A LOW COST OF SIMPLE PENDULUM EXPERIMENT APPARATUS BASED ON ULTRASONIC SENSOR AND ARDUINO MICROCONTROLLER

W. S. Mada Sanjaya[1,2*], Dyah Anggraeni[1,2], Rena Denya[1], Handi Pandriantama[1,2], Iklimah[1,2] and Indry Pritanti Dewi [1,2]

[1)]Department of Physics, Faculty of Science and Technology, Universitas Islam Negeri Sunan Gunung Djati Bandung, Indonesia

[2)] Bolabot Techno Robotic Institute, CV. Sanjaya Star Group, Bandung, Indonesia

*e-mail: madasws@gmail.com

Abstract

Simple Pendulum is a basic physics experiment about observation of harmonic oscillation motion. Generally, this experiment is performed with manual measurements and observations that are less efficient. In this paper describe numerical simulations of Simple Pendulum motion based on Python 2.7. The experimental system of real-time Simple Pendulum based on HC-SR04 Ultrasonic Sensor, Arduino microcontroller and the interface using Python 2.7. The experimental results show good agreement when compared with the numerical simulations. The advantage of this system is open source that makes physics experiments easier and low cost.

Kata Kunci: microcontroller, oscillation, pendulum, ultrasonic sensor.

INTRODUCTION

Simple Pendulum is a basic physics experiment about observation of harmonic oscillation motion. In addition, Simple Pendulum experiment can be predict the value of acceleration due to gravity after define the time period value of oscillation[1][2]. Simple Pendulum can be modeled by Ordinary Differential Equations (ODEs). The Simple Pendulum model can be solve with some method such as; Fourier[3], Runge-Kutta[4], Taylor Series[5], and other[6][7].

The manual procedure of experiment usually performed by using stopwatch, ruler, and other, but this procedure isn't effective because of less accuracy, difficult to operate and difficult to avoid human error. Recently, researchers investigate the digital experiment apparatus such as; using Arduino microcontroller [8], light sensor[9][10], ultrasonic sensor[1], accelerometer[11], image processing[12], smartphone[13][14][15][16], and other.

In this paper describe the development of real time Simple Pendulum experiment apparatus. The hardware system based on HC-SR04 Ultrasonic Sensors, Arduino microcontroller, and the interface using Python 2.7. Also, created the numerical simulations of Simple Pendulum using Runge-Kutta 4 Order (RK4) method based on Python 2.7 to confirm the experimental result. Finally, the result of experiment can be analyze and get the acceleration due to gravity.

The paper is organized as follows. In section 2, described a theoretical background of Simple Pendulum. In section 3, described the experimental method of Simple Pendulum. The numerical simulation of Simple Pendulum using RK4 based on Python software described in section 4. The experimental results described in section 5. Finally, the concluding remarks are given in Section 6.

THEORETICAL BACKGROUND

Simple Pendulum is the mechanic system which hung an object on a piece of string and then be disturbed (with little angle) so that it swung. The repeatedly swing (which have period) of Simple Pendulum is called oscillation. Figure 1 is the illustration of Simple Pendulum.

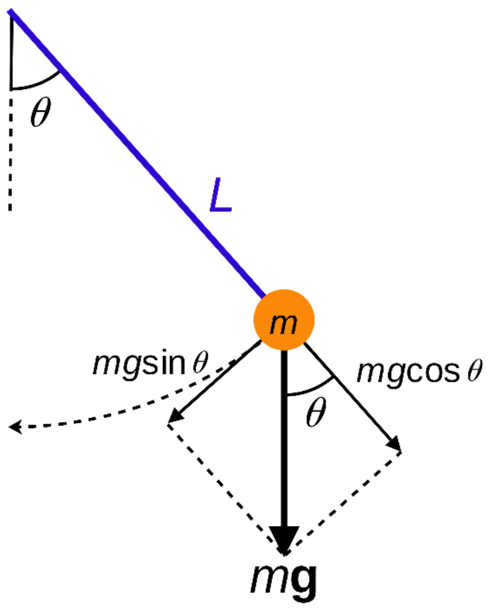


Figure 1 Simple Pendulum [17]

From Figure 1, obtained the kinetic and potential energy of Simple Pendulum;

$$\left.\begin{aligned} K &= \tfrac{1}{2} m l^2 \dot{\theta}^2 \\ V &= m\, g\, l\,(1 - \cos\theta) \end{aligned}\right\} \qquad (1)$$

Equation (1) described that K is the kinetic energy, V is the potential energy, m is the mass of pendulum, l is the length of cotton string, g is the acceleration due to gravity, θ is the initial angle position of deviation and $\dot{\theta}$ is the angle velocity. The kinetic and potential energy substitute to Lagrange (L) function $L = K - V$, obtained;

$$L = \frac{1}{2}ml^2\dot{\theta}^2 - m\,g\,l\,(1 - \cos\theta). \quad (2)$$

The Lagrange equation for non-conservative force;

$$\frac{d}{dt}\left(\frac{dL}{d\dot{\theta}}\right) - \frac{dL}{d\theta} = -b\dot{\theta} \quad (3)$$

where $-b\dot{\theta}$ is a drag coefficient. Substitute equation (2) to (3), Obtained;

$$ml^2\ddot{\theta} + m\,g\,l\sin\theta + b\dot{\theta} = 0. \quad (4)$$

From D'Alembert transformation, a 2nd order ODE of equation (4) may be transformed into the following system of two simultaneous equations of the first order:

$$\left.\begin{aligned}\dot{\theta} &= \omega \\ \dot{\omega} &= -\frac{g}{l}\sin\theta - \frac{b}{ml^2}\dot{\theta}\end{aligned}\right\} \quad (5)$$

where ω, $\dot{\omega}$ is the angular velocity and acceleration of Simple Pendulum motion.

3. Experiment Method

3.1 System Design

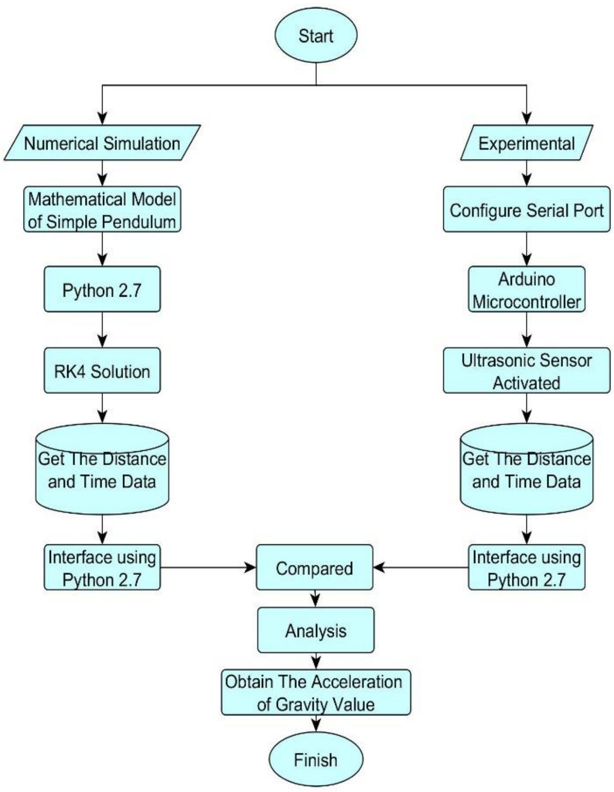


Figure 2 General Research Scheme

Figure 2 is the general scheme of this research that divided in to two process; the first process is create the Numerical Simulation of Simple Pendulum mathematical model. The mathematical model solved using RK4 solution based on Python 2.7, thus will get the distance data and the graphical interface. The second process is the experimental method of Simple Pendulum based on Ultrasonic Sensor, Arduino and Python 2.7. After the software system start, the program will be configuring the Arduino Serial Port. Then, from Ultrasonic Sensor will send the distance data from Arduino to personal computer by serial communication. The experiment result will be compared and confirmed with the numerical simulation result. Finally, the result of experiment can be analyzed to get the acceleration due to gravity, g value.

3.2 Hardware Design

The hardware of Simple Pendulum Experiment Apparatus consists by Personal Computer, Arduino board, Ultrasonic sensor type HC-SR04, ball pendulum, cotton string, stand base mechanic, and some cable connections shown as Figure 3.

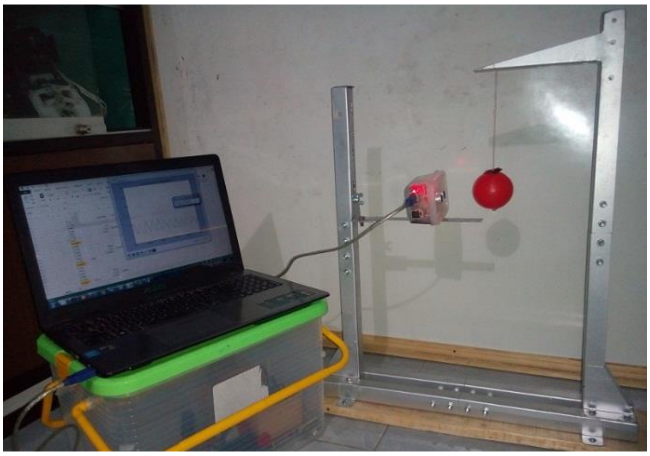
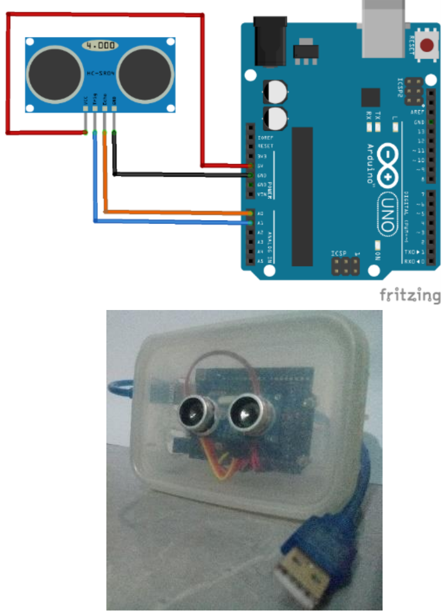


Figure 3 Simple Pendulum Experiment Apparatus



(a)

(b)

Figure 4 Electronic Circuit of Simple Pendulum; (a) Schematic (b) Realization

The electronic circuit of Simple Pendulum shown as Figure 4, consist by Ultrasonic sensor and Arduino board. The Ultrasonic sensor consist by Vcc, Trigger, Echo, and Ground pin. Each pin connects to Arduino pin; Vcc to 5v pin, Echo to A1 pin, Trigger to A0 pin, and Ground to GND pin. For the serial communication with personal computer, connect by using USB serial connector.

4. Numerical Simulation

In this study, to solve the mathematical model of Simple Pendulum used Runge-Kutta 4 Order method (RK4), because the method allow the differential solution with minimize the truncation error. The numerical simulation of Simple Pendulum system used Python 2.7 software. With the evaluation of equation (5), the RK4 solution of Simple Pendulum obtained, for θ_{i+1};

$$\left.\begin{aligned} \theta_{i+1} &= \theta_i + \left(\frac{k_1+2k_2+2k_3+k_4}{6}\right) \\ k_1 &= h(\omega_i) \\ k_2 &= h\left(\omega_i + \frac{k_1}{2}\right) \\ k_3 &= h\left(\omega_i + \frac{k_2}{2}\right) \\ k_4 &= h(\omega_i + k_3) \end{aligned}\right\} \qquad (6)$$

f or ω_{i+1};

$$\left.\begin{aligned} \omega_{i+1} &= \omega_i + \left(\frac{k_1+2k_2+2k_3+k_4}{6}\right) \\ k_1 &= h\left(-\frac{g}{l}\sin\theta_i - \frac{b}{ml^2}\omega_i\right) \\ k_2 &= h\left(-\frac{g}{l}\sin\left(\theta_i + \frac{k_1}{2}\right) - \frac{b}{ml^2}\left(\omega_i + \frac{k_1}{2}\right)\right) \\ k_3 &= h\left(-\frac{g}{l}\sin\left(\theta_i + \frac{k_2}{2}\right) - \frac{b}{ml^2}\left(\omega_i + \frac{k_2}{2}\right)\right) \\ k_4 &= h\left(-\frac{g}{l}\sin(\theta_i + k_3) - \frac{b}{ml^2}(\omega_i + k_3)\right) \end{aligned}\right\} \qquad (7)$$

where $h = \frac{b-a}{N}$ called the step size (N is a positive integer), the process will be iterated for N - 1 times. θ_{i+1} and ω_{i+1} is a solution of the Simple Pendulum system. After the numerical simulation calculate the solution, the result be plotted by using Matplotlib library for Python software shown as Figure 5.

5. Result and Discussions

Figure 6 show the hardware system of the Simple Pendulum experiment apparatus based on Ultrasonic sensor and Arduino microcontroller. This system can be measuring the pendulum distance and the time, then the data send to Personal Computer and automatically save on .csv file (can open with excel software). In addition, the data interfaced as graphic distance toward the time based on Python 2.7 software shown in the Figure 6b.

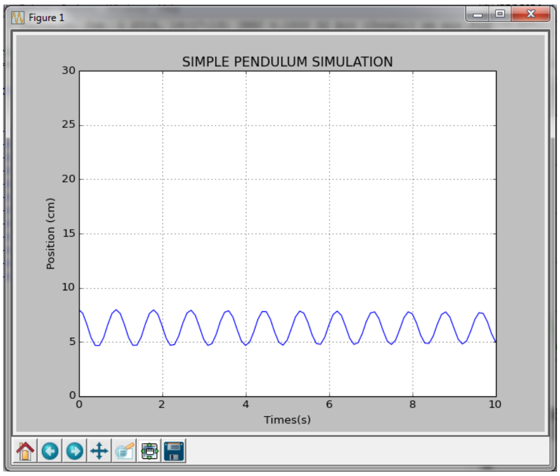
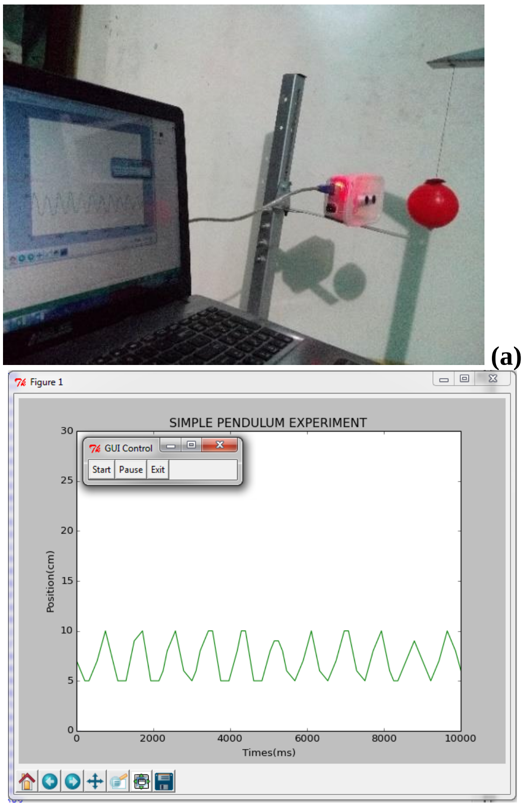


Figure 5 Numerical Simulation Result of Simple Pendulum



(a)

(b)

Figure 6 Simple Pendulum Experiment; (a) Hardware System, (b) Graphical Interface

From the graphical interface on Figure 6b, show that the data forming like a waveform. If the experiment data compare with the numerical simulation show the best agreement result of the graphic waveform. After obtain the calculated of period from the experiment data result, we can define the acceleration due to gravity. Finally, the data experiment result obtains the average value of the acceleration due to gravity is 9.811±1.067 m/s^2.

6. Conclusions

In this research, we have investigated to develop the real-time Simple Pendulum experimental apparatus. The development of Simple Pendulum Experiment

Apparatus based on Sensor Ultrasonic and Arduino was successfully presented. The numerical simulation using RK4 method based on Python 2.7 successfully presented the Simple Pendulum system. The experimental results show good results when compared with the results of numerical simulations, thus get the average value of the acceleration due to gravity is 9.811±1.067 m/s2. The advantage of this system is Open Source that makes physics experiments easier and low cost if compared with other advance experiment apparatus.

Acknowledgment

The authors would like gratefully acknowledgment the financial support from LPM2M UIN Sunan Gunung Djati Bandung, Indonesia.

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