Development of a simple line-follower robot with constant acceleration motion

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Abstract. A simple line-follower robot is an automated guided vehicle that senses the black line on a white surface using infrared (IR) sensors and then sends the signal to the Arduino Nano microcontroller. It drives two simple DC motors attached with two wheels used to move the robot's direction that is left, right, and forward according to the sensor's output, and it can control the speed of DC motors from the L298N driver circuit. This research aims to develop a simple line-follower robot with constant acceleration motion as an educational tool. The design process would allow the robot to detect white and black surfaces, travel along a 3 m straight line with a constant acceleration, and permit acceleration with a smartphone sensor by the Phyphox application. The robot is equipped with the acceleration sensor of a smartphone that can collect acceleration data. The data are then graphed and analyzed using the Phyphox application in real-time. The robot is designed to help students change acceleration by adjusting the motor's output pulse width modulation (PWM) signal from 0 to 255. The signal was set at 230, a value that can cause the robot to move with constant acceleration. The robot’s average acceleration is 0.65 m/s². This project can help students to illustrate the acceleration concept in the form of a graph together with robot motion.

1. Introduction

We are in the STEM generation whose comprehensive purpose is to resolve (1) societal needs for new technological and scientific advances; (2) economic needs for national security; and (3) personal needs to become a fulfilled, productive, knowledgeable citizen. Robotics can be an effective teaching and learning tool for STEM [1]. The line-follower robot is an autonomous vehicle that detects the black line to move over the white surface or bright surface. Serrano Pérez and Juárez López developed the line-follower robot which consists of a microcontroller board connecting a motor driver, two sensors, and a Bluetooth module [2]. Their work focused on a simple board design and easy circuit; however, students may not understand the physics concept underneath these. Thus, we have developed a simple line-follower robot with constant acceleration motion for students to investigate physics concepts within the programming application context. For this article, we asked the following two questions: What are the
components of a simple line follower robot with constant acceleration? How can students interact with the robot activity that we designed?

2. The robot designs and development

The criterions of our line follower robot are as following. It is driven by a DC motor with a maximum current of 2 A. Students can observe and measure the constant acceleration of the robot more clearly. It is programmed by a digital signal. A smartphone is used to measure acceleration which is displayed in real-time, and to communicate with computer devices through Phyphox [3].

To reach the criterions above, the structure of our robot consists of an Arduino Nano board, two IR sensors, two motors, and a L298N motor driver. The board uses 5V power, and it is connected to the computer through a USB by using the Arduino IDE interface for programming and communication. The reflective sensor TCRT5000 is used to detect black and white surfaces, as shown in figure 1.

![Figure 1. 3D model of the robot in (a) overview, (b) top view, and (c) side view.](image)

The left and right sensors are connected to the board on digital pins 10 and 9, respectively. Connecting the board directly to the motor results in the board being unable to provide enough power to the motor. The motor driver L298N is powered by a Li-Po battery with 7.4 V and 1500 mAh. The motor rotation is controlled through a PWM signal. The motor driver's input pins ENA, ENB, 1, 2, 3, and 4 are connected to Arduino's digital pins number 5, 6, 3, 4, 8, and 7. The signal from the Arduino’s board can control the motor driver circuit and can adjust the speed of the motor rotation. The robot in this project is programmed to follow the black line on a white surface [4], as shown in figure 2.
Robot construction starts with cutting two plywood plates. The first plate is 14 cm wide and 17 cm long to serve as a base for installing motors, electric circuits, and a battery. The second plate is 10 cm wide and 16 cm long to function as a smartphone mount. Plywood is a lightweight and durable material that can be easily cut and punched. The second step is installing parallel wheels on each side of the rear of the baseplate, connected to the motors, and then installing the third wheel at the front of the baseplate in the centre, so that the wheels' balancing process can help the robot move in a straight line without going outside the path. The third step is to install two infrared sensors to detect black or white surface. The sensor is about 0.5 cm above the surface. The fourth step is to install and connect an Arduino Nano board, a motor driver, and a battery. In the final step, the smartphone device support base is installed 5cm above the base plate with the circuits and motors, as shown in figure 3.

The robot has four possible conditions when the IR sensors detect white and black and then send it to the Arduino nano board. Arduino controls the direction and speed of the motor by the PWM signal.
Conditions can be summarized as follows: the first condition is if both the right and left sensors detect a white surface, then the robot moves forward with both motors to be directed with a PWM 230 signal. The second condition, if the right sensor detects a black line, then the robot shifts to the right by the right motor rotating backward with the signal PWM 110, and the left motor rotating forward with the signal PWM 230.

Figure 4. The flow chart of control system software.

In the third condition, if the left sensor detects a black line, the robot shifts to the left through the left motor rotating backward with the signal PWM 110, and the right motor rotating forward with the signal PWM 230. In the last condition, if both sensors detect the black line, then the robot is stopped with the signal PWM 0 [5]. The four logic operations of the robot were represented in the flow chart shown in figure 4.

The robot was tested on a black straight-line with a width of 2 cm and length of 3 m. The robot was tested with a mass of 0.56 kg, and it was driven by a DC motor using path and condition, as shown in figure 5. The system's robot testing results are shown in the direction of the robot, forward, left, and right. According to the robot's testing, the motors' speed can change the limitation between PWM 0 and 255. The following results are from forward, left, and right direction of the robot. A smartphone app acquired acceleration data from the smartphone sensors. This data is used to describe the motion of the robot.
Figure 5. The test path and condition.

The Phyphox application collected information from the smartphone sensors and graphed the relationship between acceleration and time, displaying the real-time results. The graph happens in real-time and is extremely useful because it shows the motion of the robot on a given straight path or outside path [6]. The data were exported from Phyphox to Microsoft Excel. The PWM signal was set at 230, a value that can cause the robot to move with constant acceleration in minimal time. The acceleration is zero from 0 to 1 s, indicating that the robot is at rest. In the next interval, 1 to 4 s, the robot’s average acceleration is 0.65 m/s², as shown in figure 6.

Figure 6. Acceleration process of the robot.

For theoretical calculations described, the motion time was calculated to be $\Delta t = 3.0$ s for a motion distance of $s = 3.0$ m. Suppose these values are applied to the distance-time equation $s = at^2 / 2$ for uniform acceleration (without initial distance and initial speed). The acceleration ($a$) is calculated with the formula $a = 2s / t^2$ [7]. The acceleration of the robot is 0.67 m/s². The theoretical value is close to that
of the value measured using a smartphone in the test. The robot's movement at constant acceleration indicates that the robot moves in a straight line without leaving the specified path and at a constant increase in speed. When the robot leaves the specified path, the program will instruct the robot to change its speed and direction, resulting in unstable acceleration.

3. Classroom implementation
The participants were 30 high school students divided into groups of three members. Students were asked to construct the follower-line robot with three conditions; (1) the robot detects white and black surfaces. (2) It travels along a 3 m straight line with constant acceleration, and (3) it permits the measurement of acceleration with the sensor of a smartphone device using the Phyphox application. During the activity, students were assessed on their programming skill and understanding of the acceleration concept using the scoring rubric, as shown in table 1.

Table 1. Assessment rubrics for the robot activity.

| Criteria                                | Excellent 3                                                                 | Good 2                                      | Fair 1                                      |
|-----------------------------------------|-----------------------------------------------------------------------------|---------------------------------------------|---------------------------------------------|
| Programming the robot                   | Able to follow the order in 4 conditions.                                   | Able to follow the order in 3 conditions.   | Able to follow the order with 1 or 2 conditions. |
| The measurement of acceleration with a smartphone | Able to activate the Phyphox application and measure the acceleration and export the data to the computer. | Able to activate the Phyphox application and measure the acceleration. | Able to activate the Phyphox application. |
| The movement of the robot               | The robot moves in a straight line with constant acceleration at a distance of 3 m. | The robot moves in a straight line with constant acceleration at a distance of 2 m. | The robot moves in a straight line with constant acceleration at a distance of 1 m. |
| The presentation of the physics concept | The presentation communicates the meaning of linear motion with constant acceleration for others to understand, correct, and explain the concept's reasoning. | The presentation communicates the meaning to others, clearly explain the reasons for linear motion with partial correct constant acceleration. | The presentation is not meaningful to others to explain the reasons for the concept of linear motion with partial correct constant acceleration. |

The results of the robot programming had a mean of 2.70, which was excellent, showing that the students had good programming skills. The measurement of acceleration with a smartphone had a mean of 2.60, which was excellent, and shows that most of the students could use their smartphones as a tool for measuring acceleration and exporting data to a computer to analyze the data with Microsoft Excel. The movement of the robot had a mean of 2.20, which was good, demonstrating that most of the students could operate the robot with constant acceleration over a distance of 2 meters. After the test, the students improved the robot by adjusting the motor speed accordingly and adjusting the wheels' structure to improve balance. The presentation of the physics concept had a mean of 2.50, which was excellent, presenting that most students were able to present the linear motion principle with constant acceleration to others.
Table 2. Summary of the students’ performance during the robot activity as scored by the rubric.

| Criteria                                      | Mean | S.D. | Performance |
|-----------------------------------------------|------|------|-------------|
| Programming the robot                         | 2.70 | 0.46 | Excellent   |
| The measurement of acceleration with a smartphone | 2.60 | 0.49 | Excellent   |
| The movement of the robot                     | 2.20 | 0.60 | Good        |
| The presentation of the physics concept       | 2.50 | 0.50 | Excellent   |
| Total                                         | 2.50 | 0.55 | Excellent   |

The overall score of the activity had a mean of 2.50, which was excellent, as shown in table 2. The results obtained confirm the validity of the use of the educational tool as appropriate to the students in teaching physics principles and programming skills [8].

4. Conclusion
This research has developed a simple line-follower robot with constant acceleration motion as educational tools through a simple design, construction, and programming process. The robot was tested on a black line and white surface, a black line was pasted in the middle of the white surface, and a smartphone using the Phyphox application was used to collect acceleration data and study motion. Where the middle was pasted black mark line a smartphone that can collect acceleration data to study motion. The data are then graphed and analyzed using the Phyphox application in real-time. The results show that the robot created can detect black lines and white surface effectively and move with constant acceleration and stability on the line without moving outside the track [9]. This project can help students to investigate physics concepts within the context of programming applications.

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