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Smart Mobility Robot: Employing Line Follower Navigation for Object Movement

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Abstract

The growing need for automation in industrial and service sectors has emphasized the importance of systems that can minimize human involvement in repetitive and labor-intensive tasks, such as object transportation. This study proposes the design and implementation of an autonomous line follower robot to address the problem of manual object transfer along a predefined route. The developed system employs a BFD-1000 infrared sensor module for line detection, an Arduino UNO microcontroller for processing and control tasks, an L298N motor driver for actuating DC motors, and a mechanical structure composed of drive wheels and a robotic arm mechanism. The robot is programmed to follow a fixed path and transport objects from a pickup point to a designated drop-off location. Experimental evaluations demonstrate that the robot is capable of reliably transporting loads up to 100 grams, with stable path-tracking performance. The results indicate the potential of the proposed system as a cost-effective solution for simple automated transportation tasks.

Keywords:
Line Follower, Object Transfer, Robot, Navigation

1. Introduction

The advancement of robotics technology has grown in recent years, offering substantial potential across various industrial sectors. One prominent application area is logistics, where robotic systems can play a vital role in automating material handling processes to improve operational efficiency and reduce human labor. Despite this progress, challenges remain in achieving improved accuracy, speed, and load-handling capabilities. Among the available robotic solutions, the line follower robot stands out as a simple yet effective approach for automating transportation tasks [3]

Designed follower robots have been widely implemented in industrial settings due to their low cost, ease of deployment, and relatively simple control systems. The selection of a line follower robot in this study is driven by several considerations. First, the technology offers simplicity and efficiency, making it well-suited for small- to medium-scale logistics operations. Second, it is cost-effective and composed of affordable components, which supports its use in resource-constrained environments [1][7]. Third, it offers flexibility; route modifications can be achieved by reprogramming or physically altering the track. Lastly, the architecture is scalable, allowing for future upgrades in terms of payload or sensor integration. Several previous studies have explored the development of line follower robots. Ridarmin et al. (2019) proposed a prototype utilizing an Arduino Uno and TCRT5000 sensors for tracking a dark line, demonstrating basic autonomous navigation. Susilo (2018)

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introduced a prototype for automatic object delivery that incorporated a load cell sensor to determine the object's weight and delivery destination, showcasing an early attempt at functional integration for logistics applications [12].

While these studies laid the foundational work, challenges remain in increasing navigation accuracy, improving payload handling, and optimizing system integration for practical use cases. This study aims to address these challenges by designing and developing an autonomous line follower robot capable of transporting lightweight objects (up to 100 grams) along a fixed path. The proposed system integrates real-time navigation and load transport using an Arduino UNO microcontroller, BFD-1000 infrared sensors (as a more accurate alternative to TCRT5000), and an L298N motor driver for efficient motor control. The novelty of this work lies in its optimized design for power-efficient movement, enhanced sensor precision, and application in small-scale logistics environments to an area that remains underexplored research. This approach is intended to contribute to the development of accessible and low-cost automation solutions for small and medium-sized enterprises (SMEs) [3][6].

The development of smart mobile robots based on line follower technology has been extensively studied and applied across various fields, particularly in logistics and healthcare industries. This technology enables robots to follow predetermined paths using infrared sensors that detect color contrasts between the line and the background surface. Mahendra et al. (2019) and Hossain et al. (2021) demonstrated that line-following navigation systems offer high reliability in structured indoor environments and are relatively low-cost to implement. In the context of object transportation automation, this approach has proven effective for tasks involving the delivery of goods or lightweight materials from one location to another without direct human involvement [14] [15].

Beyond navigation technology, another critical aspect of such robotic systems is the ability to carry or push objects. Studies by Rathore et al. (2019) and Kale et al. (2020) discuss the design of actuators and robotic mechanisms to lift or push objects automatically. The integration of additional sensors, such as ultrasonic modules, has also been explored to enhance obstacle detection and navigation safety. Recent innovations even incorporate Internet of Things (IoT) connectivity, as discussed in Hossain (2021), enabling real-time monitoring and control of the robot. Therefore, a line follower-based robotic system equipped with object-handling capabilities presents a promising solution for efficient and adaptive internal transport automation [10].

2. Related Works

Several previous studies have investigated the development of object transfer robots. These studies vary in terms of functionality, sensor types, and microcontrollers used, making them valuable references and benchmarks for the current research. Ridarmin et al. (2019) discussed the development of a line follower robot prototype utilizing an Arduino Uno and four TCRT5000 sensors. The robot follows a dark/black line on a light/white surface to perform navigation [4]. Susilo et al. (2018) presented a line follower robot that considers the weight of the object using a load cell sensor to determine the delivery destination. Janis et al. (2014) described the use of a line follower robot for food delivery. The robot is equipped with a DC motor mechanism that enables it to automatically place the food upon reaching the destination [8].

Several studies have explored the integration of object-handling mechanisms within line follower robots to enhance their functionality in specific delivery tasks. Susilo et al. (2018) designed a robot capable of determining delivery destinations based on object weight using a load cell sensor. This approach introduces intelligent decision-making into the delivery process, allowing the robot to distinguish and sort packages according to predefined weight categories. Such integration of sensors not only improves delivery accuracy but also increases the adaptability of robots in warehouse and industrial environments. Similarly, Janis et al. (2014) demonstrated the application of a line follower robot for food delivery purposes utilized a DC motor-driven mechanism to automatically place the food tray upon reaching the destination. This functionality illustrates the robot's potential in service-oriented tasks where autonomous delivery and precise placement of items are essential. These studies emphasize the versatility of line follower robots when combined with additional sensors and actuators, paving the way for intelligent robotic systems in logistics and service automation [4][8][15].

In this study, we conduct research to automate the transfer of goods by integrating a robotic arm capable of picking up and placing objects. The design incorporates the BFD-1000 sensor module for line detection and an Arduino UNO microcontroller to process instructions delivered via the Arduino IDE software. A motor driver module (L298N) is used to control the motors. The key advantage of this study compared to previous works lies in the addition of a robotic arm that enables the system to autonomously pick up objects, transport them along a predefined path, and place them accurately at the target location [4][6].

3. Proposed Method

The methodology employed in this research consists of several key stages. First, a literature review was conducted to collect, analyze, and interpret relevant information from sources such as scientific journals, books, articles, and research reports. This stage serves to establish a solid theoretical foundation for the study. Next, the system specifications were defined, including a robot structure made from aluminum and acrylic mica materials. The robot utilizes two DC motors as actuators for driving the wheels and a servo motor to control the robotic arm. The BFD-1000 sensor module is used for path detection and also functions as the motor driver, while a voltage regulator is employed to step down the DC voltage. The robotic arm is specifically designed to pick up and place objects. The system design phase is divided into hardware design and software development. Finally, the testing phase includes evaluations of sensor performance, robot movement, data transmission, and overall system functionality to ensure reliability and efficiency.

4. Experimental Setup

In this study, we design the system using an Arduino UNO microcontroller, which functions as the processor for both incoming and outgoing data. The components are integrated into a single structural frame, including motorized wheels that serve as the base support for the BFD-1000-line sensor, which is responsible for detecting the navigation path. The frame of the line follower robot is constructed from acrylic material, with the robotic arm positioned at the topmost section to facilitate efficient object pickup and placement. The following sections present the system block diagram and the workflow diagram of the object transfer robot based on line follower navigation.

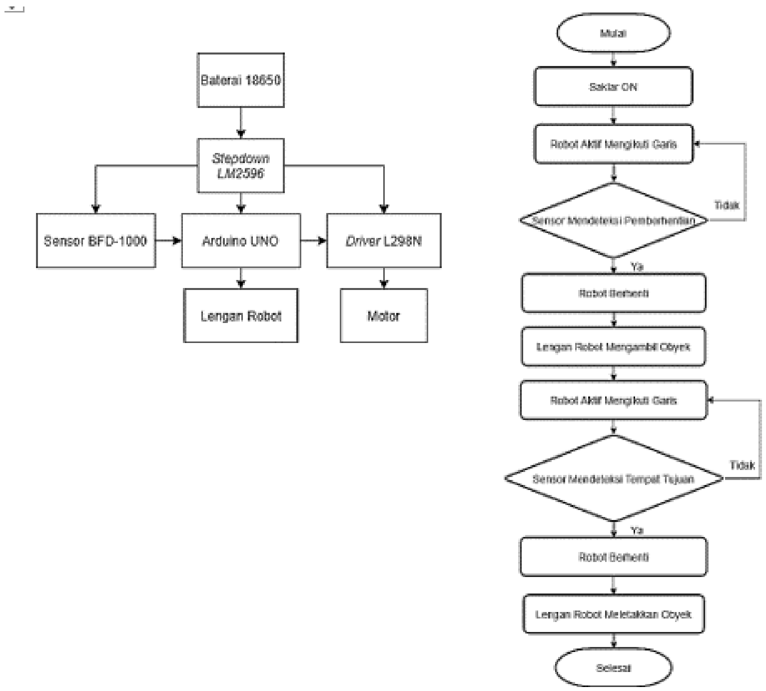

Fig. 1. Block and Workflow Diagram

4.1 L298N Driver Design

The L298N driver is used to control both the rotational speed and direction of DC motors. It receives power from a 5V input, which can be supplied either through the 5V output of the microcontroller or from a step-down voltage regulator. The driver receives control signals from the microcontroller to determine whether the motor should move forward, turn, or stop. Additionally, the microcontroller sends speed control signals based on the programmed instructions, allowing the motor to operate at the desired speed when moving forward or turning.

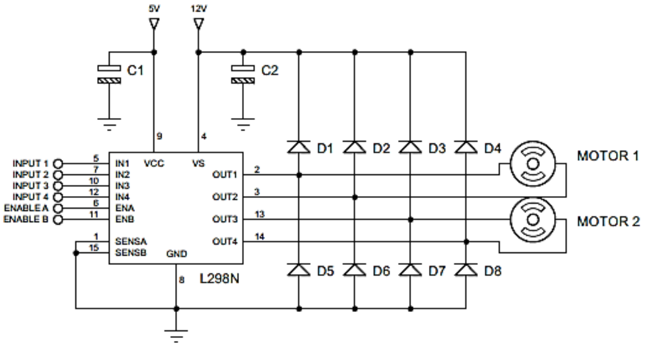

Fig. 2. Design Schematic of the L298N Motor Driver

4.2 BFD-1000 Sensor Design

The BFD-1000 sensor is used as the path detection component for the line follower robot. A total of five BFD-1000-line sensors are employed and calibrated using potentiometers. The calibration process is carried out to determine the appropriate infrared light intensity received by the photodiode sensor, enabling it to differentiate between high and low logic levels. This calibration is optimized for a sensor height of approximately 0.8 cm above the reflective surface.

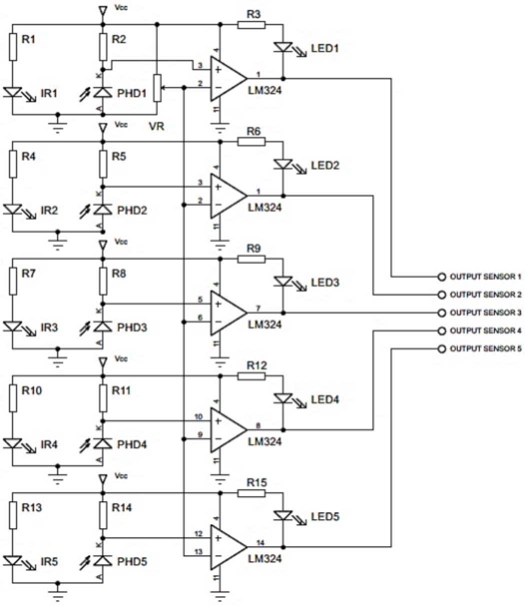

Fig. 3. Schematic Diagram of the Photodiode Sensor

4.3 Robotic Arm Design

The robotic arm is designed to assist in the picking and placing of objects. It utilizes four servo motors that function as the gripper and actuators for movement. The servo motors are directly connected to the microcontroller without the use of an external driver. The microcontroller sends control signals to the servo motors, instructing them on the direction and angle of rotation, thereby enabling the robotic arm to grasp and place objects as required. The robotic arm is assumed to consist of *n* revolute joints (rotary joints), each driven by a servo motor. The robot operates in a 2D or 3D environment.

Each joint contributes an angular rotation denoted by θi, and each arm segment has a length Li. The base frame is fixed. For a planar 2D robotic arm, the end-effector position (x,y) is calculated using:

$$x = \sum_{i=1}^{n} L_i \cos\left(\sum_{j=1}^{i} \theta_j\right)$$

$$y = \sum_{i=1}^{n} L_i \sin\left(\sum_{j=1}^{i} \theta_j\right)$$

PWM Control of Servo Motors

Servo motors respond to PWM (*Pulse Width Modulation*) signals, where the rotation angle θ is a function of the pulse width $t\ p$ in t p in milliseconds:

$$\theta = \left(\frac{180}{t_{\max} - t_{\min}}\right) \cdot (t_p - t_{\min})$$

Type values:

- $t_{\min} = 1.0\,\text{ms} \rightarrow 0^\circ$
- $t_{\max} = 2.0\,\text{ms} \rightarrow 180^\circ$

4.4 Software Design

The software design for the robotic arm is developed to control the rotation of the servo motors, which act as actuators to move the arm at specific angles. A total of four servo motors are utilized to drive the various joints of the robotic arm. The arm operates upon receiving a signal from the microcontroller, which triggers the movement. This signal is transmitted when the robot reaches either the object pick-up point or the object placement point. The following section presents the program implemented to control the robotic arm:

5. Results and Analysis

The performance of the developed robotic system was evaluated through a series of systematic tests on its core components, including sensors, microcontroller, actuators, and mechanical structure. The robot was designed to follow a black line on a white surface, with a track width of 3 cm. It employed BFD-1000 infrared sensors for line detection, operating optimally at a reflective distance of 0.8 cm. The pickup area featured a ring-shaped holder to ensure secure gripping by the robotic arm. The movement of both the drive motors and the robotic arm responded accurately to commands from the Arduino UNO microcontroller, based on real-time sensor readings. Initial tests validated the logic of the sensors in detecting black and white surfaces. Table 1 illustrates various combinations of high and low signals from the BFD-1000 sensors, corresponding accurately to surface color conditions

Table 1. Overall System Testing on Robot Response

BFD-1000 Sensor	**Condition**
Sensor 1	Sensor 2
Low	Low
Low	Low
Low	High
High	Low
High	High

The robot reliably identified object pickup and drop-off points using this logic. The built-in LEDs on the sensor modules served as indicators: a low logic state (black surface) activated the LED, while a high logic state (white surface) turned it off. This helped verify the functionality during calibration. Further trials assessed the robot’s ability to handle and transport objects of different weights over a fixed 2.4-meter track. The test results demonstrate that the system performed reliably for loads up to 100 grams. The consistent total time of 40 seconds indicates stable operational performance. The failed test at 130 grams highlights a critical design limitation in the mechanical strength of the robotic arm and overall system balance. These findings suggest that while the current system is suitable for small-scale logistics tasks, further improvements are necessary to expand its load-handling capacity. Overall, the developed robot exhibits reliable path-following and object-handling capabilities for light payloads, making it suitable for applications in structured environments such as laboratory automation, small-scale assembly lines, or warehouse item transfer. Future enhancements may include increasing mechanical strength, improving power efficiency, and integrating AI-based path planning to support dynamic and unstructured environments. After completing all system tests, the robot was further tested by moving objects of varying weights, as shown in Table 2.

Table 2. Robot Performance Testing

Weight	Distance	Pickup Time	Travel Time	Total Time	Result
10 g	2.4 m	18 s	22 s	40 s	*Successful*
30 g	2.4 m	18 s	22 s	40 s	*Successful*
40 g	2.4 m	18 s	22 s	40 s	*Successful*
100 g	2.4 m	18 s	22 s	40 s	Successful
130 g	2.4 m	-	-	-	Unsuccessful

Out of ten trials, seven were successful while one was unsuccessful. A trial is deemed successful if the robot correctly follows the black path on a white surface and successfully picks up and places the object at the designated points. A trial is considered unsuccessful when the robot fails to transport the object from the pickup to the placement point. The object's weight was the primary factor influencing success or failure. Objects weighing less than or equal to 100 g could be carried and moved by the robotic arm, whereas objects exceeding 100 g could not be transported due to limitations in the robotic arm's strength and the robot's balance. The overall success rate of the system reached 85.7%.

6. Conclusion

This study presents the design and implementation of a line follower robot system intended for autonomous object transportation. The robot was equipped with a BFD-1000 infrared sensor array and an Arduino UNO microcontroller, enabling accurate line tracking on a 3 cm wide black path and effective motion control. The system was capable of detecting pickup and drop-off points using sensor-based logic and executing object manipulation tasks through a motorized robotic arm. Experimental testing revealed that the robot could reliably transport objects weighing up to 100 grams with a consistent operation time of 40 seconds, achieving an overall success rate of 85.7%.

Failure occurred only when the payload exceeded 100 grams, highlighting the mechanical limitations of the current design. These findings demonstrate the potential of the proposed system for small- to medium-scale material handling tasks in structured environments such as laboratories, warehouse systems, and production lines. To improve the system's capabilities and extend its application scope, future work will focus on strengthening the robotic arm's mechanical structure, increasing payload capacity, improving energy efficiency, and incorporating advanced technologies such as artificial intelligence and machine learning for adaptive navigation and dynamic path planning. These enhancements aim to increase the system's flexibility, robustness, and scalability in real-world industrial environments.

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