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Keeping Course: Basic PID Control in Mobile Robots

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Abstract

Proportional-Integral-Derivative (PID) control is widely used in mobile robotics for precise and adaptive motion control. This paper presents the fundamentals of PID control and its application to line-following mobile robots. We explore the role of each component (P, I, D), the tuning process, and real-time implementation using microcontrollers such as Arduino. Experimental results demonstrate the effectiveness of PID over simple on-off or proportional-only control. The use of PID enhances robot stability, smoothness, and error correction. This paper also compares performance across different tuning values and evaluates performance in various track conditions.

Keywords: *PID Control, Mobile Robot, Line Following, Arduino, Motion Control, Tuning, Embedded Systems*

INTRODUCTION

Mobile robots require effective control mechanisms to follow paths or trajectories accurately. Among several methods, PID control stands out due to its balance of simplicity, robustness, and precision. This paper focuses on the basic implementation of PID in a mobile robot setup, particularly in a line-following scenario.

PID CONTROL OVERVIEW

PID controllers adjust system output based on three parameters:

- Proportional (P): Reacts to present error.
- Integral (I): Reacts to accumulated past errors.
- Derivative (D): Predicts future error based on rate of change.

The output is calculated as:

$$\text{Output} = K_p * e(t) + K_i * \int e(t)dt + K_d * de(t)/dt$$

where e(t) is the error between desired and actual position.

ROBOT DESIGN AND SETUP

The mobile robot used includes:

- Arduino Uno
- IR sensor array for line detection
- L298N Motor Driver
- Two DC Motors and Chassis
- PID algorithm coded in Arduino IDE

The sensor readings are processed to compute positional error which is then used in the PID formula to adjust motor speed.

TUNING THE PID PARAMETERS

PID parameters (Kp, Ki, Kd) are tuned experimentally. Too high Kp causes oscillation, high Ki causes overshoot, and high Kd can cause instability. The ideal combination balances responsiveness and stability. The Ziegler-Nichols method and trial-error are common approaches for tuning.

IMPLEMENTATION IN ARDUINO

The Arduino reads analog inputs from the sensor array to determine deviation from the line. The error value is used in the PID formula coded in C++. The output controls the PWM signal sent to the motors. The robot corrects its trajectory continuously based on feedback.

EXPERIMENTAL SETUP

The robot was tested on different tracks (straight, curved, looped). The performance was recorded by varying PID values. Table 1 summarizes performance under three configurations: P-only, PI, and full PID.

Table 1: Comparison Of Control Modes In Line Following Robot

Control Mode	Avg. Deviation (cm)	Response Time (ms)	Stability Rating (/5)
Proportional Only	3.4	290	3
Proportional + Integral	2.1	320	4
PID (Full)	1.3	350	5

The full PID controller offers the best accuracy and stability, though it slightly increases response time due to computation. PI controllers reduce steady-state error but cannot anticipate future deviations. P-only control is fastest but less accurate.

PERFORMANCE ANALYSIS

The PID-controlled robot showed smoother movement, better recovery on curves, and minimized overshoot compared to proportional-only control. The addition of I and D terms allowed for better compensation of long-term errors and anticipation of path deviation.

APPLICATIONS

PID is widely used in:

- Line-following robots
- Balancing robots (e.g., two-wheel segways)
- Speed and direction control in AGVs
- UAV stabilization
- Industrial robotic arms for trajectory control

ADVANTAGES AND LIMITATIONS

Advantages:

- Simple to implement and understand
- Real-time adjustment possible

- Works well in linear systems

Limitations:

- Poor performance in highly nonlinear systems
- Requires tuning and testing for each application
- Sensor noise can affect accuracy without filtering

FUTURE ENHANCEMENTS

Advanced versions like Adaptive PID, Fuzzy-PID, or Neural PID can dynamically adjust parameters. Integrating IMUs, Kalman Filters, or vision-based feedback can further enhance robustness and accuracy in unstructured environments.

CONCLUSION

This paper demonstrated how basic PID control can significantly improve mobile robot performance. Its effectiveness in error correction and trajectory stabilization makes it a preferred method for beginner and intermediate robotic applications. With careful tuning, PID can adapt to a range of mobile control systems efficiently.

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