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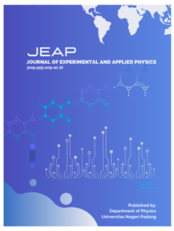

Development of Measurement Instrument of Translation Motion in Constant Acceleration Experiment using Infrared Obstacle Avoidance Sensor Module and MPU 6050 Based on ATmega32U4 Microcontroller

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Abstract: Physics is a field of study that holds significant influence in the development of science and technology. Many natural phenomena are related to physics and can be explained through experiments. From the results of conducted research, it is known that measurements for Translation Motion in Constant Acceleration experiments were carried out manually using standard measuring tools. The limitations of these measuring tools rendered the process impractical and susceptible to errors. To overcome these limitations, an experimental device equipped with automated digital measurement instruments was developed. The objective of this research is to ascertain the design specifications and performance specifications of the experimental device. The performance specifications of the experimental device include a track length of 2 meters and a width of 13mm. It involves the use of a servo motor, Infrared Obstacle Avoidance Sensor Module, and MPU 6050. The design specifications of the experimental device include an angle measurement accuracy of 92%, time measurement accuracy of 89%, velocity measurement accuracy of 87%, and time measurement precision of 92%. So, it is concluded that the measurement instrument can work properly.

Keywords: Translation Motion in Constant Acceleration; Arduino Pro Micro; MPU 6050; Infrared Obstacle Avoidance Sensor Module

1. Introduction

Physics is a scientific subject that emphasizes logic and is related to phenomena occurring in nature. Natural phenomena related to the field of physics in everyday activities can be explained using experimental methods. The experimental method is a way of presenting subject matter where students conduct experiments, experiencing and proving their own questions or hypotheses that

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are being studied [1]. One example of a teaching tool in Physics is the experiment on Translation Motion in Constant Acceleration. The application of the experimental method in experimental activities can enhance the learning outcomes of the 10th-grade students of MA Al-Iman Bulus Purworejo, specifically on the topic of Translation Motion in Constant Acceleration [2].

The most important thing to consider in conducting physics experiments is the experimental setup used. The experimental setup significantly determines the results obtained in a study. Currently, many industries are developing physics experimental sets to facilitate students in understanding physics lessons. These experimental sets can be in analog or digital form [3].

Experiments on the topic of Translation Motion in Constant Acceleration usually employ physical tools such as an inclined straight beam board, where the inclination angle can be adjusted to make an object on it slide from a higher position to a lower position. In the experiment on Translation Motion in Constant Acceleration, measurements of various physical quantities like the angle of inclination of the plane, change in position, and time are taken. These measurements are done manually. Then, by using specific equations, derived quantities like velocity and acceleration can be determined. In this experiment, there are shortcomings, namely, measurements that are quite challenging to perform and measurement outcomes susceptible to errors. These issues arise due to observer errors and the limitations of measurement tools.

In a study conducted by Deesera in 2017, measurements of various physical quantities in the experiment on Translation Motion in Constant Acceleration could be conducted more easily. This study resulted in a digital measurement tool capable of recording time and automatically calculating velocity and acceleration. This measurement tool incorporates several components, including Arduino as a microcontroller, 6 *photodiode* sensors, and a laser diode to detect objects placed on the inclined track. Based on the testing, the Translation Motion in Constant Acceleration measurement tool developed by Deesera successfully recorded travel time, automatically calculated the acceleration and velocity of the object, and displayed correlation between distance and time in graph form on the interface application. However, the tool still had a minor limitation, as it couldn't automatically measure angles, leading to potential errors in angle measurements [4].

In a study conducted by Humaira in 2016, measurement system for Translation Motion in Constant Acceleration Experiment was developed using *optocoupler* sensors based on a personal computer. The experimental setup consisted of a 2-meter air track, 5 sets of *optocoupler* sensors, a launcher, and an Arduino connected to a personal computer. The outcome of the research was a device capable of measuring and calculating time, distance, average velocity, and acceleration. However, the study identified certain limitations the suboptimal condition of the track disrupted the increase in the object's speed, resulting in inconsistent acceleration, the sensor board lacked stability, and the limited width of the object used posed constraints [5]. Based on the aforementioned issues, a digital measurement instrument is needed. With this digital measurement tool, measurement activities can be carried out more conveniently and accurately.

2. Materials and Method

The research procedure utilized in this study adheres to the steps outlined by the Research and Development (R&D) methodology. R&D methodology is a research method employed to investigate, design, produce specific products, and assess the effectiveness of these products [6]. R&D methodology represent a scientific approach aimed at generating new products or refining existing ones [7]. In this study, the developed product is a measurement instrument integrated into the Translation Motion in Constant Acceleration experiment device, utilizing the Infrared Obstacle Avoidance Sensor Module and MPU 6050 with the assistance of the ATmega32U4 microcontroller.

Microcontroller is a miniaturized computer contained within a single IC (Integrated Circuit) chip, consisting of a processor, memory, and programmable interfaces [8]. Microcontroller is an electronic component that can be programmed and has the ability to execute programmed instructions [9]. The microcontroller employed in this study is the Arduino Pro Micro, based on the ATmega32U4. ATmega32U4 features built-in USB communication without the need for a secondary processor [10]. The greatest advantage of using Arduino compared to other microcontrollers is its user-friendliness, allowing non-technicians to readily undertake and create projects in a relatively short time [11]. The Arduino Pro Micro outperforms the Arduino Leonardo by being smaller in size while maintaining the same functions [12]. However, the Arduino Pro Micro has a drawback, which is its somewhat limited capabilities in the add-on board platform [13].

The MPU6050 is an integrated circuit chip containing an *Accelerometer* and *Gyroscope* sensor. The Gyroscope is a device used to measure or maintain orientation, based on the principles of angular momentum [14]. The working principle of the Gyroscope in the MPU6050 relies on Micro-Electro-Mechanical Systems (MEMS) technology. Different types of MEMS gyroscopes vary in internal structure, but they all operate based on the *Coriolis* force principle [15]. The measurement results in this experiment device are displayed using an OLED SSD1306 Display. Despite its small size of about 1 inch, this display is highly readable due to its high-contrast OLED screen [16].

Stepper motor is a type of motor that rotates in discrete steps. Stepper motors find extensive use in industrial applications such as CNC machines, robotic arms, scanners, printers, and more recently 3D printers [17]. The motion of a stepper motor can be controlled by applying pulsed electrical voltage [18]. Power supply is a hardware device capable of directly supplying energy or electrical voltage from the electrical voltage source to other electrical voltages. The power supply takes input from Alternating Current (AC) voltage and converts it into Direct Current (DC) voltage. Power supplies can be used to provide power to electronic equipment that requires direct current [19].

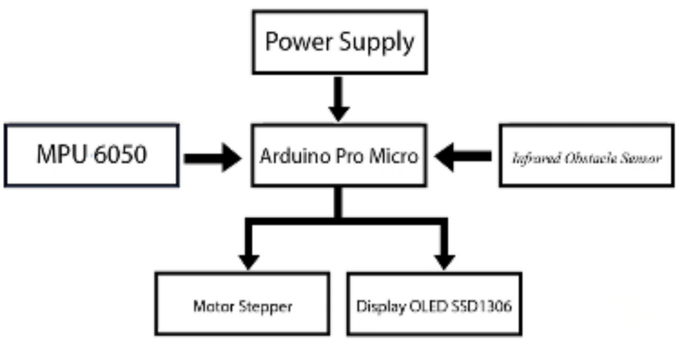

Figure 1. Block diagram of Translation Motion in Constant Acceleration experiment instrument

In the design of this system, the functioning of the device is mapped from start to finish. The device has been designed and constructed as a measurement instrument integrated into the Translation Motion in Constant Acceleration experiment setup using the Infrared Obstacle

Avoidance Sensor Module and MPU 6050 based on ATmega32U4 microcontroller. The design of the Translation Motion in Constant Acceleration experiment device can be observed in Figure 1.

According to Figure 1, the MPU 6050 is connected to the Arduino Pro Micro microcontroller. The data acquired from the sensor would be processed by Arduino and displayed on the OLED SSD1306 Display. Arduino would command the stepper motor to move to tilt up or down the track until MPU 6050 measured angle be same as angle input. Then, after pressing the time measurement button, the object would be released. When the Infrared Obstacle Avoidance Sensor Module detects the object at the starting line, the timing measurement begins. When the Infrared Obstacle Avoidance Sensor Module detects the object at the finishing line, the timing measurement is stopped. As a result, the travel time of the object on the inclined track can be obtained. The hardware design in this research is presented in Figure 2.

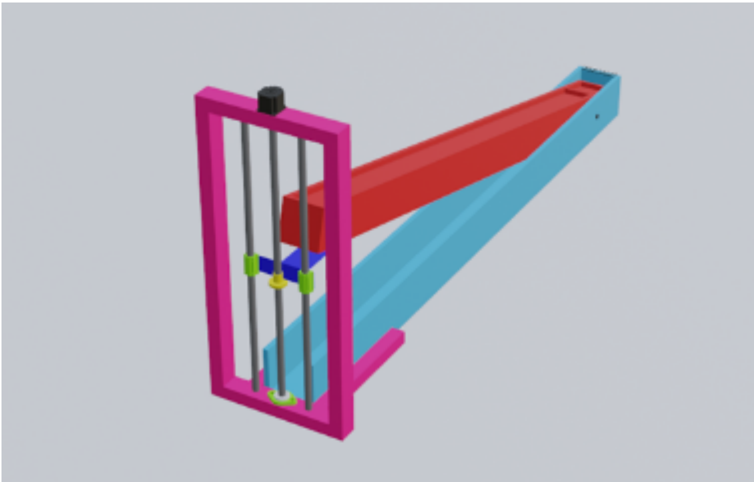

Figure 2. Hardware design of Translation Motion in Constant Acceleration experiment instrument

Based on Figure 2, it can be observed that the measurement instrument is equipped with a system capable of altering the incline of the surface by raising one end of the track using a stepper motor. According to Y.W. Best, research variables are the conditions or characteristics that researchers manipulate, control, or observe in a study [20]. From the measurements carried out in the study, research variable data is obtained. Subsequently, data processing is conducted to determine the accuracy, precision, and reliability of the developed measuring tool. Accuracy is defined as the difference or closeness between the measured value by the measurement instrument and the actual value. Precision involves comparing the measurement results of the system with theoretically calculated values through repeated measurements.

3. Results and Discussion

This research begins with a literature study of the instrument, determination of parameters and measurement tool components, research design development, incremental integration of components as per the research design, data collection, and conclusion drawing. The obtained data is utilized to calculate the accuracy and precision of the measurement system in the experimental device. The performance specification is a process of creating accurate job specifications from the required design. Performance specifications that cover the quality and quantity of system components can provide ease of use [21]. Performance specifications in a measurement tool entail a detailed explanation of the components that constitute the measurement tool and the function of each component. This experimental device has a length of 235 cm. The hardware components are constructed using 7 mm thick plywood and an 8 cm wide iron frame. The outcome of this hardware design can be seen in Figure 3.

Figure 3. The outcome hardware design of Translation Motion in Constant Acceleration experiment instrument

Based on Figure 3, it can be explained that this device has a total length of 235 cm, with a glass track surface measuring 223 cm in length and 13 cm in width. In this device, the entire circuit is connected to a microcontroller and arranged within a circuit box, serving as the input interface and the display for measurement results through the OLED SSD1306 display, as shown in Figure 4.

Figure 4. Circuit box of Translation Motion in Constant Acceleration experiment instrument

Based on Figure 4, the angle of the track incline can be adjusted by rotating the potentiometer located within the circuit box. Subsequently, the measurement results can be observed on the OLED SSD1306 Display. In this device, the angle of the track incline can be adjusted using a stepper motor connected to a lead screw with threads, enabling one end of the track to move up and down. The stepper motor and lead screw are mounted on an iron frame, as illustrated in Figure 5.

Figure 5. Actuator system

Based on Figure 5, at one end of this device, there exists a drive system capable of adjusting the incline of the experimental device's track using a stepper motor. In this device, the angle of the track incline needs to be measured to enable the stepper motor to raise or lower one end of the track as intended. The incline measurement system is installed at the starting area, as depicted in Figure 6.

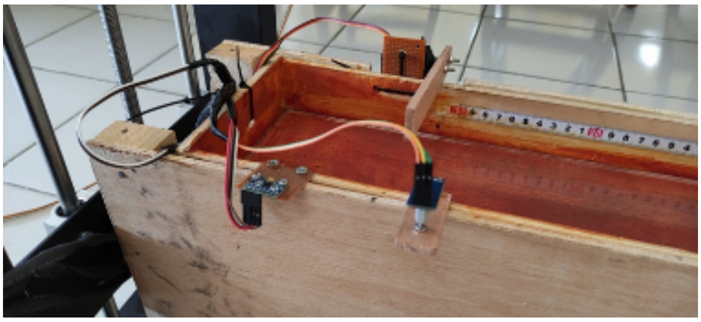

Figure 6. Angle measurement system of Translation Motion in Constant Acceleration experiment instrument

Based on Figure 6, an MPU 6050 is present to measure the track incline using a gyroscope sensor, allowing the angle of the track incline to be measured in real time. In this device, a servo motor functions to release the object at the starting point and simultaneously initiates the timing measurement as the object crosses the Infrared Obstacle Avoidance Sensor Module positioned at the starting line. The installation of the Infrared Obstacle Avoidance Sensor Module can be observed as shown in Figure 7.

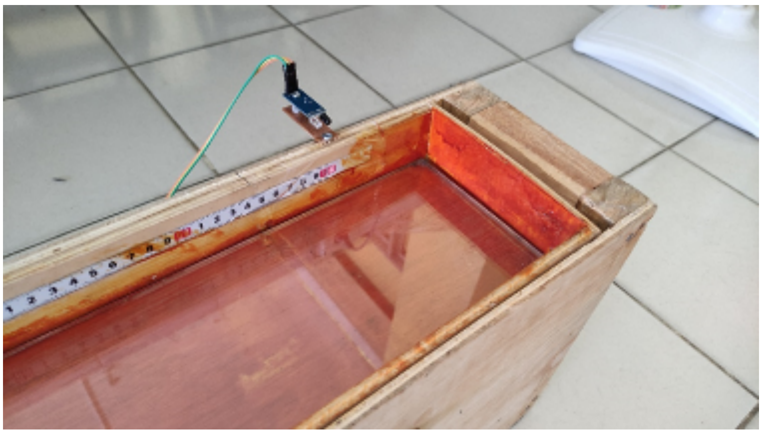

Figure 7. Infrared Obstacle Avoidance Sensor Module on Translation Motion in Constant Acceleration experiment instrument

Based on Figure 6 and Figure 7, infrared sensor modules are positioned at the starting and finishing area to detect the object, allowing the travel time to be determined. The time measuring begins when the object crosses the Infrared Obstacle Avoidance Sensor Module at the starting line and stops when the object crosses the Infrared Obstacle Avoidance Sensor Module at the finishing line. Thus, the object's time travel between start and finish line can be obtained.

Design specifications are often also referred to as product specifications. Product specifications are metrics and metric values that must be achieved by a product, not how the product should function [21]. The design specification describes the static characteristics of the product, tolerances, system-forming materials, system size, and system dimensions. The static characteristics of a system include accuracy, precision, resolution, and sensitivity. Accuracy is the proximity of the value read on a measuring instrument to the true value. Accuracy is determined by calibrating the system under specific operating conditions. A good system has accuracy close to 100%. Precision is defined as the ability of an instrument to produce the same value in repeated measurements. Precision is determined through repeated experiments using the same system on the same object for a given quantity [22].

Based on the measurement data obtained, the relationship between physical quantities can be understood. The accuracy of a relationship between physical quantities and unknown parameter values can be determined through experiments. Thus, the description and verification of a physical phenomenon are closely related to experiments [23]. The accuracy of measurements in this device's system is achieved by comparing the measurement results from the experimental device with the real value. The accuracy of the incline angle measurement tool can be assessed by comparing the angle measurements obtained from the measurement device MPU 6050 sensor based with measurements taken using a protractor. The data regarding the accuracy of the incline angle measurement tool can be found in Table 1.

Table 1. Angle Measurement Accuracy Data

Angle (°)		Experimental Accuracy Value (%)	Error Value (%)
protractor	Device		
5,5	5	91	9
8,5	9	94	6
11	10	91	9
12	12	100	0
17	15	88	12
15	17	87	13
17	19	88	12
20	20	100	0
20	17	85	15
19	18	95	5
Average		92	8

Based on Table 1, the measured incline angle values from both the protractor and the measurement device MPU 6050 sensor based can be described. The comparison between the angles measured by the device and the angles measured using the protractor yields an accuracy percentage with an average of 92%. Based on the accuracy percentage value, it can be said that the experimental tool is suitable for measuring the angle of inclination on the track.

The accuracy of the time measurement instrument can be determined by comparing the measured value by the stopwatch and the digital time measurement instrument on the device with the expected time value. The expected time value is obtained through calculations using formulas. The value of the digital time measurement is obtained through the time difference detected by the Infrared Obstacle Avoidance Sensor Module placed at the start and finish lines. Data regarding the accuracy of the time measurement tool can be found in Table 2.

Table 2. Time Measurement Accuracy Using Stopwatch and Device

Formula (s)	Time (s)		Experimental Accuracy Value (%)		Error Value (%)	
	Stopwatch	Device	Stopwatch	Device	Stopwatch	Device
1,831	2,07	1,707	87	93	13	7
	2,17	1,706	81	93	19	7
	1,85	1,307	99	71	1	29
	2,08	1,593	86	87	14	13
	1,67	1,422	91	78	9	22
	2,46	1,802	66	98	34	2
	1,44	1,594	79	87	21	13
	2,03	1,92	89	95	11	5
	2,12	1,707	84	93	16	7
	2,19	1,649	80	90	20	10
Average	2,008	1,6407	84	89	16	11

Based on Table 2, an experiment was conducted on a glass track surface that came into contact with the glass side of the experimental object. In this trial, the incline angle was set at 20 degrees. At this angle, a frictional force of 2.158 Newtons, a friction coefficient with a value of 0.234, and an acceleration value of 1.194 m/s^2 were obtained. The results from the Stopwatch measurements and measurement device were compared with the time calculated using formulas. In this experiment, it was found that the measurement device has an accuracy of 89%, whereas the Stopwatch has an accuracy of 84%. Based on this comparison, the measurement device demonstrates better accuracy compared to the Stopwatch.

Table 3. Time Measurement Accuracy Using Stopwatch and Device with Angle Variations

Angle (°)	Time (s)			Experimental Accuracy Value (%)		Error Value (%)	
	Formula	Stopwatch	Device	Stopwatch	Device	Stopwatch	Device
15	2,849	3,21	2,512	87	88	13	12
		3,35	2,325	82	82	18	18
		3,18	2,326	88	82	12	18
17	2,480	2,74	2,548	90	97	10	3
		2,67	2,266	92	91	8	9
		2,23	2,151	90	87	10	13
20	1,831	2,08	1,592	86	87	14	13
		2,12	1,934	84	94	19	6
		2,36	1,706	71	93	29	7
Average				86	89	14	11

Variations in the angle of the track incline leads to differences in frictional force, friction coefficient, object travel time, object velocity, and acceleration. Data comparing the accuracy of time measurements using the Stopwatch and measurement device on the device with varying angles can be found in Table 3. Based on Table 3, it can be described that the measured travel time by the Stopwatch has an accuracy of 86%, whereas the measurement accuracy on the experimental device stands at 89%. The experimental device demonstrates better accuracy in measuring travel time compared to the Stopwatch.

The measurement of object velocity was conducted for different angles of incline. The difference in the angle of inclination of the track causes differences in frictional force, friction coefficient, object's travel time, object's velocity, and acceleration. The average velocity over a specific time interval is equal to the average displacement during that time interval [5]. The average velocity value can be obtained by comparing the track length with the time required to travel from the start position to the finish. Velocity measurement is carried out indirectly, where the velocity value is influenced by the time measured by the time measurement tool, namely Stopwatch and the digital time measurement system integrated into this Translation Motion in Constant Acceleration experimental device. Data comparing the accuracy of velocity measurements based on time measured using the Stopwatch and measurement device on the experimental device under varying angle conditions can be found in Table 4.

Table 4. Velocity Measurement Accuracy Using Stopwatch and Device with Angle Variations

Angle (°)	Velocity (m/s)			Experimental Accuracy Value (%)		Error Value (%)	
	Formula	Stopwatch	Device	Stopwatch	Device	Stopwatch	Device
15	0,702	0,623	0796	89	87	11	13
		0,597	0,860	85	77	15	23
		0,629	0,860	90	78	10	22
17	0,807	0,730	0,785	91	97	9	3
		0,749	0,883	93	91	7	9
		0,897	0,930	89	85	11	15
20	1,093	0,962	1,256	88	85	12	15
		0,943	1,034	86	95	14	5
		0,847	1,172	78	93	22	7
Average				87	87	13	13

Based on Table 4, it can be observed that the calculated velocity values obtained from time measurements using the Stopwatch have an accuracy of 87%. Likewise, the velocity calculations derived from the experimental measurement tool also have an accuracy of 87%. The measurement accuracy of velocity by both instruments is equal to 87%. Therefore, it can be stated that the indirect measurement method for determining object velocity using the Stopwatch is as effective as using the experimental device equipped with sensors and a microcontroller.

The precision of the Translation Motion in Constant Acceleration experimental device was determined by conducting measurements for each experiment 10 times. From these 10 repetitions, it can be observed whether the device consistently yields the same or varying values. The more consistent the measurement results obtained, the higher the precision level of the measuring tool.

In this experiment, measurements were conducted on a track inclined at 20 degrees. The glass side of the experimental object came into contact with the glass surface of the track. Subsequently, time measurements were taken using the digital experimental device for 10 times. Timing began when the infrared sensor at the start position detected the object passing through, and timing ended when the infrared sensor at the finish position detected the object. Data detailing the precision of time measurement results for the 20-degree incline, utilizing the sensor-equipped measurement tool, can be found in Table 5.

Table 5. Time Measurement Precision by Device at 20-Degree Incline Angle

Time (s)	Accuracy Value (%)	Error Value (%)
1,707	96	4
1,706	96	4
1,307	80	20
1,593	97	3
1,422	87	13
1,802	90	10
1,594	97	3
1,920	83	17
1,707	96	4
1,649	99	1
Average	92	8

Based on Table 5, measurements were conducted for 10 times. Then, the difference between the values of each measurement data compared to the average measurement value was obtained, it can be observed that the precision of time measurements from the experimental device is 92%. This proves that the measuring instrument has stability in measurements and achieved a good level of precision to be used as an experimental tool.

4. Conclusion

Based on the results of testing and data analysis as well as discussion of Translation Motion in Constant Acceleration Experiment, several conclusions can be drawn. First, the experimental device can effectively demonstrate Translation Motion in Constant Acceleration experiments on a 2-meter track. Second, the design specifications of the measurement instrument in this device encompass both accuracy and precision values. The accuracy of the angle measurement system in the experimental device is 92%, with an error percentage of 8%. The accuracy of the time measurement system in the experimental device is 89%, with an error percentage of 11%. In cases where the angle is varied, the accuracy of the time measurement system in the experimental device is 89%, with an error percentage of 11%. In cases where the angle is varied, the accuracy of the velocity measurement system in the experimental device is 87%, with an error percentage of 13%. The precision value of the time measurement system in the experimental device is 92%, with an error percentage of 8%.

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