International Journal of Scientific Research & Engineering Trends
Volume 10, Issue 5, Sept-Oct-2024, ISSN (Online): 2395-566X

Self Balancing Robot with Autonomous Navigation and Obstacle Detection

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Abstract- This paper details the design and implementation of a two-wheeled self-balancing robot capable of following a predefined path while detecting and avoiding obstacles. The robot utilizes an Infrared (IR) sensor array to track the path and an ultrasonic sensor to identify and measure the distance to obstacles in real-time. The self- balancing mechanism is achieved through a feedback control system that stabilizes the robot on its two wheels using a combination of gyroscopic and accelerometer data. A proportional-integral-derivative (PID) controller is employed to maintain stability and ensure smooth navigation along the path. The system's effectiveness was evaluated through a series of experiments, demonstrating the robot's ability to maintain stability, follow complex paths, and avoid collisions with obstacles.

Index Terms- self-balancing, line following. obstacle detection, PID, etc.

I. INTRODUCTION

The self-balancing line-following robot with obstacle detection is an advanced autonomous device that integrates path-tracking, stability control, and obstacle avoidance functionalities. It utilizes an infrared sensor to recognize and follow a path, which can be a black line on a white surface or a white line on a black surface, ensuring accurate navigation. To maintain stability, the robot incorporates sensors such as gyroscopes and accelerometers, allowing it to remain upright even on irregular surfaces.

Along with line-following and self-balancing, the robot is equipped with an obstacle detection mechanism using an ultrasonic sensor. This sensor calculates the distance between the robot and any object by transmitting sound waves and interpreting the returning echoes. The obstacle detection feature prevents collisions, making the robot more reliable and effective. However, it is essential to note that some objects may not be detected by the ultrasonic sensor due to their material characteristics, which might not reflect sound waves efficiently.

The robot is managed by an Arduino UNO microcontroller, which processes information from the infrared sensor, stability sensors, and ultrasonic sensor to make real-time adjustments to movement, direction, and balance. These features make the robot ideal for applications like military operations, delivery systems, transportation networks, and aiding visually impaired individuals. In addition to the mentioned features, the self-balancing line-following robot incorporates advanced control algorithms, such as PID (Proportional-Integral-Derivative) control, to maintain stability effectively. This allows the robot to continuously adjust motor speeds based on sensor feedback, ensuring precise balance.

By combining data from the infrared sensor, ultrasonic sensor, gyroscope, and accelerometer, the robot can achieve greater accuracy and reliability in both navigation and balance control. This sensor fusion allows the robot to compensate for individual sensor limitations and provides a more holistic understanding of its environment.

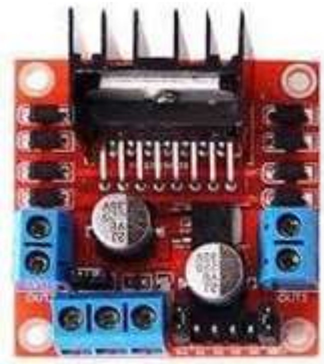
II. COMPONENTS

1. Arduino Uno

The Arduino Uno, based on the ATmega328P microcontroller, acts as the main controller for the robot. it has 14 digital I/O pins, 6 analog inputs, and a USB interface, making it ideal for connecting sensors like ultrasonic and infrared (IR) sensors, as well as motor drivers. in this project, it processes data for line following, self-balancing, and obstacle detection, and controls the motors accordingly. its simplicity, affordability, and library support make it well-suited for this application.

2. Motor Driver L298N

The l298n motor driver is used to control the dc motors It allows you to adjust the speed and direction of the motors, which is crucial for balancing, following the line, and avoiding obstacles.[1] The L298N receives signals from an arduino (or similar microcontroller) to control motor operations. For line following, the l298n is used to turn the motors based on inputs from line sensors



3. MPU6050

The mpu6050 is a sensor module that combines a 3- axis accelerometer and a 3-axis gyroscope, allowing it to measure both acceleration and angular velocity. In self-balancing line follower robot, the mpu6050 helps to keep the robot balanced by providing data on its orientation and motion. The accelerometer measures the tilt or angle of the robot, while the gyroscope measures the rate of rotation.[1]

4. IR Sensors

The IR sensors in your robot are used to detect the line it needs to follow. Each sensor consists of two parts: an IR transmitter (which sends out infrared rays) and an IR receiver (which detects reflected rays). When the robot is over a white surface, the ninfrared rays reflect back to the receiver, indicating it's on white. If the surface is black, the rays get absorbed and the receiver detects nothing, indicating the robot is on black. this way, the robot can distinguish between the black line and the white surface, helping it stay on the path.

5. Ultrasonic Sensor

The ultrasonic sensor in self-balancing line follower robot is used for obstacle detection. It works by emitting high-frequency sound waves and measuring the time it takes for the echo to bounce back after hitting an object. based on this time, the sensor calculates the distance between the robot and the obstacle.

It works similarly to radar or sonar, sending out high-frequency sound waves and then receiving the echo that bounces back from the object[3]

III. METHODOLOGY

The main objective of this project is to upgrade a balancing robot into a line-following robot with path obstacle detection capabilities. This involves using a PID controller for balancing, infrared (IR) sensors for line tracking, and an ultrasonic sensor for obstacle detection. The balancing system relies on the PID controller to maintain the robot's stability, while the IR sensors allow it to follow a predefined path. Additionally, the ultrasonic sensor enables the robot to detect and avoid obstacles in its path

1. PID-Balancing System

The control algorithm use to maintain balance in the self-balancing robot with autonomous navigation and obstacle detection is the PID controller. The proportional, integral, and derivative (PID) controller is commonly known as a three-term regulator. The input to the controller was the deviation from the system. The constants Kp, Ki, and Kd represent the proportional, integral, and derivative gains (the three components are multiplied by these gains, respectively). This is a closed-loop control mechanism, also known as a negative feedback system. The fundamental concept of a negative feedback system is that it measures the output 'y' from a sensor, subtracts it from the reference set- point value, and generates an error, which is then used by the PID controller.

Within the PID controller, this error is processed in three ways: the proportional term modifies the response based on the size of the error, the integral term helps eliminate residual errors over time, and the derivative term manages rapid changes or overshoots. Once the error is processed by the PID algorithm, the controller generates a control signal 'u.' This signal is applied to the system being controlled, which in this scenario is the two-wheeled robot. The goal of the PID control signal is to bring the system to the desired reference point, which, for the robot, is the zero-degree upright position, representing equilibrium.[4]

2. Line Following System

The line-following function is accomplished through the application of a specific algorithm that utilizes data from infrared (IR) sensors.

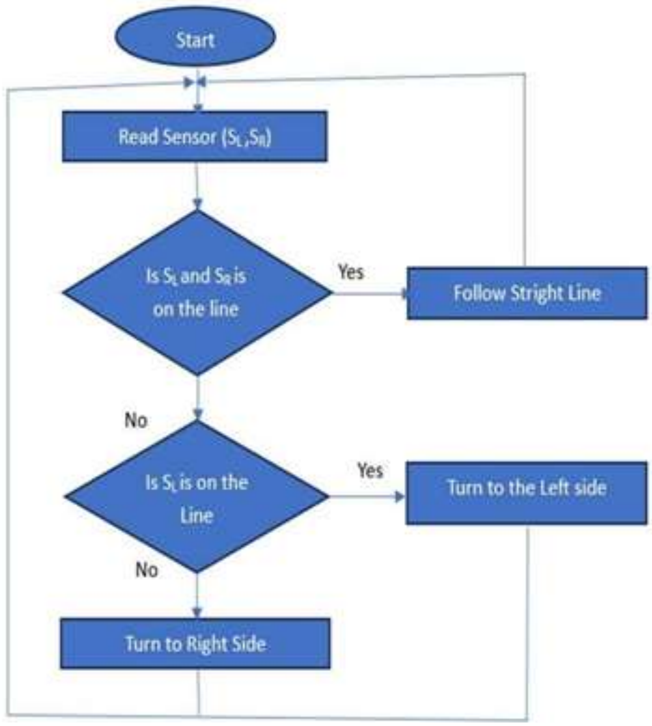


Fig 1: Line Follower

The sensor readings are processed by the programmed microcontroller, which directs the robot's continuous motion along the path. The direction and rotational speed are managed by the microcontroller. The robot will initiate line-following only when it achieves a balanced condition. If the robot becomes unstable, the stabilization process is prioritized before continuing with the line-following action.[5] for line-following robot uses infrared (IR) sensors to detect the path it should follow. these sensors are placed underneath the robot, typically in a row, and can detect contrasts, such as a black line on a white surface or vice versa. when the robot moves over the line, the IR sensors pick up changes in light reflectance—black surfaces reflect less light, while white surfaces reflect more.

The robot's microcontroller continuously receives data from the IR sensors. if the sensor detects the line the microcontroller adjusts the motors to keep the robot centered on the line. if the sensors on one side detect more of the line, the microcontroller will adjust the wheels to steer the robot back toward the line, effectively turning in that direction. similarly, if the robot moves too far to the other side, it will make adjustments in the opposite direction.

By increasing or decreasing the speed of each motor, the robot can shift left, right, or move straight ahead. when all sensors detect the line, the robot moves forward; if one of the side sensors detects the line while the others do not, the robot will turn slightly. this continuous process of detecting and adjusting allows the robot to follow the line accurately, even around curves or bends.

3. Obstacle Detection

There are several types of sensors available for obstacle detection, some of the most common ones include infrared (IR) sensors, ultrasonic sensors, cameras (for computer vision), and sonar. These sensors can measure distances over a wide range of points within their field of view.[6]

For our robot design, we are using ultrasonic sensors to detect and avoid obstacles. Ultrasonic sensors emit frequency signals continuously, and when an obstacle is present, these signals reflect back to the sensor, which then considers this as input.

Ultrasonic sensors are widely used in robotics for obstacle detection and avoidance due to their effectiveness and reliability. These sensors operate by emitting ultrasonic sound waves and measuring the time it takes for the waves to bounce back after hitting an object.

Obstacle avoidance in a self-balancing robot involves a coordinated effort between various sensors, a control system to maintain balance, and intelligent decision-making algorithms.

By leveraging the capabilities of ultrasonic and IR sensors alongside gyroscopic feedback, the robot can navigate its environment effectively while ensuring it remains upright and stable. This technology has numerous applications, including service robots, automated delivery systems, and personal mobility devices.

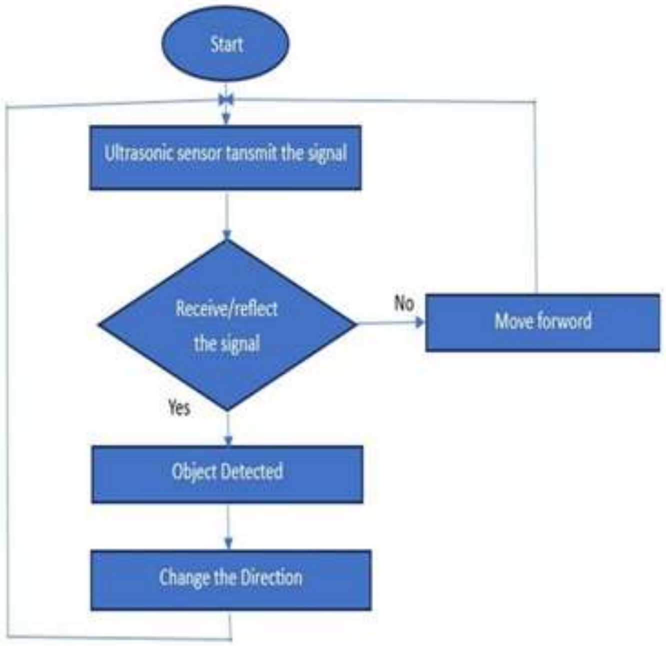


Fig 2: Obstacle Detection

4. Inverted Pendulum
An inverted pendulum is a system where a rod or stick is balanced upright on a moving platform, much like balancing a broomstick on your hand. The center of gravity is above the pivot point, making it naturally unstable, so constant adjustments are needed to keep it from tipping over.[8] this concept is often used in robotics to illustrate balance control, as it requires precise movements to stay upright. self-balancing robots work similarly by detecting when they tilt and adjusting their wheels to maintain stability.[7] an inverted pendulum is a well-known example in control systems and dynamics. it consists of a rod attached at its bottom to a pivot point, making it naturally unstable when positioned upright. to prevent it from falling over, continuous control is needed.

When the rod starts leaning in a certain direction, the pivot must be moved in the same direction to catch it and bring it back to an upright position. essentially, the system is always making corrective movements to counter the tilt.

This concept is like balancing a stick on your hand, where you move your hand left or right to prevent the stick from falling. without constant adjustments, the system would quickly lose balance and fall.

Inverted pendulums are often used in robotics, especially in self-balancing robots like segways or two-wheel robots. these robots use sensors like gyroscopes and accelerometers to measure their tilt angle. a control system, often a proportional-integral- derivative (PID) controller, determines the adjustments needed to maintain balance. by moving the wheels in the direction of the tilt, the robot prevents itself from falling, similar to how the inverted pendulum system works.

The inverted pendulum is studied in physics and engineering as a fundamental example for understanding stability and designing control systems. it serves as a model for control mechanisms used in robotics and automation.

IV. BLOCK DIAGRAM

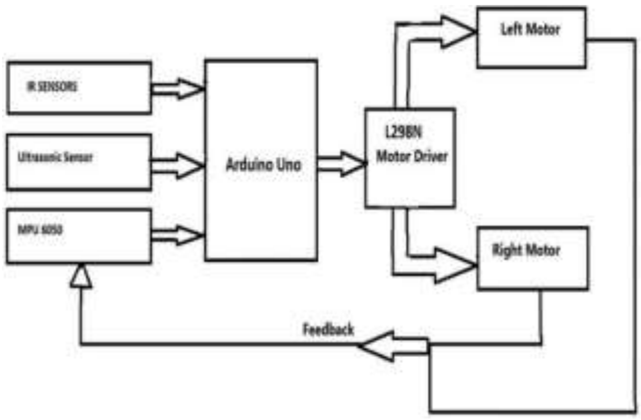


Fig 3: Block Diagram

V. CONCLUSION

In conclusion, the self-balancing, line-tracking robot with obstacle avoidance is an advanced autonomous system that combines route-following, stability management, and obstruction detection capabilities to ensure accuratemovement and dependable operation. Utilizing infrared sensors for path tracking, gyroscopes and accelerometers for maintaining stability, and ultrasonic sensors for detectingobstacles, the robot efficiently adapts to its surroundings. Theintegration of sophisticated control algorithms such as PID further improves its balance control. These attributes make the robot suitable for various applications, including defense operations, delivery solutions, transport systems, and supportfor visually impaired individuals, showcasing its adaptabilityand efficiency.

Acknowledgment
Authors taking this opportunity to thank all the people that assisted us in fulfilling this research paper. we would like to begin with our supervisor, who provided us with very precious guidance throughout, with constant encouragement and insightful feedback. we never thought that working with such an expert in this field would be considered a blessing, since they motivated us so much during the discussion about how and which direction our research should be taken. We extend

our regards to family and friends, whose encouragement and understanding kept going throughout this project.
Lastly, we thankful to Alard college of engineering and management for the provision of resources and support needed to pursue this research. Without them, this project would have been impossible.

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