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Investigation to Inertial Constant of Rotating Objects on a Slope based on Arduino

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Abstract:- This study aims to develop a device to investigate the moment constant of inertial rigid ball and rigid cylinder that rolls down an incline. The developed equipment consists of several components such as arduino, infrared sensor, Liquid Crystal Display (LCD), push button, actuator, and power supply. It is also equipped with a mechanical system. The equipment is controlled by the arduino. The developed electronic equipment serves to measure the time it takes for an object to roll on a slope. The result of the investigation shows that the change of track length does not affect the value of the inertial constant, whereas the change in the slope of the trajectory influences the value of inertial constants. The result of the investigation shows that the sphere's constant inertia is 0.405 and cylinder's constant inertia is 0.503 at the of 15° slope angle.

Keywords:- *Inertial Constants, Rolls, Arduino, Sensor.*

I. INTRODUCTION

Optimization of learning through laboratory activities is expected to improve the reasoning power and thinking power of learners which in turn hopefully promote better learning achievements [1]. The laboratory activity aims to investigate physical phenomena through experiments. Experiments in physics require equipment used to measure physical changes that occur in a phenomenon. Equipments used in the investigations can be either manual device or automated apparatus. However, to maintain the accuracy and precision of investigation results, automatic equipments are more preferable because due to higher accuracy and precision in measurements.

The advancement of science and technology produces a variety of electronic devices that aid in developing experimental equipments. Some important electronic devices in the development of equipments, among others are microcontroller, sensor, LCD, and actuator [2]. With a variety of electronic devices, the props are developed more effectively, efficiently, and have a better measurement and visualization accuracy. Microcontroller acts as a controller device that is flexible and practical because it is not too complex or requires high computational load. Microcontrollers are able to automate and control a system independently (standalone) [3]. Microcontrollers have been widely used as input and output control devices to design physical physics props. The props developed using microcontrollers are automatic, digital, and have a higher accuracy of measurement results compared to conventional props. Some of the microcontroller based physics props which have been developed include viscometer [4] [5], DC ammeter [6], strain gauge [7] [8], teslameter [9], fluid velocity measuring devices [10], and optical power measuring devices [11].

Arduino is a simple and easy-to-use microcontroller module. The application of arduino to experiments is very interesting and is a method to experiment with automated equipment. Much research has been done in utilizing arduino to develop experiments supported by several other electronic components such as sensors, LDCs, and actuators [12] [13] [14]. The use of arduino as a controller in conducting experiments consists of two important parts, namely the design of hardware and software. Arduino has both digital and analog input / output components that can be combined with other electronic devices such as sensors, LCDs, actuators, and pushbutton. Arduino software can be developed using C ++ language with the help of IDE Arduino compiler. This study aims to develop arduino-based experimental equipment in investigating the constant inertia of rigid ball and cylinder which roll on a sloping plane.

II. ROLLING MOTION

A rigid ball with a mass of m is rolled on a sloping plane will work with forces as shown in figure (1). Assume that the spokes of the rigid ball are R.

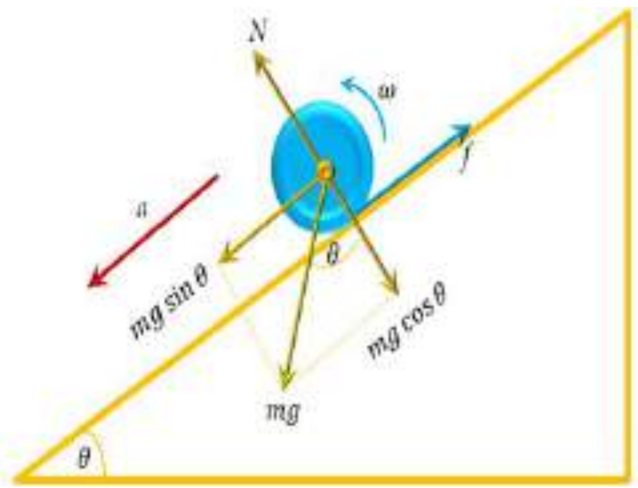

Fig 1:- The rotation of a rigid body on the incline and forces acting on the object

N is the normal force to the inclined plane, *mg cos θ* is the gravity in the y-axis direction, *mg sin θ* is the gravity in the *x-axis* direction, and *f* is the friction force that occurs during the ball rolling. The resultant force ($\sum F_x$) in the direction of *x* in the direction of the incline is:

$$\sum F_x = ma$$
$$mg\sin\theta - f = ma \quad (1)$$

With *a* as the acceleration at the center point of the object mass. In this case, the friction force experienced by the object causes the moving object to roll away. Thus, the inertial rotational moment of the rolling ball or cylinder is:

$$\sum \tau = I\alpha$$
$$fR = I\alpha \quad (2)$$

With *α* as the angular acceleration of the rotating object. Because *α = (a/R),* therefore equation (2) can be re-written as:

$$fR = I\left(\frac{a}{R}\right)$$
$$f = I\left(\frac{a}{R^2}\right) \quad (3)$$

Equation (3), when substituted into Equation (1) will obtain:

$$mg\sin\theta - I\left(\frac{a}{R^2}\right) = ma \quad (4)$$

From equation (4) we will obtain linear acceleration (*a*) as follows:

$$a = \frac{mg\sin\theta}{\left(\frac{I}{R^2+m}\right)} \quad (5)$$

If the distance covered by the ball or cylinder is *S* in t seconds and is initially released at zero initial speed, then:

$$S = \frac{1}{2}at^2 \quad (6)$$

Equation (5) substituted into equation (6) will obtain:

$$\frac{mg\sin\theta}{\left(\frac{I}{R^2+m}\right)} = \frac{2S}{t^2}$$
$$I = \left(\frac{t^2 g\sin\theta}{2S} - 1\right)mR^2 \quad (7)$$

Since the equations of moment of inertia of a rigid body is determined by the equation:

$$I = kmR^2 \quad (8)$$

Where *k* is the inertial constant. Thus, if equation (7) is compared to equition (8) then the inertial constant of a rigid body is determined by the equation:

$$k = \frac{t^2 g\sin\theta}{2S} - 1 \quad (9)$$

III. EKSPERIMENT SETUP

Prototype used in this arduino-based experiment consists of electronics and mechanical components. The electronic parts consist of several main components: arduino, IR sensor, push button, LDC display, actuator (relay), and power supply. The series of electronic components is shown in figure (2). The prototype mechanical device consists of sloping track, angle and oblique regulator, magnetic induction rod, ruler, and a protactor. The prototype setup for the experiment is shown in figure (3).

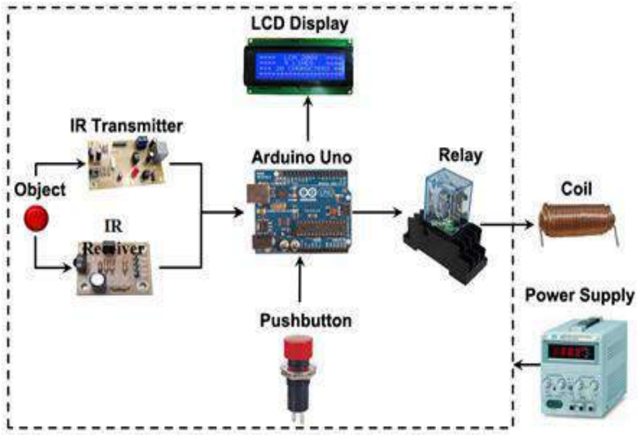

Fig 2:- An arduino-based prototype circuit diagram with various supporting electronic components

The electronic hardware diagram of figure (2) shows the arduino as the main controller in the equipment to control the work of all electronic devices and measure time with the arduino internal timer. The infrared sensor is used as a detector for detecting motion of the rigid ball, the LCD as the timer viewer, push button as input device to give enter command into the arduino, the actuator as a circuit to control the magnetic field in the iron rod, and the power supply as the current and voltage provider for the electronic circuit experiment.

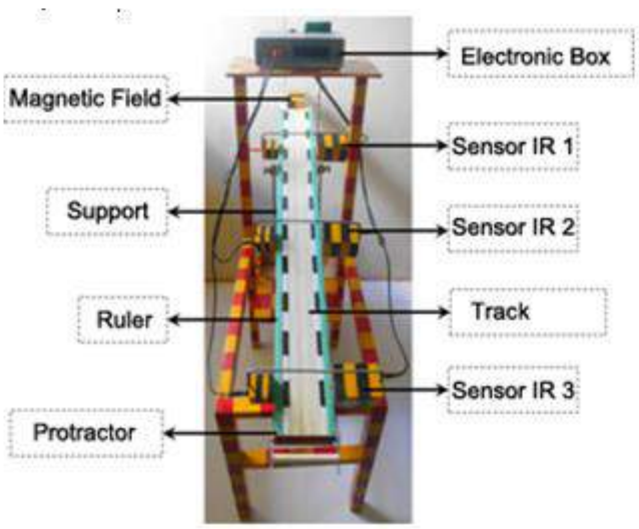

Fig 3:- Setup of prototype to determine the inertial constant rigid ball when rolling on a slope.

The main variable measured by this prototype is the time required by the rigid ball and cylinder to roll from the top of the incline to each IR sensor. The time is divided into sections using timer on arduino. The electronic device working system as shown in figure (2), ie the arduino receives the input signal from pushbutton, and then the arduino will control the actuator/ relay so that the magnetic field at the top of the incline disappears and allow the solid bulb to roll along the inclined plane. When the magnetic field disappears and the rigid ball begins to roll, the timer on the arduino activates to segregate the time it takes for ball to arrive at sensors IR_1, IR_2, and IR_3. The timing results by the arduino timer will be displayed on the LCD, readable by the user. This arduino-based hardware work system is controlled through software using C++ programming language. The software was developed by utilizing the arduino's Integrated Development Environment (IDE) compiler.

The setup for the experiment as displayed in figure (3) shows the mechanical system of the prototype. It is equipped with three IR sensors that can shift positions along the sloping plane so that the length of the path in the experiment is adjustable. The length of the track is measured using a ruler attached to both sides of the track. The prototype is also equipped with structural support beams that also serve as a regulator of the slope, so that the tilt is adjustable. The track's slope can be measured using a protractor mounted on both sides at the end of the track. In addition, at the top of the incline there is an iron rod wrapped in wire so that it can be induced into an automatically controlled magnetic field by the arduino. This device allows the rigid ball or cylinder to be attached to the iron rod and when the magnetic field in the iron rod disappears, the object can move along the sloping track with an initial velocity of 0 m/s.

IV. RESULT AND DISCUSSION

Prototype that has been developed as a device to investigate the change of value of inertial constant in rigid body that rolls on an incline possesses several qualities, including: (1) portable; (2) automatic measuring device based on arduino; (3) the length and tilt of the track are adjustable; (4) equipped with user interface. This prototype has a measurement reach of up to 90 cm with precision of 1 mm. The tilt of the slope is adjustable between 1° to 15° with precision of 1°.

In this experiment, to determine the inertial constant of a rigid ball, we use an equation (9) with measurable variables: time (t), length of track (s), and angular tilt of the sloping plane (θ). The investigation to inertial constant in this experiment is possible through a variation of track length and tilt. Results of the experiment are shown in figure (4) and (5) for rigid ball and Figure (6) and (7) for cylinder. Variation of track length is conducted on angular track tilt of 5°, 10°, and 15°, whereas variation of the track's angular tilt is measured on track length of 20 cm, 50 cm, and 90 cm.

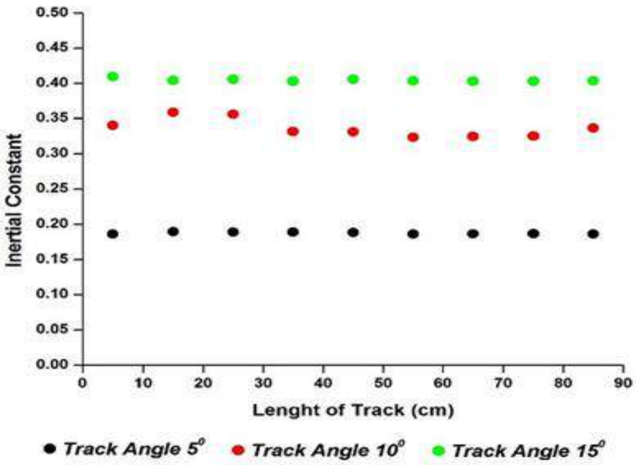

Fig 4:- Experiment results for determining the inertial constant of rigid balls when the length of the trajectory is altered at an angle of 50, 100 and 150

The experimental results presented in figure (4) show that the length of the altered trajectory does not affect the inertial constant value (k) of the rigid ball at fixed angle. The value of the constant does not change when the path length is changed because the forces acting on the rigid ball to cause the object to roll are fixed. In this investigation, the average inertial constant value of rigid ball of angular tilt of 5°, 10°, and 15° of the track is 0.188, 0.336, and 0.405, respectively. The average inertial constant value of cylinder of angular tilt of 5°, 10°, and 15° of the track is 0.238, 0.402, and 0.503, respectively. When compared to the theoretical inertial constant value of rigid ball at 0.4 and cylinder at 0.5 [15]. The proper angle for investigating the inertial constant of rigid ball is 15°, because at this angle the value of the inertial constant has the same value as the theoretical value.

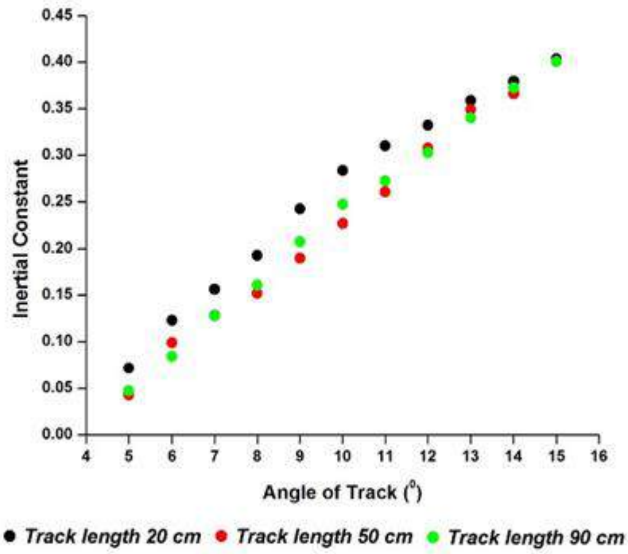

Fig 5:- Experiment results for determining the inertial constant of rigid balls when the angle of the field is altered at track length of 20 cm, 50 cm and 90 cm

The experimental results in figure (4) and (6) are supported by the experimental results displayed in figure (5) and (7), which shows that the inertial constant value of the rigid ball and cylinder changes with the adjustment of the track tilt. In figure (5) and (7) it can be observed that the value of the inertial constant becomes closer to theoretical value as the slope angle of the track becomes greater. The value of the inertia constant obtained is exactly the same as the theoretical value when the slope of the path is 15°. The value of this inertial constant transforms when the slope angle of the track changes due to the influence of friction force (*f*) and gravity (*mg*) of the rigid ball in the *x-axis* and *y-axis* direction as shown in figure (1). In this case when the tilt of the track is reduced, the friction force gets larger while the $mg \sin \theta$ becomes smaller, resulting in small inertial constant. When the tilt of the track is modified to become greater, the frictions force decreases while the $mg \sin \theta$ gets larger, resulting in large inertial constant.

In this experiment, the $mg \sin \theta$ and friction (*f*) are seen as force moments. Both of these forces cause the rigid ball to roll along the inclined plane. The touch of the slope of the path leads to change of value in both forces. In figure (1) it is shown that the term $mg \sin \theta$ is a directional force of the rotational motion of the rigid ball and rigid cylinder, whereas friction is a force in the opposite direction of the rotation direction of the rigid ball and rigid cylinder. Based on the results of the investigation it is found that (1) If angular tilt of the track is small, then the resultant force moment will also be small due to the greater friction force, whereas the $mg \sin \theta$ is smaller, (2) If angular tilt of the track is large, then the resultant force moment will also be large because the $mg \sin \theta$ is larger, whereas the friction force is small.

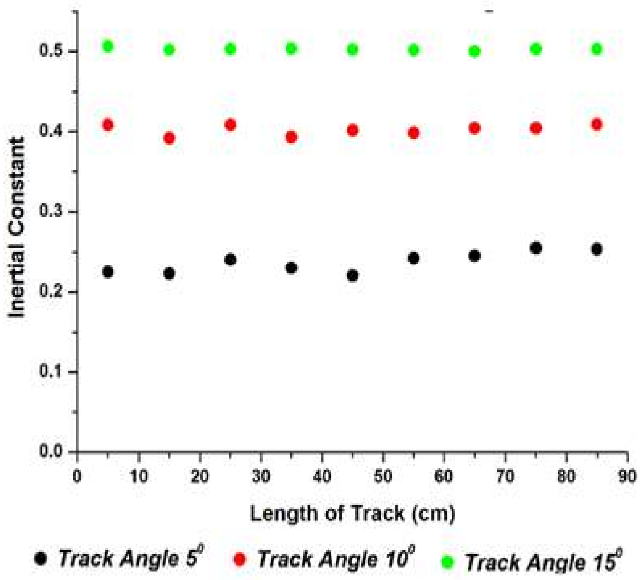

Fig 6:- Experiment results for determining the inertial constant of rigid cylinder when the length of the trajectory is altered at an angle of 50, 100 and 150

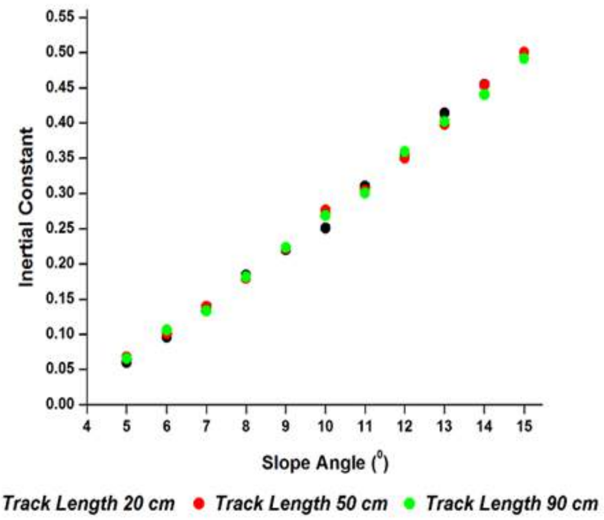

Fig 7:- Experiment results for determining the inertial constant of cylinder when the angle of the field is altered at track length of 20 cm, 50 cm and 90 cm

V. CONCLUSION

The experimental equipment developed in this study can be used to investigate the inertial constant of rigid ball and cylinder that roll on a sloping plane. The result of the investigation showed that the change of path length does not affect the value of inertial constant, while the change of the slope of the track influences the value of the inertial constant. The result of the investigation shows the inertial constant of the rigid ball and rigid cylinder is 0.405 and 0.503 at 15° tilt of the slope.

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