Manuscript Title : Atwood machine automation using Arduino and LabVIEW

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Journal : Physics Education

1. Submitted to the journal “Physics Education” – 30 April 2024
2. Editor request to fill out Copyright form – 03 May 2024
3. Revisions required – 04 June 2024
4. Revised version received – 10 June 2024
5. Paper is almost ready to be accepted – 20 June 2024
6. Video abstract invitation – 20 June 2024
7. Paper accepted for publication – 28 June 2024
8. Article is ready to check – 10 July 2024
9. Paper published – 17 July

1. Submitted to the journal "Physics Education"

30 April 2024

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COMMENTS TO THE AUTHOR(S)
Dear authors,

Your work focuses on the automation of the Atwood machine using Arduino and LabVIEW to improve the accuracy of the measurements, but to be really usefull for students and teachers, the paper should be improved by including the details of the schematic of the Arduino circuit and the codes of Arduino and LabVIEW, maybe linking to a github repository or similar.

A reference about the Atwood machine using new technologies could be added:
Martín Monteiro; Cecilia Stari; Cecilia Cabeza; Arturo C. Marti, "The Atwood machine revisited using smartphones," The Physics Teacher 53, 373–374 (2015)
https://doi.org/10.1119/1.4928357

Finaly, the writting and the grammar should be carefully revised.
Some examples:

Abstract

"The Atwood machine is an apparatus used in physics experiments to visualize"
Instead of "The Atwood machine is one of the apparatuses in physics experiments to visualize"

"Therefore, this machine can be used in physics education"
Instead of "Therefore, this machine can be used in physics learning"

Introduction

"Additionally, in higher education practicum, Atwood "
Instead of "In addition, in practicum at higher education level, Atwood"

Materials and Methods

"The Atwood machine is one of the pieces of equipment that can"
Instead of "The Atwood machine is one of the equipments that can"

Conclusion
"The automation of the Atwood"

Instead of "Automation of the Atwood"

Best regards

Editor in Chief Comments

I would like there to be some explanation of what is being taught and how this improved the teaching of that particular set of concepts. The text seems to state that data analysis was the main concept being taught but I see no mention of students carrying out data analysis. The tables look like they came straight from the computer. Perhaps the students were learning how to automate an experiment which I would liken more to engineering - which is fine but not quite the same thing as physics. Everything described in the paper seems valuable to students but it's not very clear what it was they were supposed to be learning nor how this activity improved that learning.
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Atwood machine automation using Arduino and LabVIEW

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Received xxxxxx
Accepted for publication xxxxxx
Published xxxxxx

Abstract

The Atwood machine is an apparatus used in physics experiments to visualize the 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 (GUI) 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*

1. 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 [5]. The working principle of this equipment is to determine the time taken for an object to move from point A to point B for a non-uniform motion in a straight line, and the time taken for the 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 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, 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.

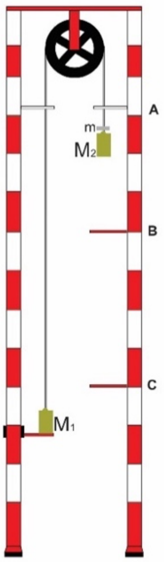


Figure 1. The Atwood Machine

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.

Reference [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 analyzed 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.

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).

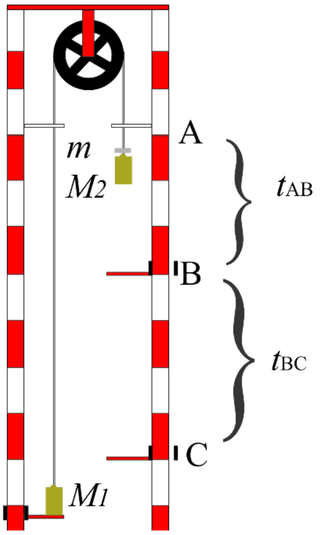


Figure 2. Working principle of Atwood Machine

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:

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

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

$$s_{AB} = \frac{a t_{AB}^{2}}{2} \quad (2)$$

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

$$v_{BC} = a t_{AB} \quad (3)$$

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,

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

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,

$$a=\frac{mg}{2M+m+\frac{I}{R^2}} \tag{5}$$

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,

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

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

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

$$g=\frac{2M+\frac{I}{R^2}}{A_1} \tag{8}$$

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.

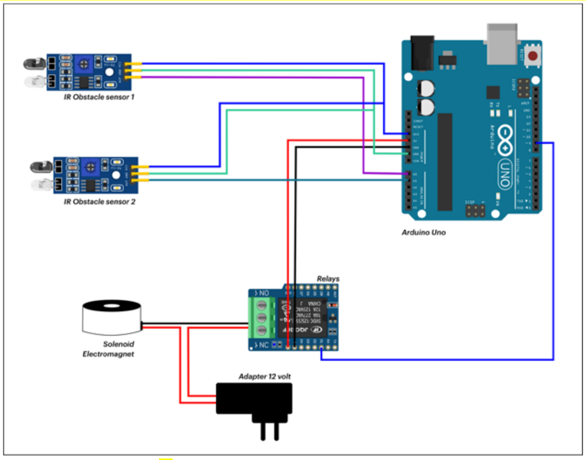


Figure 3. Scheme of automation device

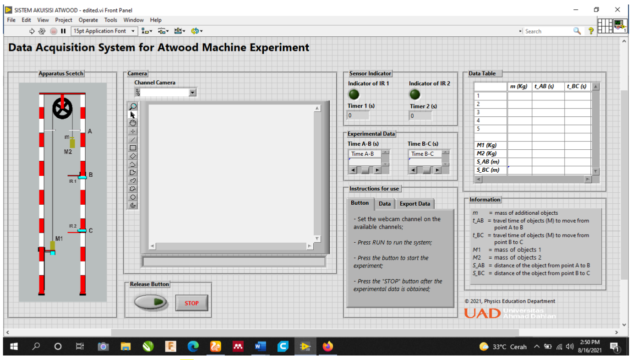
The Arduino Uno served as the controller for device performance, the mechanism for weight release, and the recorder of time data (utilized for data acquisition) throughout the experiment.

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 graphical user interface (GUI). LabVIEW, known for its block diagram-based programming 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.



Data Acquisition System for Atwood Machine Experiment

Timer 1 (s): 0

Timer 2 (s): 0

	m (Kg)	t_AB (s)	t_BC (s)
1			
2			
3			
4			
5			
M1 (Kg)			
M2 (Kg)			
S_AB (m)			
S_BC (m)			

Instructions for use

Button | Data | Export Data

- Set the webcam channel on the available channels;
- *Press RUN to run the system;*
- *Press the button to start the experiment;*
- *Press the "STOP" button after the experimental data is obtained;*

m = mass of additional objects
t_AB = travel time of objects (M) to move from point A to B
t_BC = travel time of objects (M) to move from point B to C
M1 = mass of objects 1
M2 = mass of objects 2
S_AB = distance of the object from point A to B
S_BC = distance of the object from point B to C

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Figure 4. GUI’s data acquisition system

These parts are connected in a block diagram as shown in Appendix A and Appendix B. Detailed schematics of the automated Atwood machine circuit, along with the source code, are also available on GitHub at https://github.com/tonikoes/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 controlled through a graphical user interface (GUI). Figure 5 illustrates an image depicting the automated Atwood machine.

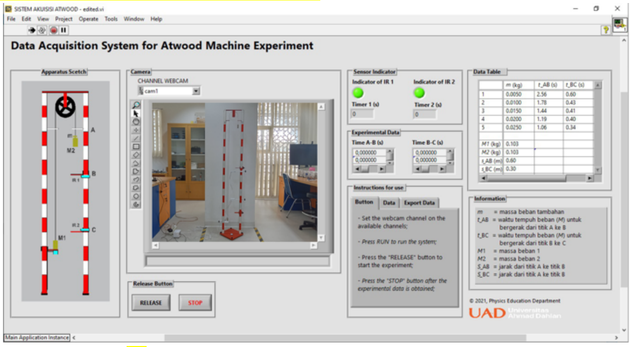
Figure 5. Image of the Atwood machine automation

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 graphical user interface (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 grams. Additionally, five ballast weights, denoted as m, were utilized, each weighing 5 grams. 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 graphical user interface (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.



Data Acquisition System for Atwood Machine Experiment

	m (kg)	t_AB (s)	t_BC (s)
1	0.0050	2.56	0.60
2	0.0100	1.78	0.43
3	0.0150	1.44	0.41
4	0.0200	1.19	0.40
5	0.0250	1.06	0.34
M1 (kg)	0.103		
M2 (kg)	0.103		
s_AB (m)	0.60		
s_BC (m)	0.30		

- Set the webcam channel on the available channels;

- Press RUN to run the system;

- Press the "RELEASE" button to start the experiment;

- Press the "STOP" button after the experimental data is obtained;

m = massa beban tambahan
t_AB = waktu tempuh beban (M) untuk bergerak dari titik A ke B
t_BC = waktu tempuh beban (M) untuk bergerak dari titik B ke C
M1 = massa beban 1
M2 = massa beban 2
S_AB = jarak dari titik A ke titik B
S_BC = jarak dari titik A ke titik B

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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

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/s², 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/s².

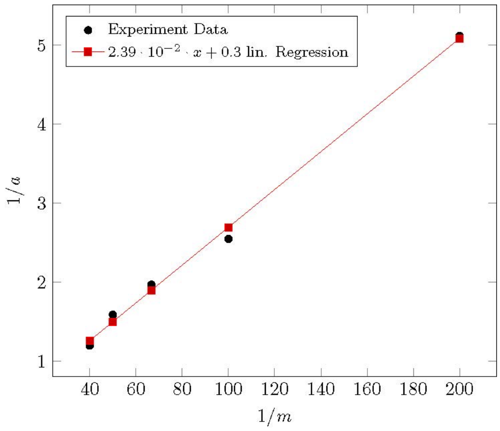

Figure 7. Graph of the relationship between $1/m$ and $1/a$

The results derived from this study exhibited a considerable resemblance to those attained in prior investigations, as documented in references [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 distance between point B and point C was varied incrementally from 30 to 70 cm, with intervals of 10 cm. The outcomes of the data analysis are presented in Table 2.

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

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 research endeavors 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 to analyze 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 Graphical User Interface (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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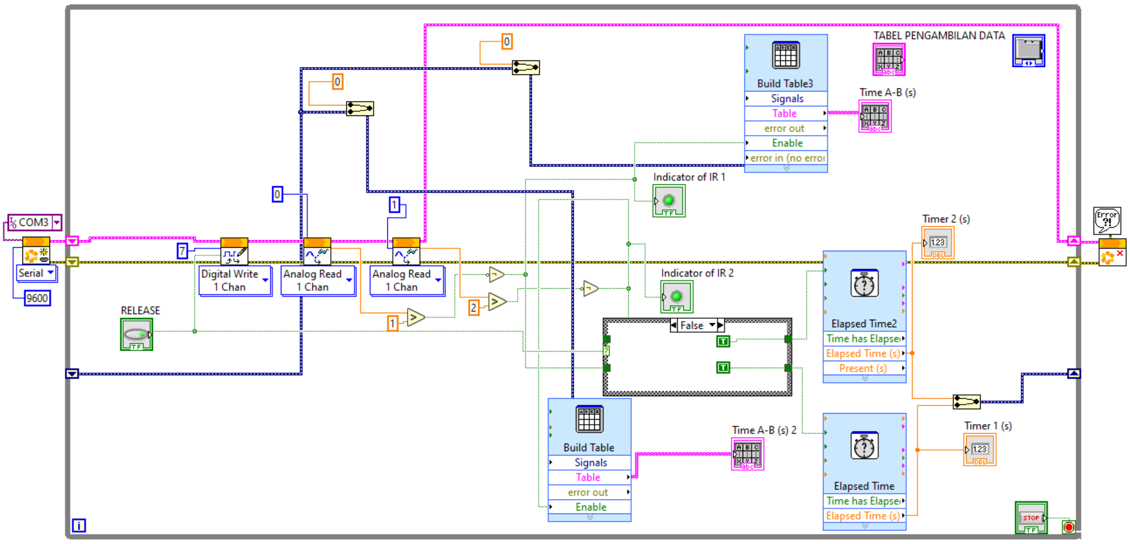
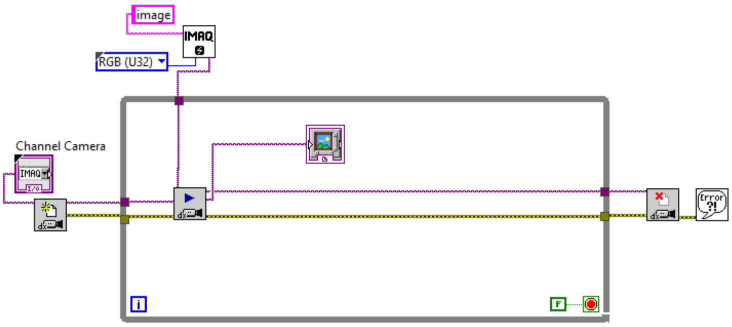
Appendix A. Block Diagram of Load Release and Time Recorder



Appendix B. Camera panel block diagram



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.

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Title
Atwood machine automation using Arduino and LabVIEW

Authors
Indratno, Toni
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Atwood machine automation using Arduino and LabVIEW

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Received xxxxxx
Accepted for publication xxxxxx
Published xxxxxx

Abstract

The Atwood machine is an apparatus used in physics experiments to visualize the 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 (GUI) 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*

1. 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 [5]. The working principle of this equipment is to determine the time taken for an object to move from point A to point B for a non-uniform motion in a straight line, and the time taken for the 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 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, 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.

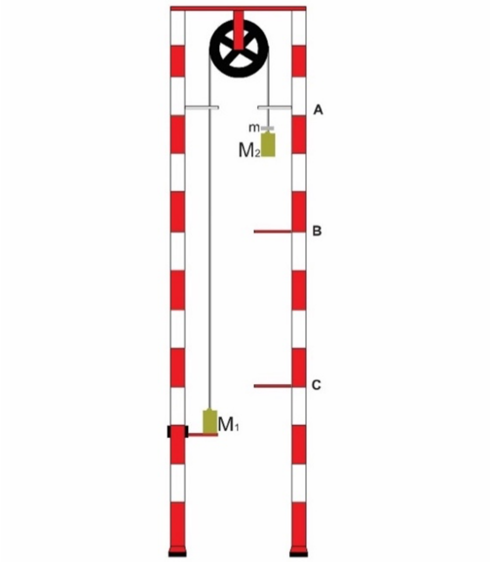


Figure 1. The Atwood Machine

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.

Reference [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 analyzed 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.

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).

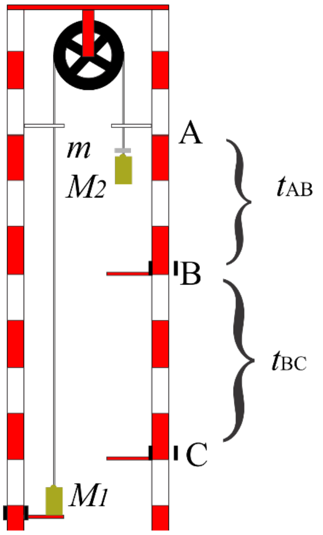


Figure 2. Working principle of Atwood Machine

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:

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

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

$$s_{AB} = \frac{at_{AB}{}^{2}}{2} \tag{2}$$

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

$$v_{BC} = at_{AB} \tag{3}$$

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,

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

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,

$$a = \frac{mg}{2M + m + \frac{I}{R^2}} \tag{5}$$

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, $y = A_1 x + A_0$. To ease the calculation, equation (5) can be written as,

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

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

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

$$g = \frac{2M + \frac{I}{R^2}}{A_1} \tag{8}$$

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.

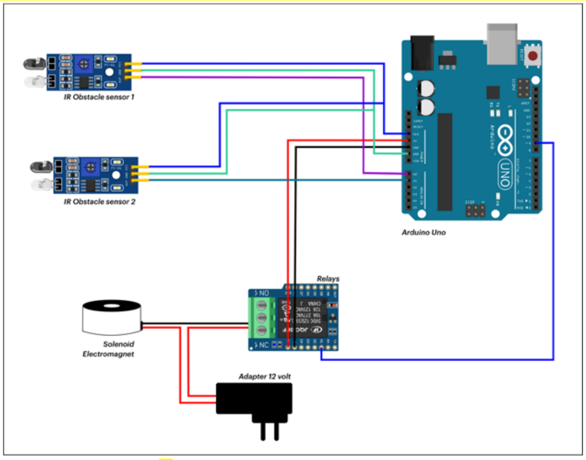


Figure 3. Scheme of automation device

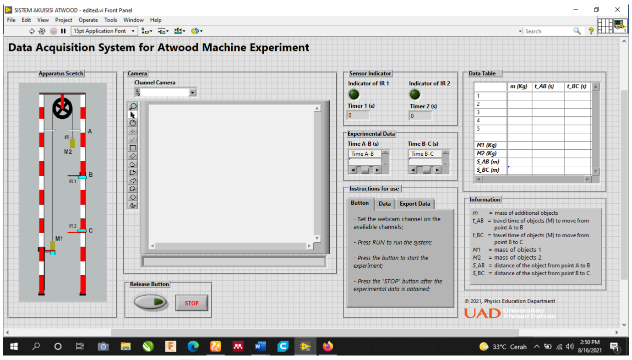
The Arduino Uno served as the controller for device performance, the mechanism for weight release, and the recorder of time data (utilized for data acquisition) throughout the experiment.

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 graphical user interface (GUI). LabVIEW, known for its block diagram-based programming 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.



Data Acquisition System for Atwood Machine Experiment

- Set the webcam channel on the available channels;
- Press RUN to run the system;
- Press the button to start the experiment;
- Press the "STOP" button after the experimental data is obtained;

m = mass of additional objects
t_AB = travel time of objects (M) to move from point A to B
t_BC = travel time of objects (M) to move from point B to C
M1 = mass of objects 1
M2 = mass of objects 2
S_AB = distance of the object from point A to B
S_BC = distance of the object from point B to C

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Figure 4. GUI's data acquisition system

These parts are connected in a block diagram as shown in Appendix A and Appendix B. Detailed schematics of the automated Atwood machine circuit, along with the source code, are also available on GitHub at https://github.com/tonikoes/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 controlled through a graphical user interface (GUI). Figure 5 illustrates an image depicting the automated Atwood machine.

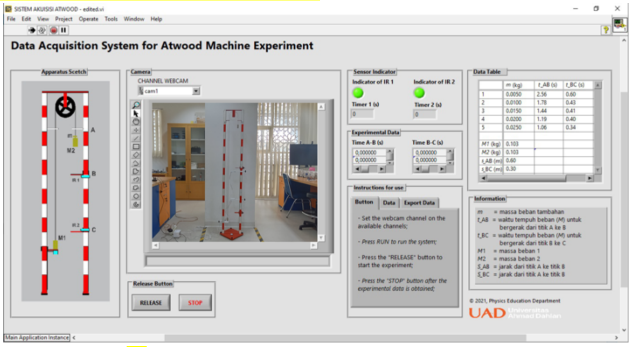
Figure 5. Image of the Atwood machine automation

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 graphical user interface (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 grams. Additionally, five ballast weights, denoted as m, were utilized, each weighing 5 grams. 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 graphical user interface (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.



Timer 1 (s): 0
Timer 2 (s): 0

Time A-B (s): 0,000000 0,000000
Time B-C (s): 0,000000 0,000000

	m (kg)	t_AB (s)	t_BC (s)
1	0.0050	2.56	0.60
2	0.0100	1.78	0.43
3	0.0150	1.44	0.41
4	0.0200	1.19	0.40
5	0.0250	1.06	0.34
M1 (kg)	0.103		
M2 (kg)	0.103		
s_AB (m)	0.60		
s_BC (m)	0.30		

- Set the webcam channel on the available channels;
- Press RUN to run the system;
- Press the "RELEASE" button to start the experiment;
- Press the "STOP" button after the experimental data is obtained;

m = massa beban tambahan
t_AB = waktu tempuh beban (M) untuk bergerak dari titik A ke B
t_BC = waktu tempuh beban (M) untuk bergerak dari titik B ke C
M1 = massa beban 1
M2 = massa beban 2
S_AB = jarak dari titik A ke titik B
S_BC = jarak dari titik A ke titik B

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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

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/s², 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/s².

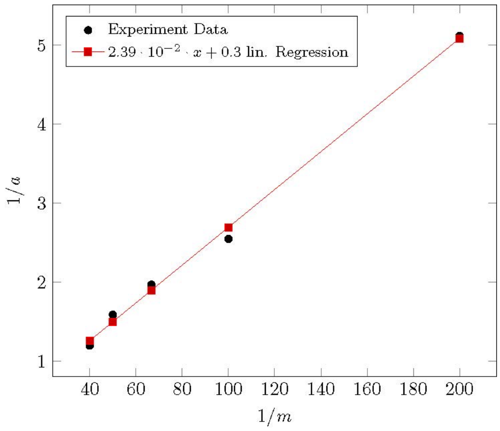

Figure 7. Graph of the relationship between $1/m$ and $1/a$

The results derived from this study exhibited a considerable resemblance to those attained in prior investigations, as documented in references [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 distance between point B and point C was varied incrementally from 30 to 70 cm, with intervals of 10 cm. The outcomes of the data analysis are presented in Table 2.

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

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 research endeavors 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 to analyze 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 Graphical User Interface (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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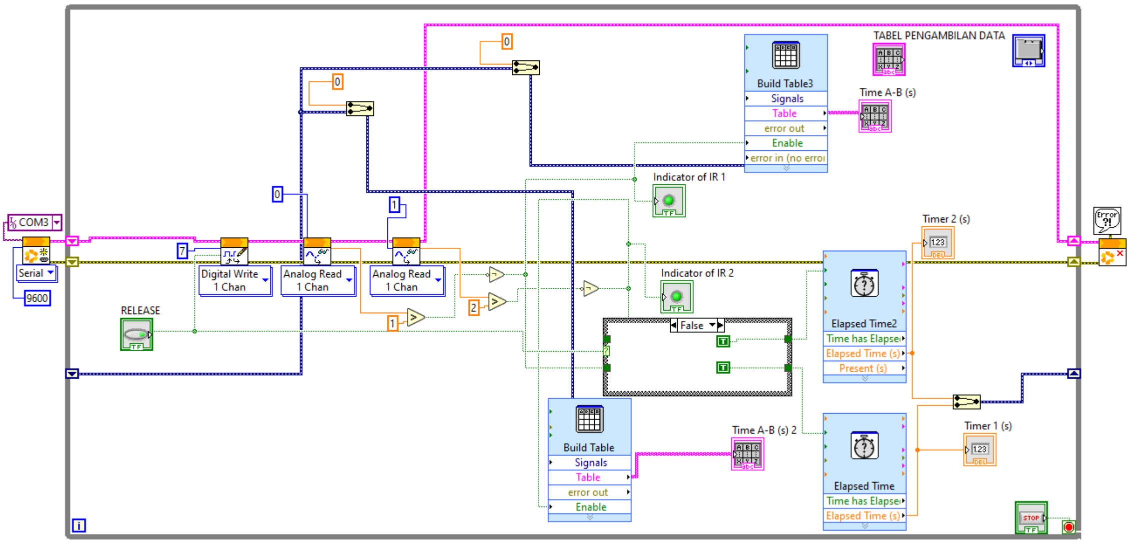
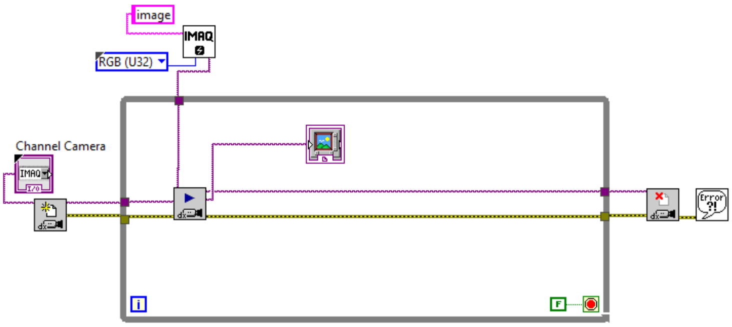
Appendix A. Block Diagram of Load Release and Time Recorder



Appendix B. Camera panel block diagram



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.

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).

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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