**BANGLADESH ARMY INTERNATIONAL UNIVERSITY OF
SCIENCE AND TECHNOLOGY, CUMILLA**

Department of Electrical and Electronic Engineering

Project Report

Project Title: Logic Gates Based Line Following Robot (LFR)

Design and Implementation of a Line Following Robot (LFR) using
Fundamental Logic Gates (AND, OR, NOT)

Course Code: **EEE-314**

Course Title: **Digital Electronics Laboratory**

Student Name:
Jawad Nahin (ID:1218017)
Arzuman Ara (ID:1218020)
Khandker Mahazabin (ID:1218028)
Adnan Hossain Bhuiyan (ID: 1218031)
M. Monsur Ahmed Evan (ID: 131014)

Supervisor:
Md. Ashraful Islam,
Assistant Professor

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Abstract

This project presents the successful design and implementation of an autonomous Line Following Robot (LFR) developed entirely using discrete digital logic components. Unlike conventional designs that rely on microcontrollers, the control system of this robot is constructed exclusively from fundamental logic gates (AND, OR, and NOT). The robot utilizes five Infrared (IR) sensors to accurately detect and follow a predefined path. A L293D motor driver is employed to interface the logic circuitry with two DC motors, enabling controlled forward motion and precise directional adjustments. The required motor control signals are generated through optimized combinational logic derived using Boolean algebra and Karnaugh map minimization techniques. The experimental results confirm that the robot is capable of stable line tracking and effective course correction, demonstrating the practical application of basic digital logic and electronic principles in robotic system design.

Acknowledgement

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1. Introduction

A Line Following Robot (LFR) is an autonomous robotic system capable of detecting and following a predefined path, typically represented by a black line on a white surface or vice versa. Conventional LFR designs generally rely on microcontrollers to process sensor data and control actuators. In contrast, this project focuses on implementing the entire control system using only fundamental digital logic gates. This approach enhances the understanding of core digital electronics principles and establishes a direct relationship between sensor inputs and motor control outputs.

2. Objectives

- To design a line following robot using only fundamental logic gates.

- To apply Boolean algebra and Karnaugh map techniques for logic minimization.

- To eliminate the use of microcontrollers and implement pure hardware control.

- To understand the practical application of digital electronics in robotics.

3. System Overview

The system consists of a five-sensor IR array for line detection, a combinational logic circuit built using AND, OR, and NOT gates, a L293D motor driver IC, a buck converter module, and two DC geared motors. The robot is powered by a 7.4 V battery, which is stepped down to a regulated 5 V using the buck converter to safely supply the IR sensors, logic gates, and control circuitry. The sensors detect the position of the line and generate digital signals, which are processed by the logic circuit to produce appropriate motor control signals. These signals are then applied to the L293D motor driver, which amplifies the control signals and drives the motors accordingly.

4. Hardware Components

(a) <u>Infrared (IR) Sensors:</u>

Five IR sensors are used to detect the position of the line. Each sensor provides a digital output indicating the presence or absence of the line beneath it.

(b) <u>Fundamental Logic Gates:</u>

ICs containing AND, OR, and NOT gates are used to implement the combinational logic required for decision making.

(c) <u>L293D Motor Driver IC:</u>

The L293D IC is used to interface the low-current logic circuit with the high-current DC motors. It allows bidirectional control of two motors.

(d) <u>DC Geared Motors:</u>

Two DC geared motors provide the necessary motion for the robot using a differential drive mechanism.

(e) <u>Power Supply and Buck Converter:</u>

A regulated 5V power supply is used to power the sensors, logic ICs, and motor driver.

5. Methodology

The methodology of this project involved assembling and calibrating a five-sensor IR array to accurately detect the line position. Based on the sensor outputs and the required motor movements, a comprehensive truth table was developed and the corresponding Boolean expressions were minimized using Karnaugh maps. The optimized logic was then implemented using only fundamental logic gates, and the resulting control signals were interfaced with the L293D motor driver to operate the DC motors. Finally, the robot chassis and all electronic components were mechanically assembled, followed by systematic testing and calibration on a line-tracking surface to ensure stable and reliable operation.

5.1 Flow Chart:
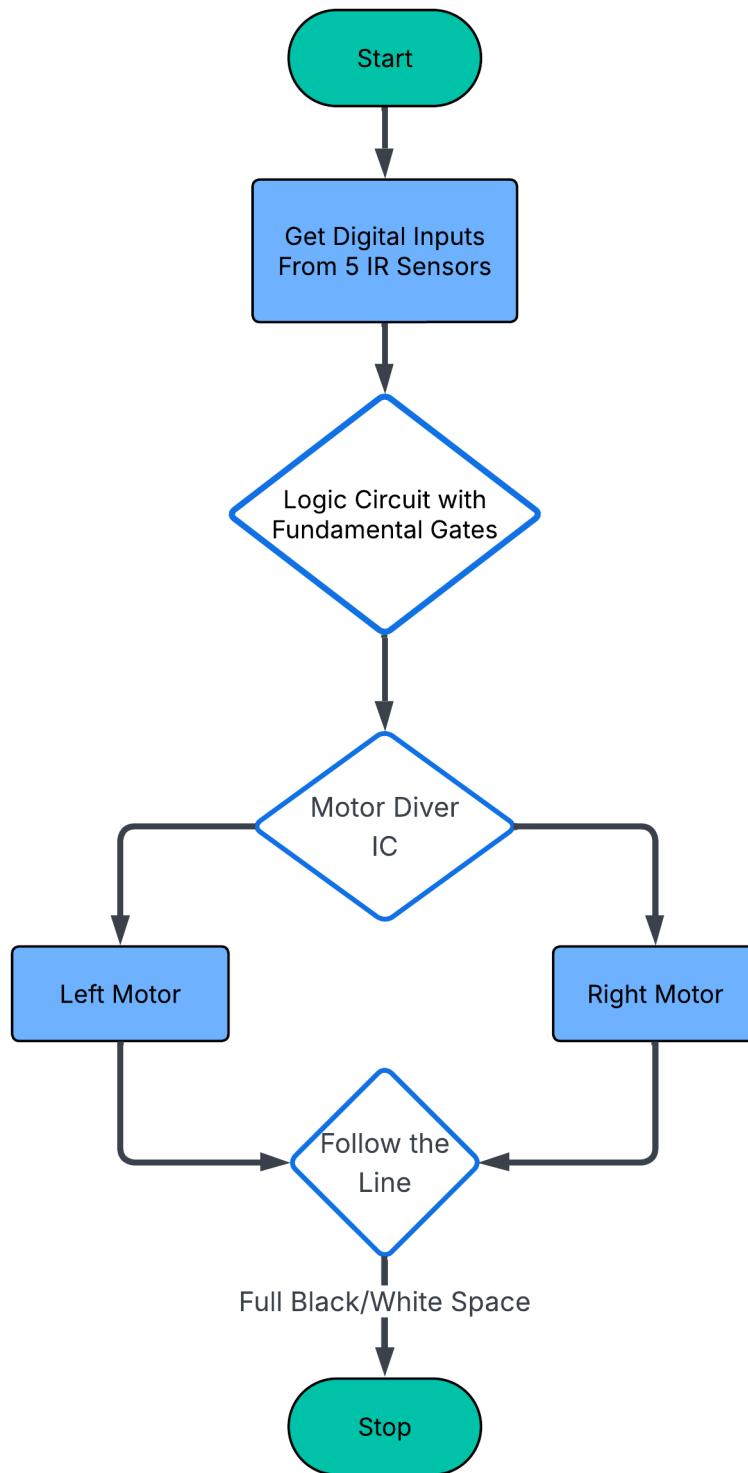
Figure: Block diagram of the working process.

5.2 Control Strategy:

The five IR sensors L1 (leftmost), L0 (left), C0 (center), R0 (right), and R1 (rightmost) generate digital outputs that serve as the input variables of the combinational logic circuit. These five inputs are arranged in a truth table to represent all possible line detection conditions. Based on the sensor input combinations, the logic circuit produces four output signals: ML0 and ML1 for the left motor, and MR0 and MR1 for the right motor. Each motor is controlled using a 2-bit control scheme, where specific combinations of the two bits determine forward, reverse, or stop operation. By following the defined truth table, the logic circuit generates appropriate motor control outputs that enable the robot to move straight, turn left or right, or stop according to the detected position of the line.

The robot uses a **differential drive** system:

- **Turn Left:** Right Motor ON, Left Motor OFF.

- **Turn Right:** Left Motor ON, Right Motor OFF.

- **Move Straight:** Both Motors ON.

- **Stop/Halt:** Both Motors OFF.

5.3 L293D IC Motor Control Logic Chart:
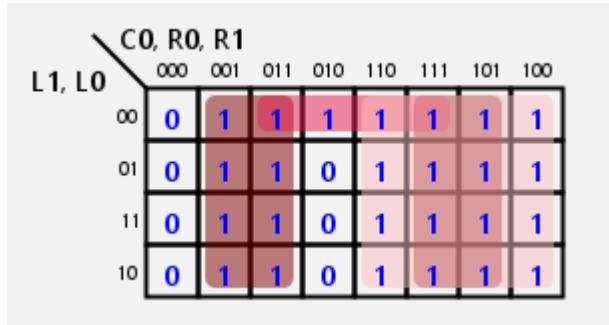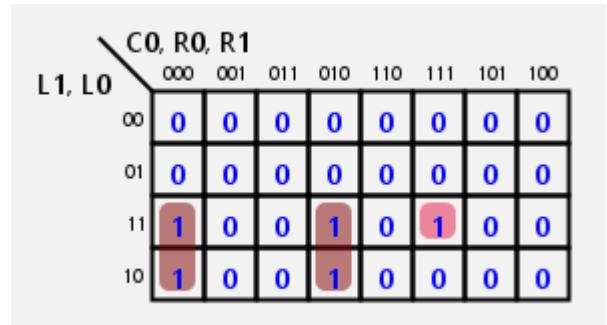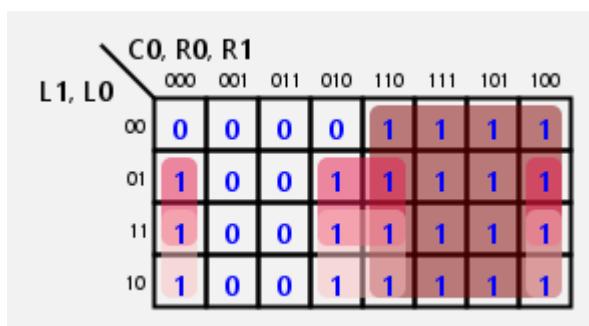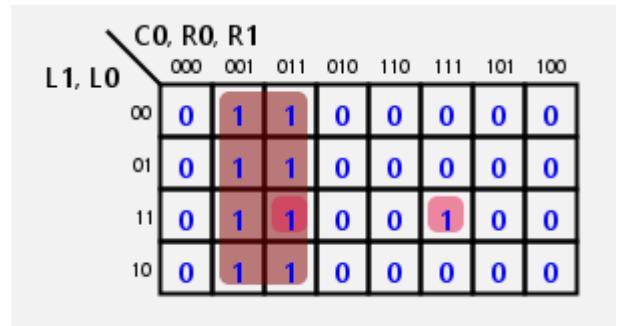
Motor	Input Pins	Forward	Reverse	Stop
Left Motor	IN1, IN2	IN1 = 1, IN2 = 0	IN1 = 0, IN2 = 1	IN1 = 0, IN2 = 0
Right Motor	IN3, IN4	IN3 = 1, IN4 = 0	IN3 = 0, IN4 = 1	IN3 = 0, IN4 = 0

5.4 Digital Logic Design:

The truth table was first constructed using the five sensor inputs (L1, L0, C0, R0, R1) and the four motor control outputs (ML0, ML1, MR0, MR1). Karnaugh map (K-map) minimization was then applied to derive simplified Boolean expressions for each output. Finally, the minimized Boolean functions were implemented as a digital circuit using IC 7408 (AND), IC 7404 (NOT), and IC 7432 (OR).

5.4.1 Truth Table:

IR Sensors Input					Left Motor		Right Motor	
L1	L0	C0	R0	R1	ML0	ML1	MR0	MR1
0	0	0	0	0	0	0	0	0
0	0	0	0	1	1	0	0	1
0	0	0	1	0	1	0	0	0
0	0	0	1	1	1	0	0	1
0	0	1	0	0	1	0	1	0
0	0	1	0	1	1	0	1	0
0	0	1	1	0	1	0	1	0
0	0	1	1	1	1	0	1	0
0	1	0	0	0	0	0	1	0
0	1	0	0	1	1	0	0	1
0	1	0	1	0	0	0	1	0
0	1	0	1	1	1	0	0	1
0	1	1	0	0	1	0	1	0
0	1	1	0	1	1	0	1	0
0	1	1	1	0	1	0	1	0
0	1	1	1	1	1	0	1	0
1	0	0	0	0	0	1	1	0
1	0	0	0	1	1	0	0	1
1	0	0	1	0	0	1	1	0
1	0	0	1	1	1	0	0	1
1	0	1	0	0	1	0	1	0
1	0	1	0	1	1	0	1	0
1	0	1	1	0	1	0	1	0
1	0	1	1	1	1	0	1	0
1	1	0	0	0	0	1	1	0
1	1	0	0	1	1	0	0	1
1	1	0	1	0	0	1	1	0
1	1	0	1	1	1	0	0	1
1	1	1	0	0	1	0	1	0
1	1	1	0	1	1	0	1	0
1	1	1	1	0	1	0	1	0
1	1	1	1	1	1	1	1	1

5.4.2 Simplified Truth Table (5-Input Logic: L1, L0, C0, R0, R1) with Karnaugh Map (K-map) Minimization:

K-Map for **ML0**

K-Map for **ML1**

K-Map for **MR0**

K-Map for **MR1**

5.4.3 Minimized Boolean Expressions (Sum-of-Products):

$$ML0 = R1 + L1 \cdot \overline{L0} \cdot \overline{R0} + C0$$

$$ML1 = L1 \cdot C0 \cdot R1 + L1 \cdot \overline{L0} \cdot \overline{C0} \cdot R0 \cdot R1$$

$$MR0 = C0 + L0 \cdot \overline{R1} + L1 \cdot \overline{R1}$$

$$MR1 = \overline{C0} \cdot R1 + L1 \cdot L0 \cdot R0 \cdot R1$$

5.4.4 <u>Logic Circuit Diagram:</u>
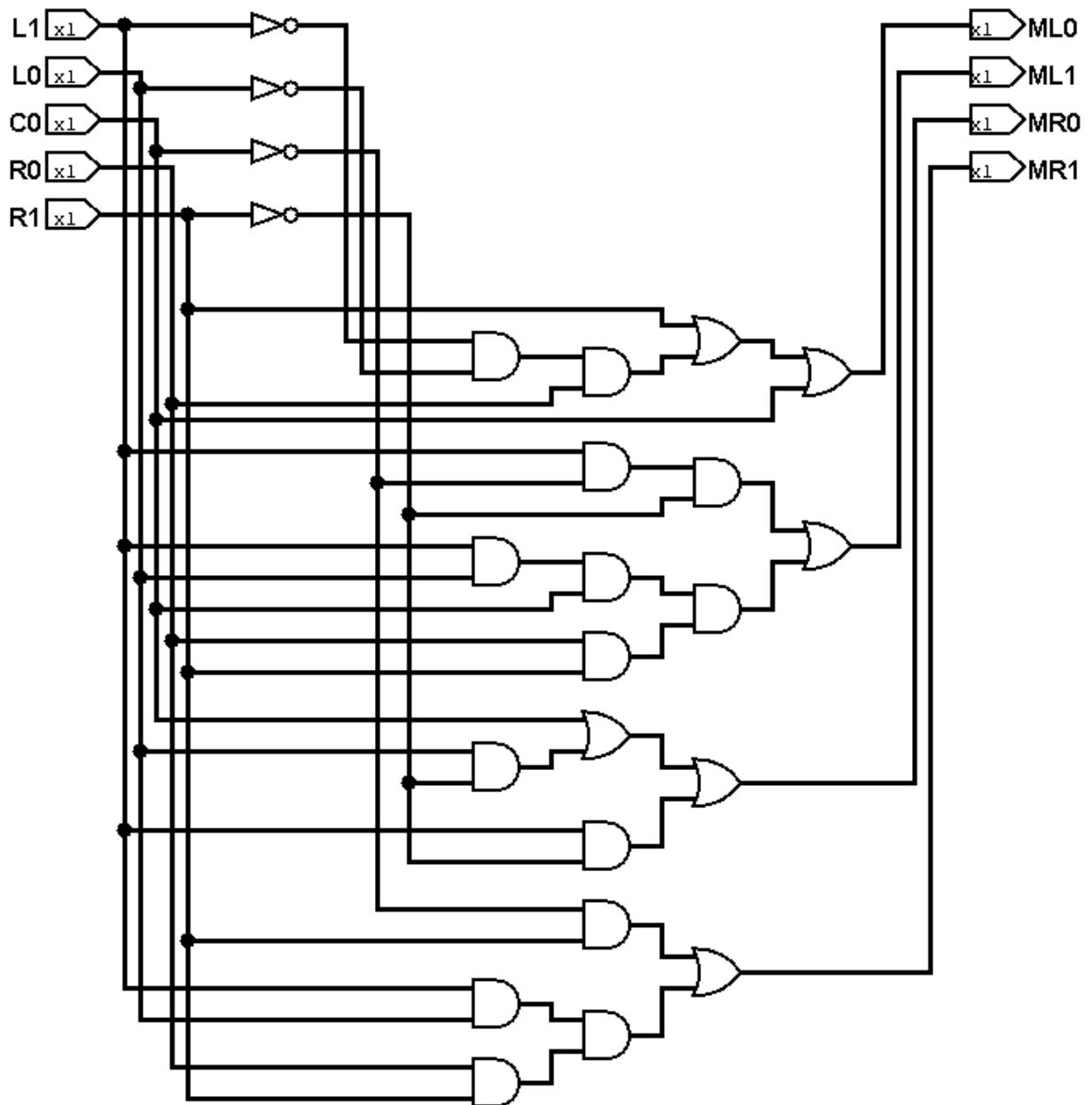
Figure: Logic Diagram of 5 IR sensors inputs and 4 outputs to motor diver.

Gate Count:

Number of NOT gates = 4
Number of AND gates = 14
Number of OR gates = 6

Number of ICs:

NOT (7404): 1
AND (7408): 4
OR (7432): 2

5.5 Circuit and Logic Diagram:
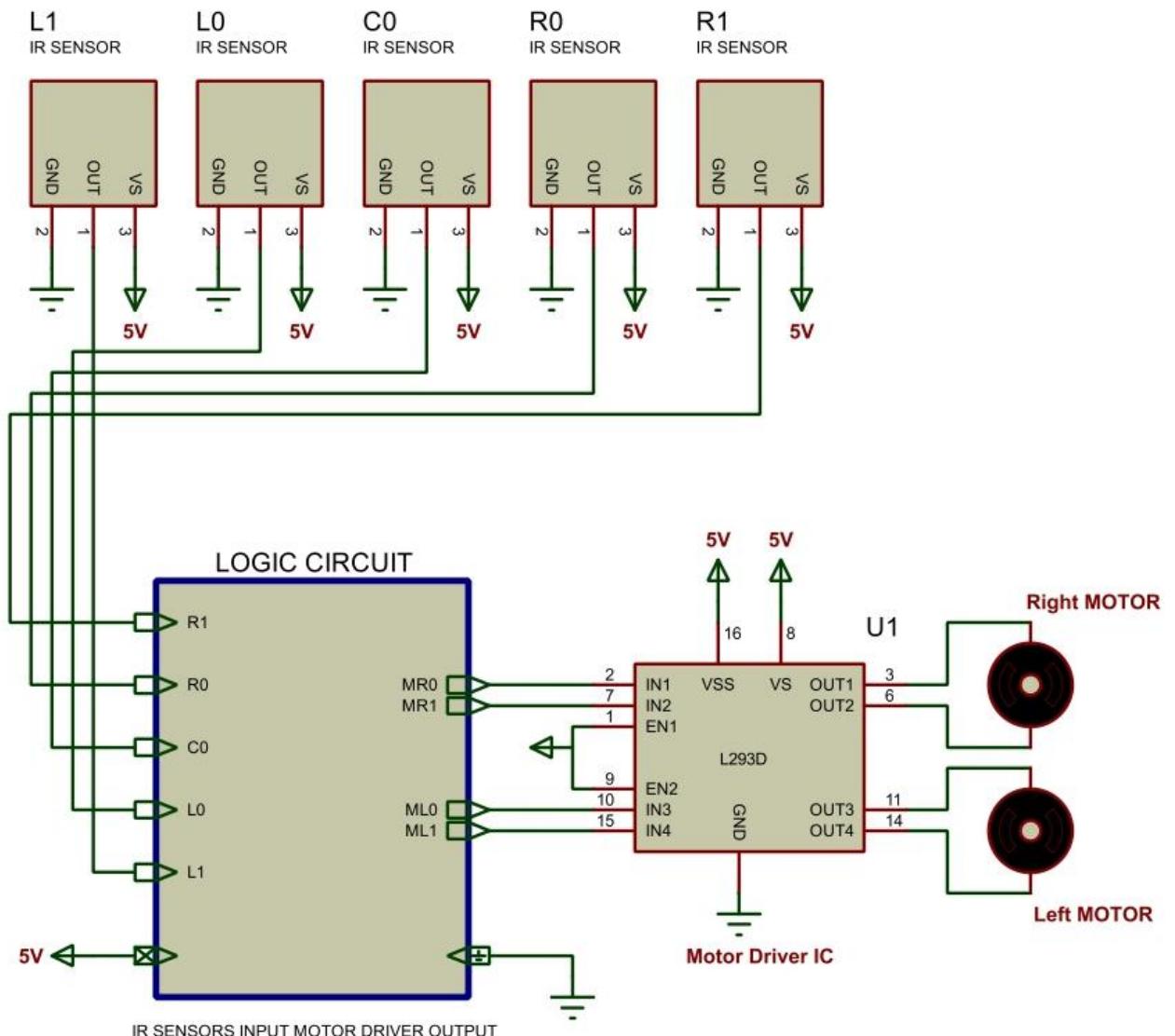
Figure: Circuit Diagram of LFR.

5.6 Implementation:

All components are mounted on a foamboard chassis. Two DC motors are attached to the chassis, and a two-layer design is used: the lower layer holds the battery and buck module along with the IR sensors, while the upper layer supports the main circuit implemented on a breadboard. The motors and IR sensors are connected to the main breadboard circuit using jumper wires. After assembly, the robot is tested on a predefined track to verify its line-following performance.

5.6.1 Cutout of the Chassis:

The placement of the IR sensors is very important. If the robot is intended to follow a wider line, the gap between the sensors should be larger, and for a narrower line, the sensors should be closer together. In this project, the sensor arrangement was designed to follow a line 4.5–5 cm wide, while keeping the design as compact as possible. The overall dimensions of the robot are 22 cm by 18 cm.
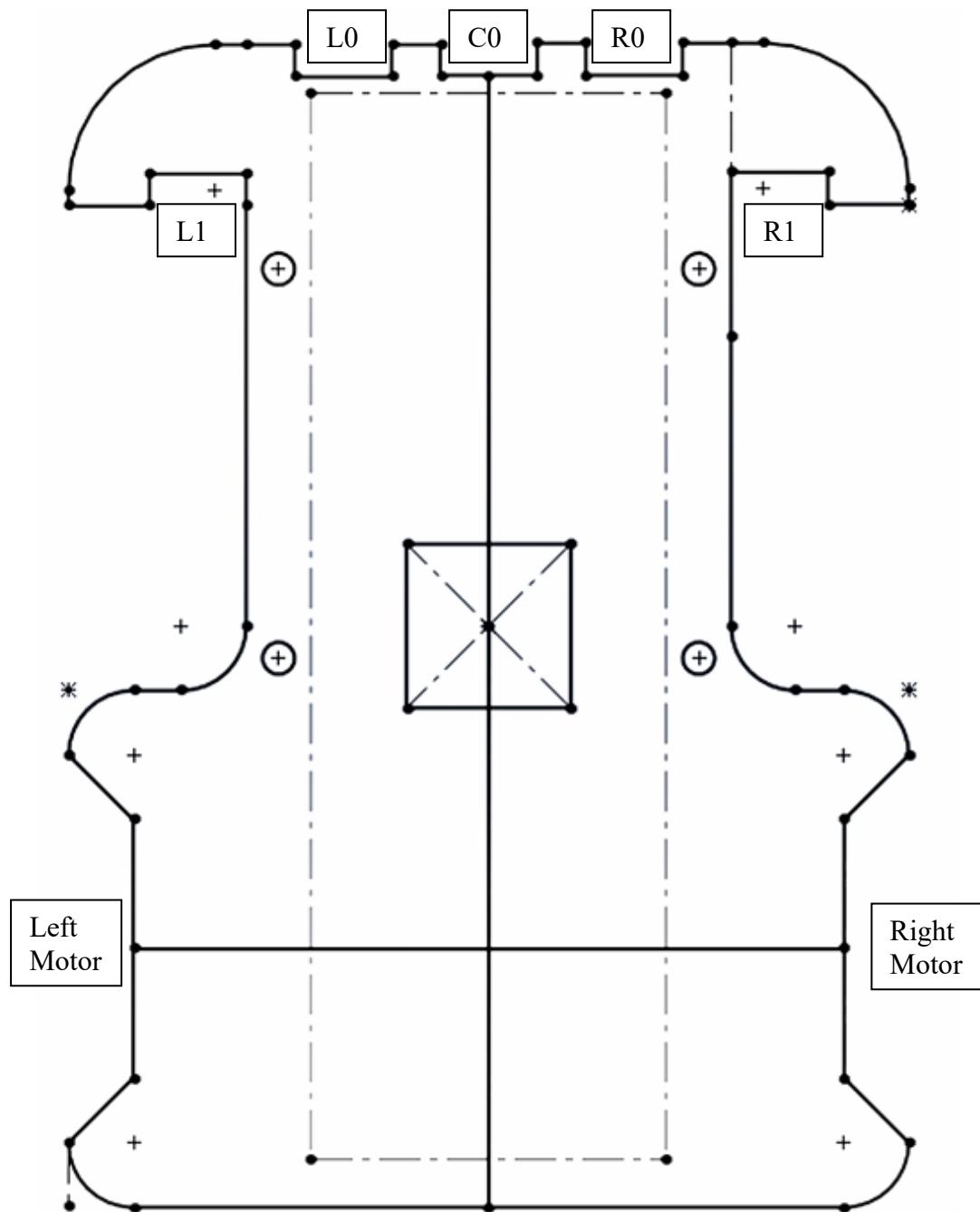
Figure: Cutout of the chassis.

6. Results and Observations

The robot successfully follows the line and performs left, right, and straight movements based on sensor inputs. It can also handle sharp 90° turns, 45° and 130° angles, as well as circular and zigzag paths, including cross-sections. The response is stable under controlled lighting conditions, demonstrating the effectiveness of the logic-based control system. However, the robot cannot reliably follow lines narrower than 4.5 cm or wider than 7.5 cm.
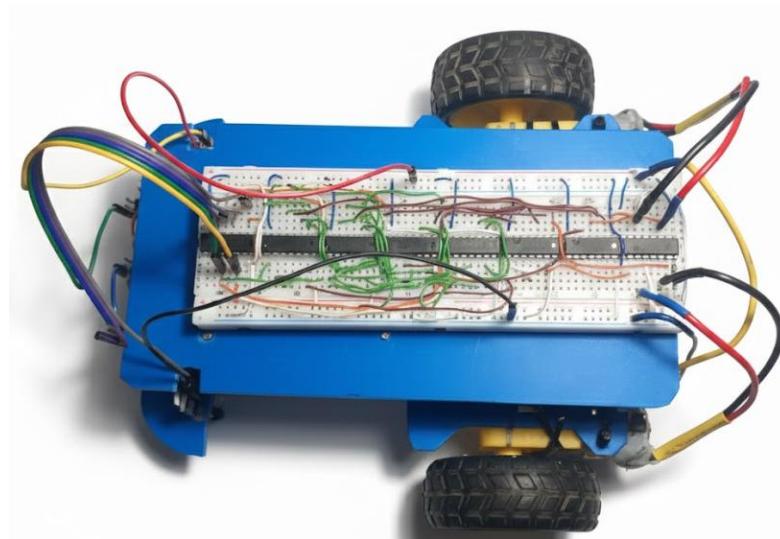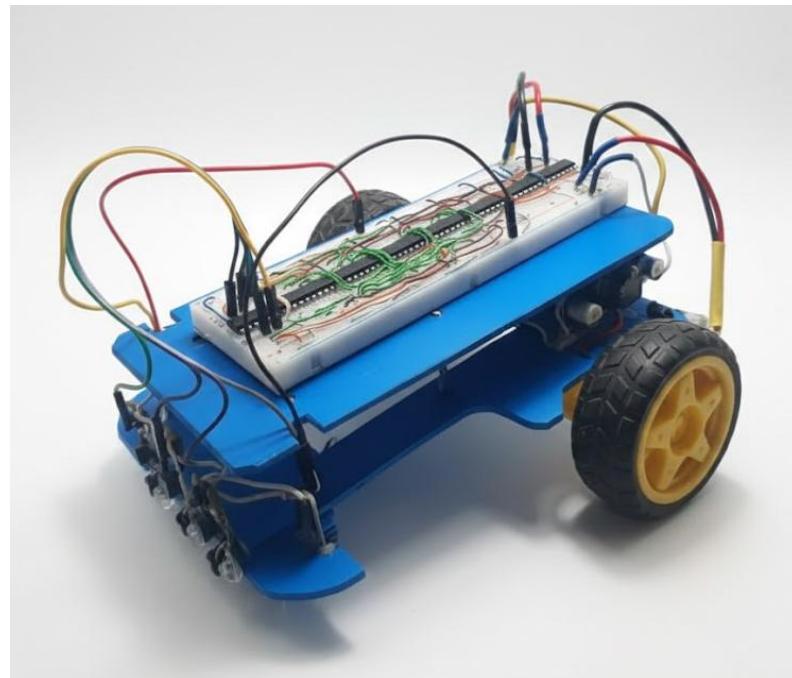

Figure: Final look of the fully built robot.

7. Advantages

- No microcontroller required.

- Clear and transparent control logic.

- Educational and cost-effective design.

- Reliable operation with minimal software dependency.

8. Limitations

- Increased hardware complexity due to multiple logic gates.

- Limited flexibility compared to programmable systems.

- Sensitive to noise and sensor misalignment.

9. Applications

- Educational robotics laboratories.

- Demonstration of digital logic applications.

- Basic autonomous navigation systems.

10. Cost Analysis

Component	Quantity	Estimate Price (TK)
Infrared (IR) Sensor	5 pcs	**200**
Fundamental Logic Gates IC	6 pcs	180
L293D IC	1 pcs	**100**
DC Geared Motors	2 pcs	200
Power Supply and Buck Converter	1 unit	200
Chassis & Wheels	As required	100
Connectors, Switch and Boards	As required	50
Glue	As required	100
Tape	As required	150
Total		**1280**

We spent some money on creating the path for the robot to follow, which increased the expenses beyond the assumed amount of around 250 Tk.

11. Conclusion

This project successfully demonstrates that fundamental digital logic gates can effectively replace microcontrollers for specific, dedicated tasks, thereby reducing software complexity and programming overhead. By utilizing a hardware-defined architecture, the robot operates with high efficiency, as the system is physically optimized for a single purpose. This highlights the practical value of Boolean algebra in creating streamlined, reliable real-world applications without the need for complex code.

12. References

- Book: Digital Design – M. Morris Mano
- L293D Motor Driver Datasheet
- GitHub Project: 4-Sensor Line-Following Robot Using Logic Gates.
  Link: https://github.com/Batushn/Logic-Gates-Line-Follower

THE END