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Design and Construction of a Mathematical Pendulum Harmonic Motion Experiment System Using Arduino Based E18-D80Nk Proximity Sensor

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Abstract: Experimentation is part of the stages of the scientific method that has a big role to test a phenomenon that occurs. One of the physics lessons proven through experiments is the harmonic motion of a mathematical pendulum. One of the problems with the existing experimental equipment is the variation in rope length and the manual measurement of rope length. One solution to overcome this problem is to create a Mathematical Pendulum Harmonic Motion Experiment System Using the Arduino-based E18-D80NK Proximity Sensor. This tool is designed to facilitate practitioners when conducting experiments and save practicum time. Research was conducted to determine the accuracy and precision of the tool. The experimental results of the device can be displayed on the LCD. The precision and accuracy of the experimental system with the following details: Average error of 0.65% for comparison of system t value and standard t and average error of 0.55% for comparison of system gravitational acceleration value with theoretical gravitational acceleration for variation of rope length. As for the average value of accuracy of 0.9990583 or 99.9% for a fixed rope length, and the average accuracy of 0.99793367 or 99.7% for a fixed number of oscillations.

Keywords: Mathematical Pendulum, Proximity Sensor, Arduino, Stepper Motor.

1. Introduction

Physics is a branch of science that studies phenomena in the universe and their interactions [1]. Physics is said to be the foundation or basis of technology. Learning physics cannot only rely on books and theories [2]. Learning physics is closely related to physics experiments. This is because learning physics requires proof of theories, concepts, laws, principles, and rules of physics. This proof can be done through trials or experiments [3]. Experiments are part of the scientific method stage that has a major role in testing a phenomenon that occurs. This activity is usually carried out by researchers both in education and industry.

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In education, a student-centered learning model based on experiments is a strategic and innovative choice [4]. Direct learning experiences with instruments to prove the truth of existing theories improve student understanding. In the industrial sector, experiments are one of the right frameworks to use [5]. The results of experiments can be a reference for the system to be worked on, so as to obtain optimal production results. The development of technology is an important factor in the success of experimental activities in this era. The use of technology makes experiments more extensive in collecting sufficient evidence, thereby reducing uncertainty before launching a product [6]. In this digital era, technology is used to accelerate the experimental process. The use of digital technology in experiments can be in the form of integration in the system being built, monitoring the process and results, processing and storing data, to publishing the results of the experiment.

Experimental activities are carried out and arranged in such a way that they can represent the physical symptoms observed to appear like real conditions. Along with the passage of time, the development of science and technology has been able to produce various research instruments that are precise and practical. What is needed in conducting an experiment is the existence of a demonstration tool or instrument. An instrument is a tool used to collect, process, analyze and present research data systematically [7]. One of the physics lessons proven through experiments is harmonic motion on a mathematical pendulum. The instrument used in this experiment consists of a load hanging at the end of a rope at a certain height. The load is made in a balanced condition and then given a deviation angle of θ. Then the load is released, because the restoring force makes the load move harmoniously. The harmonic motion that occurs in the pendulum can be observed directly.

Simple harmonic motion is a system that moves back and forth whose restoring force is directly proportional to the negative of its deviation [8]. Simple harmonic motion causes an object to oscillate through its equilibrium point. Objects can oscillate due to the restoring force on the system. The restoring force acting on the system is directly proportional to the relative position of the system's mass to the equilibrium point [9]. Several researchers have previously conducted research on simple harmonic motion. Research in 2019 conducted by Handayani et al., entitled Making a Simple Harmonic Motion Experiment Set on a Pendulum Based on Ping Sensors and Photogate Sensors with a PC Display. The results of this study are in the form of an experimental set that can determine the number of pendulum oscillations, the time required for the pendulum to oscillate and the length of the rope. The limitation of this study is that varying the length of the rope is still done manually.

Another study was in 2022 conducted by Syariffudin et al., entitled Design of Harmonic Motion Teaching Aids in the Form of Mathematical Pendulums Using Arduino-Based Photodiode Sensors. Researchers investigated the use of photodiode sensors in the study of pendulum teaching aid sets. The weakness of this tool is to vary the length of the rope and the measurement of the length of the rope is still manual, reading data that is still varied. Further related research was in 2021 conducted by Sa'adah & Prabowo entitled Development of Mathematical Pendulum Teaching Aids Based on Proximity Sensors on Harmonic Vibration Material for Grade X High School Students. The study aims to describe the validity of mathematical pendulum teaching aids based on proximity sensors to determine the value of the earth's gravitational acceleration in harmonic vibration material and to describe the suitability of mathematical pendulum teaching aids based on proximity sensors to determine the value of the earth's gravitational acceleration in harmonic vibration material against the constant acceleration of the earth's gravity in theory. This research has been successful and is classified as very good. The weakness of this tool is that there are only three variations in rope length and four variations in vibration magnitude using push buttons.

In real conditions, these solutions are still considered inadequate and still require optimization of experimental activities. The creation of a mathematical pendulum harmonic motion experimental system related to this research is based on the shortcomings and weaknesses of previous research. The experimental system created is expected to be able to adjust the length of the rope and the number of oscillations automatically as desired. This tool uses a sensor that has a higher sensitivity than previous research. This is the added value of the automatic pendulum harmonic motion experimental system so that its use is more effective and efficient. The experimental data on this tool will be displayed on the LCD, namely period data, time, rope length, and gravitational acceleration. Therefore, researchers are interested in conducting research entitled "Design and Construction of a Mathematical Pendulum Harmonic Motion Experiment System Using an Arduino-Based Proximity Sensor E18-D80NK".

2. Materials and Method

This research was conducted in the electronics and instrumentation laboratory of the UNP Physics Department, and at home. This research began in July 2024. The activity stages include the design stage, the tool manufacturing stage, the tool testing stage and the final report preparation stage (data collection and data processing). Before making the circuit and system, the researcher made a block diagram to facilitate the research process. The block diagram of the tool can be seen in Figure 1.

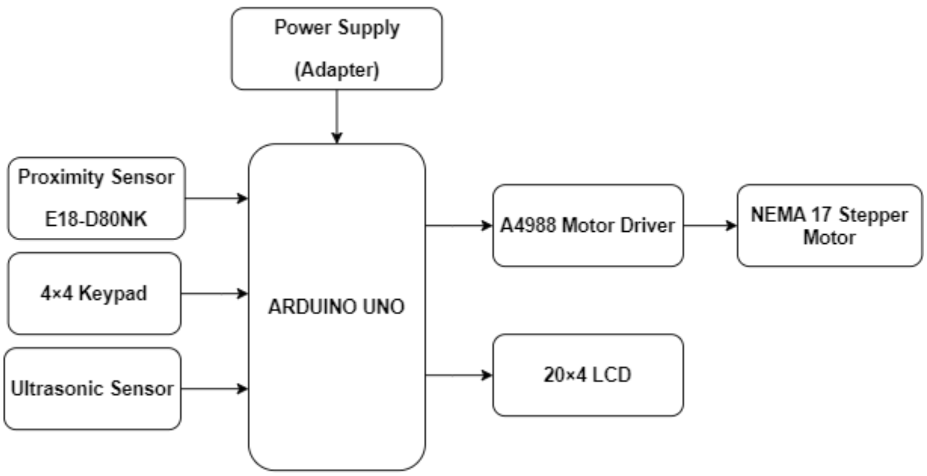

Figure 1. Tool Block Diagram

Based on Figure 1. it can be explained that in this study using Arduino Uno as a microcontroller whose power supply comes from the power supply. The keypad functions as an input for the required parameter values. The HY-SRF05 ultrasonic sensor is used as a sensor that reads the length of the rope on the tool. The E18-D80NK proximity sensor is used as an object detector to calculate the number of pendulum vibrations. NEMA 17 stepper motor to automatically adjust the length of the rope according to the length of the rope needed. The stepper motor is assisted by the A4988 motor driver to adjust the direction of rotation of the motor. The data obtained in the form of time, period, and gravitational acceleration will be displayed on the LCD. The circuit schematic design can be seen in Figure 2.

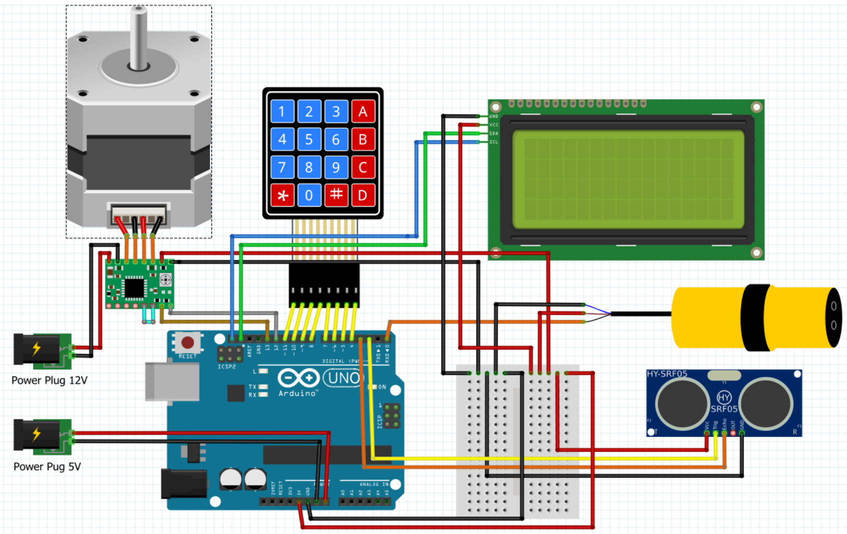

Figure 2. Circuit Schematic

The hardware design can be seen in Figure 3. The hardware design consists of a circuit box with keypad and LCD with a stative pole that has been equipped with a thread and a NEMA 17 stepper motor to adjust the length of the rope automatically.

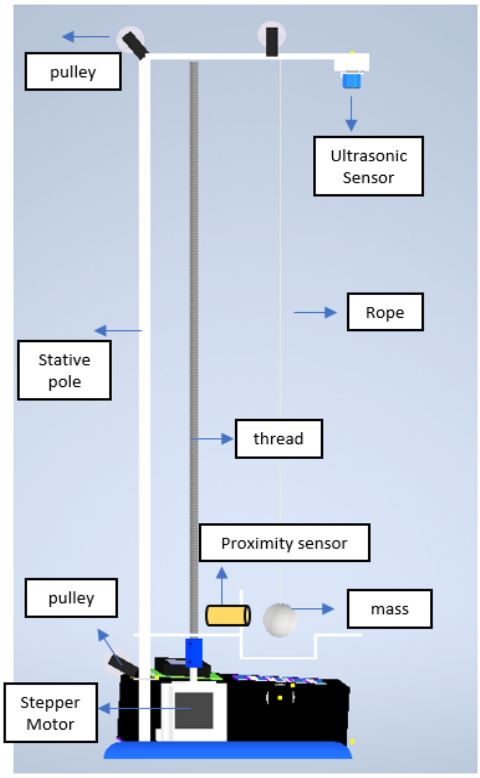

Figure 3. Hardware Design

The software design is in the form of a flowchart of a harmonic motion experiment tool on a pendulum. The flowchart of the system can be seen in Figure 4.

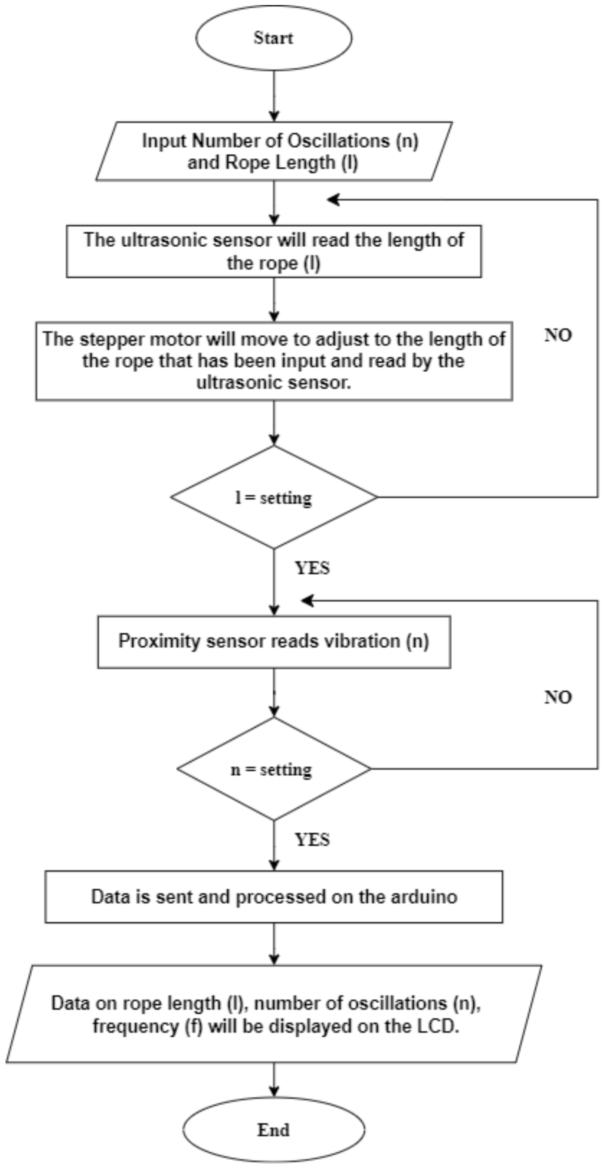

Figure 4. System Flowchart

The first step is to input the value of the number of oscillations and the length of the rope. Then the ultrasonic sensor will read the length of the rope automatically. Then the stepper motor will move to adjust the length of the rope according to the distance reading by the ultrasonic sensor. If the ultrasonic distance reading is in accordance with the input value, it will proceed to the next step. Otherwise the ultrasonic will read again. The next step is to pull the pendulum according to the angle used and the proximity sensor will read the vibration. If the vibration is in accordance with the input, the data will be sent and processed by Arduino. If the vibration reading is not appropriate, the proximity sensor will read the vibration. Data on rope length, number of oscillations, frequency will be displayed on the LCD.

3. Results and Discussion

Performance specifications are specifications related to the performance of a tool. The performance of a tool is related to the basic operating characteristics of the tool. The basic operations of the mathematical pendulum harmonic motion experiment system consist of: the system's ability to automatically read the length of the rope, the system's ability to read the time required when the system is running, the system's ability to read the number of oscillations, and the ability of the electronic circuit to display data.

This Arduino-based mathematical pendulum harmonic motion experiment system is equipped with an ultrasonic sensor that can automatically read the length of the rope. The length of the rope can be adjusted automatically with the help of a stepper motor that is equipped with a thread that can move up or down to change the length of the rope based on the change in distance inputted and read by the ultrasonic sensor. The number of oscillations in this Arduino-based mathematical pendulum harmonic motion experiment system is calculated automatically by the proximity sensor. The proximity sensor will read the number of oscillations according to the previous input and will stop reading the movement when the number of oscillations matches the input. The specifications of the Arduino-based mathematical pendulum harmonic motion experiment tool can be seen in Figure 5.

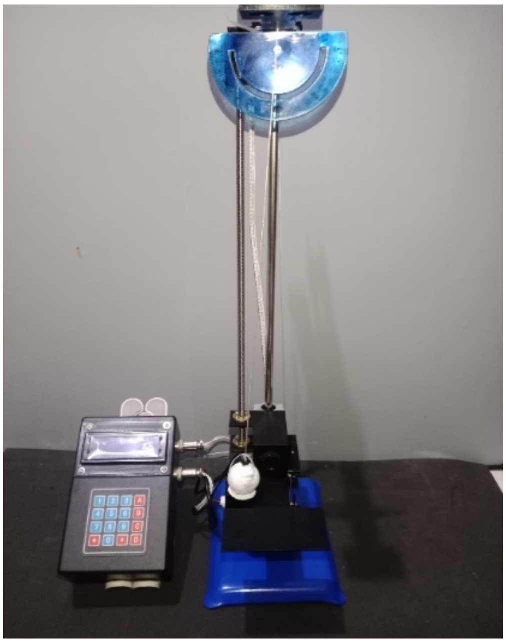

Figure 5. Tool Specifications

This Arduino-based mathematical pendulum harmonic motion experiment system is equipped with an ultrasonic sensor that can automatically read the length of the rope. The length of the rope can be adjusted automatically with the help of a stepper motor that is equipped with a thread that can move up or down to change the length of the rope based on the change in distance inputted and read by the ultrasonic sensor. The number of oscillations in this Arduino-based mathematical pendulum harmonic motion experiment system is calculated automatically by the proximity sensor. The proximity sensor will read the number of oscillations according to the previous input and will stop reading the movement when the number of oscillations matches the input.

The first data collection in this experimental system is by varying the length of the rope. Data collection was carried out for 5 variations of rope length. The mass used was 12 grams and θ was 10º. The data obtained from this experiment can be seen in Table 1.

Table 1. Measurement Result Data for Experimental Sets with Various Rope Length Variations

Measurement Order-	L (m)	t system (s)	t standard (s)	T system (s)	T^2 system (s^2)	g system (m/s^2)
1	0.25	10.062	10.05	1.0062	1.012438	9.748333665
2	0.30	11.013	11.05	1.1013	1.212862	9.764926513
3	0.35	11.811	11.90	1.1811	1.394997	9.904982404
4	0.40	12.675	12.88	1.2675	1.606556	9.829310592
5	0.45	13.498	13.56	1.3498	1.82196	9.750629828

Based on Table 1 the accuracy data on the mathematical pendulum harmonic motion experiment set based on Arduino which was carried out by varying the length of the rope, had quite good accuracy. After data analysis, the measurements carried out by comparing the system t and standard t obtained an average error percentage of 0.65% and an average relative accuracy of 99.35%. While the data analysis to compare the system g with the theory g obtained an average error percentage of 0.55% and an average relative accuracy of 99.45%. This proves that the value between the tested tools has a value that is almost the same as the measurement value using existing practicum tools. The second data collection in this experimental system is by varying the number of oscillations. Data collection is carried out for 5 variations of oscillations. The length of the rope used is 0.40 m, the mass used is 12 grams and θ is 10º. Data collection is carried out for 5 variations of the number of oscillations, namely 5, 10, 15, 20, and 25. The data obtained from this experiment can be seen in Table 2.

Table 2. Measurement Result Data of Experimental Set with Various Variations in the Number of Oscillations

Measurement Order-	L (m)	t system (s)	t standard (s)	T system (s)	T^2 standard (s^2)	g (m/s^2)
1	1	5	6.331	6.74	1.2662	1.603262
2	2	10	12.631	12.73	1.2631	1.595422
3	3	15	19.05	19.12	1.27	1.6129
4	4	20	25.387	25.47	1.26935	1.611249
5	5	25	31.7	31.91	1.268	1.607824

Based on Table 2, the accuracy data on the mathematical pendulum harmonic motion experiment set based on Arduino which was carried out by varying the number of oscillations, has quite good accuracy. After data analysis comparing t system with t standard obtained an average error percentage of 0.48% and an average relative accuracy of 99.34%. While data analysis to compare g system with g theory obtained an average error percentage of 0.29% and an average relative accuracy of 99.70%. This proves that the value between the tested tools has a value that is almost the same as the measurement value using existing practicum tools. The accuracy of the measurement is the similarity of data from a group of measurements. The accuracy of the data on harmonic motion is obtained by taking measurements 10 times on the experimental set of mathematical pendulum harmonic motion based on Arduino. The accuracy data on the experimental set of mathematical pendulum harmonic motion based on Arduino is done by taking two data by varying the length of the rope and the number of oscillations as seen in Table 3.

Table 3. Accuracy of Rope Length Variation

Measurement Order-	L (m)	t system (s)	Accuracy
1	0.45	13.495	0.9993549
2	0.45	13.473	0.9990138
3	0.45	13.514	0.9979461
4	0.45	13.472	0.9989397
5	0.45	13.475	0.9991621
6	0.45	13.475	0.9991621
7	0.45	13.499	0.9990583
8	0.45	13.473	0.9990138
9	0.45	13.493	0.9995032
10	0.45	13.494	0.9994291
Average			0.9990583

Based on Table 3, the accuracy data of the Arduino-based mathematical pendulum harmonic motion experimental system with 10 trials with the same rope length has quite good accuracy. The measurements carried out obtained an average accuracy of 0.9990583 or 99.9%. Next, the accuracy data collection was carried out on the variation of the number of fixed oscillations with 10 repeated experiments. The mass used was 12 grams, the length of the rope used was 0.45 m and θ was 10º. The data obtained from can be seen in Table 4.

Table 4. Accuracy of Variation of the Number of Oscillations

Measurement Order-	n	t system (s)	Accuracy
1	5	6.721	1.00000000
2	5	6.741	0.99702690
3	5	6.702	0.99717550
4	5	6.741	0.99702690
5	5	6.701	0.99702690
6	5	6.720	0.99985130
7	5	6.721	1.00000000
8	5	6.76	0.99420240
9	5	6.723	0.99970270
10	5	6.739	0.99732420
Average			0.99793367

The determination of system accuracy can be known by taking repeated measurements, namely measuring the pendulum oscillation time 10 times. A good tool has an accuracy close to 1 or 100%. The accuracy obtained is quite high. Based on Table 4, the accuracy data of the Arduino-based mathematical pendulum harmonic motion experimental system with 10 variations has quite good accuracy. The measurements carried out obtained an average accuracy of 0.99793367 or 99.7%. That means the data obtained is close to the actual conditions.

4. Conclusion

Specification of measurement accuracy and precision in the mathematical pendulum harmonic motion experiment system. The average error is 0.65% and the average relative accuracy is 99.35% for the comparison of the system t and standard t values and the average error is 0.55% and the average relative accuracy is 99.45% for the comparison of the system's gravitational acceleration value with the theory's gravitational acceleration for variations in the length of the rope. While for the variation of the number of oscillations in the comparison of the system t with the standard t, an average error of 0.48% and an average relative accuracy of 99.34% were obtained and the comparison of the system g with the theory g obtained an average error percentage of 0.29% and an average relative accuracy of 99.70%. This means that the data obtained is close to the actual conditions. Meanwhile, for the accuracy value of the measurement data analysis, the average accuracy is 0.9990583 or 99.9% for a fixed rope length, and the average accuracy is 0.99793367 or 99.7% for a fixed number of oscillations. This means that the data obtained has quite good accuracy.

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