ISSN 2964-4291
https://proceeding.unnes.ac.id/index.php/iset

Which Arrived First? A Simple Experiment Using Smartphone to Analyze Parabolic and Free Fall Motion Simultaneously

S. Siswanto, H. Hartono, B. Subali, P. Marwoto, R. S. Iswari

Science Education Department, Universitas Negeri Semarang, Indonesia
*Corresponding Author: siswanto@untidar.ac.id

Abstract. This study aims to describe a simple experiment by using an affordable-price smartphone to analyze two objects that do parabolic motion and free fall at the same height, at the same time. Students often experience misconceptions in understanding the concepts of free fall and parabolic motion. Not only the difficulty of the material, but this is also caused by the problem of conducting real experiments analyzing both movements. It is because both movements usually occur in a relatively short time. To be able to capture movement in detail, a high-speed camera in capturing objects is needed even though it is relatively expensive, so it cannot be reached by most teachers and students. The equipments used in this experiment are two coins, a ruler, a cardboard, and a smartphone. Videos recorded through a smartphone are analyzed by using the VidAnalysis application. The results showed that a simple experiment was able to describe two objects that move freely and parabolic at the same height, at the same time. Based on data analysis, both objects fell on the ground simultaneously. Besides, this experiment was also able to measure the acceleration of Earth's gravity.

Key words: simple experiments, smartphone, free-fall motion, parabolic motion, measuring gravitation accelertion.

How to Cite: Siswanto, S., Hartono, H., Subali, B., Marwoto, P., Iswari, R. S. (2021). Which Arrived First? A Simple Experiment Using Smartphone to Analyze Parabolic and Free Fall Motion Simultaneously. *ISET: International Conference on Science, Education and Technology, 7*(1), 533-538.

INTRODUCTION

For decades, physicists have agreed that free fall is a motion with a constant acceleration equal to the acceleration of the Earth's gravity. In this motion, the air friction, which is a barrier to motion can be ignored because of its small magnitude (Hey ,et al., 2003; Ponce Campuzano, et al., 2018). Several experiments have been carried out to prove that the free-fall motion is only influenced by the acceleration of Earth's gravity, one of which is to drop books and papers with several arrangement models (Vera & Rivera, 2011).

In addition to free-fall motion, parabolic motion is another example of motion with the same acceleration as Earth's gravitational acceleration (Salvia, 2014). Parabolic motion is a two-dimensional motion, where at the x coordinate (horizontal direction), the speed is constant. In contrast, at the y coordinate (vertical direction), the acceleration is consistent or can be said to move freely.

There are many phenomena of daily life related to free fall and parabolic motion, where the acceleration is equal to the acceleration of Earth's gravity, for example, falling of coconuts, throwing of basketball players, and moving of shuttlecocks in badminton games (Vial, et al.,2019; Azhikannickal, 2019). Therefore, in the learning process, it is possible to associate with phenomena often seen and experienced by students.

The concepts in free fall and parabolic motion are very difficult to understand by students, and even many students feel misconceptions (Borghi, et al., 2005); Zaid & Zainuddin, 2017). If this happens, it will be challenging to analyze the concept, even by giving examples of motion in everyday life (Wee, et al., 2015).. It was also experienced by students in the researcher's class. The researcher made observations in science classes to ensure the misconceptions of the students. The question asked: "if two coins at the same height move with a mechanism: the first coin is dropped straight down without the initial speed and the second coin is fired horizontally, which one is arrive first?". All students in the class answered that coins dropped straight down will arrive on the ground first. Students assumed that the object that moves with parabolic motion would be longer than the free fall. Whereas, students have previously learned about the concepts of free fall and parabolic motion.

The misconception is very easy to happen, considering that it is challenging to conduct simple experiments to observe the motion Vera & Rivera, 2011). In free fall, objects move very fast in short time intervals so its very difficult to analyse, moreover, if it is added to observe the motion in two conditions at once, free fall and parabolic motion.

However, several experiments have been carried out with the current technological advances to observe both free fall and parabolic motion. The experiment is carried out using a video of the motion and then analyzed in the form of slow-motion Vera & Romanque, 2009; Parreira & Carvalho, 2018). However, the device used for recording is a camera that can capture motion in each frame at high speed. Currently, there are already many cameras available with these specifications, but at a relatively high price. In Indonesia, teachers and students are rarely able to have cameras with these specifications.

Therefore, this study aimed to describe a simple smartphone-assisted experiment to analyze two objects that do free fall and parabolic motion at the same initial height at the same time. Motion analysis is focused on describing the coordinates of the two objects at all times so that it will appear on which object will arrive on the ground with precision and supported with its graph. Besides, measurements of the acceleration of gravity by the two objects were also measured. Experiments carried out are very simple so that teachers and students can do it.

METHODS

This research used simple experimental activities. Equipment needed were a ruler, cardboard, two coins, and a smartphone. Illustration of the equipment circuit can be seen in Figure 1. In this experiment, the activity is carried out in steps:

a) Arranging the equipment, as illustrated in Figure 1.

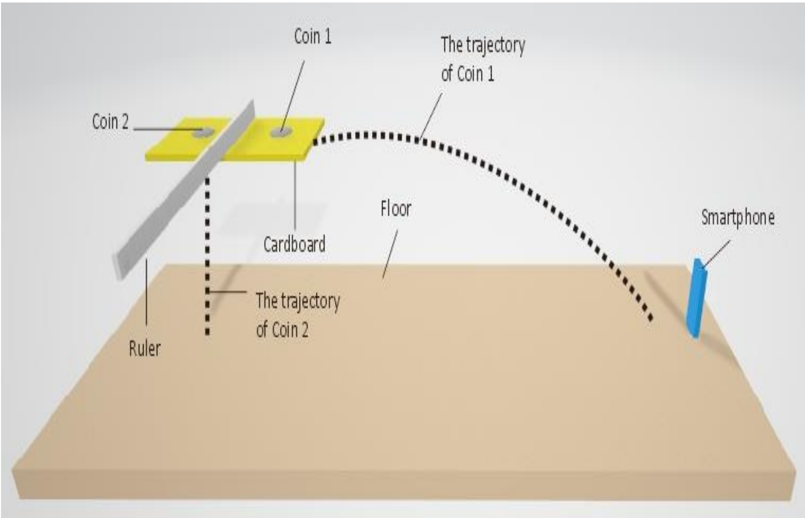

Figure 1. Equipment Design Used

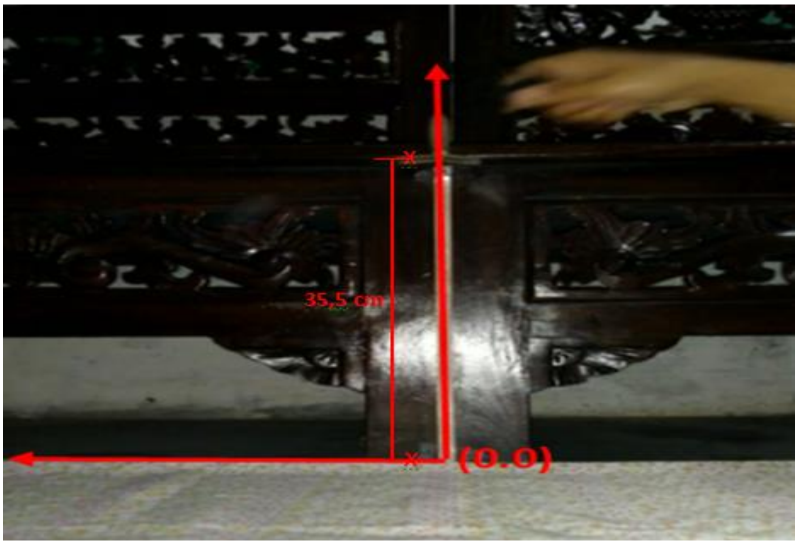

Figure 2. Calibration Process in VidAnalysis

b) Putting the set of tools at a certain height. Placing equipment on a table. It can be placed on a stand too.
c) Setting up the smartphone in recording mode on. Recording by using smartphones when both coins move.
d) Hitting the ruler hard and fast, as shown in Figure 1. This is done with the aim that the two coins can start moving exactly at the same time. Besides, this is also done, so that coin 1 starts moving in the horizontal direction (elevation angle 0^o to the horizontal axis), and coin 2 moves in a straight (vertical) downward with a zero initial velocity.
e) Analyzing recorded videos by using the "VidAnalysis" application (can be downloaded at Playstore). Doing the calibration before the analysis is performed. Calibration is done by entering the original height of the two coins into the application (see Figure 2). Furthermore, the analysis is carried out at specific points in the movements of the two coins so that the resulting time data and the coordinates of the object's points (see Table 1). This analysis is carried out to see the similarity between the two coins in each span time.
f) Calculating the Earth's gravitational acceleration.

RESULTS AND DISCUSSION

Data from video analysis by using the application can be seen in Table 1. Based on Table 1, it is obtained 6 points in free fall and parabolic motion. Free-fall motion only exists on one coordinate axis, that is the y-axis (Ponce Campuzano, et al., 2018), so that it is only obtained data of time versus y (height). Whereas the parabolic motion is two-dimensional (Salvia, 2014); therefore, in this study, the data obtained that time versus position on the x and y. Based on the data in Table 1, graphs are then made to predict the equations of the two movements so that analysis can be done easily. In the parabolic motion, data is only taken at the y coordinate. The graph of height (y coordinate) versus time of the two movements can be seen in Figure 3.

Table 1. Data of Coordinate Point of Two Moving Free Fall Objects

Free Fall Motion		Parabolic Motion		
time (s)	height (cm) / y coordinate	time (s)	horizontal distance (cm) / x coordinate	height (cm) / y coordinate
0	35.5	0	0	35.5
0.034	24.59	0.033	6.11	24.49
0.067	13.43	0.066	9.19	14.01
0.1	5.86	0.1	10.37	5.88
0.134	1.1	0.133	12.95	1.09
0.167	0.003	0.166	15.2	0.0037

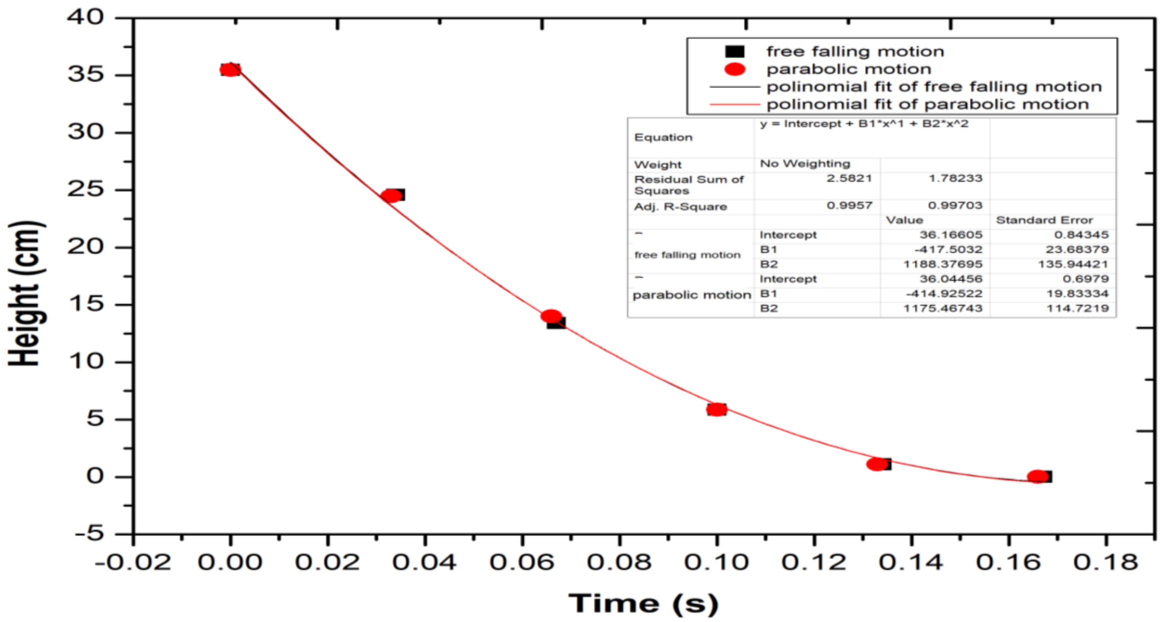

Figure 3. Graph of Time versus Height on the Both Objects Motion

Based on Figure 3, it is observed that the two motions almost coincide at each point, as shown in Table 3. Equations from the two movements also showed the same results. This is also accurate evidence of the application used. In theory, both objects must always be at the same height at all times.

In parabolic motion, the equation of motion applies as in equation (1). In this experiment, the coin's movement is initially in the direction of the horizontal axis (see Figure 4), then at the moment t = 0, voy = 0, vo = vx, and equation (1) changed to as equation (2). Equation (2) is an equation of free-fall motion to determine the height of an object at a certain time (see Figure 5). Therefore, at any given time interval, the height reached by the two coins, both free-falling and parabolic motion, showed the same height. It has happened because the direction of the first coin speed is in the direction of the horizontal axis. Therefore, although the parabolic motion looks longer than the free-fall, both coins landed on the ground at the same time as coin 1.

$$y = v_{0y}t + \frac{1}{2}gt^2 \,; \quad v_{0y} = 0 \tag{1}$$

$$y = \frac{1}{2}gt^2 \tag{2}$$

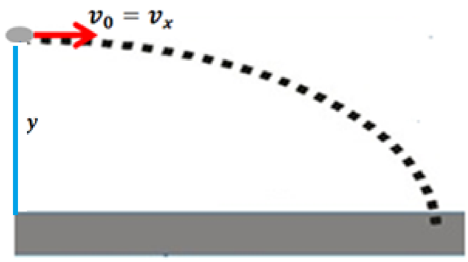

Figure 4. Parabolic Motion

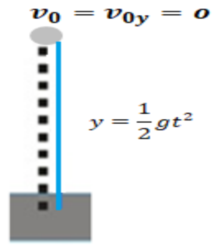

Figure 5. Free Falling Motion

Tabel 2. Prediction of Height of Both Coins Based on Equations Obtained in Graph Fittings

T (s)	y free falling (cm)	y parabolic (cm)	Dissimilarity (DS)	$\overline{DS}$	% Similarity
0	35.5	35.5	0	4.6 %	95.4
0.034	24.59	25.23212121	0.025448562		
0.067	13.43	14.22227273	0.055706478		
0.1	5.86	5.88	0.003401361		
0.134	1.1	1.098195489	0.00164316		
0.167	0.003	0.003722289	0.194044344		

Based on the experimental results in Table 1, the measured time cannot be the same between coin 1 and coin 2. This is caused by free-fall motion, which generally occurs at very short intervals (Vera & Rivera, 2011). Based on Figure 3, mathematical equations (see equation 1) for the motion of the two coins are obtained in the graphic fittings, so that the height of the two coins can be predicted for the same times between coin 1 and coin 2 (see Table 2). Based on the graphical similarity analysis, the two movements have similarities 95.4%. Therefore, the carried-out experiments were able to show that both coins would arrive on the ground at the same time, with a prediction error of around 4.6%.

Tabel 3. The Result of Measurement of Earth's Gravity Acceleration in Free Fall Motion Experiments

h (cm)	t-app (s)	t-th (s)	Δt (s)	CV (s)	t-CV (s)	g (m/s^2)	$\bar{g}$ (m/s^2)	SD
35.5	0	0	0	0.128	0		9.78	1.67
24.59	0.034	0.149	0.115		0.1618	7.63		
13.43	0.067	0.212	0.145		0.1948	11.632		
5.86	0.1	0.246	0.146		0.2278	11.42354		
1.1	0.134	0.265	0.131		0.2618	10.03805		
0.003	0.167	0.269	0.102		0.2948	8.168958		

Tabel 4. Measurement Results of Earth's Gravity Acceleration in Parabolic Motion Experiments

h (cm)	t-app (s)	t-th (s)	Δt (s)	CV (s)	t-CV (s)	g (m/s^2)	$\bar{g}$ (m/s^2)	SD
35.5	0	0	0	0.128	0		9.92	1.17
24.49	0.033	0.149	0.116		0.161	8.495043		
14.01	0.066	0.209	0.143		0.194	11.41992		
5.88	0.1	0.246	0.146		0.228	11.39581		
1.09	0.133	0.2649	0.1319		0.261	10.10261		
0.0037	0.166	0.2691	0.1031		0.294	8.213314		

Descriptions of tables 3 and 4:

t-app : t application

t-th : t-theory

Δt : (t-th – t-app)

CV : Correction Value of t-app ($\overline{\Delta t}$)

t-CV : t-app correction value (t-app + $\overline{\Delta t}$)

SD : standard deviation

This simple experiment can also be used to measure the acceleration of the Earth's gravity. However, because the object's motion is very fast, to minimize the error value, it is necessary to adjust the t value in the application frame. Adjustment of t value is made by correcting t measurement results through the application. Corrections are made by comparing the measured t value by the application with the theory t every second (see Tables 2 and 3). Although there is a difference between the value of t and measured t in the application with t theory, the results of the graph fitting in Figure 3 and the analysis of the two objects' motion have a high accuracy value. This can be seen based on the correction value for both objects. Both objects have the same correction value. It means the graph in Figure 3, can be used to analyze data together and accurately. Based on the data, earth's gravitational acceleration for free-fall motion is (9.78 ± 1.67) m / s2 and parabolic motion (9.92 ± 1.17) m / s2.

Based on the explanation above, the use of a smartphone can facilitate experimental activities in learning physics. Vidanalysis application used, effectively measures the quantities in experimental activities related to object motion. However, in analyzing using a smartphone one must be careful and thorough, especially when performing a calibration.

CONCLUSION

Using smartphone can facilitate experimental activities in learning physics. On this experiment, vidanalysis application used, effectively measures the quantities in experimental activities related to object motion. A simple experiment using a smartphone can be done to analyze two objects that move free fall and a parabolic motion simultaneously at the same height, even though the motion occurs in a relatively fast interval. Experiments can be done even though by using a smartphone with the usual camera specifications so that it can be done by all teachers and students. The results of experiments can analyze in detail the movement of the two objects and get the results that both objects moved at the same time at each coordinate point. Besides, this simple experiment can also be carried out to measure the acceleration of Earth's gravity.

ACKNOWLEDGEMENT

Thank you to the ministry of education, culture, research, and technology for providing research funding with the research grand number 287/E4.1/AK.04.PT/2021.

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