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Atwood machine automation using Arduino and LabVIEW

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Abstract

The Atwood machine ¹⁵ is an apparatus used in physics experiments to visualize the ¹² concept of Newton's Second Law of Motion. However, the data collection on the Atwood machine, which is still done manually using a stopwatch, may cause errors and can be time-consuming. To improve the efficiency and accuracy of the experiment, this research developed Atwood machine automation using Arduino Uno microcontroller. The automation enables automatic release of weights and automatic data collection through a graphical user interface developed using LabVIEW. The experiment using the automated machine obtained satisfactory results in verifying the earth's gravitational acceleration. Therefore, this machine can be used in physics learning, especially in physics experiment. The automation also enables remote utilization through internet connection, thus allowing easier and wider access for users.

Keywords: Atwood machines, Arduino, automation apparatus

⁸ Introduction

The Atwood machine was first introduced by George Atwood (1746–1807), this machine consists of two masses or weights which are connected by a string, hanging over a fixed pulley [1, 2]. This equipment is often used to visualize the concept of Newton's Second Law of Motion through practicum or experiment [3–5]. Additionally, in higher education practicum, Atwood machines are usually used to verify the

earth's gravitational acceleration [6]. The working principle of this equipment is to determine the time taken for an object to move from point A to point B ² or a non-uniform motion in a straight line, and the time taken for ⁵ object to move from point B to point C for a uniform motion in a straight line (see figure 1) [7].

In general, data collection in experiments utilizing Atwood machines is still conducted manually using two ⁹ stopwatches [8]. The first stopwatch measures the time taken for an object to travel from point A to point B, while the second measures the time taken for the object to travel from point B to point C. Unfortunately,

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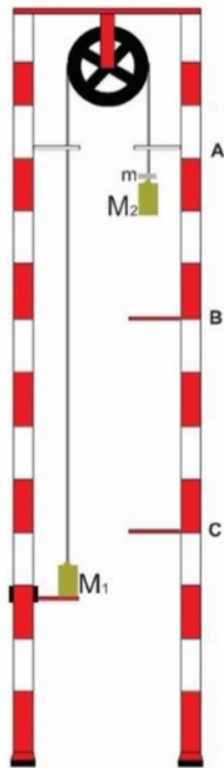


Figure 1. The Atwood machine.

this method of data collection can potentially introduce significant calculation errors [9]. Additionally, the use of stopwatches in the data collection process for Atwood machines is relatively time-consuming and often results in failures, necessitating multiple repetitions of the experiment.

Data collection using this technique is suitable for experiments aimed at enhancing students' proficiency with specific practical equipment. However, this technique is no longer relevant for practicum activities that emphasize data analysis, particularly at the higher education level. Furthermore, the data collection process using this manual method is time-consuming. Experiments

that primarily focus on improving data analysis skills should employ automated data collection methods.

Various methods have been employed to modernize the Atwood machine, including one approach by [10] that utilized the acceleration sensor on a smartphone. In this method, the smartphone was attached to one end of a string while a weight was attached to the other end. Upon releasing the weight, the smartphone recorded data in the form of time versus acceleration using the Phypox application. This data was then used to analyze the Earth's gravitational acceleration.

Asrizal *et al* [11] conducted research related to the Atwood Machine in 2022. This study introduced innovations in the data collection process by using a video tracking technique. Additionally, remote control was used to release the weights. During the data collection process, the objects were released via remote control and their movement was recorded using a camera. The recorded data was then analysed using video tracking.

Both [10] and [11] have made good innovations for improving the performance of Atwood machines in experiments, in terms of the experiment results and ICT utilization. However, these two innovations still need to be improved, particularly in terms of practicality. In research by [10], the data recorded by the smartphone still have to be transferred to a computer for analysis. Besides, there is also a risk that the smartphone will fall during the experiment. Similarly, in research by [11], the recording results from the camera also have to be transferred to a computer for analysis using video tracking. In addition, both procedures do not allow remote access because they still use the hands-on experiment method.

Based on this background, this article describes the automation of the Atwood machine. The automation was achieved by utilizing the Arduino Uno microcontroller, which was connected to a weight release actuator and an IR obstacle sensor to extract time data. Device control and data acquisition were managed through a graphical user interface (GUI) developed with LabVIEW. Additionally, the GUI could be connected to a web application, allowing for remote access via the internet.

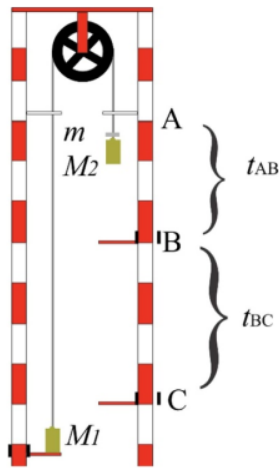


Figure 2. Working principle of Atwood machine.

2. Materials and methods

The automation process of the Atwood machine was conducted in three stages: studying the physics concept of the Atwood machine, designing the automation device, and developing the software for the control system and data acquisition system.

2.1. Atwood machine

The Atwood machine is a device that can visualize both uniform and non-uniform motion in a straight line [4, 12]. These motions are challenging to illustrate due to the numerous influencing factors [13]. Utilizing the Atwood machine enables experiments related to the concepts of uniform and non-uniform motion in a straight line.

The time taken from point A to point B (t_{AB}) is an event of non-uniform motion in straight line, while the time taken from point B to point C (t_{BC}) is an event of uniform motion in straight line (see figure 2).

The presence of ballast weight m on weight M_2 results in a non-zero resultant force acting upon weight M_2 . According to Newton's laws of motion, in the presence of a non-zero resultant force, weight M_2 experiences acceleration (a). Consequently, upon the release of weight M_1 , weight M_2 initiates accelerated motion from point A to point B. Subsequently, the relationship

between the position of the weight and time from point A to B can be mathematically expressed as:

$$s(t) = v_{AB}t_{AB} + \frac{1}{2}at_{AB}^2. \quad (1)$$

At point A, the weight does not move, so the initial velocity (v_A) is zero, so the equation can be expressed as follows,

$$s_{AB} = \frac{at_{AB}^2}{2}. \quad (2)$$

Meanwhile, the final velocity at point A to B is expressed in

$$v_{BC} = at_{AB}. \quad (3)$$

At point B, the ballast weight m becomes immobilized, while weight M_2 continues its motion towards point C. The fixation of ballast weight m at this juncture leads to a resultant force of zero acting upon weight M_2 , thereby halting its acceleration, and inducing a state of constant velocity, characterized by uniform motion in a straight line.

Through this event, we can obtain the gravitational acceleration which is expressed as,

$$a = \frac{(M_2 + m - M_1)g}{M_2 + m + M_1 + \frac{I}{R^2}}. \quad (4)$$

The weights used in the experiment using the Atwood machine have the same mass, $M_1 = M_2 = M$, equation (4) can be written as,

$$a = \frac{mg}{2M + m + \frac{I}{R^2}}. \quad (5)$$

Determining the gravitational acceleration (g) through experiments using the Atwood machine can be done using equation (5) by fitting it to the linear function equation, $y = A_1x + A_0$. To ease the calculation, equation (5) can be written as,

$$\frac{1}{a} = \frac{2M + m + \frac{I}{R^2}}{mg} \quad (6)$$

$$\frac{1}{a} = \left(\frac{2M + \frac{I}{R^2}}{g} \right) \frac{1}{m} + \frac{1}{g}. \quad (7)$$

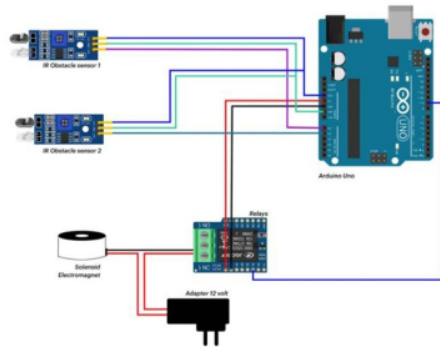


Figure 3. Scheme of automation device.

Based on equation (7), from the gradient of the line obtained, the earth's gravitational acceleration can be determined by

$$g = \frac{2M + \frac{l}{R^2}}{A_1}. \quad (8)$$

2.2. Design of automation device

The automation device's design comprises an Arduino Uno microcontroller, an electromagnet (solenoid), and an IR obstacle sensor, all interconnected as illustrated in figure 3.

The Arduino Uno served as the controller for device performance, the mechanism for weight release, and the recorder of time data (utilized for data acquisition) throughout the experiment.

The electromagnet (solenoid) was used to hold weight M_1 . Upon application of current, the resulting magnetic force effectively held the weight in place. Conversely, deactivation of the current through a relay lost the magnetic field, consequently releasing weight M_1 and initiating system movement. The IR obstacle sensor, an infrared sensor, was utilized for temporal tracking as weight M_2 traversed points A and B.

2.3. Software development

The automation system was controlled using LabVIEW, specifically through a GUI. LabVIEW, known for its block diagram-based programming

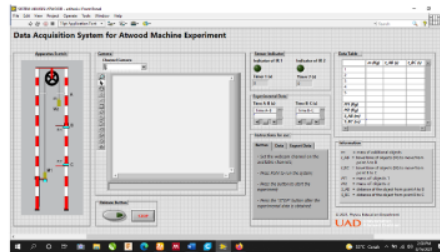


Figure 4. GUT's data acquisition system.

language, facilitates the creation of virtual instrumentation systems [14, 15]. In addition to its block diagram-based interface, which enhances user-friendliness in application development [16], LabVIEW offers web publishing tools, enabling remote access to the developed applications [14].

The GUI, depicted in figure 4, functions as the interface through which commands are issued to the automation device. The main display of the GUI comprises several components, including: (1) an illustration depicting the Atwood machine utilized, (2) a camera panel for visualizing experiments when the machine is accessed remotely, (3) a panel containing buttons for weight release, (4) a sensor indicator serving as a marker denoting the sensor's activation, (5) a panel for displaying extracted experimental data, (6) concise usage instructions, (7) a tabulated display of experimental data, and (8) information pertaining to the symbols employed.

These parts are connected in a block diagram as shown in appendices A and B. Detailed schematics of the automated Atwood machine circuit, along with the source code, are also available on GitHub at <https://github.com/tonikoesh/atwood-machine>.

3. Result and discussion

3.1. Result

The primary focus of the research entailed automating the existing Atwood machine. This automation primarily targeted the weight release and time recording functionalities, which were executed using an Arduino microcontroller

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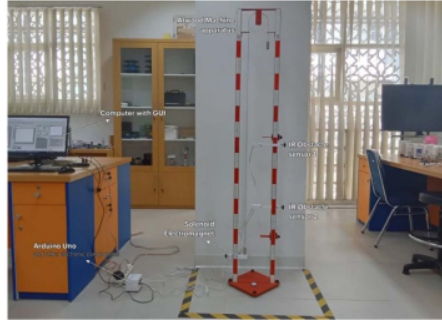


Figure 5. Image of the Atwood machine automation.

controlled through a GUI. Figure 5 illustrates an image depicting the automated Atwood machine.

In comparison to previous studies by [10] and [11], the novelty of this research primarily lies in the time recording system. Unlike the methodologies employed in [11], which utilize video tracking techniques, and [10], which rely on sensors integrated into smartphones, this study employs an IR obstacle sensor for time measurement. Additionally, novelty is evident in the developed acquisition system. This research features a device control system alongside a computerized data acquisition system facilitated through a GUI. Moreover, the system implemented in this study offers remote accessibility, thereby presenting a viable solution to enhance laboratory accessibility, particularly in regions grappling with limitations in laboratory infrastructure [14].

The developed automation of the Atwood machine underwent experimental testing to validate the earth's gravitational acceleration. In this experimental setup, identical weights M_1 and M_2 were employed, each weighing 103 g. Additionally, five ballast weights, denoted as m , were utilized, each weighing 5 g. The inclusion of various weights served the purpose of elucidating the influence of mass on the acceleration of descending objects. The distance between points A and B was set at 60 cm, while the distance between points B and C was 30 cm.

3.2. Discussion

The experimental procedures conducted in this study, encompassing data collection, were automated and overseen via the GUI. Figure 6 depicts the data recorded through the GUI throughout the experiment. Subsequently, the collected data underwent analysis, with the outcomes presented in table 1.

Utilizing the data presented in table 1, a graphical representation illustrating the relationship between $1/a$ and $1/m$ was generated in accordance with equation (7), as depicted in figure 7. Through analysis of the graph's gradient, determined to be 0.025, and subsequent application of equation (8), the value of the Earth's gravitational acceleration was computed as 9.81 m s^{-2} , with a relative error of 0.07%. This relative error was determined through comparison of the experimental findings with the established theoretical value of 9.8 m s^{-2} .

The results derived from this study exhibited a considerable resemblance to those attained in prior investigations, as documented in [9–11]. This correlation underscores the applicability of the developed apparatus for facilitating physics education, particularly in the context of Atwood machine experiments.

In addition to adjusting the ballast weight m , this study also manipulated the distance between point B and point C to ascertain the optimal range for accurate data acquisition by the sensor. The

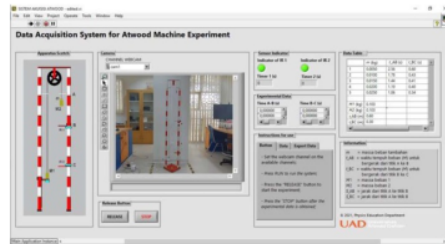


Figure 6. Results of data collection using the GUI.

Table 1. Results of experimental data analysis.

m (kg)	t_{AB} (s)	t_{BC} (s)	v_{BC} (s)	a ($m\ s^{-2}$)
0.0050	2.56	0.60	0.50	0.20
0.0100	1.78	0.43	0.70	0.39
0.0150	1.44	0.41	0.73	0.51
0.0200	1.19	0.40	0.75	0.63
0.0250	1.06	0.34	0.88	0.83

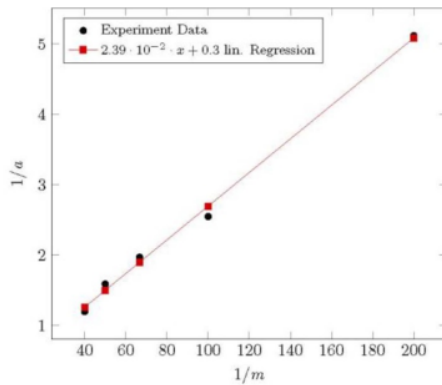


Figure 7. Graph of the relationship between $1/m$ and $1/a$.

distance between point B and point C was varied incrementally from 30 to 70 m, with intervals of 10 cm. The outcomes of the data analysis are presented in table 2.

According to the data analysis presented in table 2, the optimal distance between point B and point C for accurate sensor readings was determined to be 0.3 m. This finding highlights one of the limitations of the sensor identified in this investigation. To address this limitation, future

Table 2. Results of data analysis with variations in B–C distance.

s_{BC} (m)	g ($m\ s^{-2}$)	Relative errors (%)
0.3	9.81	0.07
0.4	8.05	17.64
0.5	7.74	20.90
0.6	7.63	21.93
0.7	7.30	25.34

research endeavours may explore the utilization of alternative sensor types, thereby facilitating further optimization of the distance between point B and point C.

3.3. Enhancement of learning

In physics learning, this Atwood Machine automation can be used for experiments on Newton’s Law II, primarily related to the discussion of uniform and non-uniform straight motion. Students can conduct experiments with this apparatus to verify the Earth’s gravitational acceleration based on Newton’s Law II. Students conduct data collection, analysis, and interpretation of the data/graphics obtained. Since the apparatus is automated and computerized, the data collection time is shorter, giving students a broader opportunity

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to analyse the data and deepen their understanding of applying the theory in the experiment. In addition, this automated apparatus introduces students to the skills of using technology in science, combining physics theory with relevant modern practices.

4. Conclusion

The automation of the Atwood machine has been successfully developed, featuring both a weight release mechanism and a computerized data recording system facilitated by a GUI. The

functionality of this machine, inclusive of its GUI interface, has demonstrated promising outcomes in validating Earth's gravitational acceleration through experimental procedures. Consequently, this apparatus stands as a valuable resource for enhancing physics education, particularly through hands-on experimentation.

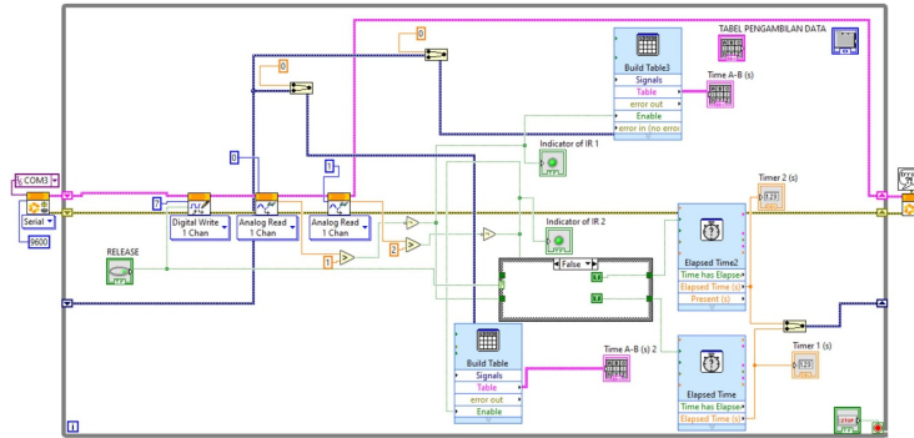
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Data availability statement

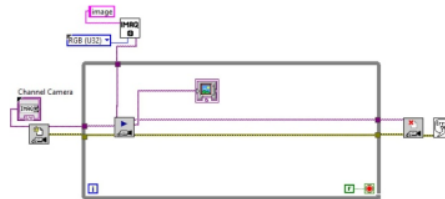
All data that support the findings of this study are included within the article (and any supplementary files).

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Appendix A. Block diagram of load release and time recorder



Appendix B. Camera panel block diagram



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Received 29 April 2024, in final form 10 June 2024
Accepted for publication 28 June 2024
<https://doi.org/10.1088/1361-6552/ad5d44>

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Yuda Dwi Prasetya is a student in the Physics Education Study Program at Ahmad Dahlan University. He is part of the team developing the remote physics laboratory. His area of interest is the development of microcontroller-based apparatus.



Yoga Dwi Prabowo is a laboratory assistant at Ahmad Dahlan University Science Learning Technology Laboratory (LTPS). Currently he is actively part of the team developing the Remote Physics Laboratory (R-Phylab).



Toni Kus Indratno is a lecturer in the physics education department at Universitas Ahmad Dahlan. His current research interest focuses on the application of ICTs (smartphones/computers) in physics learning. Besides, he and his team are developing a remote-based laboratory (R-Phylab) for distance physics learning.



Moh. Irma Sukarelawan is a doctor in physics education, especially whose areas of interests are misconceptions and evaluation of physics learning. Currently, he is involved in developing a physics learning evaluation system using R-Phylab.

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