

Analyzing Position, Velocity and Acceleration Graphs using Arduino

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Abstract

Motion graphics and their relationships within the scope of the kinematics unit are difficult topics for students to learn. In this study, an Arduino-based in-class physics activity was developed, in which students can analyze position-time, velocity-time and acceleration-time graphs practically. Within the scope of the study, Arduino UNO and HC-SR04 distance sensors, which are very low cost and easily obtainable, were used in the material development process. Data analyzes were also carried out using the Excel program. The position values and time values of a simple car moving with constant acceleration were collected with the help of Arduino and then these data were transferred to the Excel program. Instant velocity and acceleration values were determined on the Excel platform. Then, graph types and relationships between graphs were analyzed by drawing time-dependent graphs of position, velocity and acceleration with the help of Excel program. The motion acceleration was determined as 2.388 m/s^2 both by taking the second derivative of the position-time equation with respect to time and by using the slope of the time-dependent graph of the instantaneous velocity values found. Furthermore, the displacement was calculated as 0.363 m using first and last position values that were directly read from the distance sensor and 0.348 m using the area under the velocity-time graph. The two values are very close to each other, with a difference of +4.1. The change in velocity was calculated as 0.845 m/s by taking the difference of the initial and final velocity and calculating the area under the acceleration-time graph. In addition to providing students with important educational gains in graphic subjects, it is expected that such a study carried out with students in the classroom will also be effective in the development of technological literacy and data analysis skills.

Keywords: Arduino, Motion graphs, Physics education, STEM.

INTRODUCTION

Physics is a field that studies the relationship between matter and energy in order to better understand nature and the universe and to explain the events that occur. Within the scope of this purpose, it contains both conceptual and mathematical expressions. Therefore, the content of the Physics course has a conceptual and mathematical structure in parallel. The kinematic unit, in which variables such as the speed of a mass moving with constant acceleration in one dimension and the distance traveled after a certain time can be analyzed, is also in this structure. In this unit,

besides conceptual and mathematical expressions, graphics that are visual expressions are frequently encountered by students. Research on high school students revealed that students have difficulties in defining motion with constant acceleration and drawing acceleration-time graphs (Toksoy, 2020). Considering the fact that the physics course is an experimental course, it is thought that students' analysis of graphics by applying them experimentally can have an important effect on eliminating problems in learning and providing high-efficiency learning (Ruiz, 2021). An experimental application to be carried out in the kinematic unit should be of the type that requires data collection

and data analysis processes. At this point, a simple demonstration experiment does not allow students to analyze the mathematical relationships between concepts in practice. But experimental applications that allow for data analysis sometimes require expensive experimental sets that not all schools can afford.

Today, we live in the age of technology, and in parallel with this, it is of great importance to educate individuals with technological literacy. In-class training is of great importance in acquiring technological literacy, which is one of the 21st century skills (Larson & Miller, 2011). For this, educational technologies should be used by teachers. Today, many educational technologies with different characteristics are used in educational environments. Examples of these applications are mobile learning, augmented reality, virtual reality, and digital games (Johnson et al., 2016). Microcontrollers are also frequently used in educational environments, and the most widely used of them is Arduino (Plaza, Sancristobal, Fernandez, Castro, & Pérez, 2016; Ari & Meço, 2021). The fact that Arduino's software and hardware are open sources, supported by block-based coded programs and providing access to many applications from the library without any coding knowledge makes Arduino supported activities widely used in learning environments (Ocak, 2018). Arduino is a microcontroller that can be programmed in C + language and is very suitable for beginner level programming (D'Ausilio, 2012). In order to overcome the learning difficulties of students, theoretical knowledge should be supported by experiments with ICT based (Agyei & Agyei, 2021; Jimoyiannis & Komis, 2001; Timková & Ješková, 2018).

Arduino is easily accessible to people of all levels and it is possible to perform many physics experiments that can be performed with high-cost experimental sets with very low cost using Arduino (Kubínová & Šlégr, 2015; Kinchin, 2018; Organtini, 2018). In addition, instead of bringing ready-made experimental sets to the classroom and using these sets only for data collection, they can make the connection and code Arduinos, which require basic electronic skills, with students in the classroom

environment, so that students can achieve very important gains in STEM fields. Studies show that the implementation of such practices in the classroom has significant benefits for students (Hadiati, 2019; Kirikkaya & Basaran, 2019; Lee, 2020).

This study, it is aimed to develop in-class physics activity based on Arduino in which students can analyze position-time, velocity-time, and acceleration-time graphs practically. For this purpose, the position values of the vehicle moving with constant acceleration in the horizontal plane were measured with the HC-SR04 distance sensor, and these values were sent to the computer by Arduino together with the time values. Using the obtained position and time values, the time-dependent change graph and equation of the position were determined. The first derivative of the obtained equation $x(t)$ was taken to obtain the equation $v(t)$ and the second derivative was taken to obtain the equation $a(t)$. Then, by substituting time values in these equations, instantaneous velocity and instantaneous acceleration values were determined for each time value, and their graphs were drawn. Then, the types of graphs obtained and the relationships between the graphs were analyzed in detail. Thus, students will be able learn concepts, mathematical relation of them and graphs clearer while they'll able to acquire gains in data analysis and technological literacy skills, with the material development process, data collection process, and data analysis processes being carried out in the classroom.

In accordance with the vision of STEM Education, which adopts an interdisciplinary approach to education, a physics course topic was applied by using technological tools, collaborating on various engineering skills such as developing experimental material, electronic connection, and programming, and mathematical skills such as data collection and data analysis. Therefore, there are suitable activities for developing very essential skills in all STEM disciplines. Teachers can integrate the experiment presented in this article into a real-life problem. Thus, they can broaden students' horizons in STEM by providing students with experience in

science, technology, engineering, and mathematics.

METHOD

The position (x) of a particle is the position of the particle relative to a chosen reference point, which we can consider as the origin of a coordinate system. If the particle moves, its position will change. The displacement (Δx) of a particle is defined as the change in its position during a given time interval. As the particle moves from the initial position x_i to the final position x_f , its displacement is given as equation (1) (Young, Freedman, & Ford, 2013; Serway & Jewett, 2018):

$$\Delta x = x_f - x_i \quad (1)$$

If the time taken for the particle to displace Δx is Δt , the ratio of these two quantities to each other is characterized as the average velocity given by equation (2)

$$v_{avg} = \frac{\Delta x}{\Delta t} \quad (2)$$

Sometimes it is necessary to calculate the velocity of a particle or body at any instant in time interval Δt . For this, the instantaneous velocity (v_x) equal to the limit value of the ratio $\Delta x / \Delta t$ as Δt approaches zero as given at equation (3):

$$v_x = \lim_{\Delta t \rightarrow 0} \frac{\Delta x}{\Delta t} \quad (3)$$

In calculus notation, this limit is called the derivative of x with respect to t , writing dx/dt as in equation (4):

$$v_x = \lim_{\Delta t \rightarrow 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt} \quad (4)$$

The speed of an object moving in a straight line can vary. In this case, the object has acceleration. The average acceleration (a_{avg}) of the

body is defined as the change in velocity Δv divided by the time interval Δt in which this change occurs as equation (5):

$$a_{avg} = \frac{\Delta v}{\Delta t} \quad (5)$$

In general, there are two types of variables in physics, vector and scalar. A vector quantity requires both direction and magnitude to be specified. In contrast, a scalar quantity has a numerical value and has no direction. The concepts of displacement, velocity and acceleration are examples of vector quantities. As a general notation, positive (+) and negative (-) signs are used to indicate the direction of motion of an object moving along a straight line. In this study, the right direction was chosen as the positive direction for horizontal movement. Therefore, the displacement and velocity of the object moving to the right side were in the positive (+) direction. Since the toy car used in the experiment was constantly accelerating, the direction of its acceleration was also positive.

In high school and university curricula that provide basic physics education, linear motion problems with constant acceleration are usually addressed. For this, the problems and experiments of motion under the effect of a constant force are examined. Because according to Newton's second law ($F=ma$), the acceleration of an object is directly proportional to the net force and inversely proportional to the mass of the object. In this study, the experimental setup in Figure 1 was set up. Figure 1 shows a toy car attached to an object accelerating under the influence of gravitational force. The experiment of the apparatus given in Figure 1 has been carried out in basic physics laboratories since old times. However, the lack of technology-based structure of these experiments causes both experimental errors to be high and not attracting students' attention.

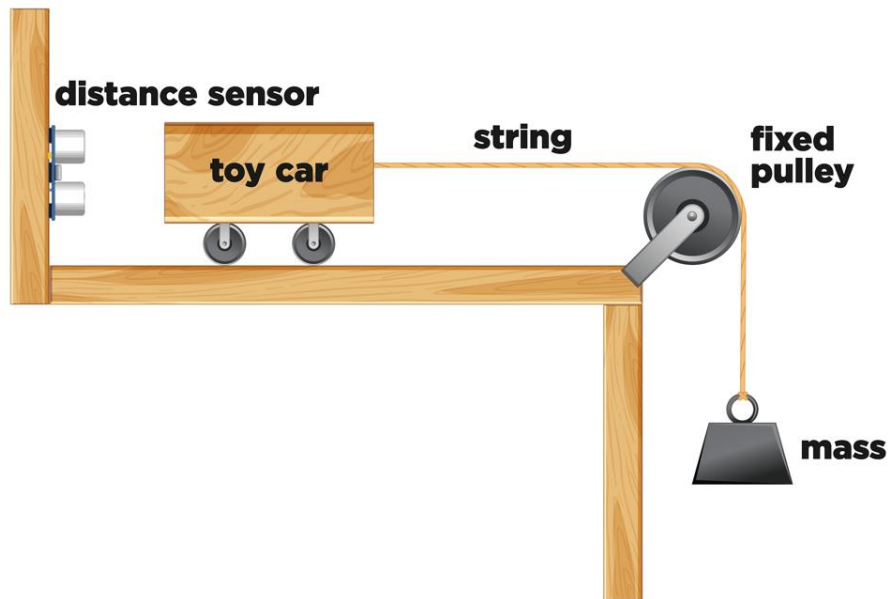


Figure 1. Diagram of experimental setup

In the study, Arduino UNO is programmed to send the position of a moving vehicle with constant acceleration and time to the computer. The code used is shown in Figure 2.

```

#define trigPin 13
#define echoPin 12

float duration, distanced, x;

void setup() {
  Serial.begin(9600);
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
}
void loop() {
  digitalWrite(trigPin, LOW);
  delayMicroseconds(5);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH)/1000000.00;

  distanced = (duration * 345.00 / 2);

  x=sqrt (pow (distanced,2)-pow(0.0130,2));

  Serial.print(millis()/1000.00,3);
  Serial.print("-");
  Serial.println(x,3);
}

```

Figure 2. The code used

HC-SR04 distance sensor was used to obtain position values.

The connections between the sensor and Arduino are as in Figure 3.

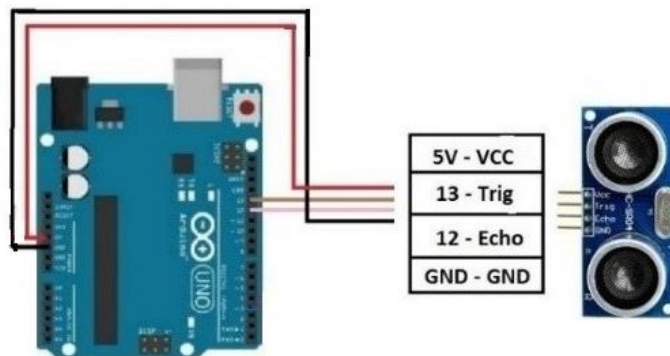


Figure 3. Connections between sensor and Arduino. Connections are made as; 5V of arduino to VCC of sensor, digital 13 pin of arduino to trig pin of sensor, digital 12 pin of arduino to echo pin of sensor and GND pin of arduino to GND pin of sensor.

The wooden block, which is connected to the car and can move freely in the vertical plane, is released, allowing the car to move with acceleration. At this point, the weight of the wooden block and the friction force only affect the acceleration magnitude, not the type of motion. Therefore, there is no need to focus on these forces

in this study. After connecting and programming, the Arduino system was placed in the opposite direction of the movement of the car, in a way to measure the position values of the vehicle moving with constant acceleration. The experimental setup is as in Figure 4.

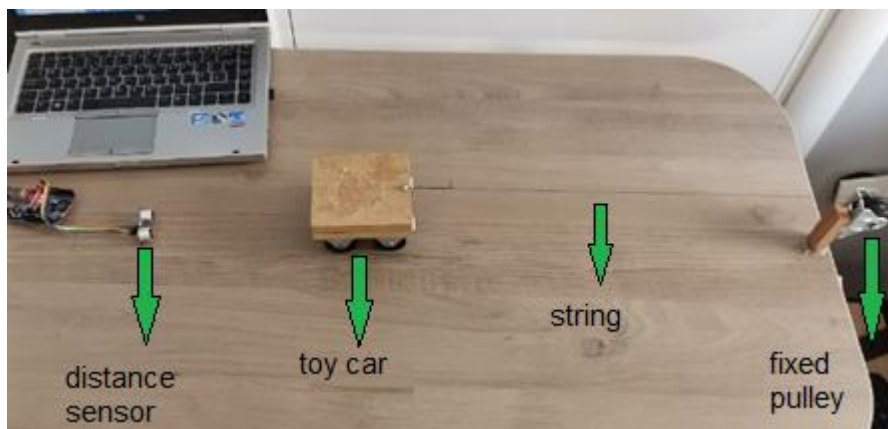


Figure 4. The distance sensor, trolley and pulley system used in the experiment and their positions relative to each other as used in the experimental process.

RESULT AND DISCUSSION

The values are read from the distance sensor and the time values are transferred to the computer using the code. From the moment the car

is released to move with constant acceleration, the data sent during the accelerated motion are determined. The position values and time values of the vehicle moving with constant acceleration and sent to the computer by the Arduino are as in Figure 5.

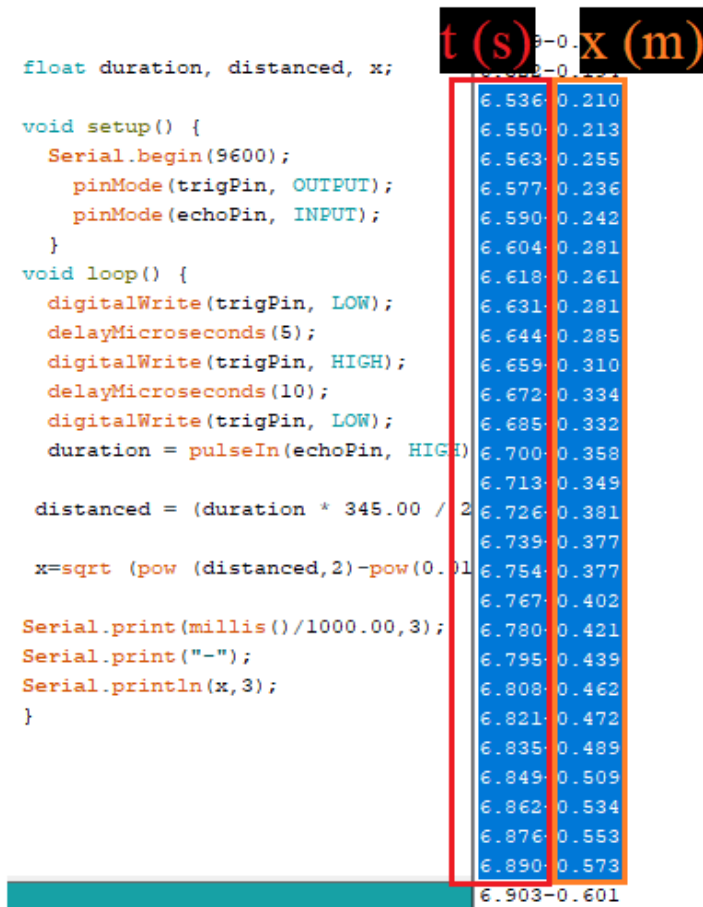


Figure 5. Screenshot of collected data. Datas on the left are time values and datas on the right are distance values.

This screenshot is from the Arduino IDE interface used to program Arduino (Arduino IDE, 2022). Using Arduino IDE, codes can be easily uploaded to Arduino and programming can be done. It is also possible to collect signals from the external environment with the help of the IDE. In order to implement an application in this direction, the serial communication feature activated with the 'Serial.begin(9600)' command, which is also included in the code, is used. It is possible to reach the serial screen by clicking the icon in the upper right part of the IDE. In this study, the distance values sent from the sensor and time values were simultaneously printed on the serial screen. The time and distance values of the section where the

vehicle moves with acceleration were obtained from these data as in Figure 5.

Since all data analyses will be performed via Excel, these values have been transferred to the Excel program. The time-dependent equation of position in motion with constant acceleration is a quadratic polynomial equation given as equation (6):

$$x(t)=At^2+Bt+C \quad (6)$$

Here, A, B and C are the constants of motion. The graph and equation were obtained as in Figure 6 by drawing the time graph of the position and using the knowledge that the time dependent equation of the position is a quadratic polynomial equation.

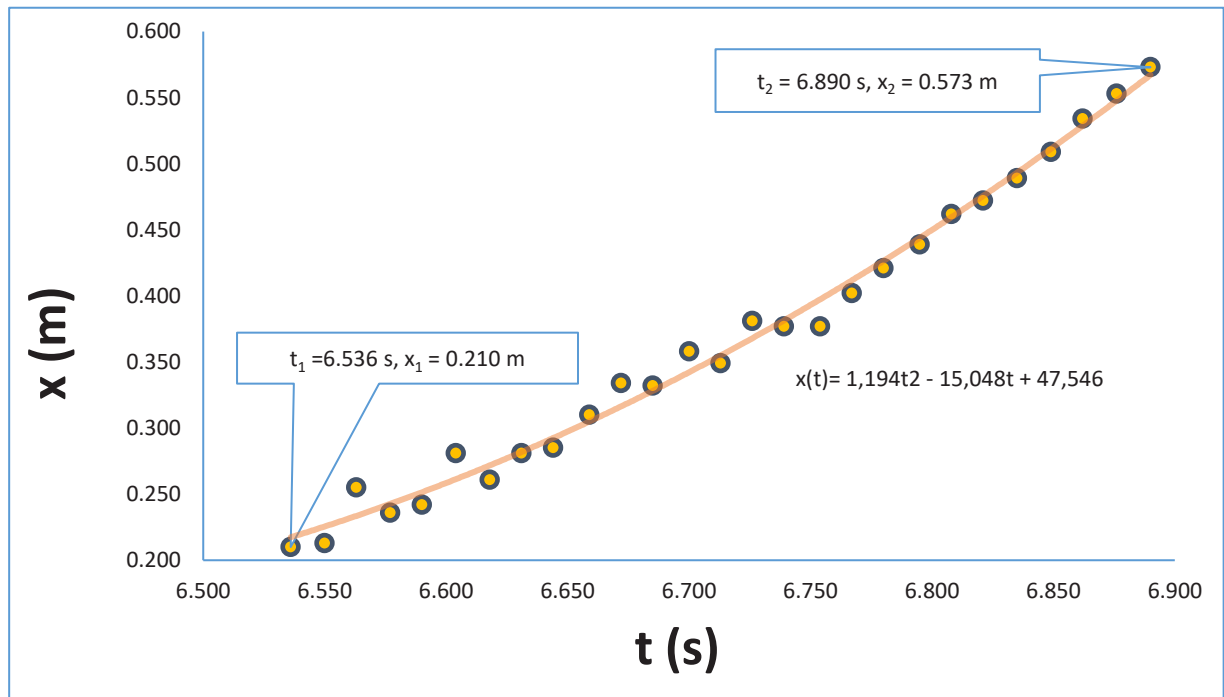


Figure 6. Position-time graph. The $t_1 = 6,536$ s and $x_1 = 0,210$ m values on the graph are the time and position values read at the beginning of the accelerated movement, and the $t_2 = 6,890$ s and $x_2 = 0.573$ m values at the end of the accelerated movement.

Here, the graph type is the graph accelerating in the + direction. The motion graph that accelerates in the negative direction by taking the distance sensor in the direction of motion, and the deceleration motion graph analysis can be performed by slowing the vehicle down. The analyses in this study were made in the + direction acceleration movement.

When Figure 6 is examined, it is seen that the equation of change of position with time is

$$x(t) = 1,194t^2 - 15,048t + 47,546.$$

The first derivative of the position with respect to time gives the velocity in constant

acceleration motion. Therefore, the velocity-time equation can be obtained by taking the first derivative of the position-time equation with respect to time. With this method, the velocity-time equation was found to be

$$v(t) = dx(t)/dt = 2,388t - 15,048.$$

By using this time dependent velocity equation on Excel, the speed values of the car at all time values were determined. The velocity-time graph drawn using these calculated instantaneous velocities is as in Figure 7.

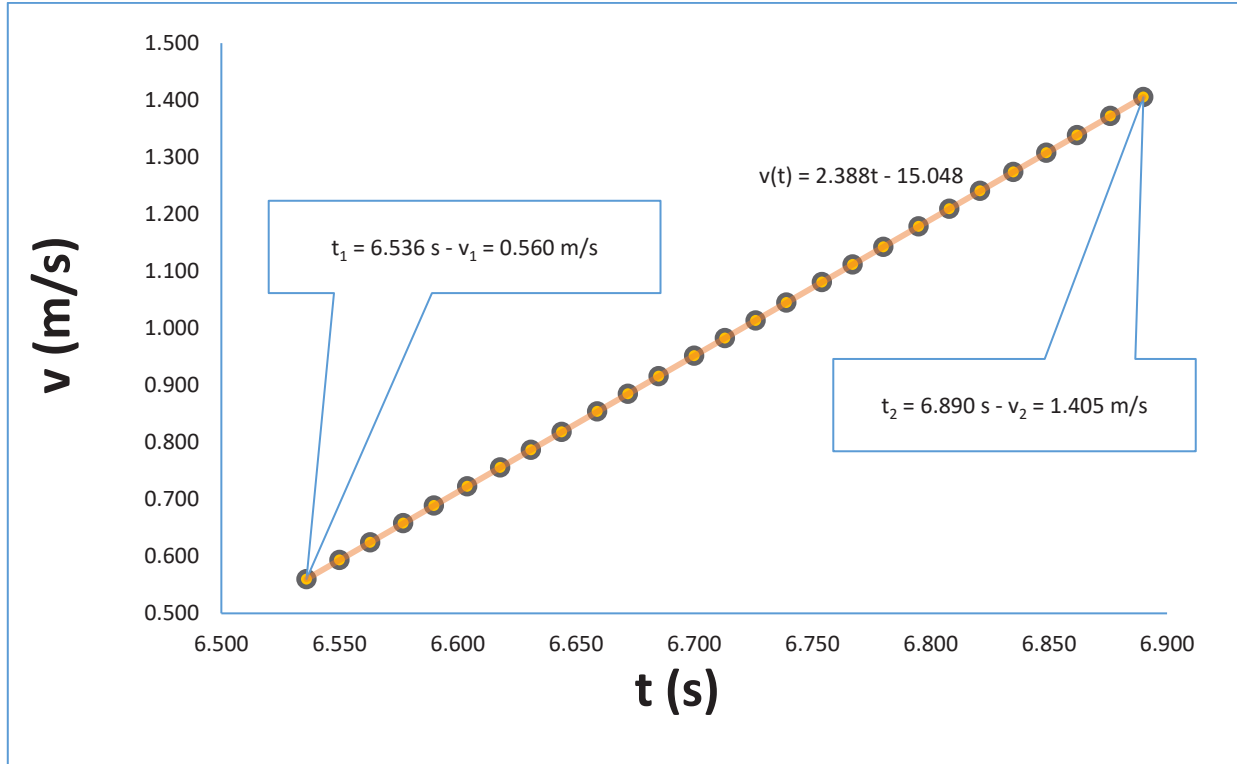


Figure 7. Velocity-time graph. The $t_1 = 6,536 \text{ s}$ and $v_1 = 0,560 \text{ m/s}$ values on the graph are the time and velocity values determined at the beginning of the accelerated movement, and the $t_2 = 6,890 \text{ s}$ and $v_2 = 1,405 \text{ m/s}$ values at the end of the accelerated movement.

When Figure 7 is examined, it is seen that the velocity-time graph is also suitable for the motion graph accelerating in the + direction.

The first derivative of the velocity-time equation with respect to time also gives the acceleration. Since the motion has a constant acceleration, the motion acceleration does not change with time and is

$$a = \frac{dv(t)}{dt} = 2,388 \text{ m/s}^2.$$

If the acceleration-time graph is drawn for all time values in order to see the graph type visually, a graph like Figure 8 is obtained.

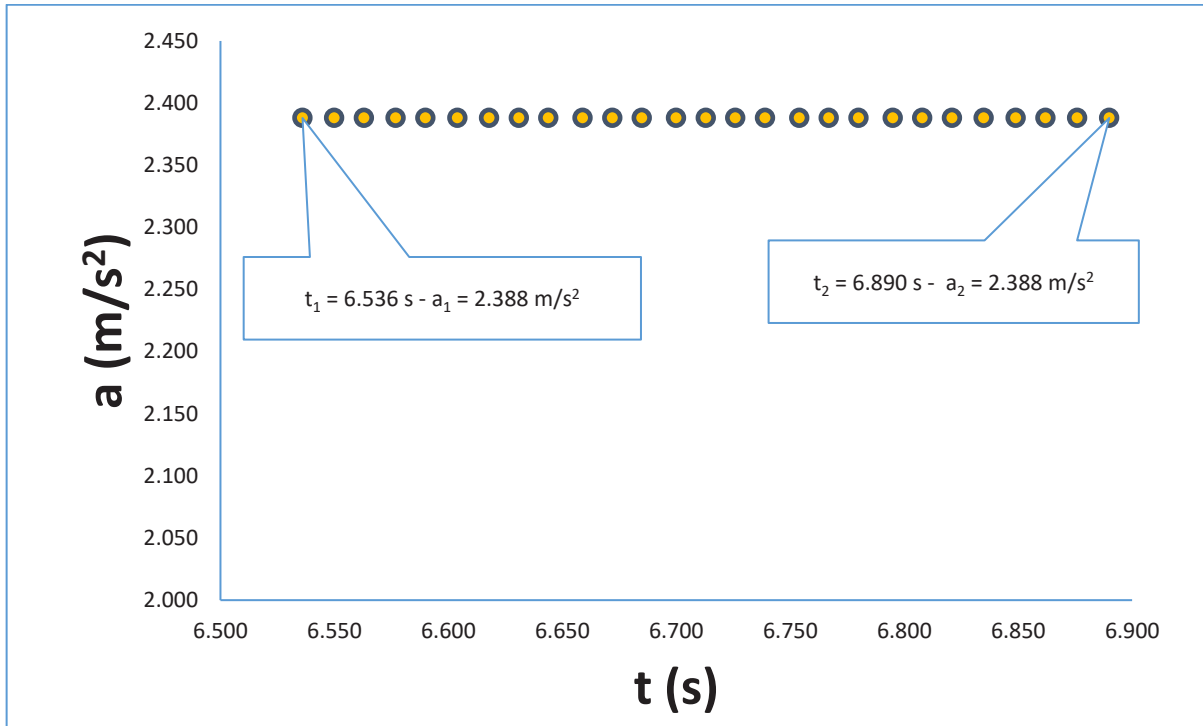


Figure 8. Acceleration-time graph.

It is seen that the acceleration-time graph is also compatible with the motion graph accelerating in the + direction.

It has been concluded that the experimental graphics obtained for all three physical quantities are compatible with the theoretical graphics. This study can be repeated for different types of movements. After analysing the chart types, studies will be carried out to analyse the mathematical relationships between the charts.

The area under the acceleration-time graph gives the velocity change in that time interval. Using the Excel program, the area under the acceleration-time graph in Figure 8 was calculated as

$$A_{a(t)} = 2,388 \cdot (6,890 - 6,536) = 0,845 \text{ m/s},$$

By using last and first velocity, Δv can be found as

$$\Delta v = 1,405 - 0,560 = 0,845 \text{ m/s}.$$

It can be seen clearly that area of $a(t)$ graph is equal to Δv . These two values, which are

theoretically equal, have also been found to be equal experimentally.

In the analyses to be made on the velocity-time graph, both the graph slope and the area under the graph will be calculated. The slope of the velocity-time graph shown in fig 7 is equal to the acceleration. This value was found to be

$$\frac{\Delta v}{\Delta t} = \frac{1,405 - 0,560}{6,890 - 6,536} = 2.388 \text{ m/s}^2$$

This slope is equal to the acceleration shown in fig 8.

The area under the velocity-time graph also gives the displacement Δx . Through the Excel program, by calculate the differences between last and first position the displacement determined as

$$\Delta x = 0,573 - 0,210 = 0,363 \text{ m}.$$

Are of the velocity-time graph should be equal to the displacement. By using the graph on fig. 7, area of the velocity-time graph was calculated as

$$A_{v(t)} = (1,405 - 0,560) * (6,890 - 6,536) / 2 + 0,560 * (6,890 - 6,536) = 0,348 \text{ m.}$$

Values that found from two different ways are equal to each other with a %4,1 difference.

The slope of the tangent drawn at a given moment in the position-time graph gives the instantaneous velocity. In this study, no application has been made in this direction, but it is possible to analyse the graph experimentally by printing it on paper.

In this study, experimental results compatible with the theoretical results were precisely determined from a physical three-dimensional system using Arduino. In similar studies, Arduino microcontrollers are used to make precise measurements in experiments related to physics topics (Coban & Coban, 2020; Casaburo, 2021)

CONCLUSION

The study's goal is to analyze graphic types in motion and mathematical relationships between graphs by developing a low-cost experimental process with significant educational benefits. For this purpose, the time change data of the position of a vehicle moving with constant acceleration were recorded, and analyses were carried out on these data. As a result of the analysis, position-time, velocity-time, and acceleration-time graphs in constant acceleration motion were obtained in accordance with their theoretical counterparts. In the mathematical relations between the graphs, the slope of the velocity-time graph and the area under it were determined, respectively, and the motion acceleration and displacement were determined in accordance with the theory. Additionally, by using acceleration-time graph, change of the velocity from beginning of the motion to the end was determined as same with velocity change that determined by taking the differences between first and last velocity values. This study, which has reached experimental results that are quite compatible with the theoretical results related to motion graphics, includes very important gains from different fields. By analyzing

the data obtained in a similar way, studies on different units can be carried out in the Physics course. Teachers can also use the experiment presented in this study by transforming it into a STEM (Science, Technology, Engineering, and Mathematics) activity.

REFERENCES

- Agyei, E. D., & Agyei, D. D. (2021). Enhancing Students' Learning of Physics Concepts with Simulation as an Instructional ICT Tool. *European Journal of Interactive Multimedia and Education*, 2(2), e02111.
- Arduino IDE software, taken at 26th May 2022 <https://www.arduino.cc/en/software>
- Casaburo, F. (2021). Teaching physics by Arduino during COVID-19 pandemic: the free falling body experiment. *Physics Education*, 56(6), 063001. <https://doi.org/10.1088/1361-6552/ac1b39>
- Çoban, A., & Çoban, N. (2020). Using Arduino in physics experiments: determining the speed of sound in air. *Physics Education*, 55(4), 043005. <https://doi.org/10.1088/1361-6552/ab94d6>
- D'Ausilio, A. (2012). Arduino: A low-cost multipurpose lab equipment. *Behavior research methods*, 44(2), 305-313. <https://doi.org/10.3758/s13428-011-0163-z>
- Toksoy, E. S. (2020). Investigation of 11th Grade Students' Knowledge About Explanation of Motion Types and Drawing, Interpreting Related Graphs. *Abant İzzet Baysal University Education Faculty Journal*, 20(3), 1423-1441. <https://dx.doi.org/10.17240/aibuefd.2020..-618011>
- Ari, A.G., & Meço, G. (2021). A new Application in Biology Education: Development and Implementation of Arduino-Supported STEM Activities. *Biology*, 10(6), 506. <https://doi.org/10.3390/biology10060506>
- Hadiati, S., Kuswanto, H., Rosana, D., & Pramuda, A. (2019). The effect of laboratory work style and reasoning with Arduino to improve scientific attitude. *International Journal of Instruction*, 12(2), 321-336. <https://eric.ed.gov/?id=EJ1210983>
- Johnson, L., Becker, S. A., Cummins, M., Estrada, V., Freeman, A. & Hall, C. (2016). NMC Horizon Report: 2016 Higher Education Edition. Austin, Texas: The New Media Consortium, 1-50. Retrieved February 1, 2023 <https://www.learntechlib.org/p/171478/>

- Kinchin, J. (2018). Using an Arduino in physics teaching for beginners. *Physics Education*, 53(6), 063007.
<https://iopscience.iop.org/article/10.1088/1361-6552/aae350>
- Kirikkaya, E. B., & Basaran, B. (2019). Investigation of the Effect of the Integration of Arduino to Electrical Experiments on Students' Attitudes towards Technology and ICT by the Mixed Method. *European Journal of Educational Research*, 8(1), 31-48.
<https://doi.org/10.12973/eu-jer.8.1.31>
- Kubínová, Š., & Šlégr, J. (2015). Physics demonstrations with the Arduino board. *Physics Education*, 50(4), 472.
<https://iopscience.iop.org/article/10.1088/0031-9120/50/4/472/meta>
- Ladeira, V. B., Calheiro, L. C., & Goncalves, A. M. B. (2022). Exploring kinematics graphs using Arduino and an interactive Excel spreadsheet. *Physics Education*, 57(2), 023007.
- Larson, L. C., & Miller, T. N. (2011). 21st century skills: Prepare students for the future. *Kappa Delta Pi Record*, 47(3), 121-123.
<https://doi.org/10.1080/00228958.2011.10516575>
- Lee, E. (2020). A Meta-Analysis of the Effects of Arduino-Based Education in Korean Primary and Secondary Schools in Engineering Education. *European Journal of Educational Research*, 9(4), 1503-1512.
- Ocak, M. A. (2018). Where does Arduino's power come from?: An extended literature review. *Journal of Learning and Teaching in Digital Age*, 3(1), 21-34.
- Organtini, G. (2018). Arduino as a tool for physics experiments. *Journal of Physics: Conference Series*. 1076(1) 012026.
<https://iopscience.iop.org/article/10.1088/1742-6596/1076/1/012026/meta>
- Plaza, P., Sancristobal, E., Fernandez, G., Castro, M., & Pérez, C. (2016). Collaborative robotic educational tool based on programmable logic and Arduino. *Technologies Applied to Electronics Teaching (TAEET)* 1-8.
<https://ieeexplore.ieee.org/document/7528380>
- Prima, E. C., Oktaviani, T. D., & Sholihin, H. (2018). STEM learning on electricity using arduino-phet based experiment to improve 8th grade students' STEM literacy. *Journal of Physics: Conference Series* 1013(1), 12030.
<https://doi.org/10.1088/1742-6596/1013/1/012030>
- Ruiz, M. J. (2021). Speed, acceleration, and distance plots from a racecar speedometer (0–300 km h⁻¹). *Physics Education*, 56(5), 055035.
<https://doi.org/10.1088/1361-6552/ac1529>
- Serway, R. A., & Jewett, J. W. (2018). *Physics for scientists and engineers*. Cengage learning.
- Timková, V., & Ješková, Z. (2018). Computer Modelling in Physics Teaching. In *The role of laboratory work in Improving Physics Teaching and Learning* (pp. 121-130). Springer, Cham.
- Van Bien, N., & Hai, D. M. (2019). An Arduino-based wireless measuring car designed to investigate Newton's II law. *Physics Education*, 54(6), 063002.
- Yasin, A. I., Prima, E. C., & Sholihin, H. (2018). Learning Electricity Using Arduino-Android Based Game to Improve STEM Literacy. *Journal of Science Learning*, 1(3), 77-94.
<https://doi.org/10.17509/jsl.v1i3.11789>
- Young, H. D., Freedman, R. A., & Ford, A. L. (2013). *University Physics with Modern Physics Technology Update*. Pearson Education.