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Mechanical Representation of Robotics Arm with PID Controller

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A B S T R A C T

This work presents a low-cost, modular approach to designing and implementing a PID-controlled robotic arm using hobby-grade servo motors and an Arduino Nano. The system uses a dual-sensor fusion method for accurate joint angle feedback, combining dynamic angular data from a gyroscopic IMU with absolute angle measurements from a potentiometer. A complementary filter merges these signals to reduce drift and noise, ensuring reliable real-time position estimation.The control algorithm follows a classical PID structure, with the proportional, integral, and derivative terms working together to minimize positional error, eliminate steady-state offset, and reduce overshoot. The Arduino Nano processes sensor data and computes control signals at a loop frequency of 500 Hz, generating high-resolution PWM outputs to actuate the servos.Mechanically, the arm is built on a lightweight sunboard frame featuring modular brackets and quick-release joints, enabling easy reconfiguration of links and payloads. This flexibility supports control system tuning, as changes in inertia or friction can be compensated using onboard auto-tuning routines based on step-response analysis.Experimental results show that the arm achieves sub-degree accuracy (±0.8°), settling times under 150 ms for 45° step inputs, and smooth operation under payloads up to 500 g with minimal overshoot. The combination of sensor fusion, efficient PID control, and mechanical adaptability demonstrates that precise robotic arm control can be realized using affordable, off-the-shelf components. The system offers a valuable platform for educational use, light-duty automation, and rapid prototyping in robotics research..

1. Introduction

Robotic arms have revolutionized industrial processes and daily life, offering unparalleled precision, repeatability, and efficiency. These automated systems mimic human arm movements and are utilized across industries such as manufacturing, healthcare, defense, and aerospace. For instance: In manufacturing, robotic arms automate welding, painting, and assembly tasks, enhancing productivity and ensuring consistent quality. In healthcare, robotic arms assist in surgeries, providing precision beyond human capability. In defense, they manage hazardous materials and perform reconnaissance tasks. In research, robotic arms enable advancements in fields like material science and space exploration, with applications ranging from the International Space Station to Mars rovers. The development of tooling planner robotic arms further enhances automation by integrating advanced design and control algorithms, enabling adaptability to complex operations and tasks.

1.1 Importance of Mechatronics in Tooling Planning

The integration of mechatronics in tooling planning is pivotal for modern automation systems. Mechatronics synergizes mechanical engineering, electronics, control systems, and computing, resulting in intelligent systems capable of performing complex tasks. In tooling planning, this multidisciplinary approach enables: Precise Design Adaptability: Robotic arms can handle diverse tools and tasks without requiring significant manual adjustments. Error Minimization: Advanced sensors and control systems reduce errors, ensuring higher quality in automated tasks. Improved Efficiency: Automation reduces human intervention, saving time and labor costs while increasing production output. This project showcases the essence of mechatronics by designing a robotic system capable of performing intricate tooling tasks, thereby emphasizing the need for seamless integration of design and control.

2. List of components

2.1. Microcontroller – Arduino Nano

The Arduino Nano serves as the central processing unit of the robotic arm. It reads sensor inputs, executes the PID control algorithm, and sends appropriate commands to the motors. Its ease of programming and versatile I/O support make it ideal for real-time motion control applications. It is a Microcontroller board developed by arduino.cc and based on Atmega328p / Atmega168.

2.2. Motors – Servo Motors

Servo motors are used to drive the joints of the robotic arm. Each motor is capable of rotating to a specified angle, controlled via PWM signals from the microcontroller. These motors enable precise, smooth, and responsive joint movements necessary for tasks like gripping, rotating, or lifting.

2.3. Sensors (Feedback Devices)

To implement closed-loop control, the system includes multiple types of sensors for position and motion feedback:

Potentiometers: Mounted on rotating joints to measure angular displacement. They provide continuous voltage feedback proportional to joint angles.

Gyroscope Sensor: Measures angular velocity and helps detect dynamic changes in orientation. It enhances the arm's ability to maintain stability during movement and compensates for overshooting or disturbances.

These sensors work together to provide real-time feedback to the controller, enabling accurate error correction through PID.

2.4. Power Supply

A 5V 2A DC power supply, often sourced from mobile phone chargers, provides the necessary power to the servos and control circuitry. A regulated power source ensures stable operation and prevents voltage fluctuations that could affect motor performance.

2.5. Robotic Arm Structure

The structure of the robotic arm is built using sun board for prototyping purposes. It includes:

Links: Rigid sections connecting joints.

Joints: Pivoting mechanisms driven by servo motors.

End-effector: The functional tip of the arm used for grasping or manipulating objects. This lightweight and customizable framework allows for experimentation and testing without expensive hardware.

2.6. PID Control Algorithm (Software Component)

The PID (Proportional–Integral–Derivative) control algorithm is implemented in C/C++ (using Arduino IDE) or Python (for simulations). It continuously calculates a control signal based on:

Proportional term (P): Current error.

Integral term (I): Accumulated error.

Derivative term (D): Rate of change of error. This control logic dynamically adjusts motor commands to bring the robotic joints to their desired positions with minimal overshoot and steady-state error.

2.7. PCB and Connecting Wires

A PCB or breadboard is used for circuit organization and component mounting. Connecting wires ensure reliable electrical connections between the Arduino, sensors, motor drivers, and servos, facilitating seamless communication and power distribution.

2.8. Mechanical Fasteners

Screws, bolts, glue, and brackets are used to assemble the physical structure of the robotic arm and securely attach motors and sensors. These components maintain mechanical stability and ensure precise alignment of moving parts.

3. Circuit diagram

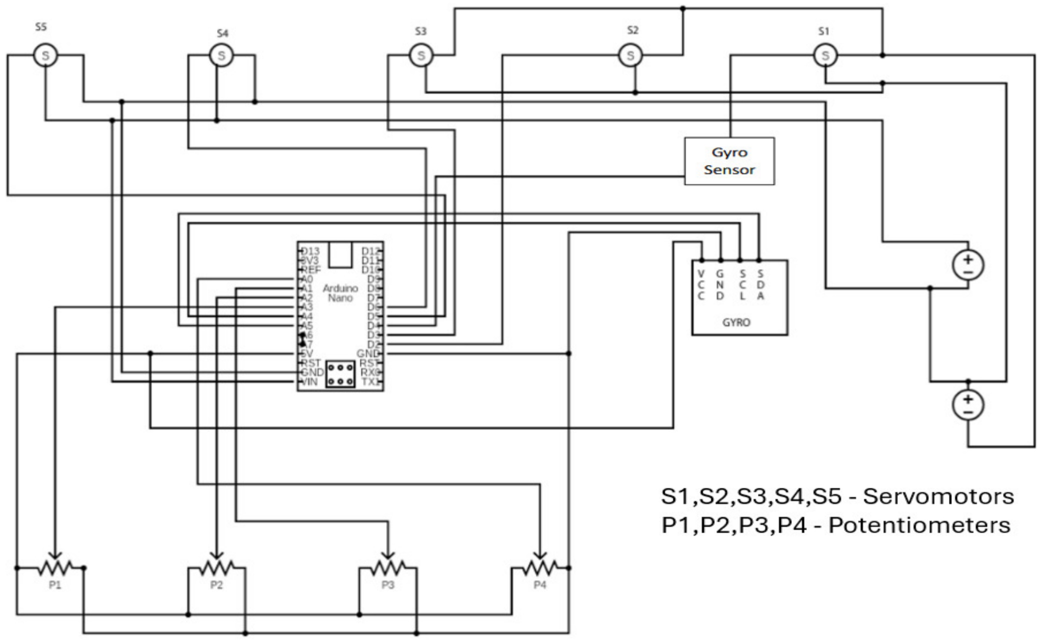


Fig. 1 - Block diagram of Robotic Arm using PID

4. Working principle

The robotic arm controlled by a PID controller operates on the principle of closed-loop feedback to maintain precise control over the arm's position. The system comprises an Arduino Nano microcontroller, a potentiometer (as position input), a servo motor (as actuator), a sunboard structure (for physical assembly), and a charger (as power supply). Here's how each component works together:

1. Input Signal – Potentiometer

A potentiometer is used by the user to provide a desired position (setpoint) for the robotic arm.

The analog voltage from the potentiometer is read by the Arduino Nano and mapped to a desired angle (typically between 0° to 180° for standard servos).

2. Feedback Signal – Servo Position

The servo motor includes an internal feedback system to maintain its shaft position.

The actual position of the servo is compared to the desired position (from the potentiometer).

The error is calculated as:

Error=Setpoint−Actual Position

3. PID Controller (On Arduino Nano)

The Arduino Nano implements a **PID control algorithm** which continuously adjusts the output to the servo motor based on the error.

The three components of PID:

Proportional (P): Reacts to the current error

Integral (I): Reacts to the accumulation of past errors

Derivative (D): Predicts future error based on its rate of change

4. Actuation – Servo Motor

Based on the PWM signal from the Arduino, the **servo motor** rotates to match the desired angle.

Servos are preferred because they provide precise control, are easy to integrate with PWM, and have built-in feedback mechanisms.

5. Structure – Sunboard Frame

The entire system is mounted on a **s**unboard frame, a lightweight and cost-effective material used to create the body and joints of the robotic arm.

The sunboard provides physical support and allows flexible design for different degrees of freedom.

6. Power Supply – Charger

A DC charger or battery pack supplies power to both the Arduino Nano and the servo motor.

The voltage and current ratings must match the system requirements (typically 5V for Arduino Nano and standard servo motors).

5. Result

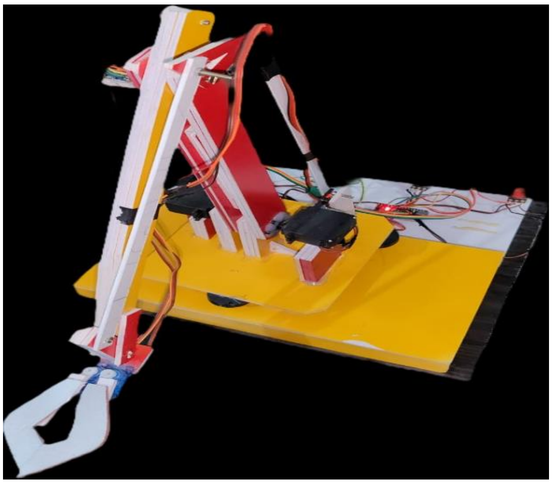
The use of a PID controller proved effective for position control of the robotic arm in a simulated environment. The key observations include:

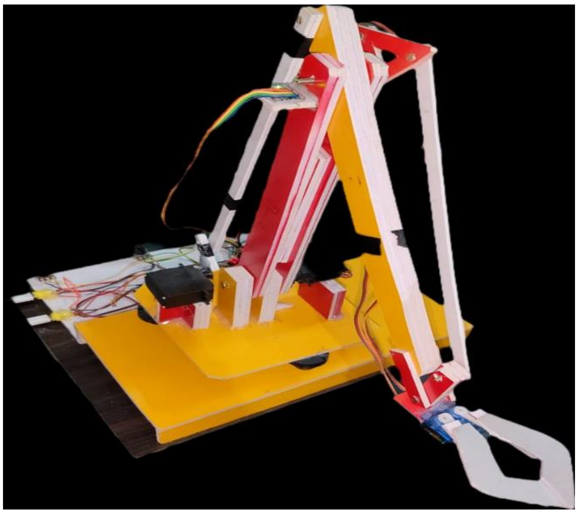
Effectiveness of PID Control: The controller was able to achieve the setpoints with acceptable overshoot and minimal steady-state error. This demonstrates that PID is sufficient for simple trajectory tracking tasks in robotic arms where model uncertainties and external disturbances are minimal.

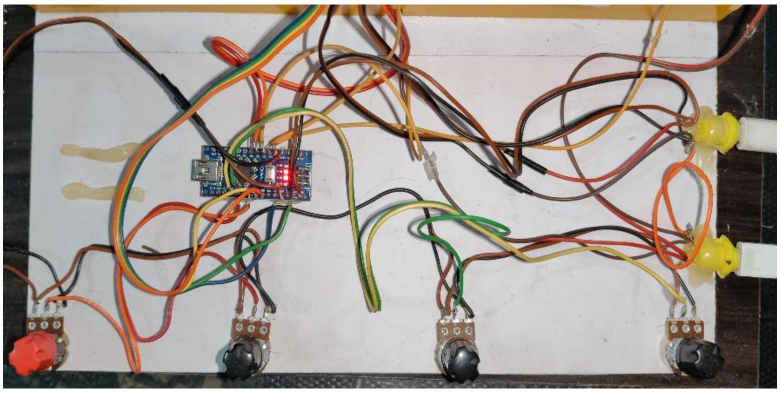
Tuning Influence: Proper tuning of the PID gains played a crucial role in system performance. A high proportional gain (Kp) improved the response time, while the derivative gain (Kd) helped reduce overshoot. The integral gain (Ki) ensured that steady-state error was eliminated but introduced some risk of oscillation if too high.

Limitations: While effective for basic control, the PID controller showed limited adaptability to nonlinearities or disturbances. In practical applications with payload variations, dynamic friction, or external forces, advanced control strategies such as Model Predictive Control (MPC) or Adaptive Control may be more appropriate.

Stability: The system remained stable under all tested setpoints. However, excessive gain values led to oscillations, confirming the need for careful tuning.







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