Optimization of Rectilinear Motion Experiments using Tracker Application

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Abstract. Physics is one part of Natural Sciences which underlies the development of technology, so that the process of learning Physics should not only emphasize the mastery of the concept but also on aspects of the discovery as the scientist did. Therefore, experimental activities are considered very important in Physics learning. In the experimental activities, it is important to have appropriate tools and methods of measurement to obtain accurate findings. One of the experimental activities of physics which conducted in school is a uniformly acceleration rectilinear motion using a set of dynamics train experiment and Atwood experiment. The measurement methods of both experiments generally use conventional tools, i.e. ruler, stopwatch and ticker timer that are susceptible to interruptions and errors in the data acquisition process. One method of measuring and processing data that considered has more precision is to use the application tracker. In this research, a uniform rectilinear motion kinematics experiments have been done with two methods of measurement using conventional tools and compared with using the tracker by recording the movement of objects using high definition camera (HD) with 24 fps shooting speed. The results showed that the result using tracker to produce some acceleration data is more constant than the result using conventional methods. In addition, time-positions graphs \( s = f(t) \) are formed in the form of quadratic and time-velocity graphs \( v = f(t) \) are straight lines with a constant gradient corresponding to the rectilinear motion theory. Based on the results of the research, the use of tracker application in the experimental kinematics of rectilinear motion produces more accurate data so it can be used as an alternative to optimize the experiments of rectilinear motion.

1. Introduction

Physics as one of the cornerstone in the development of technology, must be supported by learning activities that can provide opportunities for learners to find and apply the knowledge gained. This is linear with statement which say the nature of Physics as part of the natural science that requires learners to gain experience of discovery as scientists discover theories, concepts and laws [1][2]. Efforts in order to develop student skills as a potential scientist can be done through experimental activities, because in the experimental activities students can develop the way of thinking and how to work as a scientist [3]. In experimental activities, students are actively involved in a process, observing an object, analyzing, proving, and drawing its own conclusions about a particular object, state or process [4]. In other words, experimental activities can provide experience for students to learn directly from the activities they do.
(learning by doing) so that students are not only able to master the concept but also can develop and cultivate high-level process and thinking skills.

The use of media in learning has a great contribution on the effectiveness of learning [5], therefore the selection and use of measuring tools and methods in experiments need to be reviewed and developed in order to produce precise and accurate data. One of the most common experimental activities in a school is a uniformly changing rectilinear motion using a set of dynamics train and a set of Atwood machine as shown in Figure 1. In the data acquisition process, generally the measurement of motion parameters in both sets of experimental devices is still done manually, which uses the ruler to measure length of track and stopwatch to measure the travel time of the object motion. Manual measurement method is very susceptible to errors due to measuring factors that are less precise or error when retrieving data by students, so the data measurement results are very subjective. In addition to the ruler and stopwatch, another commonly used measuring tool is the ticker timer. Ticker timer is a tool that can provide tap on the hand with a fixed frequency, leaving a trail on the ribbon [6]. The traces generated by ticker timer can be used to investigate the relationship between the movement and the travel time of the object, the relationship between the velocity with the travel time and the relationship between the acceleration with the travel time of the object. Utilization of ticker timer has several weaknesses and constraints, i.e. the trace of the ticker timer ticks the longer it looks unclear, this is because the carbon paper used to bring the trace will be more depleted. In addition, the use of paper tape on the ticker timer directly provides obstacles to the movement of the object. Both of these have resulted in inaccurate data being obtained.

One of the predicted solutions which can generate more accurate motion parameter data is to use Tracker. Tracker is software to analyze the motion of objects through the recording of motion (video) so that the parameters of position, speed parameters, acceleration, kinetic energy, potential energy and other parameters owned by moving objects [7]. The use of tracker applications in learning and optimization of experimental tools has been widely used, such as tracker utilization to determine the acceleration of Earth's gravity through parabolic motion [8], determining fluid viscosity coefficient [9], determining the gravitational acceleration anomaly of Earth due to solar eclipse [10,11] and analyzing the leaf motion of the bauhinia purpurea leaf due to changes in the intensity of sunlight on eclipse phenomena [12]. By using this software, the measurements of motion parameter in rectilinear motion kinematics can be done with more precision and then students can obtain more accurate data.

2. Methods

In this study, the kinematical experiments of uniformly changing rectilinear motion was performed on two sets of experimental tools that generally existed in schools, namely sets of dynamics train and set of Atwood machine with schematics as shown in figure 1. The data acquisition process is done by two methods of measurement, using conventional ruler, stopwatch and ticker timer, and using measurement method with tracker application. Tracker is software to analyze video developed by Open Source Physics (OSP) with Java framework [7]. The software tracks the motion of objects by identifying the pixels of the specified area and analyzing the position of objects on each frame. To produce accurate data requires a clear video recording.
a.    b.

Figure 1. Experiment apparatus scheme: a. Atwood machine; b. dynamics train

On the set of experimental Atwood machine (Figure 1a), the initial condition of M1 loads whose mass is equal to M2 (72.26 grams) is held in the X position using a locking bolt. Then the M1 load is released so that the load moves up and the load M2 which has been given an additional load m moves down accelerated from position A to position B because the load M2 + m is greater than M1. The length of the A-B path is measured using a ruler while travel time is measured using a stopwatch. In the set of the dynamics train experiments (Figure 1b), experiments were performed by varying the mass of the dynamics trains with a fixed angle of 5°. Ticker timer is connected to AC voltage source with frequency 50 Hz.

For data processing using the tracker application, the movement of objects in both sets of experiments is recorded using a high-resolution camera (high definition, HD) with a 24 frame / sec (24 fps) shooting rate. To get a clear image of the object movement, a white board is used as the background of the experimental set of tools. Results of data processing using tracker applications compared with the results obtained using conventional methods to obtain information which data is more accurate and consistent. This is done to get a better method in the acquisition and processing of experimental data so as to obtain precise and accurate results.

3. Results and discussion
Based on the experimental results, obtained two types of data that is the video data for processing tracker and conventional data in the form of distance, time, and paper tape result of ticker timer beat. An example of the data obtained in the experiment is shown in figure 2.
Figure 2. Example of experiment result: a. tracker result on Atwood machine; b. tracker result on dynamics train; c. ticker timer beat result

According to the data processing using the tracker application on the video of motion and the data using conventional data processing, the graph of position-time function graph ($s = f(t)$), the velocity-time function graph ($v = f(t)$) and the comparison table of motion acceleration as shown in figure 3 and table 1.
Figure 3. Results of data processing using tracker: Atwood machine experiment: a. graph \(v = f(t)\); b. graph \(s = f(t)\); and for the dynamics train experiment: c. graph \(v = f(t)\)

Table 1. Comparison of object motion acceleration using tracker method and conventional method

| Experiment       | Number of experiments | Acceleration (a) cm/s\(^2\) |
|------------------|-----------------------|-----------------------------|
|                  |                       | Tracker | conventional     |
| Atwood machine   | 1                     | 18.78    | 11.05            |
|                  | 2                     | 18.23    | 12.66            |
|                  | 3                     | 18.45    | 14.17            |
| Dynamics train   | 1                     | 60.67    | 50.00            |
|                  | 2                     | 60.15    | 53.93            |
|                  | 3                     | 59.90    | 53.69            |

Based on Figures 2 and 3 and Table 1, the parameters of motion of objects in both experiments are performed. Figure 2a shows that the movement of objects on the A-B path in the experiment of the Atwood machine has accelerated motion. This is shown from the change in the position which is
enlarged at the same time and is also emphasized in Figures 3a and 3b which show that the velocity of
the object changes constantly with time and changes in the position of matter over time are changed
quadratically. This is quite easy to understand because as long as its motion path, the recorded M2 load
gets an additional load of m, so there is a force resultant on the system in the direction of M2 load
movement [13,14]. The same phenomenon is also obtained in the experiment using the set of dynamics
train, i.e. the object accelerated in its movement down the incline. This is evident in Figs. 2b, 2c, and 3c
which indicate the change in the position of the object and the change in the velocity of the object at any
time. The movement of an accelerated object as it descends the incline occurs because there is a resultant
gravitational force acting on a sloping object [13,14]. If we look again at the graph of Fig. 3, especially
the graph of time-varying velocity relation (v = f (t)) in Figures 3a and 3c, it is seen that the change in
velocity of the object occurs in a fluctuating manner but creates a straight-line tendency with a constant
slope. This fluctuating speed value occurs due to the limitations of the speed of the camera in recording
images every second (frame / second) of 24 fps, which means the camera takes 24 images in 1 second.
Thus, in order to record fast moving objects there will be recording images that are cut into pieces.

The interesting part of this research is the comparison of the consistency of the acceleration value of
the object motion using two measurement methods performed as shown in Table 1. Based on the results
of data processing using the application tracker, it is obtained that the acceleration value of experimental
motion of Atwood machine experiments and dynamics train experiments is more consistent compared
with the acceleration value of conventional data processing. For Atwood machine experiments, the
results of data processing using a tracker obtained a consistent motion acceleration at 18 cm / s², in
contrast to conventional data processing results that accelerate motion values vary in the range 11 cm /
s² - 14 cm / s². Likewise, in experiments using dynamics train sets, data processing using a tracker
produces a constant motion acceleration value of 60 cm / s², whereas with conventional methods the
acceleration value of motion is obtained in the range of 50 cm / s² - 54 cm / s². Several studies involving
motion measurements also show that tracker usage shows more accurate results [8,9]. The inconsistency
of the results obtained by using conventional methods is predicted to occur due to several factors, i.e.
less precise measuring instruments, errors during data retrieval, as well as the taping patterns seen on
tape paper are less clear, thus affecting the measurement of changes in the position of objects over time
which ultimately impact on value of other motion parameter.

4. Conclusion
Based on the results of research, measurement methods and data processing using the application of
tracker in kinematics experiments motion is able to produce more consistent and accurate data.
Utilization of tracker application can be one alternative to optimize experimental kinematics motion
straight so that resulted of finding of experiment that precise and accurate.

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