Design and implementation of an Arduino-based instrument for parabolic motion

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Abstract. The lack of a physical instrument for determining the initial speed of experiment of the parabolic motion in the Department of Physics, Tadulako University, is one problem. In this research, we have been designed, implemented, and tested to show the initial velocity value of an Arduino-based to address this problem. The stages of this research began with the design and manufacture of mechanical systems, electronic systems such as power supply circuits and infrared detector circuits, motor stepper circuit, a series of servo motors, LCD circuits, and keypad circuits using the Arduino ATmega 2560 microcontroller. The next stage is making the test program and the main program. This tool has been tested and operated so that it gets good results. The initial measured speed is displayed on the LCD. The stability of measuring objects is excellent based on a low standard deviation between 0.02 - 0.06.

1. Introduction

The availability of experimental equipment in a physics laboratory greatly affects the level of student acceptance of a topic related to that equipment [1]. The students can easily access them. Thus students get a wealth of very significant benefits by experimenting with experimental equipment [2]. However, sometimes the experimental equipment is not available for various reasons.

A few things cause the unavailability of experimental instruments within the laboratory. To begin with, the instrument for the practicum is non-existent. Also, the experiment gear is troublesome to discover or seldom delivered. Moreover, the hardware has a costly cost that's not fitting for the existing budget. This problem happens in parabolic motion experimental equipment in the Department of Physics, Tadulako University. Research must be done to overcome these problems, including research on making simple tools on the topic of parabolic motion.

Several studies have been carried out regarding the parabolic motion's two parameters, namely the initial velocity and the elevation angle. First, Sarjani has assembled digital parabolic motion experiments based on the ATmega328 microcontroller to measure motion parameters [3]. It identifies initial speed, travel distance and travel time. This research used two photogate sensors that function to count the travel time of objects and measure the objects' initial velocity. A protractor is used to measure the variation of the elevation angle. Second, the development of laboratory devices with the application of interfacing a light sensor using a stopwatch for parabolic events [4]. Determination of the initial velocity using an infrared LED sensor with an angle adjusted using a protractor and the object's tensile force is adjusted using a spring. The development of simple props for a parabolic motion can motivate students to learn...
physics about parabolic motion [5]. This research identifies the angle variation using the protractor and the maximum height of a parabolic motion. However, from those previous studies, adjusting the elevation angle and tensile force is done manually so that data collection takes a long time and allows a lack of measurement accuracy. Also, the components used in the study are economically quite expensive. Based on these reasons, this research was conducted to produce a simple physical instrument that can accelerate the data collection and reduce inaccuracy due to manual measurements. By this instrument, the speed determination and the elevation angle adjustment are controlled by the Arduino.

2. The electric components, design and method

Based on the block diagram in Figure 1, the mechanical system consists of a path with an inclined plane, detector I, detector II and detector III as well as a stepper motor and servo motor. In the electronic system, this instrument consists of the circuit of detector 1, the circuit of detector 2, the circuit of detector 3, the circuit for stepper motors, the circuit for servo motors and keypads. Each of these circuits is connected to the Atmega 2560 microcontroller input and output pins. The data will be displayed on the 4 x 20 LCD.

![Figure 1](image_url)

**Figure 1** The block diagram of the instrument for Arduino-based parabolic motion

The research begins with the design and builds the mechanical system as shown in Figure 2. The next step builds the electronic system. One of the main steps is building the program to control the instrument. The next step is to unify the system into an instrument and the final step is to operate the instrument in the form of instrument testing and data collection.
Figure 2 The mechanical system of the instrument for Arduino-based parabolic motion

The program controller and data processing for the microcontroller use open source software Arduino IDE. The binary code program was then uploaded to the ATMega 2560 microcontroller on the Arduino board. The flowchart of the program shows in Figure 3. The program started by the initialization of the microcontroller. The elevation angle and detector distance input through the keypad. When the start button hit, the spring realizes and push the projectile. It will move and pass the detectors. The travel time will be calculated based on when the projectile passes the first detector and the second detector. The projectile's initial speed will determine based on the detector distance and travel time between the detectors.

Figure 3 The flowchart of the microcontroller program for controlling, data processing, and display
3. Results and Discussion

Figure 4 shows the instrument for Arduino-based parabolic motion. The main mechanical part of the elevated plane is made of steel. There is a servo motor at the bottom of the inclined plane to initiate the release of the spring and at the top, there is a launcher cylinder where the detectors consist of IR LED and IR photodiode pairs. Figure 5 shows the circuit diagram of the whole electrical system of this instrument. It contains five primary circuits, namely Arduino mega2560 board, stepper motor circuit, LCD 4X20, servo motor, detector circuits, and power supply.

**Figure 4.** The instrument for Arduino-based parabolic motion made in this research a) launcher tube, b) inclined steel-plat, c) protractor, d) body holder and e) stepper motor

**Figure 5.** The block diagram of the electrical system of the instrument
Furthermore, the spring pulls data decrease of the initial speed at the same length of the spring stretching. It shows that the average of the initial speed is proportional to the length of the spring stretching. The longer the stretching length, the higher the initial speed. This phenomenon is caused by the magnitude of the hitting force on the projectile. If the stretching length higher, the magnitude of the produced force is also higher. However, the increase of the elevation angle causes the decrease of the initial speed at the same length of the spring stretching, as shown in Figure 6.

Table 1. The experiment data of the initial speed of the projectile for different elevation angle and different length of spring stretching

| No | Elevation angle of 5° | Elevation angle of 10° | Elevation angle of 15° |
|----|-----------------------|------------------------|------------------------|
|    | Length of spring stretching | Length of spring stretching | Length of spring stretching |
|    | 2 cm | 4 cm | 6 cm | 8 cm | 2 cm | 4 cm | 6 cm | 8 cm | 2 cm | 4 cm | 6 cm | 8 cm |
| 1  | 1.01 | 3.12 | 4.94 | 6.94 | 0.98 | 3.05 | 4.84 | 6.86 | 0.77 | 2.94 | 4.81 | 6.91 |
| 2  | 1.08 | 3.07 | 4.85 | 6.95 | 0.95 | 3.01 | 4.92 | 6.93 | 0.75 | 2.90 | 4.75 | 6.92 |
| 3  | 1.05 | 3.08 | 4.83 | 6.93 | 0.92 | 2.97 | 4.82 | 6.86 | 0.76 | 2.91 | 4.78 | 6.86 |
| 4  | 1.08 | 3.13 | 4.97 | 7.00 | 0.95 | 2.94 | 4.84 | 6.87 | 0.73 | 2.93 | 4.85 | 6.88 |
| 5  | 1.11 | 3.12 | 4.98 | 6.93 | 0.98 | 2.97 | 4.94 | 6.85 | 0.77 | 2.93 | 4.74 | 6.88 |
| 6  | 1.06 | 3.12 | 4.83 | 6.92 | 0.97 | 2.96 | 4.84 | 6.84 | 0.75 | 2.96 | 4.77 | 6.92 |
| 7  | 1.08 | 3.12 | 4.92 | 6.98 | 0.97 | 2.97 | 4.80 | 6.85 | 0.79 | 2.98 | 4.77 | 6.85 |
| 8  | 1.04 | 3.09 | 4.83 | 6.92 | 0.97 | 2.93 | 4.82 | 6.86 | 0.76 | 2.91 | 4.79 | 6.87 |
| 9  | 1.09 | 3.04 | 4.83 | 7.00 | 0.97 | 2.99 | 4.81 | 6.98 | 0.78 | 2.99 | 4.77 | 6.90 |
| 10 | 1.08 | 3.03 | 4.95 | 6.97 | 0.93 | 3.01 | 4.84 | 6.92 | 0.74 | 2.95 | 4.78 | 6.88 |

Average value | 1.07 | 3.09 | 4.89 | 6.95 | 0.96 | 2.98 | 4.85 | 6.88 | 0.76 | 2.94 | 4.78 | 6.88 |
Deviation     | 0.03 | 0.04 | 0.06 | 0.03 | 0.02 | 0.04 | 0.05 | 0.05 | 0.02 | 0.03 | 0.03 | 0.03 |

![Figure 6](image_url) The average initial value of projectile in different elevation angle (triangle for circle, diamond, and rectangle are the length of spring stretching for 2 cm, 4 cm, 6 cm, and 8 cm, respectively)
The decreasing of initial speed when increasing the instrument's elevation angle can be caused by the changing of the force against the projectile movement (see $F_{b1}$ and $F_{b2}$ in Figure 7) [8, 9]. $F_d$ is the force drive the projectile to move forward and on the other hand, $F_{b1}$ and $F_{b2}$ drive it back. If the elevation angle $\theta$ is different, i.e. $\theta_1 < \theta_2$, then the $F_{b1} < F_{b2}$. In this case, the back force's magnitude depends on the sinus value of the elevation angle.

![Figure 7. The comparison of forces effects on the projectile for different elevation angle where $\theta_2 > \theta_1$](image)

4. Conclusion
The instrument for determining the projectile's initial speed in a parabolic motion based on the Arduino ATMega 2560 has been made using an infrared photodiode to detect the presence of objects. This instrument has been tested and operated using an iron ball with good results. The initial speed value displayed is calculated based on the two detectors' distance and the time interval between them. The standard deviation is low, with a value of 0.02 - 0.06.

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