Analog Line Following Robot

Fully Analog PID-Controlled Mobile Platform

Team Outlaws
Department of Electronic & Telecommunication Engineering
University of Moratuwa, Sri Lanka

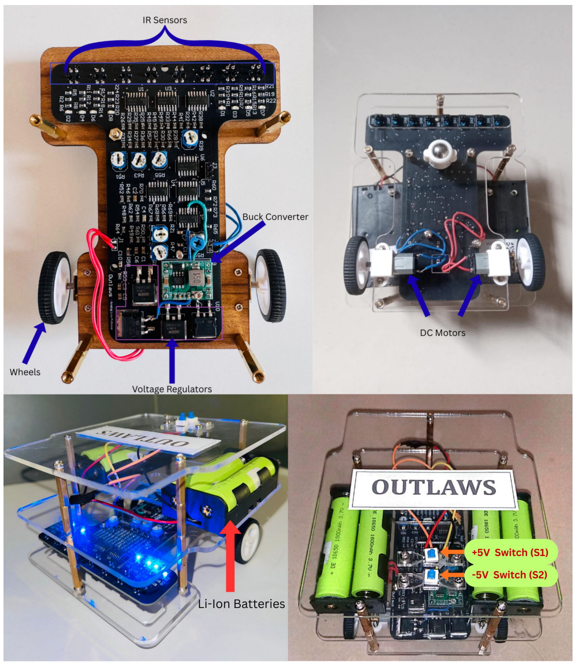

Fig. 1: Analog Line Following Robot hardware platform

***Abstract*—This datasheet presents a fully analog line following robot designed without the use of microcontrollers or digital computation. The system employs an infrared reflective sensor array, real-time analog signal conditioning, and a complete analog PID controller to generate smooth motor control through analog PWM generation. The platform demonstrates deterministic behavior, low latency, and robustness, making it suitable for robotics education, control system demonstrations, and line-following competitions.**

I. Product Overview

The Analog Line Following Robot is an autonomous mobile robot that tracks a predefined path using a fully analog control architecture. Unlike conventional robotic platforms that depend on microcontrollers and software algorithms, this system implements sensing, error computation, control, and motor actuation entirely using analog circuits.

The robot continuously detects line position using an infrared reflective sensor array. Sensor signals are processed through buffering, weighted summation, and an analog PID controller. Motor speed and direction are controlled via analog PWM generation, resulting in fast and deterministic response without software latency.

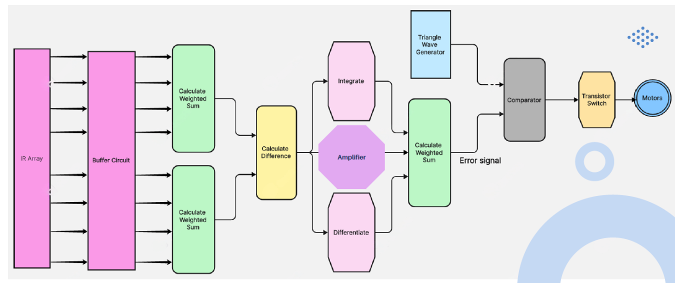

Fig. 2: Functional block diagram of the analog line following robot

II. Key Features

- Fully analog control system (no firmware, no MCU)
- Eight-channel IR reflective sensor array
- Real-time analog PID controller (P, I, D)
- Analog PWM motor control
- Onboard trimmer potentiometers for tuning
- Compact SMD-based PCB

III. System Block Diagram

The system begins with an IR sensor array that detects surface reflectivity. Buffered sensor outputs are processed by weighted scaling adders to compute positional information. A differential amplifier generates the line error signal, which is fed into a fully analog PID controller. The PID output is converted into PWM using a triangular wave generator and comparator, driving the motors via transistor-based power stages.

IV. Sensor and Detection System

The robot employs eight infrared reflective sensors based on the TCRT5000 module. Each sensor produces a continuous analog voltage proportional to the reflected infrared light intensity. Black surfaces absorb IR radiation and produce lower voltages, while white surfaces reflect more light, producing higher voltages.

Each sensor output is buffered using op-amp voltage followers to eliminate loading effects and preserve signal integrity. Weighted summation circuits then convert raw sensor data into meaningful positional information for accurate line deviation detection.

Detection Characteristics:

- Sensor type: IR reflective (TCRT5000)
- Number of sensors: 8
- Output: Continuous analog voltage
- Line type: Black line on white surface

V. Analog Control Circuit

The control system is implemented using LM324 operational amplifiers and discrete passive components. Buffered sensor signals are processed through weighted scaling adders and a subtractor to generate a signed line error signal.

This error signal is processed by:

- **Proportional block (P):** Immediate response to line deviation
- **Integral block (I):** Eliminates steady-state error
- **Derivative block (D):** Improves dynamic stability

The summed PID output is converted into a PWM signal using an analog triangular wave generator and comparator. The resulting PWM signal drives DC motors through transistor-based motor drivers.

All gains and offsets are adjustable using onboard trimmer potentiometers.

VI. Applications

The analog line following robot serves multiple applications in both educational and competitive environments. Its purely analog architecture makes it an excellent teaching tool for demonstrating classical control theory without the complexity of digital systems. The platform is ideal for undergraduate laboratories focusing on feedback control, sensor integration, and power electronics.

In competitive robotics, the deterministic behavior and zero-latency response provide advantages in high-speed line following competitions. The absence of software delays enables faster response times compared to microcontroller-based systems. Additionally, the robot serves as an effective demonstration platform for control system principles in technical exhibitions and outreach programs.

Primary Application Areas:

- Line-following competitions
- Analog control education
- Robotics laboratories
- Control system demonstrations

VII. Performance Characteristics

The robot demonstrates excellent line tracking performance across various track configurations. The analog PID controller provides smooth and stable operation with minimal oscillation around curves. Response time is significantly faster than digital implementations due to the elimination of sampling delays and computational overhead.

The control loop operates continuously in real-time with near-zero latency, limited only by the bandwidth of operational amplifiers and passive components. This results in superior dynamic response, especially during rapid directional changes and tight corners.

TABLE I: Performance Specifications

Parameter	Value
Maximum speed	0.5 m/s
Minimum detectable line width	1.5 cm
Maximum turning response time	60 ms
Control loop latency	Near-zero (analog)
Line tracking stability	High (PID-controlled)

TABLE II: Electrical Specifications

Parameter	Specification
Control method	Fully analog PID
Analog supply voltage	± 5 V regulated
Motor supply voltage	6 V
PWM generation	Analog comparator-based
Power source	Li-Ion batteries

VIII. Electrical Specifications

The robot operates on dual power supplies to separate analog control circuitry from motor drive electronics. The analog control section requires a regulated ± 5 V dual supply for operational amplifiers and signal conditioning circuits. Motor drivers operate from a separate 6 V supply to minimize electrical noise coupling into sensitive analog stages.

Li-Ion batteries provide portable power with sufficient capacity for extended operation. Voltage regulators ensure stable supply voltages despite battery discharge characteristics. The PWM motor control system is generated using analog comparators comparing the PID output signal with a triangular carrier wave.

All power supply rails include appropriate decoupling capacitors to maintain signal integrity and prevent oscillations in the analog control loops.

IX. Mechanical Specifications

The mechanical design of the analog line following robot prioritizes compactness, stability, and ease of assembly. The chassis is fabricated using an acrylic 3D-printed enclosure, providing sufficient rigidity while maintaining low weight. A differential drive configuration with rubber-coated DC motor wheels ensures good traction and precise maneuverability on typical line-following tracks. The printed circuit board is securely mounted directly onto the chassis, minimizing vibration and maintaining reliable electrical connections during operation. The overall dimensions are optimized to house all analog circuitry, power components, and motors within a compact form factor suitable for educational and competitive applications.

X. User-Adjustable Parameters

The robot provides seven onboard trimmer potentiometers (presets) for field adjustment and optimization. These presets allow users to tune the control system behavior without circuit

TABLE III: Mechanical Specifications

Parameter	Specification
Chassis material	Acrylic (3D-printed enclosure)
Dimensions (L × W × H)	14.2 cm x 13.1 cm x 10 cm
Wheel type	Rubber-coated DC motor wheels
Drive configuration	Differential drive (2-wheel)
Mounting method	PCB mounted on chassis

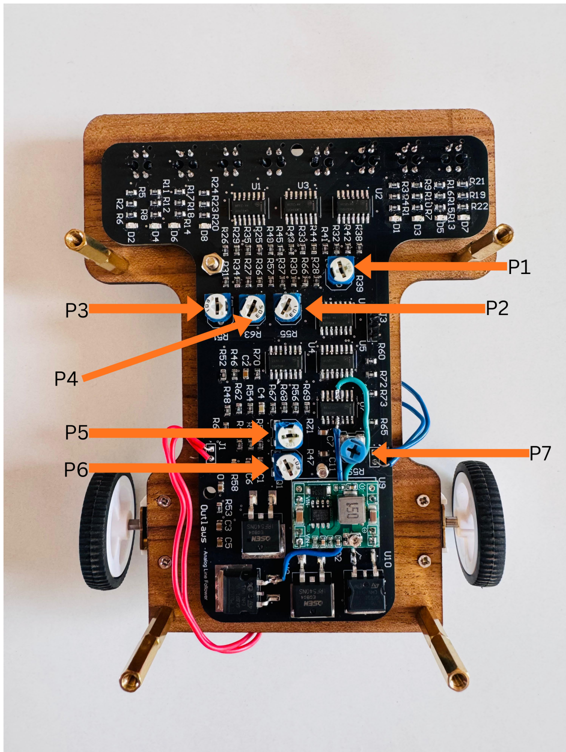

Fig. 3: Preset potentiometer locations on PCB

modifications. Each preset adjusts a specific parameter of the PID controller or signal conditioning chain.

Proper adjustment of these parameters is critical for optimal performance. The P1 preset corrects any DC offset in the error signal, ensuring centered operation. P2, P3, and P6 adjust the integral, derivative, and proportional gains respectively, allowing customization of the control response. P4 provides overall gain scaling, while P5 corrects offset in the PID output. P7 adjusts the PWM carrier frequency to optimize motor response.

Users should adjust these presets iteratively while observing robot behavior on the test track. Start with moderate gain settings and increase gradually until optimal tracking is achieved without oscillation.

XI. Safety and Handling

Safe operation of the robot requires attention to both electrical and mechanical hazards. Always disconnect the battery before making any adjustments to preset potentiometers to prevent accidental short circuits or component damage. The

TABLE IV: Onboard Preset Functions

Preset	Function
P1	Total error zero-offset correction
P2	Integral gain adjustment
P3	Derivative gain adjustment
P4	Overall PID gain scaling
P5	PID output zero-offset correction
P6	Proportional gain adjustment
P7	PWM carrier frequency adjustment

motor wheels can generate significant torque, so keep hands and loose objects away from rotating components during operation.

The robot is designed for operation on dry, non-reflective surfaces with adequate contrast between the line and background. Wet surfaces or highly reflective materials may cause erratic sensor behavior. Ensure battery terminals are properly insulated and never allow them to short circuit, as Li-Ion batteries can deliver high currents that may cause burns or fire.

Store the robot in a cool, dry place when not in use. Inspect the PCB periodically for signs of component damage or loose connections.

Safety Guidelines:

- Disconnect power before adjusting presets
- Avoid wet or reflective surfaces
- Do not short battery terminals
- Keep hands away from rotating wheels
- Inspect connections regularly
- Use appropriate battery charging procedures

Developed by: Team Outlaws **Institution:** University of Moratuwa