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Development of circular motion experiment tool using sensor smartphone for high school students

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Abstract. The growth of smartphone users in Indonesia can be a good potential for various fields, one of which is education. This research aims to produce a circular motion experiment tool using sensor smartphone in the horizontal and vertical position and find out its feasibility for use by high school students. The method of research used is research and development or R&D with the ADDIE development model (Analysis, Design, Development, Implementation, and Evaluation). The research result shows that the experimental tool has shown the influence of object distance directly proportional to centripetal acceleration when the angular velocity is constant. In addition, there is also a difference in tangential acceleration at the top of the circle and under the circle in a vertical position. In the questionnaire test, the average score of the feasibility of the experimental tool was 91.25% with a very good category. While the average score of module feasibility is 86.25% with a very good category. The average score obtained based on the response from students is 94.5% with a very good category.

1. Introduction

The topic of circular motion is one of the phenomena in everyday life [1]. However, the topic of circular motion has a concept that is difficult to understand, making students have many conceptions about this topic, especially in the explanation of everyday phenomena [2]. The method that can be used by teachers regarding circular motion is the experimental method. The success of this method is supported by the experimental tools used. The development of technology and information is expected to facilitate the creation of a circular motion experimental tool so that it can be used by teachers and students in understanding the concept of circular motion.

One of the results of information technology developments today includes smartphones. According to eMarketer's survey, smartphone penetration and digitization processes continue to occur very rapidly in Indonesia. The eMarketer survey also predicts that by 2019 there will be around 92 million smartphone users in Indonesia. Based on observations at school, many students use smartphones in their daily lives. There are still many uses for non-academic activities, for example social media [3]. The growth of smartphone users in Indonesia among young people can be a good potential for various fields, one of which is education. Some smartphones are equipped with various sensors that can retrieve data in realtime, such as an accelerometer sensor, gyroscope, magnetometer, light, pressure, etc. Because all sensors can be read by the required application, a number of quantitative studies can be done with smartphones [4]. In addition, smartphones have provided opportunities for new learning

perspectives, including relationships between teachers, students, and learning materials [5]. Therefore, smartphones can be used as experimental tools in education, including physics [6][7]. This study aims to develop a smartphone-based circular motion experiment tool that can be used horizontally or vertically. The expected results of this study are smartphone-based physics experiment tools that can be used to analyze phenomena in circular motion.

1.1. Uniform Circular Motion
An object that moves in a circle at a constant velocity is said to experience uniform circular motion. The velocity remains constant, but the direction of velocity keeps changing while the object moves in the circle [8]. If an object experiences uniform circular motion it maintains its fixed velocity, it means that there is an acceleration that is always perpendicular to the direction of its velocity, so that the trajectory is always circular. The required acceleration leads to the center of the circle and is called centripetal acceleration, which can be formulated: [9]

$$a_s = \omega^2 r \tag{1}$$

or

$$a_s = \frac{v^2}{r} \tag{2}$$

The relationship of the distance of objects with centripetal acceleration depends on velocity or angular velocity. If the velocity is constant then equation (2) is used, while if the angular acceleration is constant then equation (1) is used.

1.2. Vertical Circular Motion
When objects are at the top of a vertical circle, objects have a minimum velocity to be able to rotate one full circle as in figure 1 below.
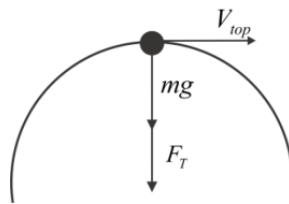
Figure 1. Velocity of an object at the top of a circle

The velocity of the object changes at one point to another. When at the top of a circle, objects have a minimum speed that can be taken from the application of Newton's Second Law:

$$F_T + mg = m\frac{v_{top}^2}{R} \tag{3}$$

Because it is at the top of a circle, it can be assumed that $F_T = 0$. So that the velocity at the top of the circle can be calculated:

$$v_{top} = \sqrt{gR} \tag{4}$$

When under a circle, objects need a minimum velocity too to be able to spin one round. This velocity can be taken from the application of work and energy equations:

$$mgh_1 + \frac{1}{2}mv_{top}^2 = mgh_2 + \frac{1}{2}mv_{bot}^2 \tag{5}$$

Where h_1 is the height at the top of the circle which is worth $2R$, while h_2 is the height below the circle which is worth 0. Then, the velocity of the object under the circle can be calculated:

$$v_{bot} = \sqrt{5gR} \tag{6}$$

The value of tangential acceleration in circular motion is equal to linear acceleration which can be expressed:

$$a_T = \frac{v}{t} \tag{7}$$

If the minimum velocity of this object is associated with tangential acceleration, it is found that when the peak of a circle objects will experience tangential acceleration that is smaller than below the circle. Tangential acceleration of an object increases when an object moves down to the lower point of the circle and decreases the tangential acceleration as the object moves up to the peak.

1.3. Sensor Smartphone

Smartphones have a high degree of flexibility that is motivated by the increasingly varied availability of internal sensors, such as GPS, accelerometer, gyroscope, temperature, light, even unique sensors such as heart rate and step speed for professional medical applications [10]. One of the smartphone sensors that can be used in the world of education especially in physics education is the accelerometer sensor. The Accelerometer sensor measures acceleration due to the movement of objects attached to it and the output response when detected is sinusoidal. The Accelerometer sensor used has 3 degrees of freedom, measuring acceleration along the x, y and z axes. The x-axis is horizontal to the right, the y-axis is vertically pointing up and the z-axis is pointing out the front surface of the screen [11][12]. While the negative z value is in the coordinates behind the screen as in figure 2.
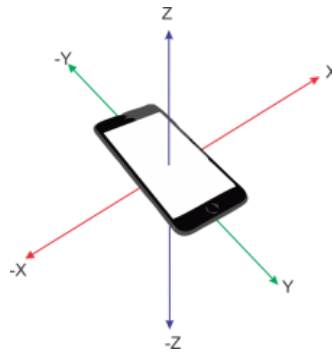
Figure 2. Accelerometer sensor configuration on a smartphone

Besides the accelerometer sensor, there is also a Gyroscope sensor. This sensor is a device in the form of a gyro sensor to determine motion orientation. This sensor relies on wheels or discs that rotate quickly on the axis [13]. Just like an accelerometer sensor, the gyroscope sensor produces three-dimensional values as shown in figure 3. The value in the gyroscope sensor is an angular velocity that shows how fast the device rotates around the axis [14].

2. Methods

This research uses research and development methods or R&D. This method is a process or steps to develop a new product or perfect existing products that can be accounted for [15]. For the development model, this study uses the ADDIE development model (Analysis, Design, Development, Implementation, and Evaluation) which consists of 5 stages, namely the stages of analysis, design, development, implementation, and evaluation [16].

Product development in the form of practicum guides and experimental tools are carried out in two conditions, namely horizontal and vertical. The type of data obtained in this study is quantitative. The processing of qualitative data is taken based on suggestions and comments from the validator and student responses. The data is used as a reference in the revision of practicum tools and modules. While in the quantitative data processing process, validation sheets that have been assessed by the validator are analyzed to determine the quality and validity of the product. The scores for each questionnaire are obtained using the following formula:

$$P(\%) = \frac{S}{N} \times 100\% \qquad (8)$$

with:

P = Feasibility rate (%)

S = Amount of total score obtained

N = Total maximum total score

From the percentage obtained, it is changed into qualitative sentences. Qualitative criteria are shown in table 1.

Table 1. Value intervals for the level of media feasibility

Interval (P)	Criteria for Feasibility Level
80% – 100%	Very Worthy / Very Good / Strongly Agree
66% – 79%	Decent / Good / Agree
56% – 65%	Less Worthy / Less Good / Less Agree
0 – 55%	Not Worthy / Not Good / Disagree

This study is considered feasible if the value interval is obtained at 80% - 100% with the category "very feasible" and 66% - 79% in the "feasible" category.

3. Result and Discussion

3.1. Analysis Phase
Based on the analysis above, the product to be developed in this study is a smartphone circular motion experiment tool that can be used horizontally and vertically. The material discussed in the experimental tool is the effect of the distance of objects on centripetal acceleration and the effect of the position of objects on tangential acceleration in a vertical circular motion.

3.2. Design Phase
Based on the analysis that was made previously, researchers designed an experimental tool and guidebook as a practicum device. The experimental tool is equipped with a DC motor as an automatic player that can be set speed. In addition, the experimental tool was also designed to be used horizontally and vertically. The design of the experimental tool used in this study can be seen in figure 4.

3.3. Development Phase
The result of this development stage is a smartphone-based circular motion experiment tool as shown in Figure 3.
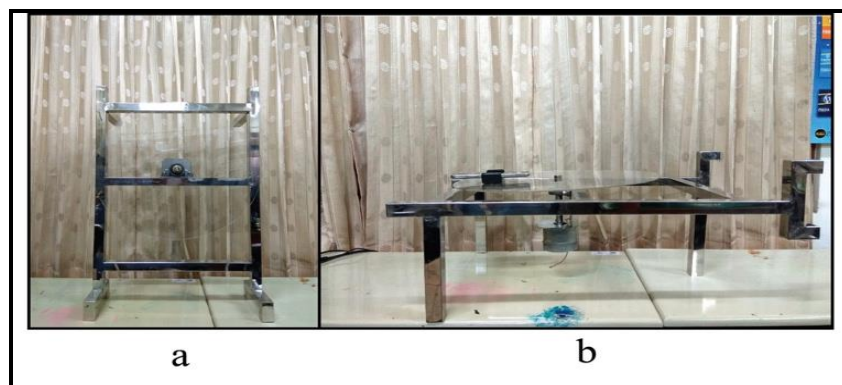
Figure 3. Smartphone-based circular motion experiment tool (a) an experimental tool in a vertical position (b) an experimental tool in a horizontal position

Experiments were carried out on smartphone-based circular motion experiment tools for two positions namely horizontal and vertical. In the horizontal position, the effect of the distance of the object on centripetal acceleration is obtained. Whereas in the vertical position the effect of the position of the object is obtained on tangential acceleration.

The angular velocity recorded on the smartphone sensor can answer constant with an average value of 12.714 rad/s. The centripetal acceleration value in one radius position is taken based on the average value when constant acceleration. Data obtained in the horizontal position obtained the relationship of the distance between objects to centripetal acceleration as shown in Figure 4.
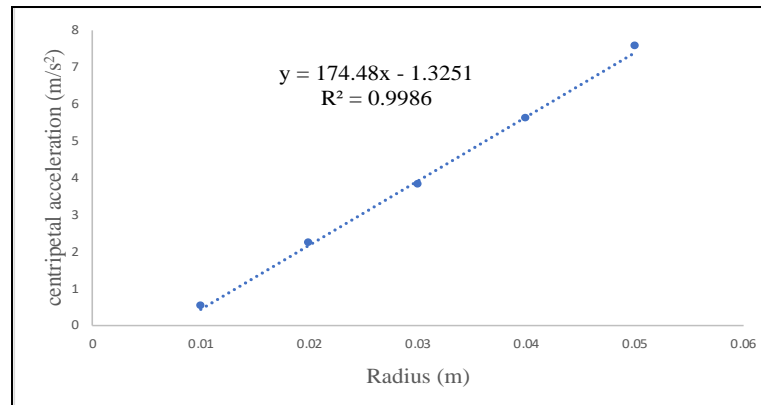
Figure 4. Graph of distance relations with centripetal acceleration

The graph above explains the relationship between and namely the distance of objects directly proportional to centripetal acceleration. The farther the distance of the object to the center, the greater the value of centripetal acceleration. This is in accordance with equation (2) when the angular velocity is constant.

In a vertical position, data is obtained regarding the relationship of tangential acceleration to time. The smartphone rotates 1 round with a graph that can be seen in figure 5 below.
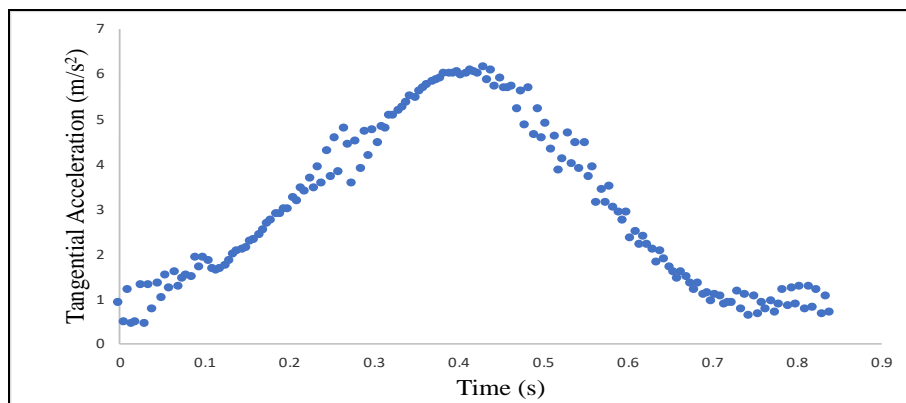
Figure 5. Graph the relationship between time and tangential acceleration in vertical circular motion

Based on the graph above, the phenomenon of vertical circular motion is obtained, namely the difference in tangential acceleration at the apex and bottom of the circle. When peaked in a circle, objects experience tangential acceleration that is smaller than below the circle. The tangential acceleration of an object increases as the object moves down to the lower point of the circle and decreases acceleration as the object moves up to the top of the circle. This is in accordance with equations (4) and (6) where the velocity of the object under the circle is greater than the peak of the circle.

3.4. Implementation Phase

Based on the questionnaire data analysis conducted, it was found that the circular motion experimental device was feasible to use. The average score for the validation of the experimental tool is 91.25% with a very good category. The average score for the manual validation is 86.25% with a very good category. The average score obtained based on the response from students is 94.5% with a very good category. It can be stated that the experimental tools and guidebooks that have been made are suitable to be used as smartphone-based circular motion practical devices.

3.5. Evaluation Phase

At this stage, product evaluation is developed and improvements are made. Evaluation is based on expert tools and modules on the questionnaire that has been given. The experimental tool needs to be developed again to verify the value of theoretical and experimental calculations.

4. Conclusion

A smartphone-based circular motion experiment tool has been developed, which is used to determine the effect of object distance on centripetal acceleration and the effect of the object's position on tangential acceleration in a vertical circular motion. The results showed that the distance of the object is directly proportional to the centripetal acceleration. In addition, the difference between tangential acceleration at the top of the circle and the bottom of the circle is also obtained. When peaked in a circle, objects experience tangential acceleration that is smaller than below the circle. Based on the questionnaire, the average score of the feasibility of the experimental tool was 91.25% with a very good category. While the average score of module feasibility is 86.25% with a very good category. The average score obtained based on the response from students is 94.5% with a very good category.

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