Design and development equipment to measure the motion quantities of an object that moving in air or in fluid

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Abstract. We have developed an equipment for time interval measurement of an object that move free fall in air or in water by using microprocessor Arduino as a clock timer and is controlled by pair of laser diode and photo diode. By this technique, the main problem how to find the equation of motion can be obtained. The results show that the equipment work well. The equipment is able to measure time interval of an object that move free fall in air or in water which position change up to 10 cm. By positioning the pair of laser diode and photo diode in six different heights we can plot the position as a function of time. By the aid of a personal computer software it is easily to obtain the equation of motion of the object move both in air or in water. This equipment is useful for high school and under graduate university student to measure the gravity intensity and to study the drag force in fluid.

1. Introduction

Physics is the most basic of the sciences. It deals with the behavior and structure of matter [1]. There are three pillar of physics: mechanics, electrodynamics and quantum, these three pillar deals with the behavior and structure of matter. Mechanics talk about how and why an object move. The basic law of mechanics is the Newton laws of motion [2,3]. Because the mechanics is the fundamental concept to the two another pillar, the student from elementary until university learn this topic. The equation of motion is the first topic of Newton laws of motion. The motion study has been starting from elementary school. The teacher was introducing what mean of an object move. When the student goes to high school the teacher introduces the quantities of motion (position, velocity and acceleration), and how the three quantities related one to another. In high school only introduce the motion of constant acceleration with straight line path with phenomena example is the motion of free fall object. When the student goes to university also they study about the motion of an object, but now they study motion in general cases where all quantities of motion is a function of time. In general, the study of motion is introducing theoretically with mathematics as a back bond with some examples of phenomena. It is very rarely to find the teacher introduce the study of motion with experiment especially in our country, Indonesia. These due to it is not easily to measure time interval of the change position of an object moving.

This work is aimed to give the solution how to teach the student not only by mathematics approach but also by observe the phenomena, so that the student could be increased their deductive thinking to the topics they are learning [4,5]. Lee, et all says that to teach Newton’s law of motion is easily mathematically but difficult to show the phenomena because it is not easy to measure position of motion as a function of time [6]. Especially in study of physics, learning by doing is one of the very effective
method because in learning by doing method the student and teacher is guided how to solve the problem and how to measure the quantities they are observing and then how they formulate the phenomena [7-9]. From my experience when go to some high school in our country, Indonesia, when the student desire to measure the gravity acceleration from free fall object the student only use the conventional stop watch to measure the time interval for an object free fall from the desired height, which of corse not accurate measurement. In our physics laboratory we have equipment for experiment free fall down object which was equipped electronically to measure time interval, but is not useful for fluid medium. In this work we design and develop an equipment that can formulate the equation of motion of an object moving both in air and fluid media. The focus of the equipment tends how to measure time interval of the change of position of an object moving. All materials and component used in this work is marketable, so that the teacher and student can easily construct the same equipment and not too expensive. The working principle of the equipment is to measure the time interval of an object that free fall in air and in liquid for many position so that the student can comparing the phenomena of an object move with constant force and varying force.

2. Design and construction of equipment

![Figure 1. Design of equipment to be built.](image)

![Figure 2. Equipment that was constructed. There are six laser diode, (b) six photo diode, (c) magnetized iron cord.](images)
2.1. Materials /components
Microprocessor Arduino Uno R3 (ATmega328), Laser diode (LD) (5 V, 150 mW, 650 nm 5 mW), Photo diode (PD), Aluminum tube, iron cord, accumulator, iron ball, acrylic tube (outer diameter 5 cm), personal computer.

2.2. Working principle
Magnetized iron cord holds iron ball. By switch is turn off the iron ball fall down and in the same time the beam from laser diode trigger photo diode to produce output signal [10-12]. This signal is used to order the microprocessor to start measure time [13,14]. The first pair of LD and PD was sign as timer 1 with value 0. When the iron ball passes through the second pair of LD and PD the microprocessor counts the time and sign as he timer 2 and so on until the sixth pair of LD and PD. The output signal of sixth PD is used to order the microprocessor to send the values of all timer to personal computer and display them. The vertical separation between each pair of LD and PD was set 10 cm, that’s mean we have 6 points in height and time coordinate system. By the aid of computer, we can plot the relation of position and time and formulate the equation of position as a function of time. From this equation we can derive the equations of velocity and acceleration of the iron ball free fall down both in air and in water.
Should be noted that the vertical position of all six pair of LD and PD, should be in line with the axis of acrylic tube, so that the laser beams always entering the Photo diode. Also the position of magnetized iron cord must be on the axis line of tube to guarantee when iron ball fall down always cross the laser beam.

3. Experimental results and discussion

3.1. Accuracy of clock timer
Figure 3 shows the picture of time that have measured by microprocessor. The unit of time is in millisecond(ms). Data were taken in six series of the same condition. The result of the data that has been evaluated for each timer using excel it’s found that the mean error of six series measurement is 0.7%, which is high accuracy (99.3%) of time measurement. This result shows that the microprocessor which was controlled by the out put signal of photo diode work well.

Figure 3. Computer display of time measurement by microprocessor arduino uno of iron ball object free fall down in air, only 3 from 6 time series shows.
3.2. Measurement of motion quantities

![Figure 4](image.png)

**Figure 4.** Relation of height and time of the iron ball object free fall down in: (a) air and (b) water.

The six time series of time measurement in the same condition both in air and in regular water has been evaluated by using excel soft ware. Six coordinate points were plotted as shown in figure 4. The equation of height as a function of time was obtained by using best fitting trend line of polynomial order 2 ($y = 5.1083t^2 + 0.0859t + 0.0027$) in (a) and polynomial order 4 ($y = 1.0061t^4 - 1.3017t^3 + 0.0808t^2 + 0.8514t - 0.0018$) in (b). $y$ is height (meter) and $t$ is time (second). It is clearly seen that the motion of object in air follow the straight line motion with constant acceleration. The value of acceleration is 10.2 ms$^{-2}$. This acceleration is due to the gravitation intensity ($g$). The mean value of $g$ in equator region is 9.8 ms$^{-2}$. The measured value of $g$ by this equipment is higher than the common value of $g$ in equator region. The error up to 4% which is higher compare to the error of time measurement which only 0.7%.

The high error of $g$ measurement may be due to the position of LD and PD which was placed by reference “the beam from LD enter PD”. The diameter of hole where LD and PD was placed is 6 mm while the diameter of LD is 4 mm and PD is 3 mm that may make shift their position from the true position.

Contrast to the motion of an object in air that is regular, the motion in water is complicated. The equation of motion of an object in water have 4th order polynomial, which shows that the acceleration not constant but varying with time which is not like the motion of an object move in air. According to the theory of the motion of solid object in fluid, the fluid exert drag force to solid object which its values depend on the velocity of object and viscosity of fluid. Also the another force act on solid object that is buoyant force which it’s value depend on the kind of fluid and dimention of solid. In certain value of solid speed the net force act on objec is zero so that the object tend to move with constant speed. This speed is known as a terminal velocity. From figure 4(b) this terminal velocity not yet achieved in 50 cm motion. But look like the curve tend to linear after 50 cm motion. This experimental results is very important to the student to show that the motion of an object is not simple many variable can be involved. The theory only can be used to predict what will be happened to the future, if we give some treatments to the object that we will be learning.

4. Conclusion

From the experience of construction this equipment and the results of experiment can be concluded as follows:

- The equipment work well as a time measurement for an object move in straight line both in air and in water with high precision
- This equipment can be used to study motion of an object in fluid to see the terminal velocity phenomena
- The result of gravity intensity measurement have 4% uncertainty
- When placed the pair of laser diode and photo diode we must take care about the precision of its position that must be perfectly in line with the axis of the tube used
The student can built this equipment because all materials and equipments now days was marketable and the price not expensive.

References

[1] Douglas C G 2014 Physics: Principles with Applications (Volume 1) 7th Edition (USA: Pearson Education, Inc)

[2] Jearl Walker 2011 Fundamental of Physics, 9th ed. (John Wiley and sons inc.)

[3] Stephen T Thornton and Jerry B Marion 2004 classical Dynamics of Particles and systems, 5th edition

[4] Muhammad F 2017 Belajar dan Pembelajaran Modern. Konsep Dasar, Inovasi dan Teori Pembelajaran (Yogyakarta: Garudhawaca)

[5] M Khoirina 2018 Identify Student’s Scientific Ability at Senior High School Journal of Physics: Conference Series 1097, 012-024

[6] Lee, Han Su and Jgwon park 2012 Deductive Reasoning to Teach Newton’s Law of Motion. Taiwan International Journal of Science and Mathematics Education (2013) 11 1391-1414

[7] Jana hackatorn et al 2011 Learning by doing: an empirical study of active teaching techniques, the journal of effective teaching 11(2) 4-54

[8] Xiang yuan 2018 Re Examining”Learning by doing: implication from learningstylemigration, The Design journal 21(3)

[9] Alexander A N 2009 Teaching research Methods, Learning by doing journal of public affairs education 15(2)

[10] Marius G 2010 The physics of semiconductors, 2nd ed, chap 13, [Online] Retrieved from: https://www.google.com/search?q=Marius+Grundmann+(2010),+The+physics+of+semiconductors,+2nd+ed&spell=1&safe=strict&safe=strict&spell=1&ved=0ahUKEwir797enpXiA

[11] Balkanski M and Wallis R F 2000 Semiconductor Physics chap 13 Laser (Oxford University Press)

[12] Courseess diode and photo diode introduction [Online] Retrieved from: http://coursessengr.illionis.edu/ece445

[13] Yukifli 2018 Development of Digital Archimedes Experiment System Based on Microcontroller for Physics Education Journal of Physics: Conference Series 1120 012093

[14] Indra S W S T 2017 Mikrokontrollerplatform arduino, Politeknik Negeri [Online] Retrieved from: Malang,https://www.academia.edu/36503609/MODUL_MIKROKONTROLER_PLATFOR M_ARDUINO