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Analysis of Rolling Motion to Obtain Moments of Inertia in a Compound Objects With Video-based Laboratory (VBL)

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ABSTRACT

This study aims to get the moment of inertia in compound objects by comparing the calculation results with the help of Video-based Laboratory, namely Tracker software. The variable used is the difference in the number of balls to fill the cavity on the cylinder which is a hollow cylinder containing 1 solid ball, a hollow cylinder containing 2 solid balls then a hollow cylinder containing 3 solid balls. The balls have the same radius. Based on the results of the comparison of the moment of inertia between the value obtained with the help of the tracker and the value of the integral calculation result obtained results on a hollow cylinder containing one ball, there is a difference in value comparison of about ±0,070 x10^{-3} kg m^2, on hollow cylinders containing two balls about ± 0,041 x10^{-3} kg m^2, and on hollow cylinders containing three balls, there is a difference of ± 0,002 x10^{-3} kg m^2. The biggest difference between the three data is when the hollow cylinder is filled with only one ball, but when it is filled with three balls, the value of the moment of inertia is almost the same or the difference is getting smaller. So in this study, it can be concluded that the more balls in a hollow cylinder, the closer the value of the moment of inertia. In addition, the greater the mass of objects, the greater the moment of inertia produced.

Keywords: Compound, Moment of inertia, Rolling motion, Tracker

ABSTRAK

Penelitian ini bertujuan untuk mendapatkan momen inersia pada benda bersusun (*compound*) dengan membandingkan hasil perhitungan dengan bantuan *Video-based Laboratory* yaitu *software Tracker*. Variabel yang digunakan adalah perbedaan jumlah bola untuk mengisi rongga pada silinder yaitu silinder berongga yang berisi 1 bola pejal, silinder berongga yang berisi 2 bola pejal kemudian silinder berongga berisi 3 bola pejal. Bola-bola tersebut mempunyai jari-jari yang sama. Berdasarkan hasil perbandingan momen inersia antara nilai yang diperoleh dengan bantuan *tracker* dan nilai dari hasil perhitungan integral didapatkan hasil pada silinder berongga berisi satu bola, terdapat selisih perbandingan nilai sekitar ±0,070 x10^{-3} kg m^2, pada silinder berongga berisi dua bola sekitar ± 0,041 x10^{-3} kg m^2, dan pada silinder berongga berisi tiga bola terdapat selisih ± 0,002 x10^{-3} kg m^2. Selisih terbesar dari ketiga data tersebut adalah saat silinder berongga hanya diisi oleh satu bola, tetapi saat diisi tiga bola, nilai dari momen inersia hampir mendekati sama atau selisihnya semakin mengecil. Sehingga dalam penelitian ini dapat disimpulkan bahwa semakin banyak bola dalam silinder berongga, maka nilai momen inersia semakin mendekati sama. Selain itu, semakin besar massa benda, maka semakin besar juga momen inersia yang dihasilkan.

Kata kunci: *Compound*, Menggelinding, Momen inersia, *Tracker*

INTRODUCTION

The use of multimedia to analyze the symptoms of physics has been widely done in the teaching and learning process. Using multimedia can provide a new and fun experience. The use of multimedia is also considered effective for obtaining data on physical symptoms that are difficult to observe and experiment with. The delivery of learning materials using multimedia will give a good impact and the attractiveness of material exposure with multimedia can motivate and provide satisfaction to students (Wahyuni, 2012). In addition, using interactive multimedia, can improve the achievements in learning physics (Saprudin & Hamid, 2018a; Saprudin & Hamid, 2018b; Rahmawati & Dewi, 2019). Video analysis of physical events, is useful to prove the concept contained in the occurrence of physics in real life to existing theories, so that physics can be better understood contextually (Fadholi et al., 2018).

Moment of inertia is one of the subjects in physics courses. The moment of inertia is the tendency of an object to maintain its angular velocity, identical to the mass in translation motion (Rustan & Handayani, 2020). Circular motion learning in the suburb of the moment of inertia is mostly the study of theory in the form of theory, the lack of psychomotor domain from theory to practice so that students do not understand the concept of the material moment of inertia (Anisah et al., 2021). The equilibrium of rigid objects and moments of inertia is also one of the essential materials in the study of physics science in high school because this topic is still difficult for students to learn and difficult to teach my high school physics teachers (Zulirfan et al., 2011). In a rotational moving object, a moment of inertia may indicate the degree of inertia of the object (Astro et al., 2018; Wahid & Rahmadhani, 2019). The value of the moment of inertia, is influenced by the radius of the cylinder (Nurfadilah et al., 2020). In addition, some of the things that affect the moment of inertia are the shape of the object, the center of rotation, and the mass of the object.

There have been many studies to calculate or analyze moments of inertia. The research was to examine the moment of inertia using software tracker and analyzed with Logger Pro with samples of solid cylinders and hollow cylinders (Yusuf, 2015). In addition, determining the moment of inertia by comparing the results of data processing tracker and integral techniques of solid cylinders by varying the radius (Chusni et al., 2018). Determining the coefficient of the moment of inertia of a particular shape such as a solid cylindrical sphere, a rectangular plate, or another shape is the most common example of an object being studied. But what if the objects are combined for analysis e.g. hollow cylinders are combined with solid cylinders inside, hollow cylinders combined with balls that we can later vary the number of balls contained in the hollow cylinder. In theory, the moment of inertia can be calculated by formula, but it would be more practical if we analyze it using the help of Video-based Laboratory (VBL).

VBL is an analysis of the physical symptoms of video, which is real documentation. This analysis consists of its physic variables and is represented in the form of equations, graph data, and quantitative data simultaneously and interactively. In analyzing the video using the computer as a tool (Setiono et al., 2012). VBL is an object analysis-based learning medium found in a video (Agustina et al., 2018).

VBL needs to use analysis software to assist in analyzing the physical phenomenon of the video (Aisya & Ishafit, 2019). In its use, VBL can combine theoretical and experimental aspects in the study of physics (Ariefka & Pramudya, 2019). Some software that can be used for VBL are video point physics fundamental, Logger Pro, and tracker. So far software Logger Pro has been widely used as VBL media. Logger Pro is one of the right programs to build analytics and problem-solving skills, able to display the symptoms of physics and its representations interactively in the form of graphs, equations, and quantitative data simultaneously (Firdaus et al., 2017;

Erawati & Ishafit, 2021; Subhan et al., 2020). However, in this study, researchers used software tracker to analyze rolling motion. Tracker is a software that can to analyze an object recorded on a video and get more accurate data, which can then represent quantitative data and graphs simultaneously, and provide some convenience and advantages in learning physics (Habibbulloh & Madlazim, 2014; Marliani et al., 2015; Utari & Prima, 2019; Asrizal et al., 2018).

The purpose of this study was to examine the large moments of inertia in compound objects on the slope. The uniqueness of this study compared to existing research is that if other studies only use 1 object without being combined then analyzed but in this study using more than one object to be combined then analyzed the moment of inertia. Like a hollow cylinder filled with 1 steep ball, 2 steep balls and then filled with 3 steep balls. In addition, the variables used are different. The variable used is the difference in the number of balls to fill the cavity on the cylinder. The balls have the same radius. In calculating and analyzing the moment of inertia, it will also be compared the results of calculations through tracker tools and calculations in an integral way.

METHODOLOGY

This research is an experimental study in the laboratory. The design of the research tool is shown on Figure 1. The tools and materials used in this study include:

a. Materials; The object in question is a hollow cylinder with a length of 10 cm, an outer radius of 3.9 cm, and a radius within 1.5 cm and has a mass of 384.59 grams. for the filling of the hollow cylinder is a solid ball that will be varied in number for stuffing on the hollow cylinder. Ball 1 has an outer diameter of 2.55 cm, a mass of 11.98 grams; Ball 2 has an outer diameter of 2.55 cm, a mass of 12.36 grams, ball 3 has an outer diameter of 2.55 cm, a mass of 11.96 grams. all objects used are made of the same material that is jati wood.
b. Wooden planks (slope); The wooden planks used as a trajectory come from *sengon laut* wood. then one end of the board is varied in height, so that the board forms a slope. The board used is selected which has a certain roughness.
c. Ruler, used for measuring.
d. Laptops, are used to analyze data.
e. Digital Camera; Digital cameras serve as recorders to produce videos. The camera used is a type of Handycam Sony DCR-HC52E model with a video resolution of 720x576 pixels, 25 frames per second, zooming 40x.
f. Software Tracker; The software used is tracker. In addition to being able to display recorded images, tracker also displays experiment data in the form of position as a function of time (t). Video analysis starts by entering video data into tracker software. The length between the two pixels in the video is then calibrated using the calibration stick feature (Prima et al., 2016).

Based on the design of the tool that has been designed, the data retrieval method steps are:

a. Prepare the objects to be studied, namely a hollow cylinder filled with 1 ball, a hollow cylinder filled with 2 balls, and a hollow cylinder filled with 3 balls.
b. Rolling objects one by one, such as a hollow cylinder filled with ball 1 first until the object falls to the floor. Then proceed with a hollow cylinder filled with ball 2 and finally a hollow cylinder filled with ball 3.
c. Various events in the research design were recorded using a digital camera (Handycam)

d. Footage of such events is transferred into a computer in the form of a video file. Each of the video files is analyzed using tracker, To get the data on the position of objects in each time interval. Then the data from the tracker is taken for further analysis.

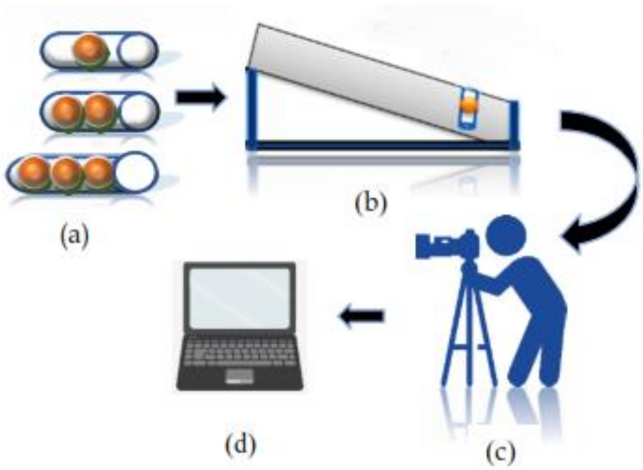

Figure 1. The design of the research tool

The data obtained from the analysis using software tracker is the average distance (*dr*), time on each movement (*dt*), and speed on each movement. The magnitude of the moment of inertia in the hollow cylinder can be determined by the equation:

$$I = \frac{1}{2}M\left({R_2}^2 + {R_1}^2\right) \quad (1)$$

where I is the moment of inertia (kgm^2), m is the mass of objects (kg) and R_1 is the inner radius (m) and R_2 is the outer radius (m). This result will be compared to the magnitude of the moment of inertia sought by using integral calculations, namely:

$$I = \iiint_V \|r\|^2 \rho(r) dV \quad (2)$$

where V is the volume occupied by the object (m^3), ρ is the function of the spatial density of the object (kg/m^3) and r is the vector perpendicular to the axis of rotation between the axis of rotation and the point in the object.

RESULTS AND DISCUSSION

The data that has been obtained from tracker, automatically displays a graph between t (time) with x (position of objects on the horizontal axis) and y (position of objects on the vertical axis). In this study, 5 experiments were conducted on each hollow cylinder containing 1 solid ball, 2 solid balls, and 3 solid balls. It is rolled with a variation in height of 0.1 m, 0.15 m, 0.2 m, 0.25 m, and 0.3 m. Once obtained data from the tracker, the results will be compared directly through the calculation of the moment of inertia of the Tracker data as well as the calculation using integrals.

Figure 2 is a view of the tracker after capturing the data of a hollow cylinder containing a solid ball.

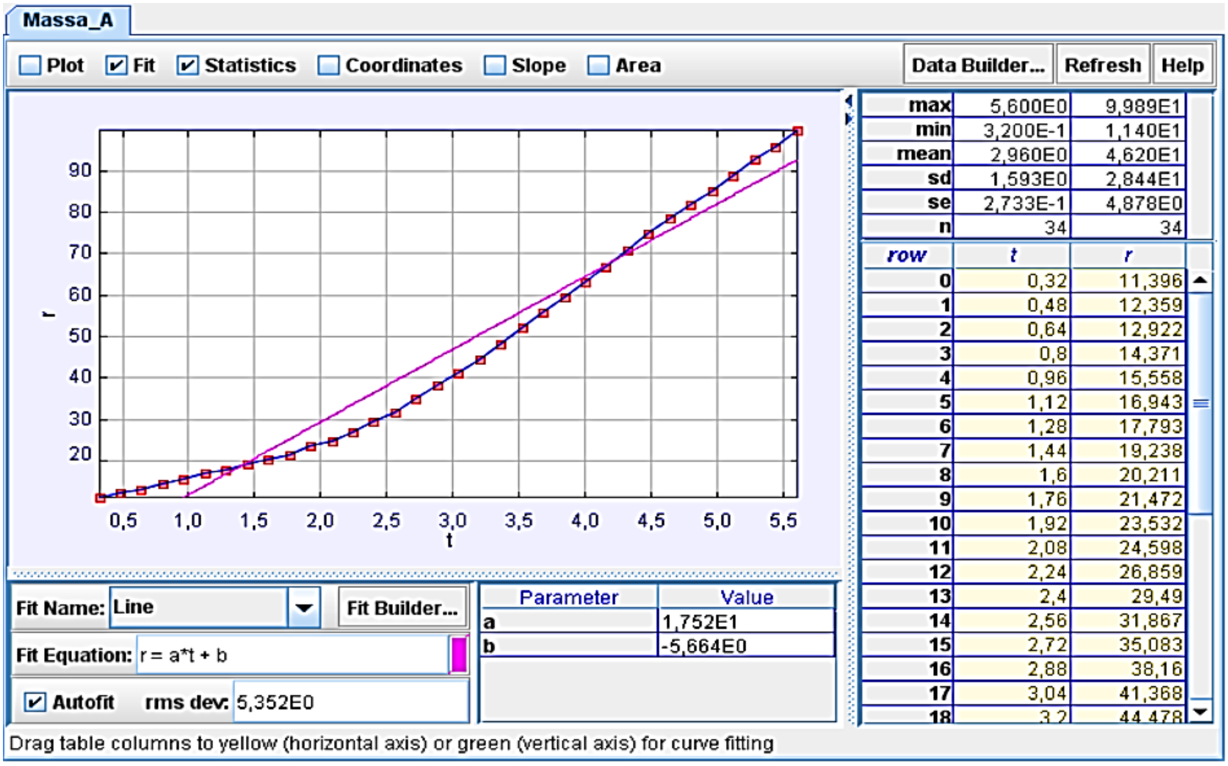

Figure 2. View on tracker at the time of data analysis

From the data retrieval, the results are obtained as shown in table 1.

Table 1. Data tracker results

No.	Materials	$R\ (m)$			$dr\ (m)$	$dt\ (s)$	v (m/s)
		Hollow cylinder		Ball			
		Outside	Inside				
1	Hollow cylinder fills 1 ball	0,039	0,015	0,013	1,4 x 10^{-2}	0,66	0,021
2	Hollow cylinder fills 2 balls	0,039	0,015	0,013	1,6 x 10^{-2}	0,66	0,024
3	Hollow cylinder fills 3 balls	0,039	0,015	0,013	1,9 x 10^{-2}	1,9	0,01

The data in Table 1 is the tracker result data. *dr* is the average distance produced by each click of movement on each path and each click of the path produces a different time i.e. *dt* (Nurfadilah et al., 2020). In the table above, the increase in the contents of the ball, results in the value of the *dr* getting bigger. A hollow cylinder containing one ball has a value of 1.4 x 10^{-2} m, a hollow cylinder containing two balls of 1.6 x 10^{-2} m, and a hollow cylinder containing three balls of 1.9 x 10^{-2} m.

Table 2. Inertia moment calculation data

No	Materials	$V\ (m)$	$\rho\ (kg/m^3)$	I assisted Tracker $(kg.m^2)$	I with integrals $(kg.m^2)$
1	Hollow cylinder fills 1 ball	4070 x 10^{-5}	9,743	6,39 x 10^{-3}	6,460 x 10^{-3}
2	Hollow cylinder fills 2 balls	4071 x 10^{-5}	10,036	6,42 x 10^{-3}	6,461 x 10^{-3}
3	Hollow cylinder fills 3 balls	4072 x 10^{-5}	10,328	6,46 x 10^{-3}	6,462 x 10^{-3}

Table 2 shows the results of the calculation of the moment of inertia. The result shown in the calculation of the tracker and the result of the indexing. If the inertia moment value comparison data is displayed in graphic form, it can look as shown in figure 2. In the picture, the value 1 is a hollow cylinder containing one ball, a value of 2 is a hollow cylinder containing two balls, and a value of 3 is a hollow cylinder of three balls. On a hollow cylinder containing one ball, there is a difference in the value comparison of about ±0.070 x 10^{-3} kg m^2, on a hollow cylinder containing two balls about ± 0.041 x 10^{-3} kg m^2, and on a hollow cylinder containing three balls, there is a difference of ±0.002 x 10^{-3} kg m^2.

The biggest difference between the three data is when the hollow cylinder is filled with only one ball, but when it is filled with three balls, the value of the moment of inertia is almost the same or the difference is getting smaller. This is according to the theory that the difference in value between mass and moment of inertia is that the mass of an object depends only on the substance contained in the object, but the magnitude of the moment of inertia depends not only on the amount of substance but also influenced by how the substance is distributed on the object (Banjarnahor, 2012).

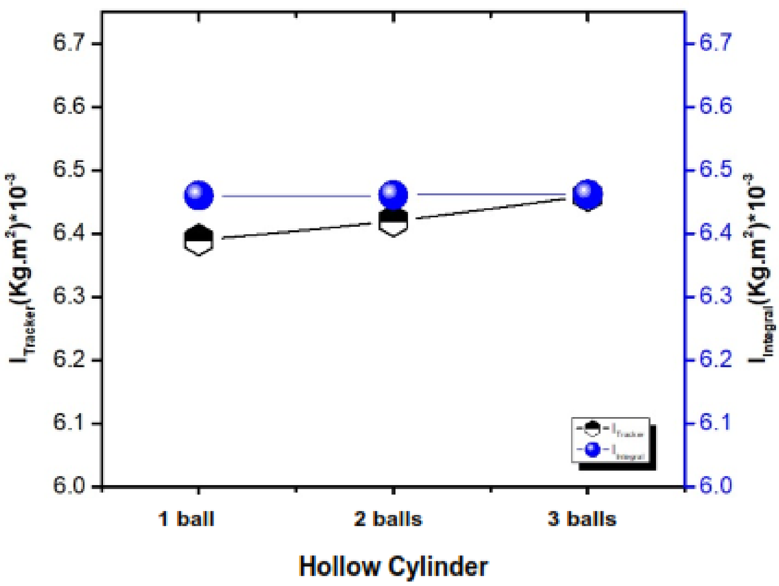

Figure 3. Tracker-assisted calculation comparison value data with integral calculations

The value of the moment of inertia, is influenced by the radius of the cylinder. The bigger the radius, the greater the value of the moment of inertia (Nurfadilah et al., 2020). However, in this study, the large hollow cylindrical spokes used were all the same, i.e. the outer radius was 0.039 m and the inner radius was 0.015 m. While the radius of the ball used to fill the hollow cylinder is 0.013 m so it has no significant effect.

In the study of calculating the moment of inertia of Atwood aircraft using pulleys, the value is generated that the greater the additional load given, the greater the value of the moment of inertia (Wahid & Rahmadhani, 2019). This corresponds to the value of the moment of inertia obtained from the experiment, both calculations with a tracker and integrally. Analysis using the tracker application, obtained data with lower errors (Utari & Prima, 2019). Hollow cylinders filled with balls have a summing mass of the mass of hollow cylinders and solid balls, so the more balls, the greater the mass. Results in the value of the moment of greater inertia as shown in Table 2.

CONCLUSION

Based on the results of the comparison of the moment of inertia between the value obtained with the help of the tracker and the value of the integral calculation result obtained a value that is close to the same, that is, the more balls in the hollow cylinder, the closer the value of the moment of inertia is the same. In addition, the greater the mass of objects, the greater the moment of inertia produced.

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