$\therefore Resolution = \frac{No.of\ Steps}{Revolution} = \frac{360°}{\beta} \text{………. (3)}$$

Microstepping

A4988 driver microstepping pin for bipolar NEMA17 stepper motor controller has adjustable current limiting, over-current and over-temperature protection, as well as 5 unique micro step resolutions which are Full-Step, Half-Step, 1/4 Step, 1/8 Step and 1/16 Step revolution. It operates between 8V to 35V and can give up to 1A per phase without a heat sink or forced air flow (it is rated for 2A per coil with ample extra cooling). A4988 offers greater resolutions by permitting intermediate step positions, which are accomplished by energizing the coils with intermediate amounts of current. The quarter-step mode, for example, the motor completes one rotation in 200 steps. 800 micro steps per rotation by using four distinct current levels. According to Table 1, the A4988 motor controller has a total of three resolution selector inputs (MS1, MS2, and MS3) that allow for the selection of one of five step resolutions (Sharma et al., 2019).

Table 1
Resolution (Step size) Selector Input

MS1	**MS2**	**MS3**	**MICROSTEP RESOLUTION**
LOW	LOW	LOW	FULL STEP
HIGH	LOW	LOW	HALF STEP
LOW	HIGH	LOW	1/4 STEP
HIGH	HIGH	LOW	1/8 STEP
HIGH	HIGH	HIGH	1/16 STEP

A PWM current control circuit manages each full bridge with a predetermined off-time that restricts the load current to the desired value, I_{Trip}. Initially, a pair of diagonal sources and sink FET outputs are activated, and current flows via the motor winding and the current sensing resistor, R_{Sx}. Next, the current sense comparator resets the PWM latch when the voltage across R_{Sx} equals the D_{AC} output voltage. The latch then deactivates the corresponding source driver and enters an off-time decay mode.

The maximum current limiting value is determined by the R_{Sx} option and the V_{REF} pin voltage. Approximating the transconductance function is the highest value of current limiting, $I_{TripMAX}$(A) in (4), which is determined by:

$$I_{TripMAX} = \frac{V_{REF}}{(8 \times R_S)} \text{ ………… } (4)$$

where R_S is the sensing resistor's resistance (Ω), and V_{REF} is the REF pin's input voltage (V).

Methodology

The methodology section includes a summary of the research methodologies used in the study. In addition, the study's research design and the explanation for its selection are highlighted. Detailed information is also provided on the data collection method and the methods used to complete this project. Finally, the instruments needed to develop this project are described in-depth as the procedures utilized to complete it.

Flowchart

Choosing the correct type of motor is very important to develop a product to avoid any problems regarding rotation and accuracy. Therefore, selecting the type of motor is the primary step in producing this project, as shown in Figure 2. The motors chosen are continuous servo motor, unipolar 28BYJ-48 stepper motor and bipolar NEMA17 stepper motor.

Next, the three types of motors selected will be filtered by measuring and characterizing the accuracy of the rotation angle by looking for the error accuracy angle so that the motor selection is more effective. The motor with the lowest error accuracy angle will be selected to continue the following analysis on ‘holding torque’. A load is applied to the motor to test the speed of the motor which affects the accuracy of the motor in each condition.

Next, the analysis continues by measuring the heat temperature of the motor at a specific value of current and time. The applied current affects the heat of the motor and causes problems with the motor. Therefore, this analysis is done so that the current value can be set on the motor to be used on the product.

Finally, optimize the performance of the motor by using the microstepping technique so that the speed when loaded is more consistent. After all the analysis is done, the optimized motor will be used on the product which is an automatic self-cleaning litter box.

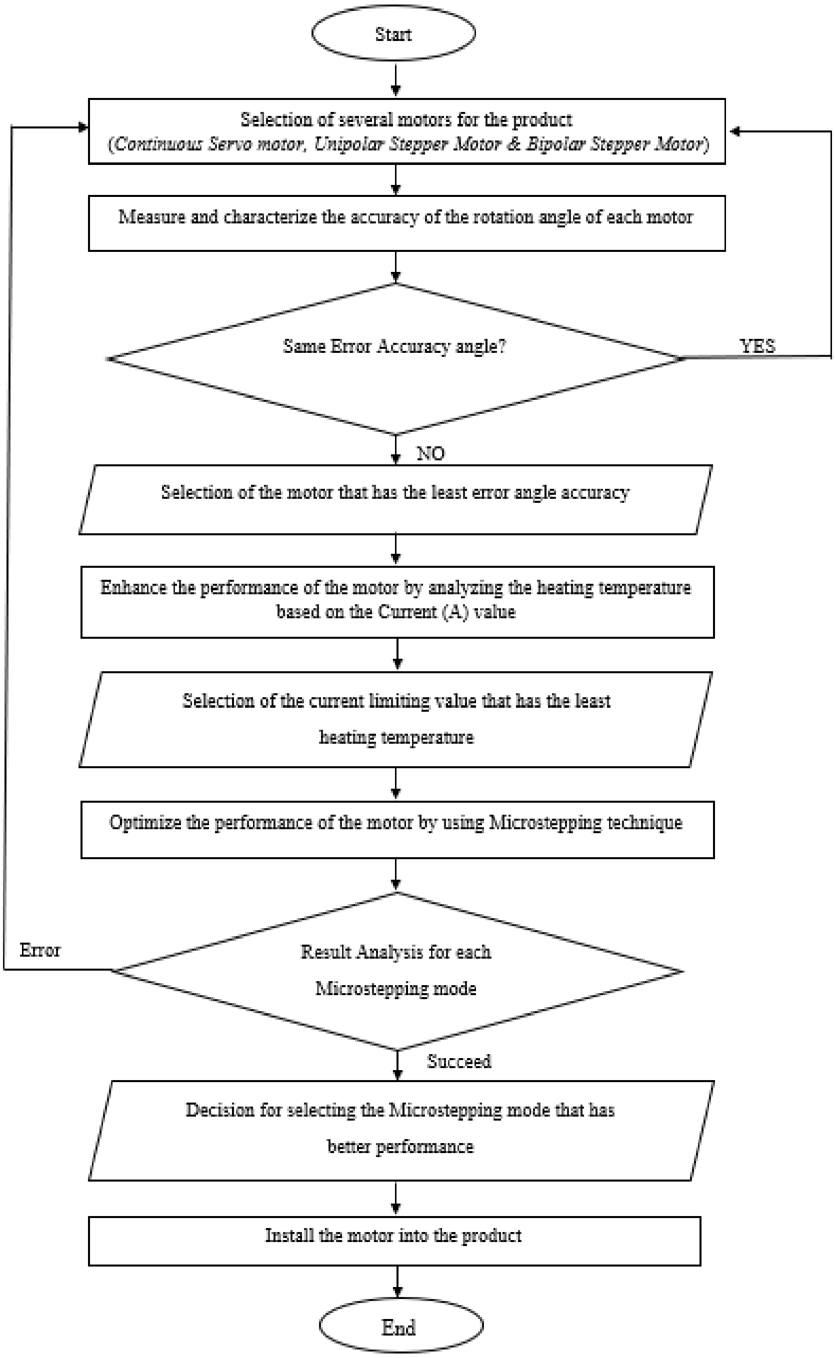


Figure 2: Research and analysis flowchart Method for Research and Analysis Element

Experiment and Analyse Setup

Figure 3 shows the apparatus and setup equipment for measuring the angle accuracy position of the continuous servo motor, unipolar and bipolar stepper motor. All the motors are attached to a 360-degree protractor and always secured above the container. The microcontroller used is a NODEMCU ESP8266, and a 5V supply powers it. Each angle value was programmed and recorded three times to observe the difference in accuracy and error accuracy on the rotation angle. ULN2003 and A4988 Driver have been used to connect to the unipolar and bipolar stepper motor, respectively. Bipolar NEMA17 stepper motor have external power source of three 3.7V rechargeable batteries.

Figure 3: Unipolar 28BYJ-48 Stepper Motor Setup

Besides, Figures 4 show the apparatus and arrangement of equipment to analyse the strength, speed and accuracy of stepper motors, namely unipolar and bipolar stepper motors. The load used was weighed using a mini weighing scale and the load is pulled horizontally on a flat surface. The set distance is 20 revolutions (60cm).

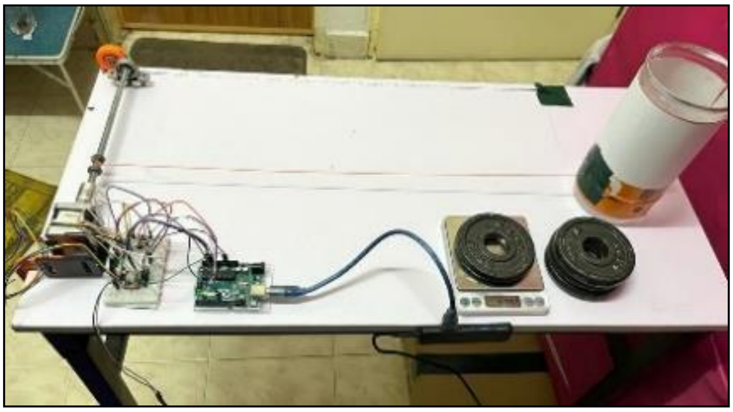


Figure 4: Bipolar NEMA17 Stepper Motor with Load Setup

Finally, Figure 5 shows the circuit connection and equipment setup to adjust a specific current value on the adjustable potentiometer on the A4988 Driver. The motor current limit is an essential setting to adjust when using these drivers. This is particularly crucial when utilising a greater input voltage than the motor's rating. Higher voltage typically allows for greater torque and a quicker step speed. However, it must actively restrict the amount of current passing through the motor coils to avoid destroying the motor. The first technique is to physically measure the current flowing through one of the coils using a multi-meter. The second approach, which we will examine, is to calculate and then modify the reference voltage on the driver, which does not need the motor to be connected or operated. The adjustable potentiometer on the Driver sets the V_{ref} value on the Driver to achieve a specific current value using the formula. After the current value has been adjusted, the stepper motor is operated continuously for 12 minutes. Next, an infrared thermometer is utilized every 2 minutes to measure the stepper motor's heat temperature.

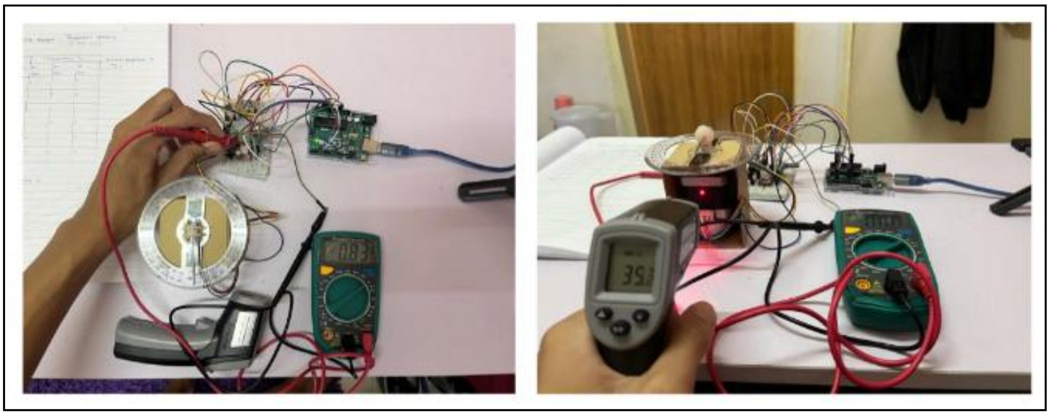


Figure 5: Current and Heating Temperature Analyzing Setup Block Diagram of the System

IOT and Interface Setup

Based on Figure 6, the block diagram starts from an Android smartphone with an internet connection, either Wi-Fi or Cellular Data. When the user controls or clicks a specific button on the application, the data will be sent to Google Firebase in the Realtime Database section. Realtime Database will work when a user is controlling at that time. It will remain online even if the user's device is offline.

Furthermore, A real-time database is a system that uses real-time processing to handle workloads whose state is constantly changing. All information such as passwords, emails, and user privacy will be stored on Firebase or Cloud for users to access this product repeatedly without creating a new account. Then, back to the function of the buttons in the application, when the states on the Firebase change when the user clicks the button on the application, the data will be triggered on the microcontroller, which is NODEMCU ESP8266 because the microcontroller has been programmed each component.

To turn on the microcontroller necessarily requires a power supply. The user can use a direct plug with an adapter or a low voltage supply which is any 5V supply. Next, the microcontroller will work to turn on the servo motor and stepper motor which is to execute sand container and feces filter. Lastly, if automatic self-cleaning is “ON’, the motion sensor will start triggered, and the feces filter will start the operation automatically.

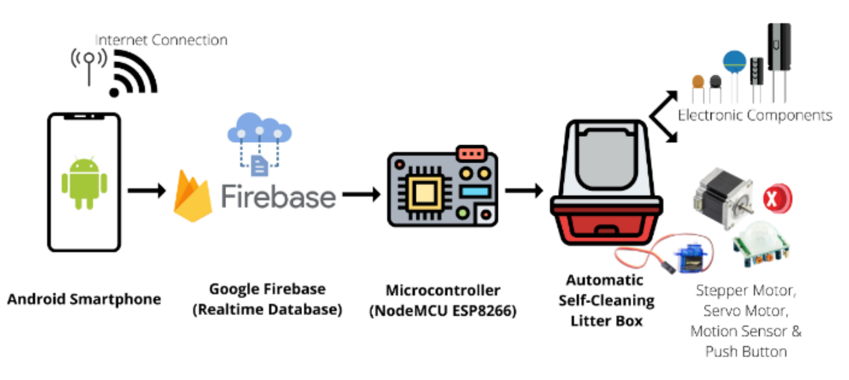


Figure 6: Block Diagram of the System

Finding

The results are presented under the three primary concerns: To measure and characterize the accuracy of rotation angle and position of the servo motor and stepper motor for use on the product, to optimize the rotational performance by analyzing the heating temperature and using the microstepping technique of the stepper motor used in the automatic litter box. Lastly, to develop and verify the litter box output for pets using the stepper motor controlled by a smartphone using IoT Technology that assists pet owners in dealing with their pet's waste easily and practically. It also fabricates a pet's litter box with an automated system to test whether this automatic litter box is safe and practical.

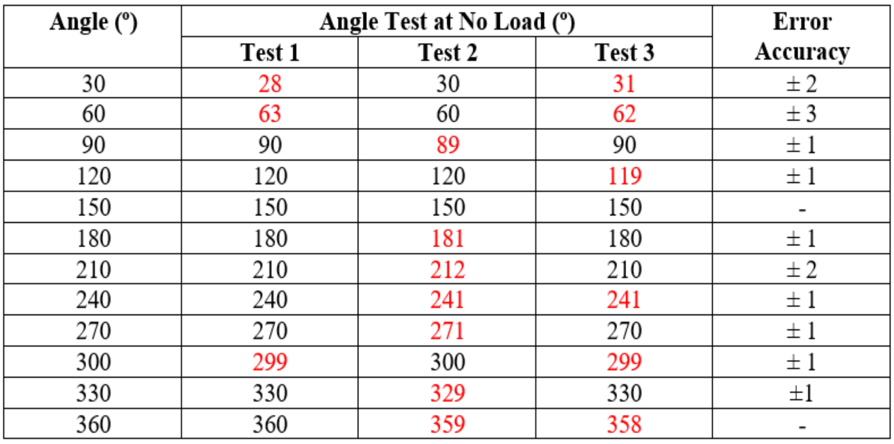
Measuring and Characterize the Accuracy of Rotation Angle and Position of Servo Motor and Stepper Motor for use on the Project

Table 2
Error Accuracy Angle for Continuous Servo Motor

Time (ms)	Angle (°)			Error accuracy
	Test 1	Test 2	Test 3	
50	27°	25°	25°	± 2
100	40°	40°	40°	-
150	48°	49°	48°	± 1
200	72°	72°	71°	± 1
250	100°	98°	100°	± 2
300	120°	118°	120°	± 2
350	135°	135°	136°	± 1
400	155°	155°	153°	± 3
450	170°	171°	173°	± 3
500	200°	195°	195°	± 5
550	215°	220°	220°	± 5
600	245°	240°	245°	± 5
650	275°	274°	270°	± 5
700	310°	308°	308°	± 2
750	325°	324°	325°	± 2
800	352°	353 °	353°	± 3
850	360° + 15°	360° + 15°	360° + 15°	-

Table 2 shows that three attempts were recorded to identify the error accuracy value of the continuous servo motor (FS90R). The continuous servo motor does not have a setting to set the angle value. Therefore, continuous servo motors can be programmed with time values (milliseconds). The time value may determine a specific angle. If an application uses a motor, the accuracy of the angle and movement of the gear must be carefully observed. If the rotation movement of the gear motor moves consistently, it will not cause problems in the development of an application such as overlapping. Error precision is shown in red every 50 milliseconds until the angle completes a full rotation of 360 degrees: every 50 milliseconds, the angle value changes. As a result of this analysis, this continuous servo motor may be characterized as having a very low angle accuracy, as almost all angles have an accuracy error. The highest accuracy error is up to 5 degrees.

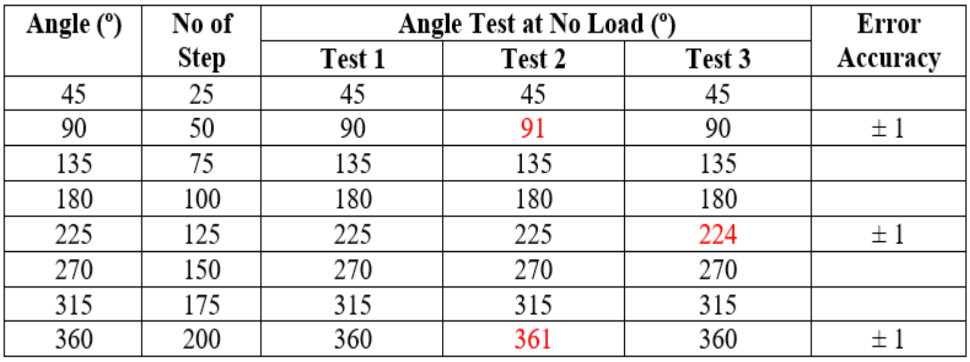
Table 3
Error Accuracy of Unipolar Stepper Motor (28BYJ-48)



Angle (°)	Angle Test at No Load (°)			Error Accuracy
	Test 1	Test 2	Test 3	
30	28	30	31	± 2
60	63	60	62	± 3
90	90	89	90	± 1
120	120	120	119	± 1
150	150	150	150	-
180	180	181	180	± 1
210	210	212	210	± 2
240	240	241	241	± 1
270	270	271	270	± 1
300	299	300	299	± 1
330	330	329	330	±1
360	360	359	358	-

The accuracy error for the Unipolar 28BYJ-48 stepper motor is recorded in Table 3. Stepper motors move in discrete steps. Each step on the stepper motor has its angle value. This stepper's analysis for angular accuracy observation starts every 30 degrees up to 360 degrees. As a result of the observation from the analysis, there is still an error in the accuracy of the angle, even if there is no load. However, the angle accuracy of this stepper motor is higher than the continuous servo motor because the highest angle accuracy error is only 3 degrees.

Table 4
Error Accuracy of Bipolar Stepper Motor (NEMA17)



Angle (°)	No of Step	Angle Test at No Load (°)			Error Accuracy
		Test 1	Test 2	Test 3	
45	25	45	45	45	
90	50	90	91	90	± 1
135	75	135	135	135	
180	100	180	180	180	
225	125	225	225	224	± 1
270	150	270	270	270	
315	175	315	315	315	
360	200	360	361	360	± 1

Finally, the observation is focused on the bipolar stepper motor (NEMA17) regarding the accuracy of the angle without any loads. This NEMA 17 hybrid stepping motor has a step angle of 1.8° (200 steps per revolution) at Full-Step operation. Based on Table 4, the analysis starts from an angle of 45 degrees up to 360 degrees. This angle can be identified using programming (C++) by changing the number of revolutions to determine the angle. This observation was performed three times, and the data revealed that only a few angles had inaccuracies. The inaccuracy in the angle is also visible as 1 degree. This demonstrates that the bipolar stepper motor has a much higher angular precision than continuous servo and unipolar stepper motors. Therefore, this bipolar stepper motor is appropriate for developing IoT technology devices such as automated litter boxes without any accuracy or strength issues.

Analysis on the Holding Torque of Both Stepper Motor

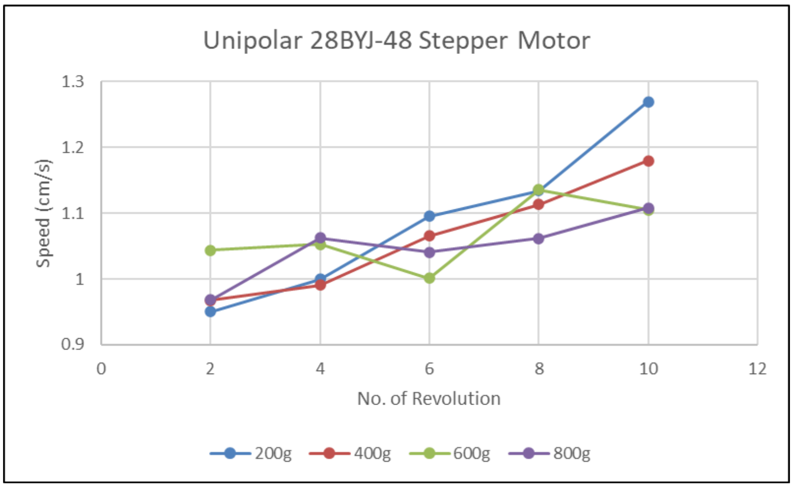


Figure 7: Graph Speed VS No. of Revolution for Unipolar 28BYJ-48 Stepper Motor

After characterizing the angle accuracy of all three different kinds of motors, the analysis showed that unipolar and bipolar stepper motors have the potential to be utilized in the production of sustainable products such as self-cleaning litter boxes. To ensure that the system on the product operates smoothly, an analysis is performed on the strength and speed of the unipolar and bipolar stepper motor to determine whether the number of rotations of a motor operating horizontally on a flat surface affects the motor's speed.

If examined in Figure 7, the resulting distance for each load applied to the stepper motor needs to be more consistent. Therefore, the unipolar stepper motor cannot support the load applied even though the manufacturer's specification of the unipolar stepper motor can pull a high load horizontally on a flat surface. As seen in Figure 7, this Unipolar 28BYJ-48 has an issue with the precision of the rotation angle; as the number of spins rises, the speed fluctuates. However, when the load amount rises, the speed will decrease.

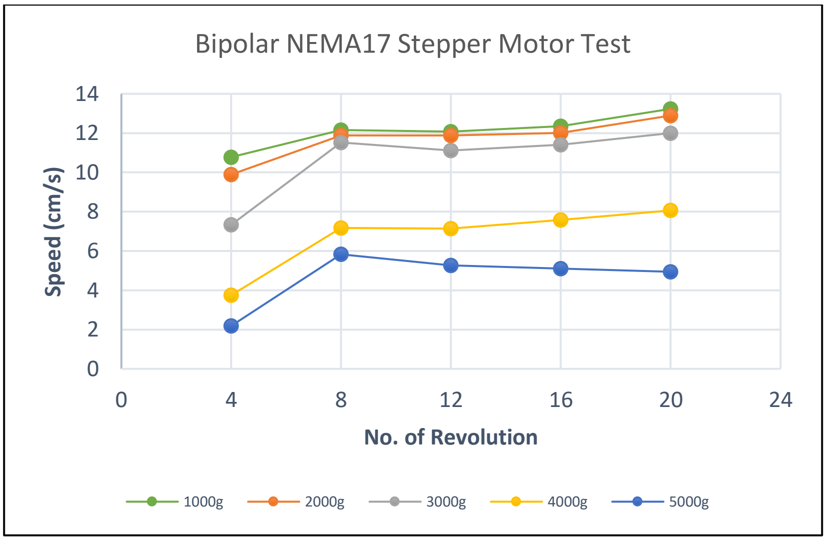


Figure 8: NEMA17 Stepper Motor Holding Torque Test

In general, bipolar stepper motors can handle very high loads compared to unipolar stepper motors. Therefore, the analysis of the bipolar stepper motor is increased from 1000 grams to 5000 grams to observe the change in distance and speed, as shown in Figure 8. The analysis is evaluated by increasing every four revolutions up to 20 revolutions.

From observation, the distance is affected by the value of the applied load, even horizontally on the surface. However, the distance change is more apparent and more consistent when compared to a unipolar stepper motor. In addition, it can be observed that the distance value is only consistent until the load is at 2000 grams. Therefore, it can be concluded that the maximum load that the bipolar stepper motor can accommodate at Full-Steps Microstepping is around 2000 grams.

Apart from speed being affected by time and distance, some changes occur if a load is applied to the stepper motor. Although the change in speed value is very significant, the bipolar stepper motor can still pull a load of up to 5000 grams. The graph demonstrates that the speed at each revolution and the load is almost consistent. In conclusion, rotational speed is influenced by the value of the applied load. The higher the load applied, the slower the motor rotation. At the same time, the addition of revolution to the motor affects the speed even though the stepper motor torque is high.

Enhancing the Rotational Performance of Stepper Motor by Analyzing the Heating Temperature

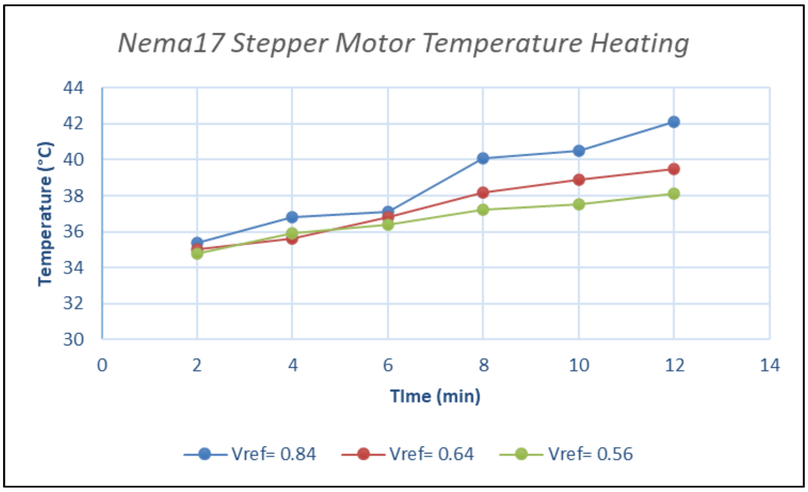


Figure 9: NEMA17 Stepper Motor Temperature Heating

Based on Figure 9, the analysis started by testing the temperature level of the Bipolar NEMA17 stepper motor every two minutes up to 12 minutes. The temperature data is recorded based on the current value set on the A4988 driver, which is the Voltage Reference, Vref 0.84V, 0.64V, and 0.56V. Each Vref gives the value of the current flowing in the stepper motor, which is 2A, 1.6A, and 1.2A, respectively.

Figure 9 shows a Time (in minutes) graph versus Temperature (in Celsius). The data graph shows that the current value affects the stepper motor heat temperature. The current value at 2A is higher than at 1.6A and 1.2A. This is because the higher the current applied, the higher the heat temperature will be produced but the higher the 'holding torque' can be produced. Therefore, the current at 1.2A is more effective in protecting the performance of the stepper motor because it has the lowest percentage of heating increment compared to other current values. However, reducing stepper motor current does not impair accuracy but reduces the "holding torque" characteristic.

A stepper motor's holding torque is its ability to keep its position when a torque is applied to its axis of rotation. Furthermore, the output current is controlled, allowing for noiseless stepper motor operation and avoiding resonance or ringing, which is prevalent in unregulated stepper driver systems. Lastly, greater current from higher applied voltage results in increased winding power loss. This power loss raises the stepper motor's temperature, which might harm it if excessively.

Optimizing Stepper Motor by Using the Microstepping Technique

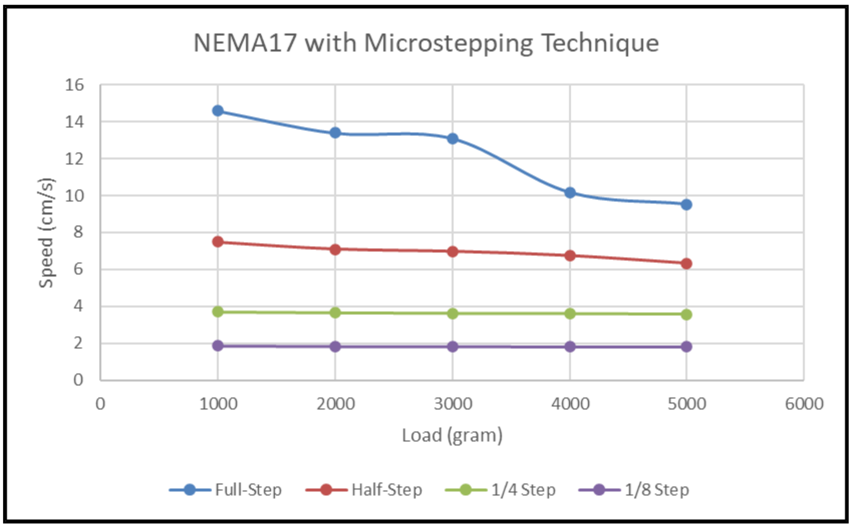


Figure 10: NEMA17 Stepper Motor with Microstepping Technique

This analysis measures the state of speed against the load applied to the stepper motor in each type of microstepping mode. Figure 10 shows the graph of each microstepping mode at speed (in cm/s) versus load (in grams). The difference in the line graph can be clearly seen, where the larger the step applied to the stepper motor, the resulting speed is not consistent at a load of 1000 grams, up to 5000 grams.

Suppose the Microstepping resolution is changed from Full Step. In that case, Half Step, 1/4 Step, 1/8 Step, and 1/16 Step, speed changes will be seen where the Microstepping control divides each full step into smaller steps to help smooth out the motor's rotation, especially at slow speeds. For example, at 1/4 Step resolution, the speed is almost no different even if the value of the load is added compared to Full Step resolution; that is, the change in speed will be affected if the weight of the load is added.

Therefore, the smaller the step applied, the greater the torque that can be applied. The selection of microstepping mode is very important for an application or product that uses precision on every revolution and rotation in all conditions so that problems such as overlapping steps do not occur. Therefore, based on the analysis above, 1/4-Step is suitable for use on this stepper motor because the speed produced is consistent in every situation.

However, 1/8-Step can still be used because the speed is more consistent, but the resulting speed will decrease, and it is not suitable for use on this product because it is too slow.

At the same time, by using this microstepping technique, some other observations can be observed. The sound and vibration produced on the stepper motor will decrease if the step is smaller. In addition, the smaller the step applied, the higher the holding torque can be applied. This is an important advantage of the stepper motor to produce better performance.

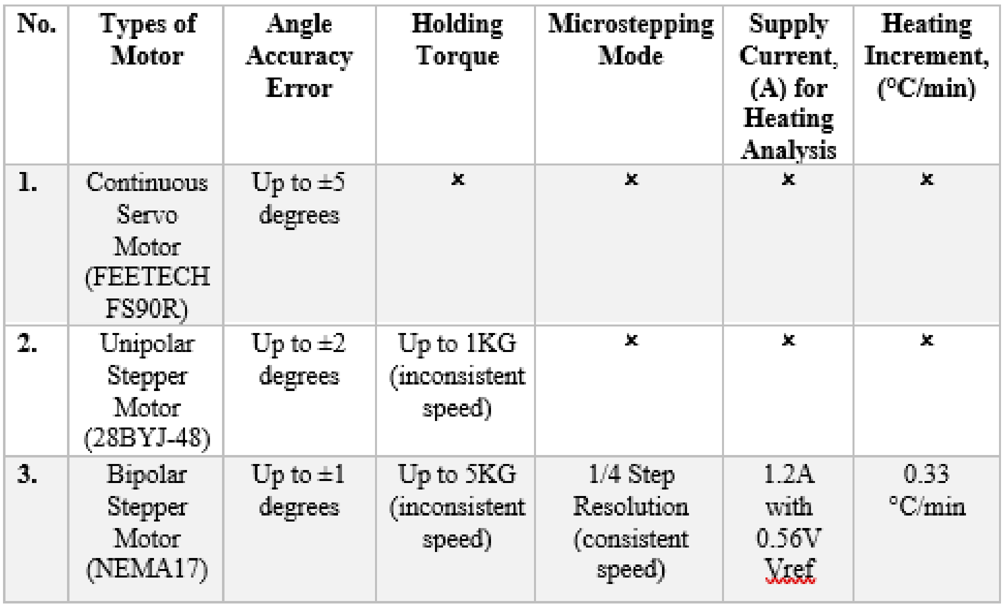
Discussion

Table 5 shows a summary of the result of the research that has been measured. First, the angle accuracy error of a continuous servo motor is too high compared to other motors, which is up to 5 degrees of error. Therefore, only unipolar and bipolar stepper motors are continued for the following analysis to test the holding torque and speed change.

Based on the analysis, unipolar and bipolar stepper motors do not have a consistent speed when the load is added to the motor. However, bipolar stepper motors have a more consistent speed graph than unipolar stepper motors. Therefore, the bipolar stepper motor is the best choice to use in the product. After the bipolar stepper motor is selected, an analysis of the temperature of the stepper motor is done to observe the temperature condition of the motor when the current value is changed.

Based on the analysis of the heat temperature, the current value at 1.2A and V_{ref} 0.56V is the best value to reduce the heat temperature of the motor to avoid damage to the motor. Next, because the bipolar stepper motor does not have a consistent speed when under load, a technique is used, which is the microstepping technique, to optimize the performance of the stepper motor so that the speed is more consistent in every situation. Based on the analysis results, ¼ Step resolution has become the best choice for bipolar stepper motors.

Table 5
Summary of Research and Analysis



No.	Types of Motor	Angle Accuracy Error	Holding Torque	Microstepping Mode	Supply Current, (A) for Heating Analysis	Heating Increment, (°C/min)
1.	Continuous Servo Motor (FEETECH FS90R)	Up to ±5 degrees	×	×	×	×
2.	Unipolar Stepper Motor (28BYJ-48)	Up to ±2 degrees	Up to 1KG (inconsistent speed)	×	×	×
3.	Bipolar Stepper Motor (NEMA17)	Up to ±1 degrees	Up to 5KG (inconsistent speed)	1/4 Step Resolution (consistent speed)	1.2A with 0.56V Vref	0.33 °C/min

Experiment of the Product Effectiveness

Table 6
Observation on Automatic Self-Cleaning Litter Box

OBSERVATION	RESULTS
Sand Weight Limit in Sand Container/Storage	2L @ 1KG
Time Taken to Complete a Process Filtering Pet's Wastes	65 Seconds
Time Taken to Complete the Process of Refilling the Sand	50 Seconds
Average a Pet Stay Inside the Litter Box (in minutes)	45 Seconds
Average Cleaning Pet's Wastes (Percentage)	88% clean per session

Based on Table 6, several observations of automatic self-cleaning litter boxes have been recorded. First, the sand weight limit inside the sand storage is 2 Liters or 1 Kilogram. This amount needs to be followed so that the system in the sandbox is not blocked and has problems with rotation.

In addition, the time taken to complete the process of filtering pet waste is 65 seconds. This process filters out lumps and clusters in the sand and sequesters these lumps into a pet's waste plastic bag. At the same time, the time taken to complete the process of refilling the sand is 50 seconds. This process consists of three systems: a spin system on the sand container, a system of pushing the sand into the litter box, and a sand levelling system to the center of the litter box space.

Finally, the average pet stays in the litter box for 45 seconds. However, it is dependent on the state of the pet for excrement. Some randomly formed pieces of plasticine clay, as many as 10 pieces, were placed in the litter box with sand. Clusters filtered by the litter box were recorded. The average of all tests was that 8.8 or 88% of clusters were filtered. This shows the cleaning level of this automatic self-cleaning litter box is practical and effective.

Conclusion and Future Work

Both stepper and servo technologies play major roles in mechatronic machine designs. However, the benefits and drawbacks of servo and stepper motor systems are evident, particularly concerning the process or job. Thus, the ideal option for a specific application becomes more apparent. Assuming that the desired process can be accomplished with a stepper or servo motor solution that meets the application's repeatability, accuracy, and flexibility requirements for current and future needs, the remaining factors are likely to be environment, life expectancy, operating noise, and energy consumption.

Next, the sustainability of product and design technology is essential to convince consumers and buyers. This automatic self-cleaning litter box provides more convenience than conventional litter boxes. Among the advantages is that this product utilizes an Internet of Things (IoT) technological system that can be remotely controlled and monitored using a smartphone, inexpensive and low maintenance product, less time-consuming, and environment and user-friendly.

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References

Yu, R., Zhang, X., & Zhang, M. (2021). Smart home security analysis system based on the Internet of Things. In 2021 IEEE 2nd International Conference on Big Data, Artificial Intelligence and Internet of Things Engineering (ICBAIE 2021) (pp. 596–599). https://doi.org/10.1109/ICBAIE52039.2021.9389849

Kumar, S., Tiwari, P., & Zymbler, M. (2019). Internet of Things is a revolutionary approach for future technology enhancement: A review. Journal of Big Data, 6(1). https://doi.org/10.1186/s40537-019-0268-2

Ufa State Aviation Technical University, Power & Energy Society, & Institute of Electrical and Electronics Engineers. (2020). Proceedings, ICOECS: 2020 International Conference on Electrotechnical Complexes and Systems: 27-30 October 2020.

Zhao, T., Shen, W.-J., Ji, N.-Y., & Liu, H.-H. (2018). Study and implementation of SPWM microstepping controller for stepper motor. In 2018 13th IEEE Conference on Industrial Electronics and Applications (ICIEA) (pp. 2298-2302). https://doi.org/10.1109/ICIEA.2018.8398093

Vyas, D. C., Patel, J. G., & Shah, H. A. (2019). Microstepping of stepper motor and sources of errors in microstepping system. International Journal of Engineering Research and General Science, 3.

Sahu, S. (2022, August). An adaptive control of a stepper motor drive using a hysteresis current control approach.

Harrouz, A. (2022, June). Control strategy of the permanent magnet stepper motor. Algerian Journal of Renewable Energy and Sustainable Development.

Zhao, T., Shen, W.-J., Ji, N.-y., & Liu, H.-H. (2018). Study and implementation of SPWM microstepping controller for stepper motor. In 2018 13th IEEE Conference on Industrial Electronics and Applications (pp. 2298-2302). https://doi.org/10.1109/ICIEA.2018.8398093

Vyas, D. C., Patel, J. G., & Shah, H. A. (2019). Microstepping of stepper motor and sources of errors in microstepping system. International Journal of Engineering Research and General Science, 3.

Deeraj, S., Rao, P., & Kumari, M. (2024). Smart sensing for automated pet waste management using IoT. International Journal of Smart Environmental Systems, 12(1), 23-29.

Singh, A., Verma, T., & Das, P. (2024). Automated waste compaction using actuators in IoT-enabled systems. IEEE Transactions on Automation Science and Engineering, 21(2), 120-127.

Al-Naib, A. (2019). Stepper motor. Mosul: Northern Technical University.

Sharma, S., & Harish, S. B. (2019). XY-drawing robot using Arduino. College of Engineering, Pune-Satara Road, Pune, 411043, 6(2).