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Production of an Orbital Shaker Device with Time and Rotational Speed Control Using Potentiometer Based on Arduino Uno

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Abstract

Mixing solutions is an everyday activity performed in laboratory spaces. Mixing solutions manually by shaking is less effective, as it takes a long time and requires much effort. Therefore, an orbital shaker has been created to mix solutions with a digital unidirectional movement. This device is designed using a DC motor as the driver, an L298N motor driver, an Arduino Uno as the processor, a potentiometer to adjust the speed and rotation time, a seven-segment TM1637 display to show the set values, and push buttons as start and reset buttons. Testing the orbital shaker begins by inputting PWM values on the potentiometer and then measuring the DC motor's rotation speed (rpm) using a tachometer. The calibration testing includes calibrating the rotation speed values (rpm) and time. The results of rotation speed calibration testing show an average error value of 1.09%, accuracy of 98.91%, and precision of 99.77%. In comparison, time calibration yields an average error value of 2.45%, accuracy of 97.55%, and precision of 99.99%. Subsequently, speed testing is conducted using a solution load ranging from 100 to 1000 g, with each increment of 100 g testing rotation speeds from 240 to 360 rpm. The results indicate that when a load is applied, there is a decrease in the measured rotation speed compared to the input speed. The orbital shaker can rotate within a speed range of 240 to 374 rpm and a maximum time of 90 minutes with a maximum load of 1000 g.

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Abstrak

Mencampur larutan merupakan kegiatan yang dilakukan pada ruang laboratorium. Proses pencampuran larutan jika dilakukan dengan cara mengocoknya secara manual akan kurang efektif, karena memakan waktu yang lama dan memerlukan banyak tenaga. Oleh karena itu, dibuatlah alat orbital shaker yang digunakan untuk mencampurkan larutan secara digital dengan gerakan satu arah. Alat ini dirancang menggunakan motor DC sebagai penggerak, driver motor L298N, Arduino Uno sebagai prosesor, potensiometer untuk mengatur nilai kecepatan dan waktu putar, seven segment TM1637 untuk menampilkan nilai yang diatur, serta push button sebagai tombol start dan reset. Pengujian alat orbital shaker diawali dengan menginput nilai PWM pada potensiometer, lalu mengukur nilai kecepatan putar motor DC (rpm) menggunakan tachometer. Pengujian yang telah dilakukan diperoleh bahwa pada saat nilai input PWM ditambahkan, nilai kecepatan putar motor DC juga akan bertambah. Selanjutnya, pengujian kalibrasi alat yaitu kalibrasi nilai kecepatan putar (rpm) dan waktu. Hasil yang didapatkan dari pengujian kalibrasi kecepatan putar yaitu nilai error rata – rata sebesar 1,09%, akurasi 98,91%, dan presisi 99,77%, sedangkan pada kalibrasi waktu didapatkan nilai error rata – rata 2,45%, akurasi 97,55%, dan presisi 99,99%. Kemudian, melakukan pengujian kecepatan putar dengan menggunakan beban larutan sebesar 100 – 1000 g dan setiap kelipatan 100 g dilakukan pengujian kecepatan putar dari 240 – 360 rpm. Hasil yang didapatkan yaitu pada saat diberikan beban, nilai kecepatan putar yang diinput dengan yang terukur tachometer terjadi penurunan. Alat orbital shaker dapat berputar dengan range kecepatan putar sebesar 240 – 374 rpm dan waktu maksimal 90 menit dengan beban maksimal 1000 g.

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1. Introduction

The development of technology can assist and simplify human life. Technological advancements in electronics impact the creation of sophisticated devices, transforming everything that was once manual or analog into digital. The progress of these tools has a significant influence in the world of education, especially in laboratories (Saputra & Kurniawati, 2021).

A laboratory is a designated place or room with tools and equipment for conducting experiments, investigations, tests, calibrations, and similar activities (Widiastuti, 2019). Laboratories are essential components and integral to the teaching and learning process. The presence of laboratories is crucial for the advancement of scientific knowledge and the effective implementation of the learning process (Saputra & Kurniawati, 2021).

Activities conducted in a laboratory invariably require specific tools and facilities according to their specifications to facilitate the tasks at hand. Mixing solutions is a typical activity carried out in laboratory settings. Mixing is a process that involves combining different substances to create a homogeneous product (Kholisatin et al., 2014). A homogeneous mixture combines two or more substances whose constituent particles cannot be distinguished, resulting in uniform properties. Such homogeneous mixtures are also known as solutions (Iskandar, 2015). Manually shaking solutions for mixing purposes is often ineffective due to the extended time it takes and the substantial amount of effort required.

Additionally, specific solutions can be hazardous to handle. Therefore, there is a need for a device to digitally mix solutions, making the process more efficient and yielding ideal (homogeneous) results. This device is called an Orbital Shaker (Adriana & Hamrin, 2020).

An orbital shaker is a laboratory instrument used to agitate or mix one solution with another to achieve homogeneity through unidirectional circular motion. A shaker performs circular vibrations (in an orbit or around its axis) to operate under specific conditions as desired. The orbital shaker is equipped with controls for adjusting the stirring speed (RPM) and the duration of stirring. It also includes an oscillating platform that can hold sample containers in place while the device vibrates to agitate or mix the solutions within the containers. Orbital shakers are commonly utilized in chemical, pharmaceutical, and microbiology laboratories. Solutions play a critical role in chemistry, as nearly all chemical reactions occur in solutions. The components present in a solution are typically categorized into two types: the solvent and the solute. Common solvents used in shakers include water, alcohol, ammonia, chloroform, benzene, oil, and acetic acid. In pharmaceutical laboratories, orbital shakers are employed to test the solubility of drugs using circular motion to ensure the drug dissolves in water. In microbiology laboratories, orbital shakers find applications in cell culture shaking, bacterial growth, bacterial suspensions, staining procedures, and bacterial washing (Adriana & Hamrin, 2020).

The orbital shaker is highly significant and serves numerous functions to support research in both educational and health-related laboratory settings. Research related to the orbital shaker has been conducted previously by Yoka Hary Abrianto (2021) using the Atmega 2560 microcontroller, an LCD as a monitor, and a DC motor as a driver to stir samples, whether they are solutions or substances to homogeneity. The DC motor is connected to the microcontroller through the L298N DC motor driver, which functions to control the speed and direction of the DC motor. Additionally, this research utilizes push buttons to input values for rotation speed and time, and it requires setting the rotation rhythm using the pulse-width modulation (PWM) method. The output of this research is a DC motor that moves according to the set rotation speed in PWM and the specified rotation time. The LCD will show the rotation speed and time set values (Abrianto, 2021). Another study was conducted by Muhammad Fauzi (2021) using a mini water pump to facilitate mixing solutions by filling fluids into tubes. This research uses a type of DC Gearbox Motor, a DC water pump of R385 type, controlled by an Arduino Uno, and displays information on a 20x4 character LCD. The motor speed in the created Orbital Shaker device is set at 100 RPM and 150 RPM (Fauzi, 2021).

An orbital shaker device has also been developed in prototype form in the research conducted by Esyana Septiani (2022) titled "Design and Construction of a Shaker Device with Input Using Arduino-Based Keypad." The prototype utilizes a NEMA 17 stepper motor as the main driver, a 4x4 membrane keypad as an input for adjusting RPM and rotation time values, Arduino Uno as the processor, and a seven-segment TM1637 display to show RPM and rotation time values. In this research, the keypad did not function well because it was sometimes challenging to control, and the device's design could have been better. Therefore, an orbital shaker device will be developed as a ready-to-produce and use a tool in laboratory applications, titled "Production of an Orbital Shaker with Time and Rotational Speed Control using a Potentiometer Based on Arduino Uno." This device is designed using a DC motor with an L298N DC motor driver as the driving mechanism, input from 2 potentiometers for adjusting rotation time and speed (RPM), Arduino Uno as the processor, and the values of time and rotation speed (RPM) will be displayed on a seven-segment TM1637.

2. Research Methods

The tools and materials used in this research are Arduino Uno, DC motor, L298N motor driver, potentiometer, TM1637 seven-segment display, power supply, LM2596 step-down module, push button, switch, jumpers and cables, DC fan, ball caster, protoboard, tachometer, stopwatch, bearing, and laptop.

2.1 Research Stages

The stages in producing a time- and speed-controlled orbital shaker using a potentiometer based on Arduino Uno consist of a literature study on the Arduino Uno-based orbital shaker, followed by creating the system design. The system design is divided into 2 parts: hardware design (circuit creation) and software design (program creation). Subsequently, the entire device was assembled, and testing on the orbital shaker was conducted. Afterward, data collection and data analysis are performed. For more clarity, please refer to the research flowchart in **Figure 1**.

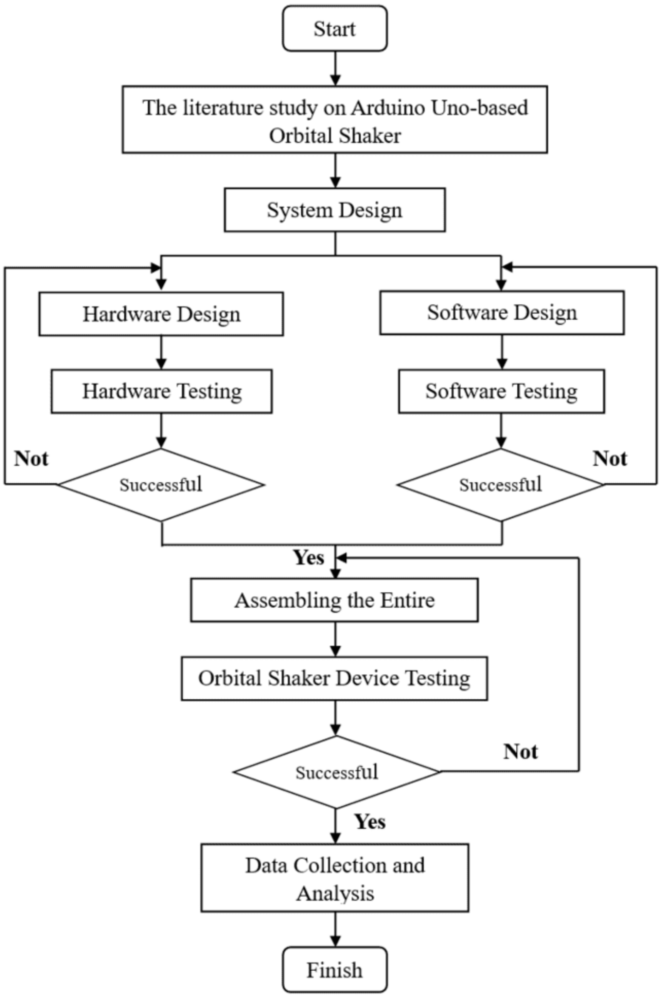


Figure 1. Research Flowchart

2.2 Sketch of Orbital Shaker Device

The orbital shaker device to be created utilizes the rotating motion of a DC motor as the main driving force, along with bearings and 4 ball casters to facilitate the rotation of the DC motor during operation and provide a rotating-like movement. The design sketch of the orbital shaker device can be seen in **Figure 2**.

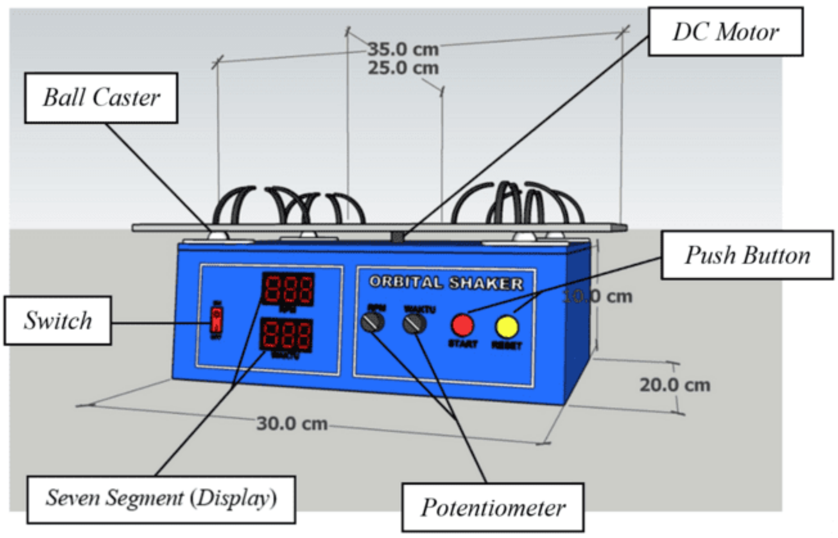


Figure 2. Sketch of Orbital Shaker Device

The design of the orbital shaker device resembles that of a digital scale. This device has dimensions of 30 cm in length, 20 cm in width, and 10 cm in height. The rotating plate section has a length of 35 cm and a width of 25 cm.

2.3 Hardware Design

The hardware design of this orbital shaker device utilizes a DC motor as the main driving force, an L298N DC motor driver to control the DC motor such as adjusting the rotation time and speed, a power supply circuit to convert AC voltage to DC, an LM2596 module to lower the DC voltage, a potentiometer as an input to adjust the speed and rotation time of the DC motor, push buttons as start buttons, a seven-segment display, and an Arduino Uno as the controller for the entire device operation. The hardware design block diagram can be seen in **Figure 3**.

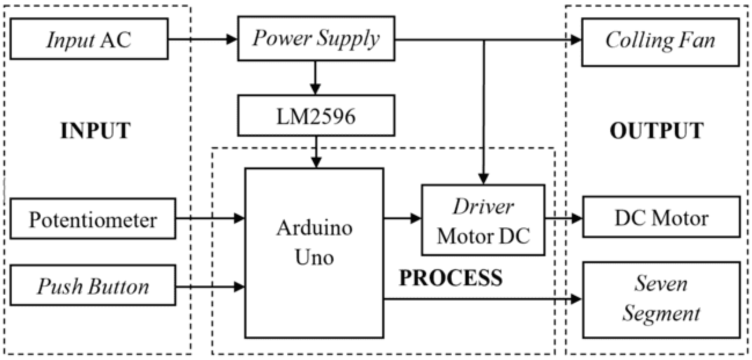


Figure 3. Block Diagram of the Orbital Shaker Device

Based on **Figure 3**, it can be explained that the inputs of this orbital shaker device are the AC input, 2 potentiometers, and a push button. The processes within this device occur within the power supply, LM2596 step-down module, Arduino Uno, and the DC motor driver, which will result in outputs such as the DC fan, DC motor, and seven-segment display. The orbital shaker device is designed to take input from a 220 V AC voltage source (from the power grid), which is then converted into DC voltage using the power supply circuit to provide power to the DC motor and DC fan. The DC voltage from the power supply is lowered using the LM2596 module, serving as the input voltage for the L298N DC motor driver and Arduino Uno to ensure it is compatible with the circuit. The DC fan is directly connected to the power supply, providing cool air intake and expelling hot air to ensure optimal performance. This device also features potentiometers to adjust the speed and rotation time inputs for the DC motor, as well as a push button as the start button to initiate the stirring process and a reset button. Once all inputs are configured, the design system within this device will be processed by the Arduino Uno. The output will be the rotational movement of the DC motor by the potentiometer input, and the seven-segment display will indicate the speed and rotation time values on the orbital shaker device.

The overall circuit diagram of the orbital shaker device can be seen in **Figure 2.4**.

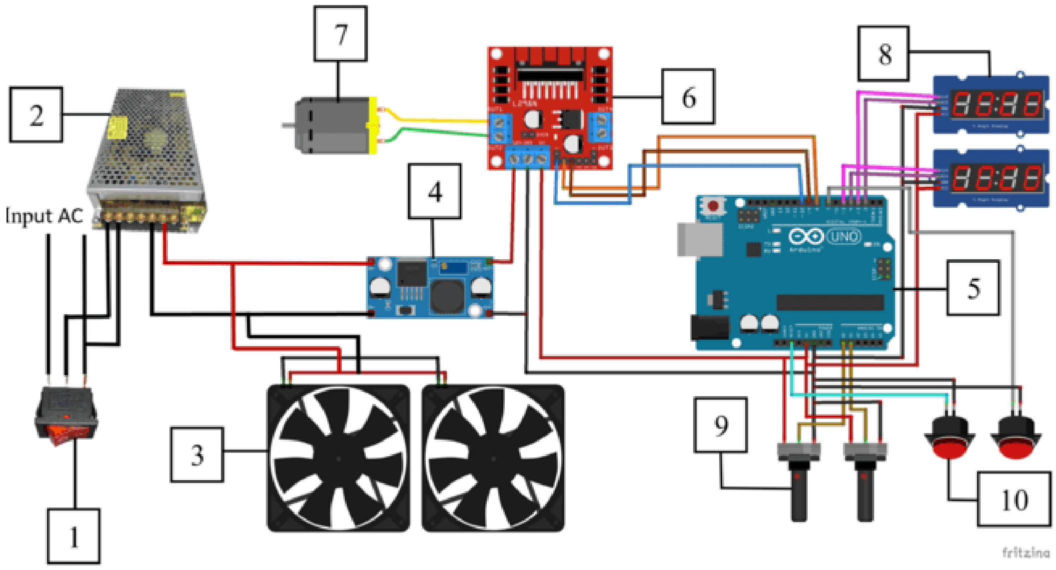


Figure 4. Circuit Diagram of the Orbital Shaker Device

From Figure 4. it can be observed that at number (1) there is a switch, (2) a power supply, (3) a DC fan, (4) an LM2596 stepdown, (5) an Arduino Uno, (6) an L298N DC motor driver, (7) a DC motor, (8) a TM1637 seven-segment display, (9) a potentiometer, and (10) a push button. The circuit of this orbital shaker device starts with an AC (from the power grid) going to the ON/OFF switch. When the switch is ON, the voltage and current flow to the power supply, which converts AC voltage into DC. This power supply provides voltage to the DC fan and the LM2596 stepdown module by reducing the DC voltage from the power supply, which will be connected to the L298N DC motor driver and Arduino Uno. The L298N DC motor driver has 16 pins, but only 8 pins are utilized in this design. Pins 1 and 2 on the L298N DC motor driver will be connected to the DC motor. The 12V pin is connected to the (+) pin of the stepdown as the output of the voltage that has been reduced from the power supply. Then, the GND pin is connected to the (-) pin of the stepdown and the GND pin of the Arduino Uno. The 5V pin is connected to the 5V pin of the Arduino Uno. Next, the ENA pin (Enable motor A), input out 1 and input out 2 pins will be connected to the digital pins 10, 8, and 9 of the Arduino Uno.

2.4 Software Design

The software for the orbital shaker device is developed using the Arduino IDE application. The program that has been created will be uploaded to the microcontroller, and then the orbital shaker device will operate according to the programmed instructions. The DC motor's rotation will correspond to the speed and rotation time values inputted through the potentiometers. The seven-segment display will display these adjusted speed and rotation time values. During the stirring process, the time segment on the seven-segment display will show the remaining time (timer), and when the set time has elapsed, the orbital shaker device will stop. The microcontroller used in this orbital shaker device is the ATmega328 microcontroller, commonly used in the Arduino Uno. The flowchart of the program design can be seen in **Figure 2.5**.

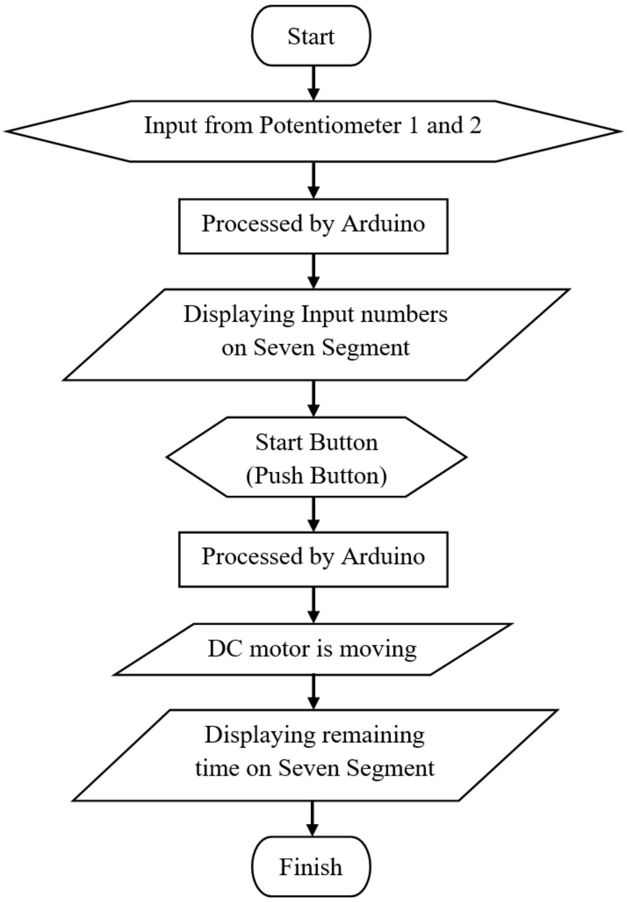
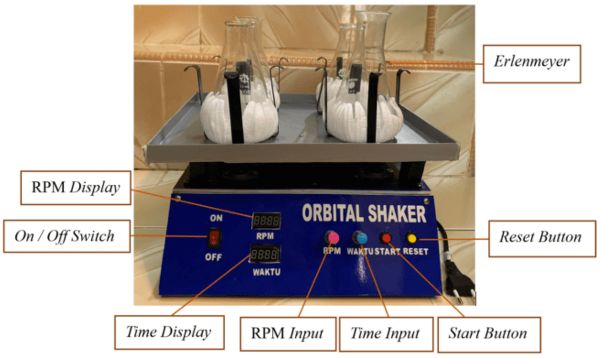


Figure 5. Programming Flowchart

3. Results and Discussions

3.1 Results of Orbital Shaker Device Implementation

The design of the orbital shaker device has been successfully implemented, utilizing input from 2 potentiometers based on the Arduino Uno and powered by a DC Gearbox Planetary motor with an L298N DC motor driver. On the front of the orbital shaker device, there is an on-off switch to power the device, 2 potentiometers for adjusting the speed and rotation time inputs, 2 TM1637 seven-segment displays to show the adjusted speed and rotation time values, and 2 push buttons as start and reset buttons. At the back of the orbital shaker device, there are 2 DC fans for air intake and exhaust to maintain an optimal temperature for the DC motor. Additionally, at the back, an AC cable is connected to a circuit breaker (MCB) to prevent the incoming current from exceeding the limit and minimize the risk of damage to the power supply. The realization of the orbital shaker device can be seen in **Figure 6**.

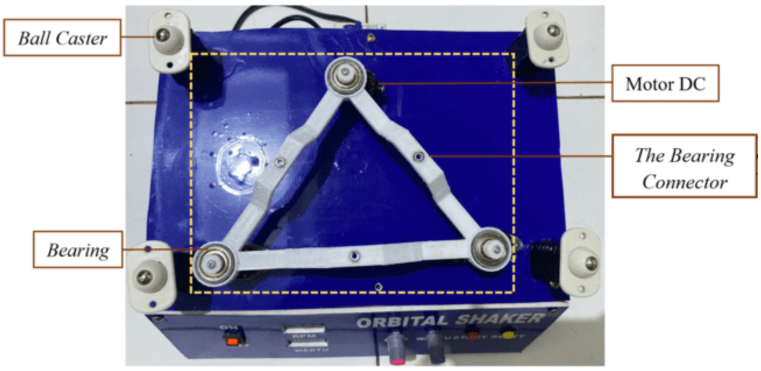


(a)

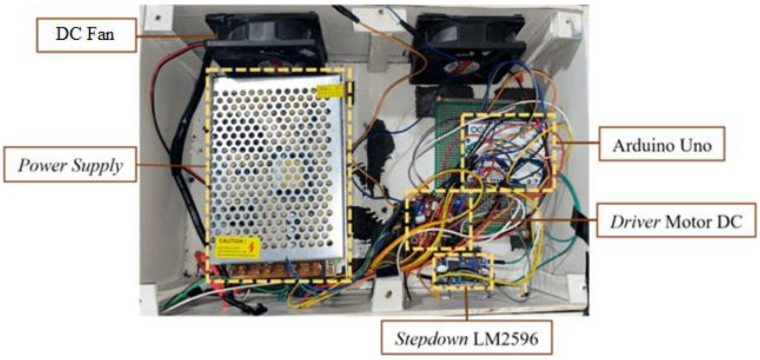
(b)

Figure 6. Realization of the Orbital Shaker Device: (a) Front View, (b) Back View

Between the acrylic plate and the main body of the orbital shaker box, there is a triangular-shaped mechanical arrangement that houses bearings, facilitating the rotation of the DC motor. This mechanical arrangement is created through a 3D-printed design using PLA+ material with a thickness of 6 mm and a base size of 180 mm by 120 mm height. Within the mechanical arrangement are 3 bearings placed along the triangle, and 2 are positioned beneath it, accommodating the DC motor. Furthermore, inside the orbital shaker device, there is an electronic circuitry to operate the device. The visual representation of the mechanical arrangement and the interior of the orbital shaker device can be seen in **Figure 7**.



(a)



(b)

Figure 7. (a) Mechanical Arrangement View, (b) Interior View of the Orbital Shaker Device

This orbital shaker device's operation is as follows: First, connect the orbital shaker to a power outlet and press the power switch to the 'on' position. Secondly, adjust the desired speed and rotation time values by turning the potentiometer wiper, and these values will be displayed on the screen. Once the speed and rotation time are set as desired, press the start button, and the orbital shaker will rotate according to the input speed and rotation time. If we wish to change the speed or rotation time value, press the reset button first and then press the start button again. The input range for rotational speed is between 240 to 374 rpm, and the maximum rotation time is 90 minutes (1 hour 30 minutes), with a maximum load of 1000 grams for the solution being used.

3.2 System Testing

3.2.1 DC Motor Testing

The DC motor used in this study is a type of DC motor called a Gearbox Planetary DC motor. DC motor testing begins with measuring the rotational speed of the device when it is operated using a PWM signal. The purpose is to observe the relationship between PWM values and the rotational speed of the DC motor. This testing is conducted by varying the input PWM values and using a tachometer to measure the DC motor's rotational speed corresponding to the provided PWM values. Subsequently, the Revolutions Per Minute (rpm) value of the DC motor is determined based on the input PWM value. The PWM range on the Arduino Uno microcontroller ranges from 0 to 255, with 0 being the minimum value and 255 being the maximum. In this study, the testing is performed 18 times by varying the input PWM values from 90 to 255 with increments of 10 PWM values. The results of testing the relationship between PWM values and the speed of the DC motor can be observed in **Table 1**.

Table 1. Relationship Between Input PWM Values and DC Motor Speed Without Load

No.	PWM *Input* Potentiometer	*Duty Cycle* (%)	The DC Motor Speed (rpm) using a Tachometer
1	0 – 89	-	DC motor cannot rotate.
2	90	35.4	130
3	100	39.3	160
4	110	43.2	190
5	120	47.1	220
6	130	51.0	250
7	140	54.9	265
8	150	58.9	280
9	160	62.8	295
10	170	66.7	310
11	180	70.6	320
12	190	74.5	330
13	200	78.5	340
14	210	82.4	345
15	220	86.3	350
16	230	90.2	360
17	240	94.1	370
18	250	98.0	380
19	255	100	390

Based on **Table 1**, it can be observed that there is a change in the rotational speed of the DC motor. As the PWM value increases, the resulting rotational speed of the DC motor also increases. When the PWM values range from 0 to 89, the DC motor does not rotate and function properly. However, the DC motor can rotate when the PWM values range from 90 to 255. The duty cycle values were obtained from testing using an oscilloscope, and the equation for calculating the duty cycle is as follows.

$$D = \frac{PW}{T} \times 100\% \quad (1)$$

with D = duty cycle (%), PW = pulse width of the active time (t_{on}), and T = total period of the signal ($t_{on} + t_{off}$).

An example of the signal waveform resulting from testing the duty cycle values using an oscilloscope based on the input PWM values can be seen in **Figure 8**.

Next, in **Table 1**, the DC motor rotational speed (rpm) values measured using a tachometer were obtained corresponding to the input PWM values. These two sets of values will be visualized graphically using Microsoft Excel to determine regression values and multiple R^2 values. The resulting graph from the input PWM values and the measured rotational speed against a standard tool is shown in **Figure 9**.

Figure 9. illustrates that the input PWM values influence the rotational speed of the DC motor. The graph yields a promising outcome, with a regression equation of $y = -0{,}0079x^2 + 4.1468x - 169.63$ and a multiple R^2 value of 0.9901. The regression equation derived from this graph visualization will be incorporated into the calibration programming of the device to convert PWM values into rpm for the DC motor's rotational speed.

Subsequently, calibration testing of the DC motor's rotational speed (rpm) was conducted by running the device without load and comparing the input rotational speed (rpm) values from the potentiometer with the measured rotational speed (rpm) values of the DC motor using a tachometer. The testing of DC motor rotational speed values for calibration purposes ranged from 150 rpm to 360 rpm in increments of 30 rpm. This testing was carried out with 3 repetitions for each rotational speed value. The data obtained from the calibration testing results for DC motor rotational speed (rpm) can be seen in **Table 2**.

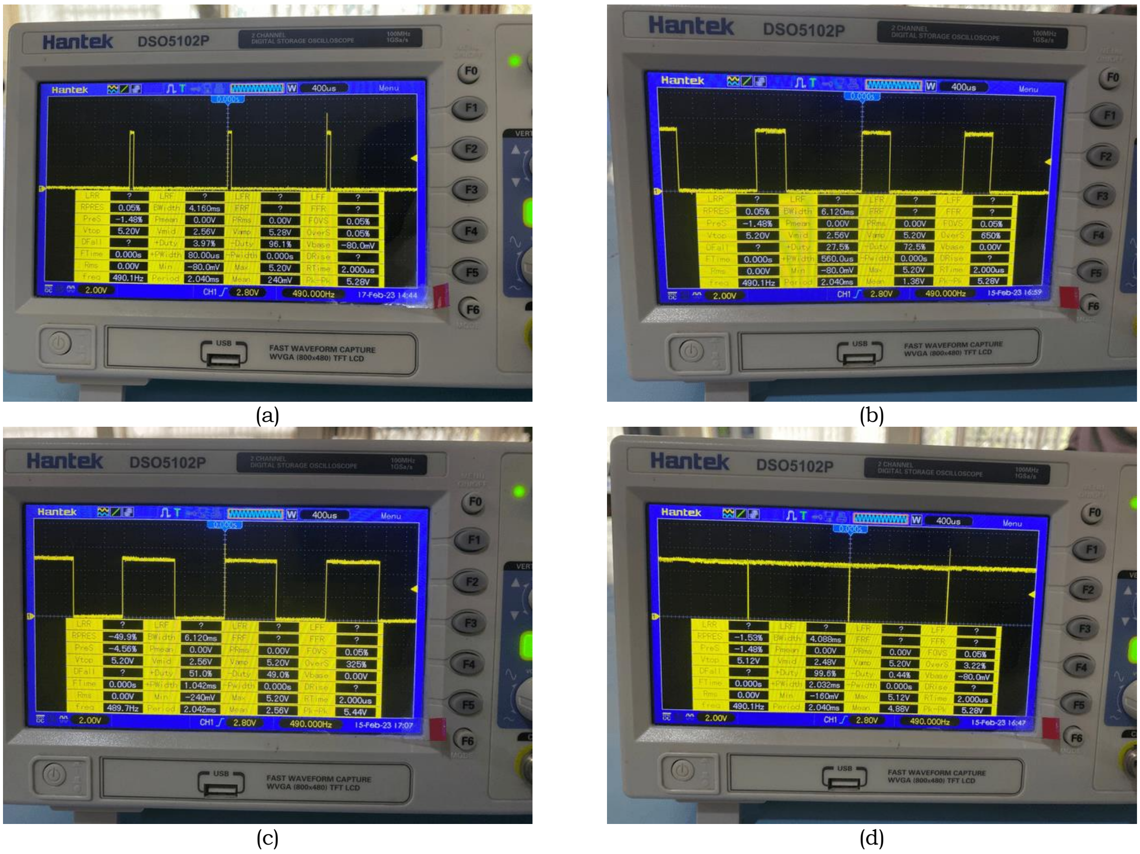


Figure 8. PWM Signal Waveforms: (a) Duty Cycle 3.97%, (b) Duty Cycle 27.5%, (c) Duty Cycle 51.0%, (d) Duty Cycle 99.6%

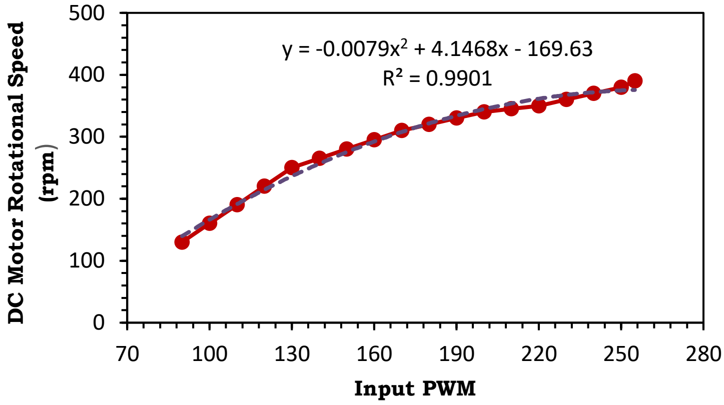


Figure 9. Graph of the Relationship Between PWM Values and Rotational Speed (rpm)

Table 2 Calibration Testing of DC Motor Rotational Speed (rpm) Without Load

Rotational Speed Input from Potentiometer (rpm)	Measured Rotational Speed from Tachometer (rpm)			Average Rotational Speed (rpm)	*Average Error* (%)	Accuracy (%)	Precision (%)
	1	2	3				
150	150.2	150	150.7	150,30	0,20	99,80	99,82
180	180.4	180.1	180.8	180,43	0,24	99,76	99,86
210	210.6	210.9	210.5	210,67	0,32	99,68	99,93
240	240.1	240.2	240.5	240,27	0,11	99,89	99,94
270	270.7	269.4	269.9	270,00	0,17	99,83	99,83
300	297.7	295.5	294	295,73	1,42	98,58	99,56
330	322	318.6	321	320,53	2,87	97,13	99,60
360	349.5	346.6	347.2	347,77	3,40	96,60	99,67
Average					1.09	98.91	99.77

Based on the results of the calibration testing of the DC motor's rotational speed, an average error value of 1.09% was obtained, resulting in an accuracy of 98.91% and a precision of 99.77%. The following equations calculate the error value, accuracy, and precision.

$$\%E = \left|\frac{Y - X_n}{Y}\right| \times 100\% \quad (2)$$

$$\%A = \left[1 - \left|\frac{Y - X_n}{Y}\right|\right] \times 100\% \quad (3)$$

$$\%P = \left[1 - \left|\frac{X_n - \bar{X}_n}{\bar{X}_n}\right|\right] \times 100\% \quad (4)$$

with E = Error Value (%), A = Accuracy Value (%), P = Precision Value (%), Y = Reference Parameter Value, X_n= Measured Parameter Value at nth Trial, $\bar{X}_n$= Average of Measured Parameter Values at nth Trial.

The resulting graph from the calibration testing of the DC motor's rotational speed, comparing the input rotational speed values from the potentiometer and the measured rotational speed values from the tachometer, can be seen in **Figure 10**.

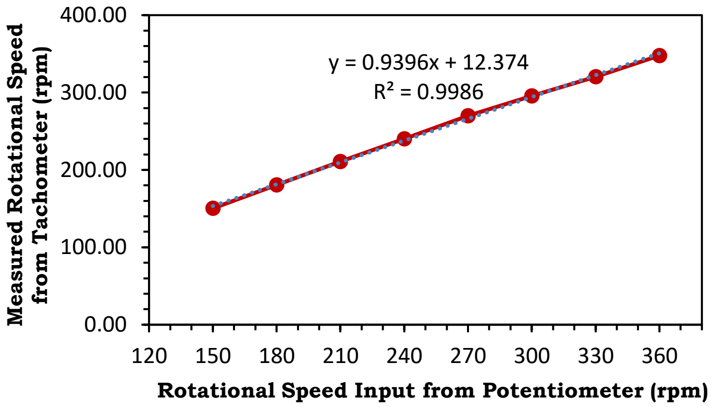


Figure 10. Graph of Calibration Testing of DC Motor Rotational Speed (rpm) Without Load

Figure 10. depicts the graph resulting from the calibration testing of DC motor rotational speed. The graph exhibits a predominantly linear trend, indicating that the measured rotational speed (rpm) values from the tachometer closely match the input values from the potentiometer. However, there is a decrease in the measured rotational speed from the tachometer compared to the input values in the range of 300 – 360 rpm.

Next, we tested the rotational speed values of a DC motor using a load. The load consisted of a water solution in Erlenmeyer flasks, ranging from 100 g to 1000 g in increments of 100 g. The initial weight before adding the water solution was 1024.74 g, including the combined weight of 4 Erlenmeyer flasks, the acrylic structure used to hold the Erlenmeyer flasks, and the mechanical setup's weight. For each 100 g increment, testing was performed at various rotational speeds ranging from 240 to 360 rpm in 30 rpm increments. Each variation of testing was repeated 3 times. The data obtained from the testing of the DC motor's rotational speed using the load can be seen in **Table 3**.

Table 3. Testing of DC Motor Rotational Speed with Load

Load Solution (g)	**DC Motor Rotational Speed (rpm)**							
	150	**180**	**210**	**240**	**270**	**300**	**330**	**360**
100	0.00	74.70	108.17	131.63	159.03	183.80	204.83	222.43
200	0.00	68.40	105.67	129.90	156.10	179.77	200.00	218.67
300	0.00	57.70	95.27	117.77	142.47	165.70	184.80	205.10
400	0.00	50.93	88.43	110.10	135.27	157.93	177.17	196.33
500	0.00	0.00	78.03	103.43	123.53	145.37	165.27	180.70
600	0.00	0.00	74.00	99.67	118.60	139.40	156.53	173.23
700	0.00	0.00	0.00	91.07	111.50	134.23	152.97	167.63
800	0.00	0.00	0.00	84.73	108.40	132.87	151.50	165.67
900	0.00	0.00	0.00	78.87	105.53	130.93	150.43	164.10
1000	0.00	0.00	0.00	71.60	100.17	125.83	145.87	161.60

Based on **Table 3**, after applying the load from the mechanical setup, acrylic as a plate, and the Erlenmeyer flask with the water solution, the measured rotational speed of the DC motor using a tachometer will decrease or not correspond to the input DC motor speed set by the potentiometer. The larger the load applied, the more the rotational speed of the DC motor will decrease. The research results show that at an input potentiometer speed of 150 rpm, the DC motor cannot rotate. Furthermore, at an input potentiometer speed of 180 rpm with a load of 500 – 1000 g, the DC motor cannot rotate, and at 210 rpm input with a load of 700 – 1000 g, the DC motor also cannot rotate. Therefore, the adjustable input rotational speed on the potentiometer that allows the orbital shaker device to function with the given solution load ranging from 100 – 1000 g is between 240 – 374 rpm. The graph generated from the testing data of the DC motor's rotational speed using the load can be seen in **Figure 11**.

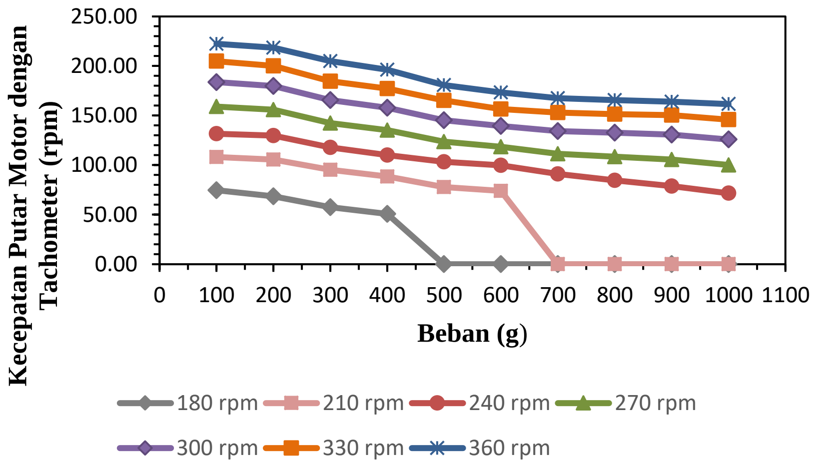


Figure 11. Graph of Testing DC Motor Rotational Speed with Load

From **Figure 11**, it can be seen that there is a difference between the DC motor rotational speed measured by the tachometer and the speed set by the potentiometer. It is due to the added load. However, this orbital shaker device can still function or rotate effectively even after being loaded with a solution of up to 1000 g, albeit at a different rotational speed than the one set on the potentiometer. The range of DC motor rotational speed values that can be set through the potentiometer on this orbital shaker device is between 240 and 374 rpm.

3.2.2 Testing of Time Rotation Calibration

The calibration testing of the orbital shaker's rotation time was conducted by comparing the time values set on the potentiometer with the time measured using a stopwatch. This testing was repeated thrice with time intervals of 1800, 3600, and 5400 seconds. The data obtained from the calibration testing of the orbital shaker's rotation time can be observed in **Table 4**.

Table 4. Rotation Time Calibration Testing

Potentiometer Input Rotation Time (s)	Measured Stopwatch Rotation Time (s)			Average Rotation Time (s)	*Average Error* (%)	Accuracy (%)	Precision (%)
	1	2	3				
1800	1844.18	1844.76	1844.21	1844,38	2,47	97,53	99,99
3600	3688.51	3688.58	3688.25	3688,45	2,46	97,54	100,00
5400	5532.12	5531.71	5531.75	5531,86	2,44	97,56	100,00
Average					2.45	97.55	99.99

The rotation time calibration testing results yielded an average error value of 2.45%, demonstrating an accuracy of 97.55% and a precision of 99.99%. It is reasonable since the error value obtained is still below 10%. The graph generated from the rotation time calibration testing data can be seen in **Figure 12**.

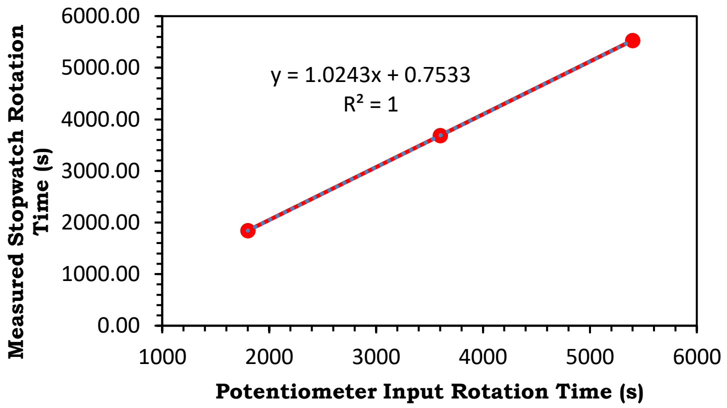


Figure 12. Graph of Rotation Time Calibration Testing

Figure 12 shows that the rotation time testing of the orbital shaker yielded a linear graph. However, the results show that when the input rotation time is set, the stopwatch-measured time slightly increases beyond the time the potentiometer sets. The maximum limit for the rotation time that can be input through the potentiometer on the orbital shaker is 5400 seconds.

4. Conclusions

Based on the conducted research, it can be concluded that the Arduino Uno-based orbital shaker has been successfully created with a well-designed structure, utilizing a DC motor as the driving mechanism, a potentiometer for adjusting rotation time and speed, a TM1637 seven-segment display to show the potentiometer-adjusted rotation time and speed values, and push buttons for the start and reset functions. The orbital shaker device can rotate within a range of input rotational speeds between 240 and 374 rpm, with a maximum operation time of 90 minutes and a maximum load of 1000 grams. From the testing results, for DC motor rotational speed (RPM) without a load, an average error of 1.09%, accuracy of 98.91%, and precision of 99.77% were obtained. Meanwhile, an average error of 2.45%, accuracy of 97.55%, and precision of 99.99% were recorded for rotation time testing.

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