PID Control of Main Maneuver for Three-Wheeled Omniwheel Robot

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Abstract. *The maneuverability and precision of three-wheeled omniwheel robots are essential for effective navigation in various environments. This study aims to implement a PID (Proportional-Integral-Derivative) control system on a three-wheeled omniwheel robot using the arduino platform, with compass sensor data serving as the primary reference for orientation control. The omniwheel design allows the robot to move freely in any direction, making it suitable for applications that require high flexibility and responsiveness. In this research, mathematical modeling of the robot's dynamics was conducted to understand its behavior during movement. The PID control algorithm was implemented to manage the speed and angular velocity of each wheel, utilizing feedback from the compass sensor to maintain the desired heading and stability during maneuvers. The experimental setup involved various maneuver scenarios, including rapid direction changes and navigation through complex paths. Results indicate that the integration of PID control with compass data significantly enhances the stability and accuracy of the robot's maneuvers. The proposed control system effectively reduces heading error and improves response time, demonstrating its effectiveness in maintaining precise movement under dynamic conditions. In conclusion, the combination of Arduino platform, PID control, and compass data provides a robust solution for controlling the main maneuver of a three-wheeled omniwheel robot, particularly in applications demanding high maneuverability and directional stability.*

Keywords: PID Controller, omniwheel robot, compass sensor.

INTRODUCTION

In the era of modern technology, robotics competitions such as the ASEAN Skills Competition (ASC) have become important events to measure the technical skills and innovation of participants from across Southeast Asia. These competitions not only test technical abilities in designing and building robots but also challenge participants to create robots with precise and responsive maneuvers under time pressure and competitive scenarios[1]. Among the various categories of robotics, the three-wheeled omniwheel robot is a popular choice due to its ability to move omnidirectionally, allowing for high flexibility in confined spaces[2].

Omniwheel robots can move in multiple directions without rotating the robot body, making them highly efficient for scenarios requiring complex maneuvers. However, to maximize this advantage, a precise and responsive control system is needed, particularly in terms of stability and motion accuracy[3]. One commonly used method for this purpose is PID control (Proportional-Integral-Derivative). PID control has the ability to regulate the speed and position of the robot by adjusting the control action based on the error between the actual condition and the desired

condition. With proper tuning, PID control can provide stability, accelerate response time, and minimize overshoot in the system[4].

The results obtained from this study are expected to yield a reliable and competitive control system that can support the robot in achieving optimal performance in the ASC arena. Furthermore, this study also aims to contribute to the development of omniwheel robot control systems in broader robotics competitions.

METHODS

A. System block diagram

The robot uses three omniwheels as the main drive wheels, labeled M1, M2, and M3, mounted at 120-degree angles from each other, along with three DC motors, motor drivers, an Arduino controller, and a compass sensor.

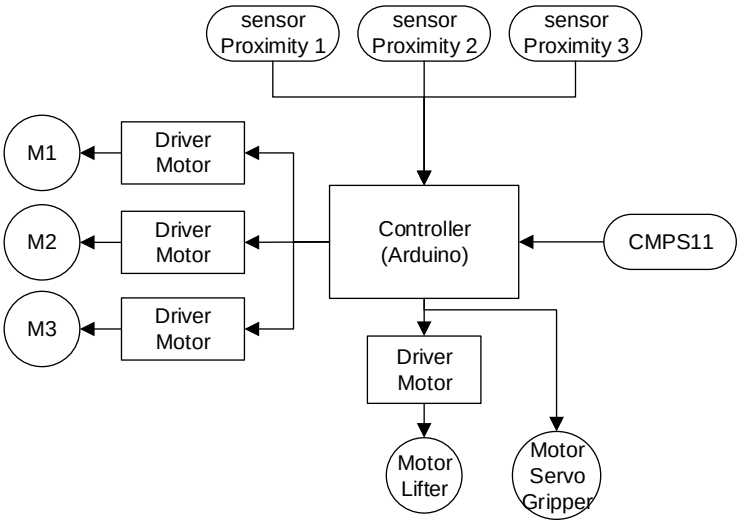

FIGURE 1. system block diagram

Block Diagram of a 3-Wheeled Omniwheel Robot with 3 Motors and Supporting Components

- Input (Direction and Speed Setpoint) The setpoint is the desired direction (obtained from the compass sensor) and speed for the robot to move forward.
- Arduino Controller The Arduino functions as the system's central control. It receives signals from the CMPS11 compass sensor to determine the robot's current orientation. Based on the difference between the setpoint and actual orientation, the Arduino adjusts the parameters for PID control, which then regulates the motors through motor drivers. The Arduino is also responsible for sending PWM signals to the motor drivers to set the speed and direction of each motor so that the robot moves accurately.
- CMPS11 Compass Sensor The CMPS11 sensor is used to detect the robot's orientation or angle relative to the desired direction. This sensor sends real-time orientation data to the Arduino, which uses it to calculate the error between the actual angle and the desired angle. This error is used as input to the PID control on the Arduino.
- PID Control The Arduino executes a PID control algorithm to adjust the signals sent to the motor drivers based on orientation error. The PID signal is converted into a PWM signal to be sent to the motor drivers.
- Motor Driver The motor driver controls the power supplied to each motor based on the PWM signals from the Arduino. In a three-wheeled omniwheel robot, each motor is connected to a motor driver responsible for independently regulating each wheel's direction and speed. This configuration enables the robot to move in any direction without changing its physical orientation, including forward, backward, or rotational movement.
- DC Motors Coupled to Omniwheels The three-wheeled omniwheel robot is equipped with three DC motors, each mounted to an omniwheel. Each motor receives signals from the motor driver to control the

speed and rotation direction of each wheel. The combination of speed and direction across all three wheels allows the robot to move according to commands, whether it's moving straight forward, rotating, or moving sideways.

- Feedback Loop Data from the CMPS11 compass sensor is sent back to the Arduino to update the error calculation. With this feedback loop, the Arduino can continuously correct movements based on orientation changes, allowing the robot to maintain a direction or follow a path according to the setpoint.

B. Mechanical Design View of the Omniwheel Robot

Figure 2 shows a side view of the omniwheel robot chassis. In Figure 2, the arrangement of the three omniwheels is visible, positioned in a triangular configuration on the chassis.

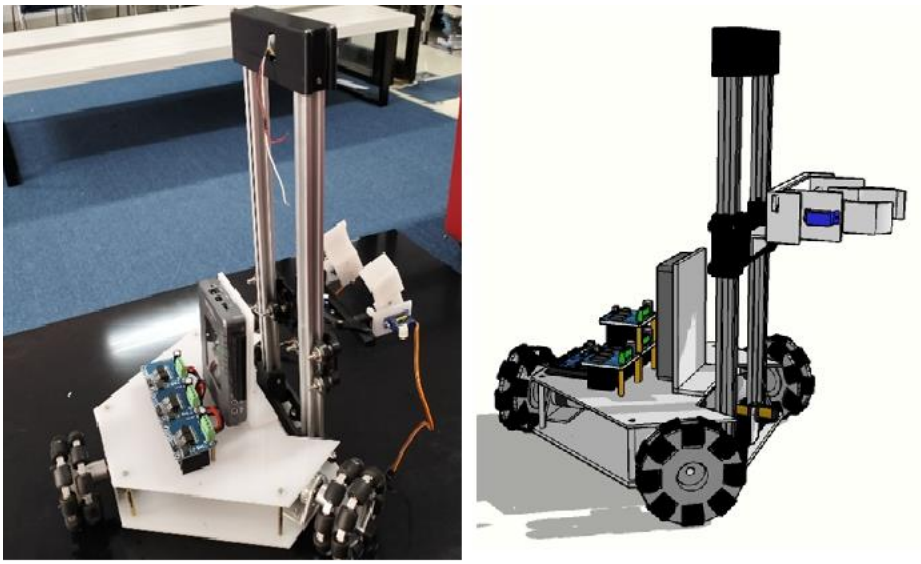

FIGURE 2. overall view of the robot mechanics

C. PID Controller

The PID (Proportional-Integral-Derivative) control formula consists of three main components: Proportional (P), Integral (I), and Derivative (D). Here's an explanation of each component along with the general PID formula:
The PID control formula can be expressed as:

$$u(t) = K_p \cdot e(t) + K_i \cdot \int_0^t e(\tau)\, d\tau + K_d \cdot \frac{de(t)}{dt}$$

Where:

u(t): Control output at time ttt
e(t): Error at time ttt, defined as the difference between the desired value (setpoint) \
and the actual value (process variable).
Kp: Proportional gain
Ki: Integral gain
Kd: Derivative gain
$\int_0^t e(T)dT$: Integral of the error over time
$\frac{de(T)}{dT}$: Derivative of the error over time

PID Component :

- Proportional (P): Produces an output that is proportional to the current error.

$$P = K_p \cdot e(t)$$

- Integral (I): Produces an output that is proportional to the accumulation of past errors over time. This helps eliminate steady-state error.

$$I = K_i \cdot \int_0^t e(\tau)\, d\tau$$

- Derivative (D): Produces an output that is proportional to the rate of change of the error. This helps speed up the system response and reduce overshoot.

$$D = K_d \cdot \frac{de(t)}{dt}$$

D. Discrete PID Implementation

In many applications, especially those using microcontrollers, PID control is often implemented in discrete form. In discrete form, the formula can be written as:

$$u(k) = K_p \cdot e(k) + K_i \cdot T \cdot \sum_{j=0}^{k} e(j) + K_d \cdot \frac{e(k) - e(k-1)}{T}$$

Where:
K : Discrete time index
T: Time interval between two control updates

E. Implementation in Arduino Programming Language

```
// PID constants declaration
double Kp = 2.0;     // Proportional gain
double Ki = 1.0;     // Integral gain
double Kd = 0.5;     // Derivative gain
// Other variables
double setpoint = 100;   // Desired value
double input;            // Sensor value (process value)
double output;           // Output to PWM
double error;            // Current error
double lastError = 0;    // Previous error
double integral = 0;     // Error accumulation (for the integral part)
double derivative;       // Rate of change of error (for the derivative part)
double dt = 0.1;         // Sampling time interval (100 ms)
int Rpwm,Lpwm;
int pwmSet;

// Setup function
void setup() {
  // Initialize necessary hardware such as sensor and actuator pins
  // Inisialisasi io Motor, Data dan PWM
  Serial.begin(9600);
  //zArduino Mega2560
}
```

```
// Loop function (executed repeatedly)
void loop() {
  // Read sensor value (process value)
  input = readCompas();  // Example reading from an analog sensor
  // Calculate error
  error = setpoint - input;
  // Calculate integral part
  integral += error * dt;
  // Calculate derivative part
  derivative = (error - lastError) / dt;
  // Calculate PID output
  output = Kp * error + Ki * integral + Kd * derivative;
  // Apply output (for example, to an actuator like a motor)
  pwmSet = output;
  actuator(maju, pwmSet);// kirim ke fungsi menggerakkan motor
  // Store the previous error for the next iteration
  lastError = error;
  // Wait according to the sampling time
  delay(dt * 1000);  // Convert from seconds to milliseconds
}
```

RESULTS AND DISCUSSION

To illustrate the testing results from compass data and PWM control using a PID controller for differential wheel control, let's consider a scenario where an autonomous robot uses a compass to maintain a specific heading while adjusting the speeds of two motors (left and right wheels) accordingly.

Testing Scenario

1. Setup: An autonomous robot equipped with:
   - Cmps11 compass for heading measurement.
   - Two DC motors for left and right wheels.
   - An Arduino for controlling the motors and reading the compass.
   - A PID controller to adjust motor speeds based on the heading error.
2. Objective: Maintain a desired heading (setpoint) by adjusting motor speeds using PWM. The robot should correct its heading based on compass readings.

PID Parameters

- Kp=1.0K_p = 1.0Kp=1.0 (Proportional gain)
- Ki=0.1K_i = 0.1Ki=0.1 (Integral gain)
- Kd=0.5K_d = 0.5Kd=0.5 (Derivative gain)
- Setpoint: Desired heading (e.g., 0°)

Results :

Assuming the robot is commanded to maintain a heading of 0°, and you record the heading data along with the PWM output for the left and right motors, the results might look something like this:

TABLE 1. PID Control Testing Table with Compass Sensor Reference

Time(t)	Heading(^{0})	Right Motor (pwm)	Left Motor (pwm)	Heading Error (^{0})
0	0	150	150	0
1	5	145	155	-5
2	10	140	160	-10
3	8	143	157	-8
4	3	148	152	-3
5	0	150	150	0
6	-2	153	147	2
7	-5	155	145	5
8	0	150	150	0
9	1	149	151	-1
10	0	150	150	0

Explanation of Results:

- Time: Each row represents a snapshot at a specific time interval (e.g., 1 second).
- Heading: The actual heading of the robot as read from the compass.
- Motor PWM Values: The PWM values sent to the left and right motors to adjust their speeds. These values are calculated based on the PID controller's output.

Heading Error: The difference between the desired heading (0°) and the actual heading. This value is crucial for the PID calculations.

How PID Control Works:

- Proportional Control (P): Adjusts motor speeds based on the current heading error. A larger error results in a larger adjustment.
- Integral Control (I): Accumulates past errors to address persistent offsets. If the robot consistently drifts from the desired heading, this term helps correct it over time.
- Derivative Control (D): Predicts future errors based on the rate of change. This helps smooth out the control action and prevents overshooting the target heading.

CONCLUSIONS

This test demonstrates how the PID controller adjusts the PWM output for the left and right motors based on the heading error. As the robot moves, the PID controller continuously computes the necessary adjustments to keep the robot aligned with the desired heading.

In real-time applications, you can monitor and log this data for further analysis, adjusting the PID parameters as necessary to achieve optimal performance in maintaining the desired heading.

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