Momentum: Physics Education Journal
8 (1), 2024, 23-31
Available at: ejournal.unikama.ac.id/index.php/momentum
ISSN 2548-9127(print) | 2548-9135 (online)

Kinematics analysis on accelerated motion using tracker video analysis for educational purposes

Jelita Renika, Eka Cahya Prima*, Amprasto

Universitas Pendidikan Indonesia, Dr. Setiabudhi St, No. 229, Bandung, West Java, 40154, Indonesia
e-mail: ekacahyaprima@upi@upi.edu
* Corresponding Author

Received: 12 July 2023; Revised: 5 September 2023; Accepted: 7 September 2023

Abstract: This study aims to determine the effectiveness of video analysis tracker-based practicum on the material of the motion of objects on an inclined plane and the motion of objects in free fall. The use of video tracker analysis-based practicum is useful for determining some kinematics parameters of objects that cannot only be calculated by traditional practicum methods. By using the video tracker analysis method, all object kinematics parameters can be found directly in visual form. The results show that (1) There is no relationship between mass and kinematics parameters. (2) There is an influence due to air friction on the acceleration value of the object. (3) The suitability of the concept with the tracker application produced with the error value in the experiment of object motion on an inclined plane ($v_{error} = 8.33\%$; $a_{error} = 4.79\%$) (4) The suitability of the concept with the tracker application produced with the error value in the experiment of object motion in free fall ($v_{error} = 12\%$; $a_{error} = 6\%$) (5) The graphical representation of the tracker is in accordance with the theory studied. This research implies that the existence of learning using practicum, especially practicum-based video tracker analysis can improve understanding and process skills in understanding science concepts. This research is written so that the programme can be further applied to science education
Keywords: kinematic motion; tracker video analysis; parkticum

How to Cite: Renika, J., Prima, E. C., & Amprasto, A. (2023). Kinematics analysis on accelerated motion using tracker video analysis for educational purposes. *Momentum: Physics Education Journal*, *8*(1), 23-31. https://doi.org/10.21067/mpej.v8i1.8883

Introduction

Science lessons are a very significant part of the school curriculum and have a crucial role. This should not be ignored because in the process of learning science, the values of scientific attitudes are instilled, which are essentially connected to the objectives of national education listed in Law No. 20 of 2003 (Rejekiningsih et al., 2023). Science learning itself is divided into several branches, including physics learning. Physics teaching is complex theoretical concepts, challenges in recognising physics variables, and difficulties in applying related formulas (Schalk et al., 2019). In general, physics learning often faces various challenges. The learning process still often relies on conventional methods, such as the use of direct teaching approaches (Erickson et al., 2019). Causing many students to experience misconceptions about physics learning, especially in some metres that are quite difficult to understand.

Physics learning is not only about teaching theories and formulas that need to be memorised, but also focuses on efforts to explain natural phenomena and natural processes by finding and presenting factual data (Molina-Bolívar & Cabrerizo-Vílchez, 2014). For example, a phenomenon of a car crashing into a motorbike, is this case included in the criminal or accidental category, by looking at the speed of the car or motorbike when it wants to collide. Such phenomena often occur in everyday life that can only be observed with the five senses, but not much information can be obtained.

Someone who observes the event is difficult to determine whether the phenomenon is a planned event or accidental. Based on the phenomenon told earlier, the implementation of practicum is an important component in the physics learning process that plays a role in building a solid understanding and developing knowledge of physics concepts properly (Hodosyová et al., 2015).

Learning by using the practicum method can improve students' understanding of concepts in understanding physics concepts. Teaching students to understand real problems and prove them directly by using practicum (Flegr et al., 2023). Physics education that begins with a practical lab provides benefits to every teaching-learning process because it involves students in the observation and manipulation of objects and related materials, and encourages student involvement in the observation and manipulation of the concepts and materials they learn (Kokkonen et al., 2022). The implementation of practicum in learning can foster students' independence from the career prospects of junior scientists in discovering or exploring knowledge itself (Shibayama, 2019). The application of practicum in learning will reduce the time needed to understand concepts theoretically. In addition, this practicum trains and teaches students to find problems in groups (Abeysiriwardana et al., 2022).

Tracker is free software that was created to serve as a data input tool in video recordings of object movement, and has been widely used in the context of physics education to analyse and simulate physical phenomena in mechanics (Aguilar-Marín et al., 2018). Tracker is free software developed in the OpenSource Physics Java code library that can be used for video analysis and physics modelling (Wati et al., 2020). The Tracker application has steps in analysing the video it has recorded as follows: (1) Calibrating objects in the video with a blue line, (2) Determining the coordinate points of the x & y axes with a purple line, (3) Determining the track of object movement, with a red circle that will be positioned by the object, (4) The tracking process has two ways manual and auto track, (5) The track results produce graphs and tables (Dewi, 2023). Tracker functions to monitor object movement through video, creating a distance-time graph by calibrating the distance on the screen using a ruler (Oktavia et al., 2019).

The following are some studies that have been conducted by several previous experts related to the use of tracker applications on physics material problems on object kinematics: the use of tracker applications to analyse the friction coefficient of circular motion (Molina-Bolívar & Cabrerizo-Vílchez, 2014), the use of Tracker video applications to analyse parabolic motion experiments (Wee et al., 2012), the use of Tracker video to analyse pendulum mechanics material (Malgieri et al., 2014), the use of Tracker video in analysing optics practicum (Rodrigues & Simeão Carvalho, 2014), and the use of Tracker to analyse harmonic motion practicum videos (Poonyawatpornkul & Wattanakasiwich, 2013). So that research is carried out in the form of video analysis of experiments on the motion of objects in two conditions, namely the motion of objects on an inclined plane and free fall motion which will later be analysed using the help of the Tracker application comprehensively.

Method

Theory

The theoretical method that shows the equations of the kinematics parameters of object motion concerning position, velocity and acceleration is taken from the material described by Tipler, (1998). The following are the equations and explanations of the concept of kinematics of objects. This theoretical equation is analyzed with the help of the tracker application. Furthermore, the tracker application data obtained from the video recording plot results also produces a graph explaining the kinematics parameter equation. This equation is analyzed to evaluate the motion characteristics of previously tested objects.

Straight Motion with Regular Change

Straight motion with regular change is defined as the motion of an object on a straight-line trajectory with fixed acceleration. Fixed acceleration means that both the magnitude and direction are set.

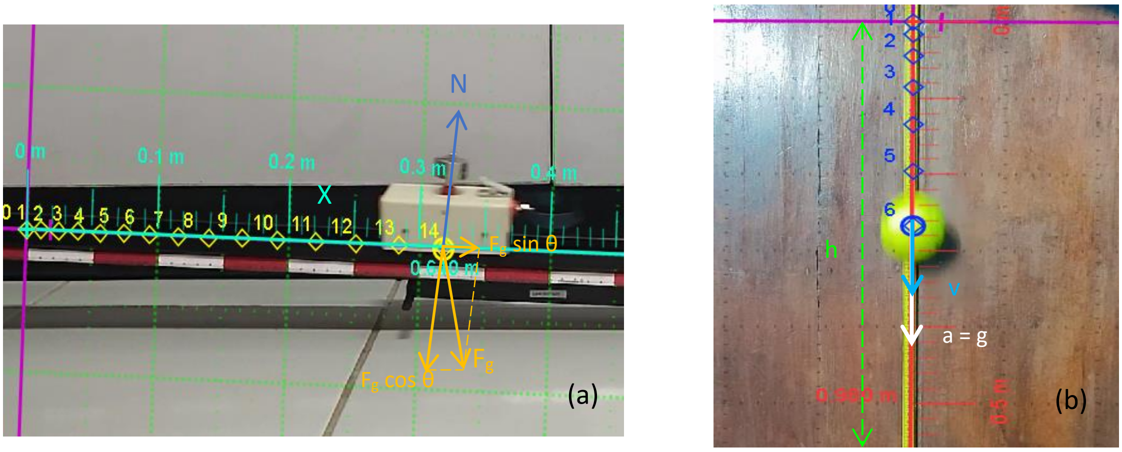


Figure 1. (a). Angled Plane Motion, (b). Free-Fall Motion

In Figure 1a, we see an object angled plane motion, while in Figure 1.b, the object is seen in free-fall motion. In both figures, there is a change in the distance and velocity values of the object, with a constant acceleration value.

For straight motion with regular change (GLBB) both on an angled plane motion and free-fall motion, the average acceleration is equal to the constant instantaneous acceleration, and the formula applies:

$$x = v_{(average)}\, t = \frac{1}{2}(v_0 + v)t \qquad ...(1)$$

$$x = x - x_0 = v_0\, t + \frac{1}{2}\, at^2 \qquad ...(2)$$

$$v^2 = v_0^2 + 2a\Delta x \qquad ...(3)$$

Material

This research involved two experiments with different experimental tools to prove the concept. First, the experiment of angled plane motion, namely two types of rails of 50 cm precision, two types of rail legs, two types of clamps at both ends of the rail, one type of rail connector, and four types of masses weighing 20 grams per unit. Two types of toy cars.

Figure 2. Tools and Materials for Angled Plane Motion Experiment

Figure 2 is intended to show how object angled plane motion can be assembled using the materials above it.

Second, the free fall motion experiment uses tools and materials: scissors, markers, tape, a meter, and three types of mass with different weights (baseball, bekel ball, and plastic ball).

Figure 3. Tools and Materials for Free-Fall Motion Experiment

Figure 3 is meant to show how object free-falling motion can be assembled using the materials above it.

Variables

This experiment contains three kinds of variables: independent, dependent, and control. These variables are detailed in Table 1 below. The breakdown of these variables determines the meaning of the research (Prima et al., 2016).

Table 1. Experimental Parameters

Parameter	Description
Independent	Type of mass used
Dependent	Position, speed, and acceleration
Control	Types of angles, times, and heights

Procedure

The following is a scheme that shows how the series of experiments will be carried out to prove whether there is an effect of mass on the kinematics parameters of the object's motion.

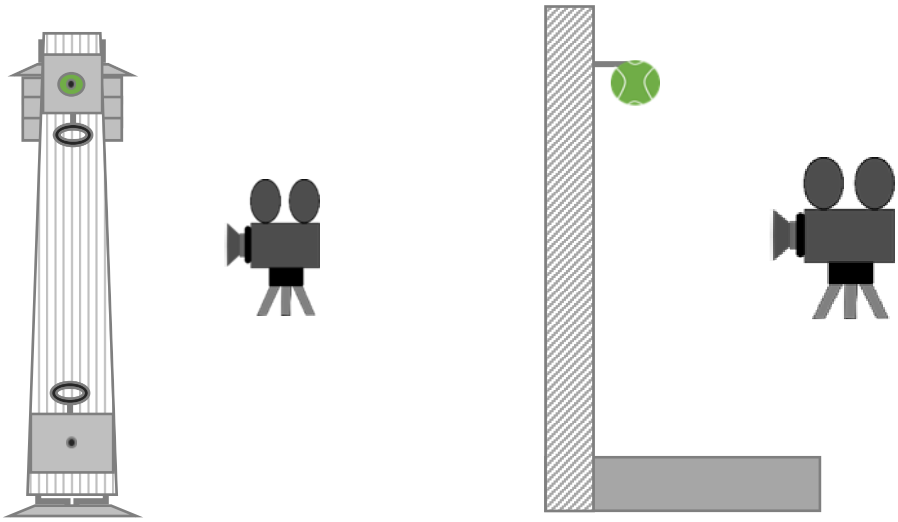
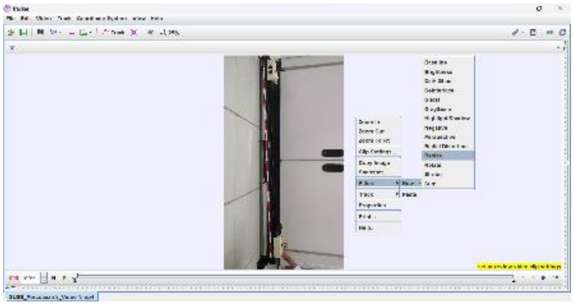


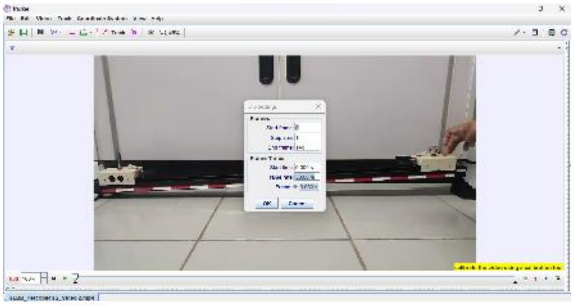
Figure 4. (a). Toy car moving on an inclined plane, (b). A moving baseball in free fall

Experiment 1, arrange all the tools and materials according to the scheme of Figure 4. a so above. After assembling according to the existing scheme, the next step is to drop the toy car in the higher part so that it hits the toy car in the lower part. Experiment as much as the mass prepared on the material tools provided earlier. Experiment 2 is almost identical to experiment 1, arranging the tools and materials supplied according to the scheme in Figure 4.b above. After assembling according to the project, the next step is to drop the mass in the picture until it hits the floor. Experiment as much as the mass that has been described before. During the first and second experiments, the recording stage was carried out using the help of a mobile phone; later, the video was analyzed using a tracker.

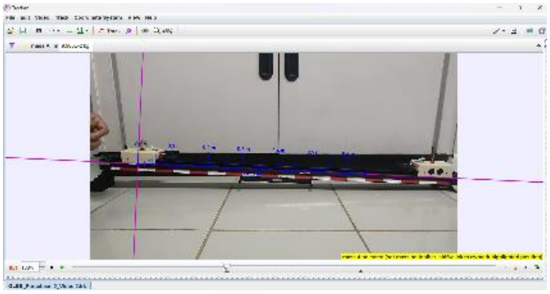
Next, the experimental videos that have been created will be analyzed using a video tracking application, as shown in Figure 5.



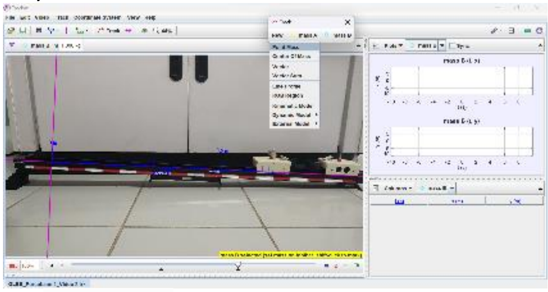
First, click open/select video >> click rotate to position the video.



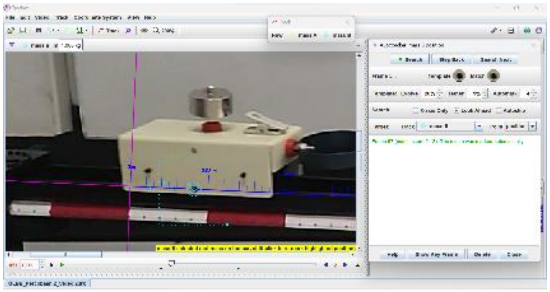
Click to set the start and end of the video to be analyzed.



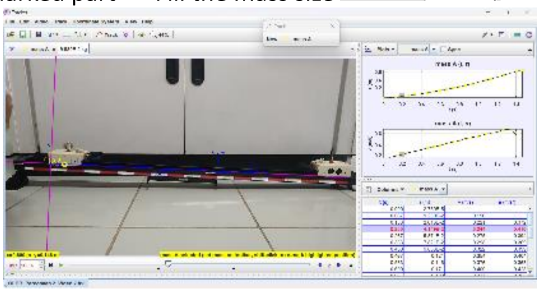
Click coordinate line define x & y axis>> click for calibration line.



Click Track to track the movement of the object, click as shown >> click Ctrl+Shift to the marked part >> Fill the mass size mass A m 9.980E-2 kg



After the track, we can manually or automatically match each object track point.



Finally, it generates a graphical form & tabular data of the kinematics parameters of the tested object.

Figure 5. Video analysis steps using the Tracker

The use of tracker software helps students to describe the motion of objects based on video recordings of the object's trajectory. Visualization of the experiments can help students understand the concept of motion.

Results and Discussion

The following is a description of the results of the kinematic analysis of objects in 2 states against changing mass values using the tracker application to prove the kinematic parameters of objects, such as time to position, speed, and acceleration in each experiment that has been carried out. The following is an overview of the graph of objects moving on an inclined plane to explain how the shape of the motion of time to position, velocity, and acceleration in experiment 1.

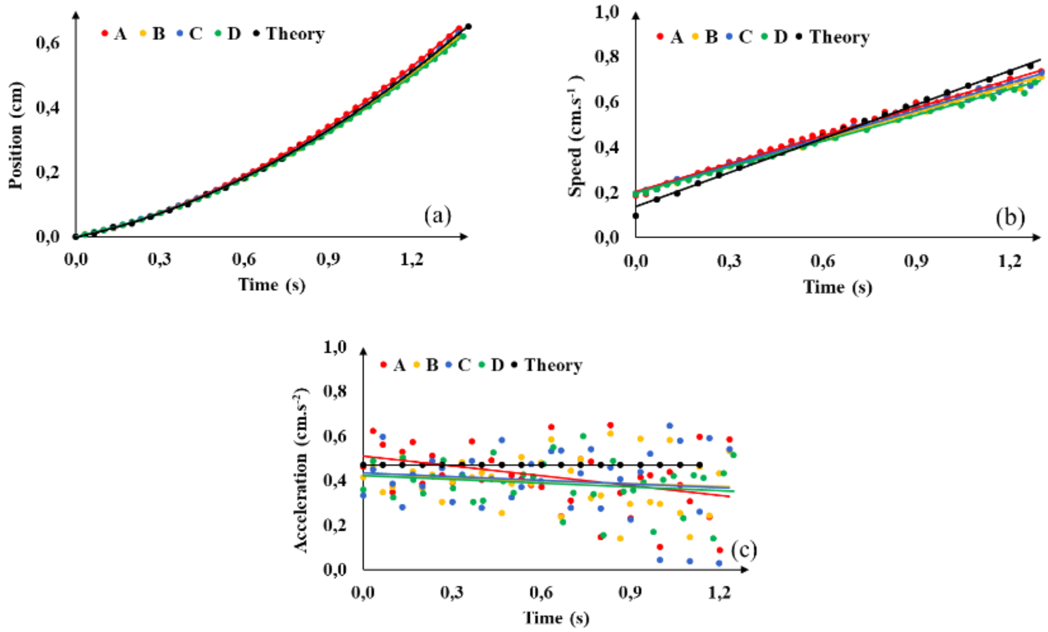


Figure 6. (a) Time to position graph, (b) Time to velocity graph (c) Time to acceleration graph on an inclined plane.

Figure 6 shows the experimental time (t) results against the function (x, v & a) with different mass values for each kinematics parameter. Figure 6a, 6b & 6c represent time against position, velocity, and acceleration of objects that have the same results as the theoretical graphs we have understood so far. The three kinematics parameters of objects moving on an inclined plane according to Figure 6 have no effect on the mass of the kinematics parameters of these objects, and the harmony of theory with the use of tracker applications is in accordance with research developed by previous experts (Maslova et al., 2020).

Furthermore, a description of the graph of a moving object in free fall motion on a surface explains how the shape of the graph of time to position, velocity, and acceleration in experiment 2 of regular straight motion.

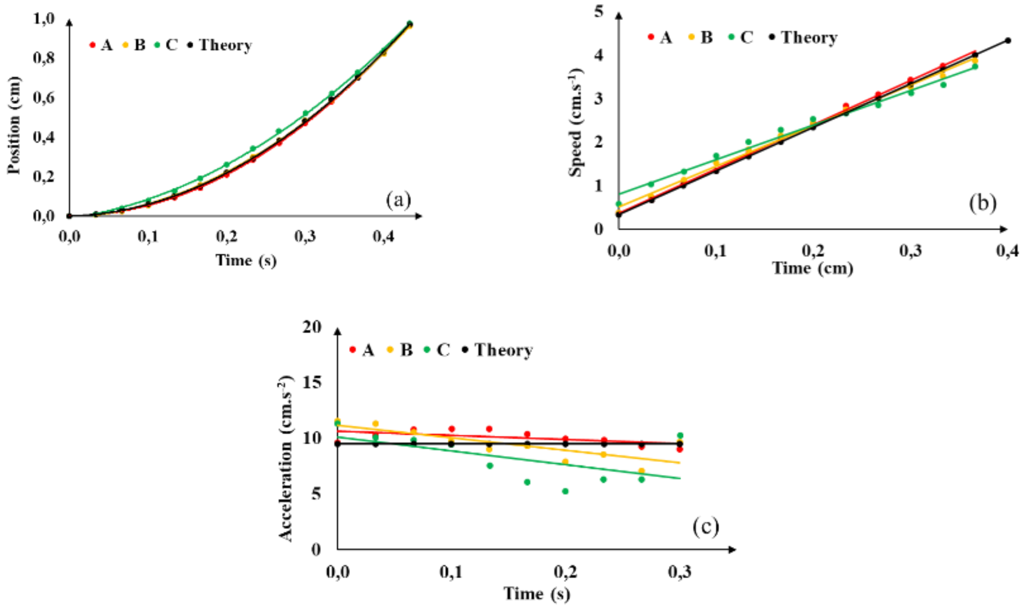


Figure 7. (a) Time to position graph, (b) Time to velocity graph (c) Time to acceleration graph on a free fall.

Figure 7 shows the experimental results of time (t) against functions (x, v & a) with different mass values for each kinematics parameter. Figure 7a, 7b & 7c represent time against position, velocity, and acceleration of objects that have the same results as the theoretical graphs we have understood so far. The three kinematics parameters of objects moving in free fall according to Figure 7 have no effect of mass on the kinematics parameters of these objects, and the theoretical harmony with the use of tracker applications is in accordance with the research developed by previous experts (Wee et al., 2015).

Based on the graphical images of the two experiments tested, the theory graph and the tracker graph have almost similar results. According to (Prima et al., 2016; Teiermayer, 2016; Wee et al., 2012), in research that has been conducted on measuring an object's kinematics parameters, the data generated from the experiments analyzed by researchers produces the same graph as previous research. Various motion characteristics can be observed through this tracker application, and learning the basics of classical physics can be fun. The use of tracker applications in these two experiments is to prove whether there are external influences, such as air friction on the position, speed, and acceleration experienced by objects. The graphical results produced in this study align with the research conducted (Neto & Souza, 2018; Nugraha et al., 2018), the value of the time graph against the function of distance, speed, and acceleration by comparing it to the design of manual experiments produces the same graph.

The following Table 2 shows the results of the consistency of the theory of objects moving on an inclined plane, which produces values and equations related to the mass of objects that change with the position, speed, and acceleration of an object according to the graph above.

Table 2. Effect of Body Mass on Kinematics Parameters of Pendant Motion on an Inclined Plane

Object	Mass (gr)	Functions (t)			V_{exp} (m/s)	V_{theory} (m/s)	a_{exp} (m/s²)	a_{theory} (m/s²)
		Distance (m)	Speed (m/s)	Acceleration (m/s²)				
M1	0.095	$y = 0.21t^2 + 0.19t - 0.003$	$y = 0.41t + 0.20$	$y = -0.15t + 0.51$	0.73		0.51	
M2	0.145	$y = 0.20t^2 + 0.18t - 0.001$	$y = 0.40t + 0.20$	$y = -0.04t + 0.42$	0.71	0,78	0.42	0.47
M3	0.195	$y = 0.20t^2 + 0.18t - 0.001$	$y = 0.40t + 0.20$	$y = -0.06t + 0.44$	0.73		0.44	
M4	0.245	$y = 0.19t^2 + 0.19t - 0.001$	$y = 0.38t + 0.20$	$y = -0.06t + 0.42$	0.69		0.42	
%Error					8.33 %		4.79%	

Table 2 explains that the speed results of objects moving on an inclined plane in theory and the results of the video analysis tracker have the same value. Also, the human error resulting from using the tracker application has a minimal percentage value of 8.33% for the speed value and 4.79% for the acceleration value.

The following Table 3 shows the results of the consistency of the theory of objects moving in free fall motion, which produces values and equations related to the changing mass of objects to the position, speed, and acceleration of an object according to the graph above.

Table 3. Effect of body mass on the kinematics parameters of penda motion in free fall.

Object	Mass (gr)	Functions (t)			V_{exp} (m/s)	V_{theory} (m/s)	a_{exp} (m/s²)	a_{theory} (m/s²)
		Distance (m)	Speed (m/s)	Acceleration (m/s²)				
M1	0.0465	$y = 5.10t^2 + 0.02t + 0.0004$	$y = 10.2t + 0.4$	$y = -3.7t + 10.6$	4.00		10,6	
M2	0.0585	$y = 4.66t^2 + 0.22t - 0.0072$	$y = 9.3t + 0.5$	$y = -11.2t + 11.1$	3.86	4.39	11,1	10
M3	0.0043	$y = 3.95t^2 + 0.57t - 0.0113$	$y = 8.0t + 0.8$	$y = -12.3t + 10.1$	3.73		10,1	
%Error					12.00 %		6.00 %	

Table 2 explains that the speed results of objects moving on an inclined plane in theory and the results of the video analysis tracker have the same value. Also, the human error resulting from using the tracker application has a very small percentage value of 12.00% for the speed value and 6.00% for the acceleration value.

The results of the calculations carried out in this study have the same conclusions related to several studies conducted by several previous experts related to video analysis of science experiments based on video tracker analysis in improving student understanding of kinematics material from several existing subchapters (De Jesus et al., 2019; Nuryadin, 2020; Suárez et al., 2020).

Conclusion

The tests that have been carried out to measure the parametric kinematics of the motion of objects in GLBB (straight motion changes regularly) to prove how the position, speed, and acceleration generated from two experiments, namely the motion of the inclined plane and free fall motion, of course, using the help of the Tracker application Compared to traditional methods carried out by applying such as timer stickers, the method using Tracker video analysis has proven all kinematics parameters of each experiment that has been carried out. As for the consistency of the experiments carried out using Tracker, the results show that (1) Mass does not affect the kinematics parameters of the object through observation of the resulting graph; (2) Proof of the accuracy of the kinematics parameters of objects on an inclined plane produces a very small error value, namely *(v = 8.33% & a = 4.79%)*; (3) Proving the accuracy of the kinematics of object parameters in free fall produces a very small error value, namely *(v =12% & a =6%)*; (4) The influence of air friction on each experiment so that there is a slight change in the graph found against different masses of objects.

References

Abeysiriwardana, P. C., Jayasinghe-Mudalige, U. K., & Kodituwakku, S. R. (2022). “Connected researches” in “smart lab bubble”: A lifeline of techno-society space for commercial agriculture development in “new normal.” *New Techno Humanities*, *2*(1), 79–91. https://doi.org/10.1016/j.techum.2022.05.001

Aguilar-Marín, P., Chavez-Bacilio, M., & Rosas, S. J. (2018). Using analog instruments in Tracker video-based 13 experiments for understanding electricity and magnetism 14 15 phenomena in physics education. *European Journal of Physics*, *10*, 0–16.

De Jesus, V. L. B., Pérez, C. A. C., De Oliveira, A. L., & Sasaki, D. G. G. (2019). Understanding the gyroscope sensor: A quick guide to teaching rotation movements using a smartphone. *Physics Education*, *54*(1). https://doi.org/10.1088/1361-6552/aae3fc

Dewi, C. T. (2023). *Developing A Simple Parabolic Motion Props : Steps and Their Applicability*. *9*(1), 31–44.

Erickson, M. G., Erasmus, M. A., Karcher, D. M., Knobloch, N. A., & Karcher, E. L. (2019). Poultry in the classroom: effectiveness of an online poultry-science-based education program for high school STEM instruction. *Poultry Science*, *98*(12), 6593–6601. https://doi.org/10.3382/ps/pez491

Flegr, S., Kuhn, J., & Scheiter, K. (2023). When the whole is greater than the sum of its parts: Combining real and virtual experiments in science education. *Computers and Education*, *197*(February), 104745. https://doi.org/10.1016/j.compedu.2023.104745

Hodosyová, M., Útla, J., MonikaVanyová, Vnuková, P., & Lapitková, V. (2015). The Development of Science Process Skills in Physics Education. *Procedia - Social and Behavioral Sciences*, *186*, 982–989. https://doi.org/10.1016/j.sbspro.2015.04.184

Kokkonen, T., Lichtenberger, A., & Schalk, L. (2022). Concreteness fading in learning secondary school physics concepts. *Learning and Instruction*, *77*(August 2020), 101524. https://doi.org/10.1016/j.learninstruc.2021.101524

Malgieri, M., Onorato, P., Mascheretti, P., & De Ambrosis, A. (2014). Pre-service teachers’ approaches to a historical problem in mechanics. *Physics Education*, *49*(5), 500–511. https://doi.org/10.1088/0031-9120/49/5/500

Maslova, K., De Jesus, V. L. B., & Sasaki, D. G. G. (2020). Understanding the effect of rolling friction in the inclined track experiment. *Physics Education*, *55*(5). https://doi.org/10.1088/1361-6552/ab9217

Molina-Bolívar, J. A., & Cabrerizo-Vílchez, M. A. (2014). Determination of the static friction coefficient from circular motion. *Physics Education*, *49*(4), 400–405. https://doi.org/10.1088/0031-9120/49/4/400

Neto, F. S., & Souza, P. V. S. (2018). Modeling human gait in high school. *Physics Education*, *53*(5). https://doi.org/10.1088/1361-6552/aad4ca

Nugraha, M. G., Kirana, K. H., Nugraha, F., Nurinsani, E. A., & Sholihat, F. N. (2018). Optimization of Rectilinear Motion Experiments using Tracker Application. *IOP Conference Series: Materials Science and Engineering*, *288*(1). https://doi.org/10.1088/1757-899X/288/1/012096

Nuryadin, B. W. (2020). The falling chain analysis using kitchen scales. *Physics Education*, *55*(3). https://doi.org/10.1088/1361-6552/ab7d11

Oktavia, D. A., Nursuhud, P. I., Kurniawan, M. A., Jumadi, Wilujeng, I., & Kuswanto, H. (2019). Application of Multimedia Learning Modules assisted by "tracker" Virtual Laboratory to Train Verbal Representation of Class XI High School Students. *Journal of Physics: Conference Series*, *1233*(1). https://doi.org/10.1088/1742-6596/1233/1/012055

Poonyawatpornkul, J., & Wattanakasiwich, P. (2013). High-speed video analysis of damped harmonic motion. *Physics Education*, *48*(6), 782–789. https://doi.org/10.1088/0031-9120/48/6/782

Prima, E. C., Mawaddah, M., Winarno, N., & Sriwulan, W. (2016). Kinematics investigations of cylinders rolling down a ramp using tracker. *AIP Conference Proceedings*, *1708*(December 2012). https://doi.org/10.1063/1.4941183

Rejekiningsih, T., Maulana, I., Budiarto, M. K., & Qodr, T. S. (2023). Android-based augmented reality in science learning for junior high schools: Preliminary study. *International Journal of Evaluation and Research in Education*, *12*(2), 630–637. https://doi.org/10.11591/ijere.v12i2.23886

Rodrigues, M., & Simeão Carvalho, P. (2014). Teaching optical phenomena with Tracker. *Physics Education*, *49*(6), 671–677. https://doi.org/10.1088/0031-9120/49/6/671

Schalk, L., Edelsbrunner, P. A., Deiglmayr, A., Schumacher, R., & Stern, E. (2019). Improved application of the control-of-variables strategy as a collateral benefit of inquiry-based physics education in elementary school. *Learning and Instruction*, *59* (September 2018), 34–45. https://doi.org/10.1016/j.learninstruc.2018.09.006

Shibayama, S. (2019). Sustainable development of science and scientists: Academic training in life science labs. *Research Policy*, *48*(3), 676–692. https://doi.org/10.1016/j.respol.2018.10.030

Suárez, A., Baccino, D., & Martí, A. C. (2020). An experiment to address conceptual difficulties in slipping and rolling problems. *Physics Education*, *55*(1). https://doi.org/10.1088/1361-6552/ab4d1e

Teiermayer, A. (2016). Problems based on phenomena and experiments in secondary school involving a digital camera. *Physics Education*, *51*(6), 63002. https://doi.org/10.1088/0031-9120/51/6/063002

Tipler, P. A. (1998). *Fisika : untuk sains dan teknik* (J. Sutrisno, R. W. Adi, & L. Prasetio (eds.); 3rd ed.).

Wati, S., Halim, A., & Mustafa. (2020). The impact of the media tracker on student critical thinking skills. *Journal of Physics: Conference Series*, *1460*(1). https://doi.org/10.1088/1742-6596/1460/1/012139

Wee, L. K., Chew, C., Goh, G. H., Tan, S., & Lee, T. L. (2012). Using tracker as a pedagogical tool for understanding projectile motion. *Physics Education*, *47*(4), 448–455. https://doi.org/10.1088/0031-9120/47/4/448

Wee, L. K., Tan, K. K., Leong, T. K., & Tan, C. (2015). Using Tracker to understand "toss up" and free fall motion: A case study. *Physics Education*, *50*(4), 436–442. https://doi.org/10.1088/0031-9120/50/4/436