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To: Professor Katie Fitzsimons

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Subject: Initial Research for Designing a Line-Following, Differential Drive Robot

Summary

To better understand autonomous robots, a mechanical engineering design course at Pennsylvania State University has asked our team to design a line-following robot. As per project requirements [4], the robot should autonomously follow a track using an Arduino board, a reflective infrared sensor, and a differential drive mechanism. This report presents our team's initial research on designing a line-following, differential drive robot and the design limitations of this project. The robot will function by using the infrared sensor to determine if the robot is on the line. Using this data, the Arduino will control the differential drive system to keep the robot on course. One design limitation is that the differential drive system is slow as compared to a 4-wheel drive. A second limitation is that since the tests are conducted outdoors, sunlight can obscure the infrared sensors readings. Finally, because we are required to use an Arduino kit, an additional motor driver and power source are required for the mechanics to function fluidly.

Introduction

The growing industry of online shopping has created a need for automation within warehouses. One solution to the problem is the use of line-following robots. Robots can streamline in-house transportation and improve overall efficiency of the warehouse [6]. Unlike traditional human operated machinery, these robots are autonomously configured to follow any tracks inside a factory or commercial space. To help mechanical engineering students better understand these types of robots, the Design Methodology course (ME 340) at Pennsylvania State University has asked our team to design a line following robot. This report presents our team's initial research on this project.

According to the project description [4], the robot needs to be capable of quickly traveling along a straight line outdoors and stop at the end of the track autonomously. The system needs to be robust to small disturbances and its ability to support its mass. Although most of the physical robot will be fabricated by the team, electronic components such as an Arduino board will be purchased. To have the robot follow the track, the project description calls for a reflective infrared sensor and differential drive mechanism. A line following robot works by using the reflective infrared sensor to provide information about the position of the robot. Data collected from the sensor can be used to tell the differential drive system how to operate to get back on course.

The next section of this report discusses how the transmission for the robot using a differential drive works. Presented in the report's third section is how the reflective infrared sensor works. The fourth section highlights the needed supplies from the Arduino kit and the role of the supplies in the design. Using the information from the three sections, the fifth section presents the device limitations that will impact the design.

How a Differential Drive Robot Works

As stated in the project description [4], one requirement is for the robot's wheels to be powered using a differential drive mechanism. This section provides information on how a differential drive robot mechanically functions. The differential drive is a two-wheeled drive system where each wheel contains independent actuators [9]. How a differential drive works can be represented using three state variables $[x, y, \theta]^T$, which are described by the following equation:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \frac{r_R}{2} \cos(\theta) & \frac{r_L}{2} \cos(\theta) \\ \frac{r_R}{2} \sin(\theta) & \frac{r_L}{2} \sin(\theta) \\ \frac{r_R}{2b} & -\frac{r_L}{2b} \end{bmatrix} \begin{bmatrix} \dot{\phi}_R \\ \dot{\phi}_L \end{bmatrix}$$

where r_R denotes radius of the right wheel, r_L is the radius of the left wheel, b is the distance between wheels, θ is the angle of the robot, ϕ_R is the angle of the right wheel, and ϕ_L is the angle of the left wheel.

Differential drive systems are systems in which the drive wheel is directly connected to the motor. Such a system contains two wheels driven by separate motors, while the remaining wheels for stability are non-driven. To navigate the robot, one drive motor may slow down or completely stop. For instance, to turn left, the right wheel would have to turn faster than the left or the left wheel could remain stationary. To make a differential drive robot move in a straight line, the drive motors have to turn at the same rate [9]. As seen in Figure 1, identifying the wheel position of the robot is important to control the direction of its motion.

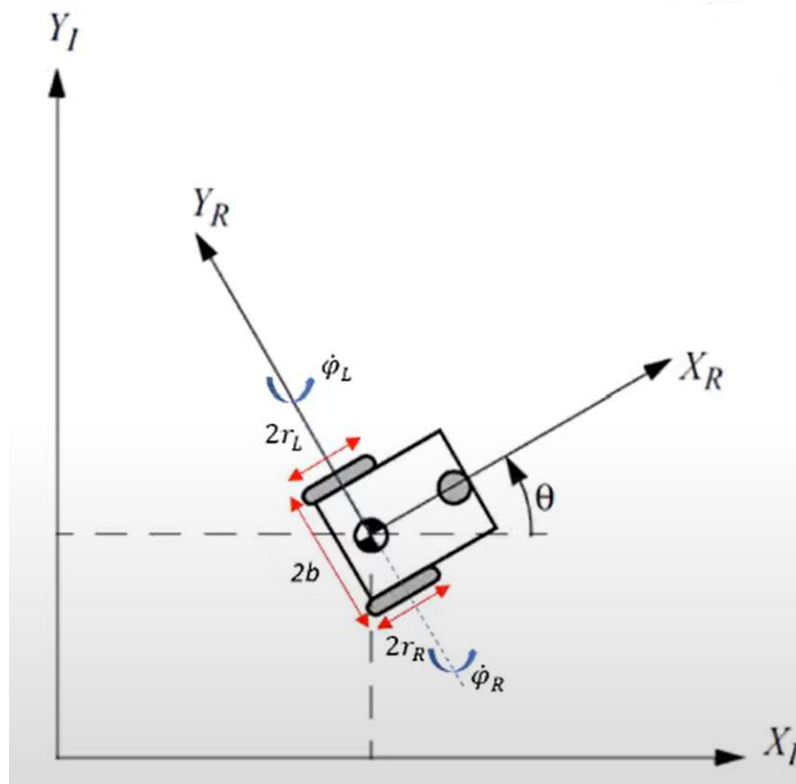


Figure 1. Differential drive coordinate diagram [7]. The diagram shows how the angles and dimensions of the robot are used to determine the position. It is a two-dimensional coordinate system. The variables are the same as described in the differential drive equation.

How a Reflectance Sensor Works

One goal of the differential drive robot is to have it function autonomously. To achieve this goal, our team will use a reflective infrared sensor (RIR). The RIR emits a 940-nanometer wavelength light wave that will reflect from the ground back towards the sensor [8]. Because RIR sensors emit and detect infrared light, they are classified as an active infrared sensor [3]. The information collected from the infrared sensor can be processed by uploaded code. Using the processed code, the robot can react to its environment to stay on course. This code changes aspects such as the delay on the wheels after reflected light is detected and the rate at which the wheels turn [4].

After the infrared light is reflected to the sensor, the sensor will perform a calculation to estimate the distance between the sensor and the object that reflected the wave (overall process illustrated in Figure 2). This calculation helps to signal the robot when to stop and start. Because the sensor receives light, there is a part on the infrared sensor that is called the proximity sensor. The proximity sensor detects the light and performs a calculation to estimate distance [1].

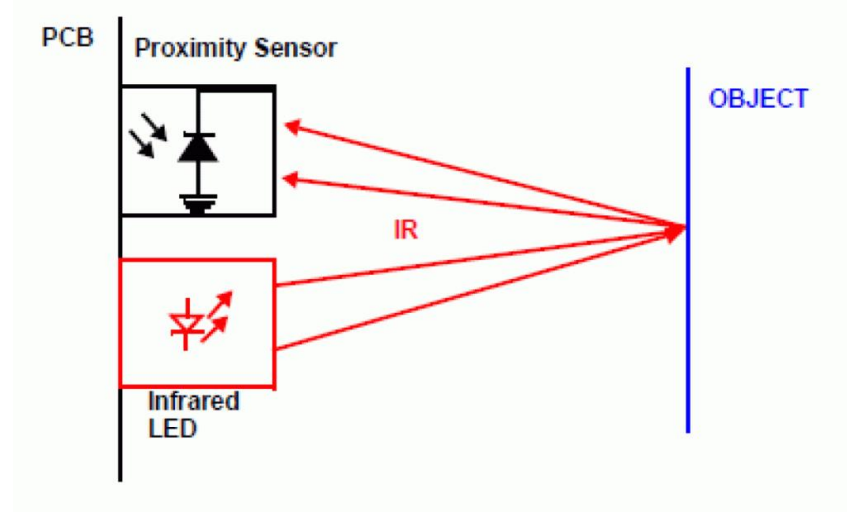


Figure 2. How the reflectance sensor works [11]. The diagram shows how the reflectance sensor functions using the proximity sensor to calculate the distance of the object.

Components in Supply Kit to Be Used in the Design

An Arduino kit contains the necessary electrical supplies for the robot. The two main pieces of the Arduino kit are the breadboard and the Arduino Uno. The breadboard will be used to build temporary circuits and hold wires in place so that an electrical current can form. The Arduino Uno allows for the connection from the circuit to the computer so that the code can be executed. Wires connect these two pieces and will be placed into certain inputs on the Arduino Uno. By placing wires into different inputs on the Arduino Uno, the motors will receive different commands from the code being executed.

An element of the Arduino kit that is more specific to our robot is the TB6612 H-Bridge motor. Otherwise known as the motor driver, the H-bridge motor determines when the wheels turn and the rate at which they turn. This motor driver is wired to two motors which are the physical components that the wheels are connected to. Batteries that are connected to the circuit through a battery pack, will act as the power supply for the circuit. The wiring of all parts in the circuit are shown in Figure 3.

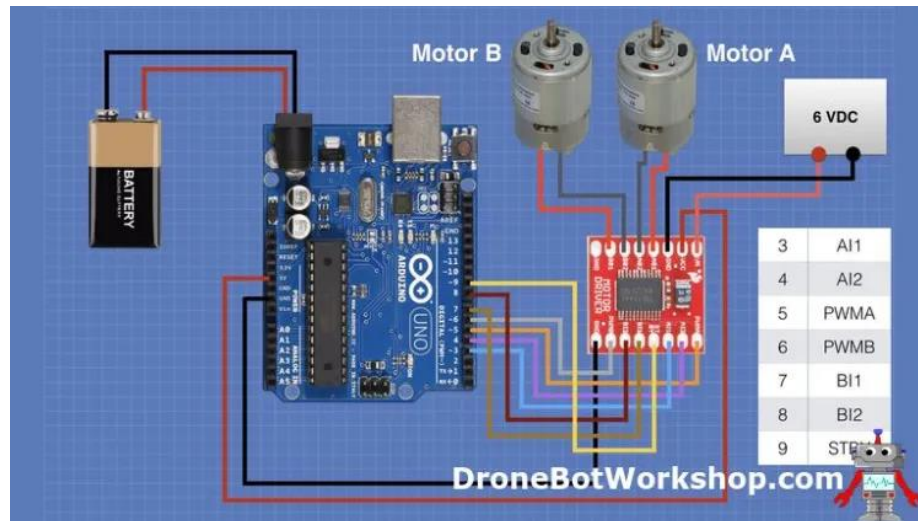


Figure 3. Layout of Circuit [10]. The diagram shows how each element is wired, excluding the breadboard, which the motor drive would be plugged into. The legend on the bottom right depicts where each outlet of the motor drive is plugged into on the Arduino Uno.

Device Limitations That Impact Design

This section presents constraints on parts of the product that limit the effectiveness and efficiency of the design. Starting with the overall differential drive design, the key disadvantage is speed. For a full 90 or 180 degree turn to occur, one wheel remains stationary, while the other rotates. As a result, differential drives are slower compared with regular 4-wheel drives. Another key factor concerns uneven terrain. If one wheel is facing an obstacle or not touching the ground, the robot will have difficulty correcting itself and getting back on track.

Another limitation on the design has to do with the Arduino circuit. Our Arduino kit does not include key components such as a motor driver and a power source. Therefore, an additional motor driver and power source are required for the mechanics to function fluidly. Adding an additional motor driver and power source complicates the final circuit because of extra wiring and additional small parts.

Finally, using infrared sensors further limits our team's design. One severe issue is that since the tests will be outdoors during the day, sunlight will reflect differently. The sunlight can pollute and obscure the sensors infrared readings causing the robot to malfunction and go off course.

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Conclusion

This report has presented the initial research on the background, specifications, and limitations of a project to design an autonomous, differential drive robot. The main goal of the

project is to design and create a fully autonomous line-following differential drive robot. The main hardware used in the project will be a 3D printed exterior and wheels, an IR sensor, and an Arduino kit. Our robot's microcontroller, the Arduino, will include all the coded software for the project. Because an Arduino kit is used, a supplementary motor driver and power source must be utilized. Another major limitation is related to the IR reflective sensors and the conditions of the testing because sunlight can cause some pollution and confusion with the sensors which may lead to a malfunction.

Over the next couple months, our design team will continue to design and configure the robot. Consequently, we will start incorporating the controls and mechanical components, prototyping, and testing the robot. This process will not only test us creatively but will also provide insights into designing a product. Aside from the submission of this project, a line-following robot has much value in warehouses for the online shopping industry.

Appendix A: Specifications of Components from Supply Kit

This appendix shows a list of all Arduino kit supplies expected to be used in the robot's hardware system. Table A-1 lists each component, the quantity, and the specifications of each component. Table A-1 will also present the breadboard in Figure A-1 because it was not pictured in Figure 2.

Table A-1. Components of the robot's hardware system, along with the components' quantity and specifications [5].

Component	Quantity	Specification
Breadboard	1	Holds wires, motor driver, battery pack, and Arduino Uno in place so a current can be formed between components
Arduino Uno	1	Allows for circuit to receive code from computer through wires being plugged into different inputs
TB6612 H-Bridge Motor	1	Connects motors to the Arduino Uno so motors can perform tasks based on infrared sensor detection
Motor	2	Turns wheels based on detection from infrared sensor
Battery Pack	1	Holds batteries and connects to the Arduino Uno so it has power to execute the code

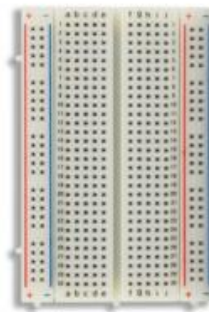


Figure A-1: Picture of breadboard. The T6612 H-Bridge Motor gets plugged across the split line in the middle of the breadboard [2].

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