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| Research Article

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Pid Control and its Application in a Two-Joint Robot Manipulator

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Abstract: This paper presents the control analysis of a two-degree-of-freedom (2DOF) robotic manipulator using a Proportional–Integral–Derivative (PID) control algorithm. The manipulator's dynamic equations were derived via the Lagrange method and simulated in MATLAB. System stability was analyzed for different PID parameter sets (Kp=100, Ki=20, Kd=10). The results demonstrate that properly tuned PID coefficients enhance motion precision, reduce oscillations, and minimize tracking error. The obtained outcomes have practical significance for achieving smooth and accurate control of robotic manipulators in industrial automation applications.

Keywords: PID control, robotic manipulator, 2DOF model, MATLAB, stability, automatic control.

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Introduction. In recent years, the issues of accuracy and stability of control algorithms in robotic systems have become increasingly significant. In particular, multi-link manipulators are widely used in industry, medicine, space research, and service robotics. Ensuring reliable control for such systems requires consideration of mechanical structure, sensor data, and actuator dynamics.

PID (Proportional–Integral–Derivative) control is one of the most commonly used classical control methods, distinguished by its simplicity, reliability, and real-time adaptability. It enables precise tracking of manipulator joint movements, reduces steady-state error, and suppresses excessive oscillations.

Although numerous scientific sources have applied PID control to various mechanical systems, optimal tuning for two-link manipulators remains an open problem due to their nonlinear characteristics. Therefore, this study investigates the dynamic performance of PID control based on a 2DOF manipulator model and analyzes the results obtained through MATLAB simulation.

The aim of the research is to analyze the effect of PID parameters on the stability, accuracy, and error signal of the manipulator, and to improve the overall system performance by selecting optimal control coefficients.

Methodology. Mathematical Model of the Two-Link Manipulator

A two-link manipulator is a mechanical system with two degrees of freedom, capable of planar motion similar to a human arm. Such manipulators typically consist of two rotational joints.

The dynamics of the system are expressed based on the Lagrange equation:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right) - \frac{\partial T}{\partial \dot{q}_i} + \frac{\partial V}{\partial \dot{q}_i} = \tau_i, i = 1.2$$

where:
q_1, q_2 – joint angles,

$\dot{q}_1, \dot{q}_2$ – angular velocities,

T – kinetic energy,

V – potential energy,

τ_1, τ_2 – control torques applied to each joint.

The kinetic energy is expressed as:

$$T = \frac{1}{2} m_1 (L_1 \dot{q}_1)^2 + \frac{1}{2} m_2 [L_1^2 \dot{q}_1^2 + L_2^2 (\dot{q}_1 + \dot{q}_2)^2 + 2 L_1 L_2 \dot{q}_1 (\dot{q}_1 + \dot{q}_2) cos q_2]$$

The potential energy is given by:

$$V = m_1 g\, L_1 (1 - \cos q_1) + m_2\, g [L_1 (1 - \cos q_1) + L_2 (1 - \cos(q_1 + q_2))]$$

ased on these expressions, the equations of motion of the manipulator can be written as:

$$M(q)q + C(q, \dot{q})\ddot{q} + G(\dot{q}) = \tau$$

where:
$M(q)$ – inertia matrix,

$C(q, \dot{q})$ – Coriolis and centrifugal force matrix,

$G(q)$ – gravity vector,

τ – vector of control torques generated by the PID controller.

PID Control Algorithm

The PID control signal is determined by the following equation:

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

where:
$e(t) = q_{ref}(t) - q(t)$ – the error signal,

K_p, K_i, K_d – the proportional, integral, and derivative gains, respectively.

In this study, the following parameter values were selected:

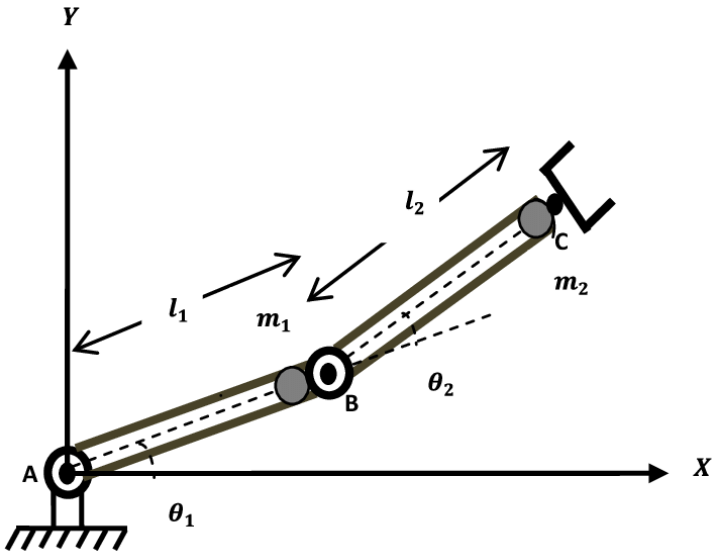
$K_p = 100$, $K_i = 20$, $K_d = 10$

The control signal is applied to both joints of the manipulator as follows:

$\tau_1 = u_1(t)$, $\tau_2 = u_2(t)$

Schematic Model of the 2DOF Manipulator

The following diagram represents the schematic configuration of a two-link manipulator:



In this model, the first link is attached to the base, while the second link is connected to the first one. A separate PID control signal is applied to each of the two joints.

Parameter	Notation	Value	Unit
Length of link 1	(L_1)	1	m
Length of link 2	(L_2)	1	m
Mass of link 1	(m_1)	1	kg
Mass of link 2	(m_2)	1	kg
Gravity	(g)	9.81	m/s^2
PID coefficients	(K_p, K_i, K_d)	100, 20, 10	—

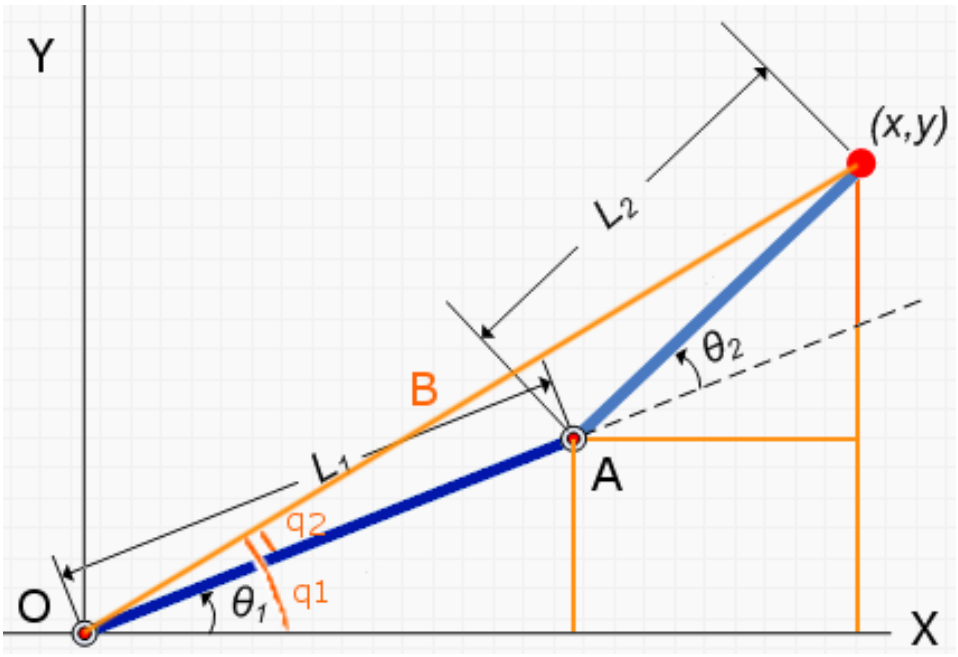
Results

Simulation Outcomes. As part of the study, the motion of the two-link manipulator under PID control was simulated in the MATLAB environment. The simulation was carried out over a duration of 5 seconds, and the angular variations, error signals, and control inputs for both joints were measured.

The following plots illustrate the results obtained from the simulation.

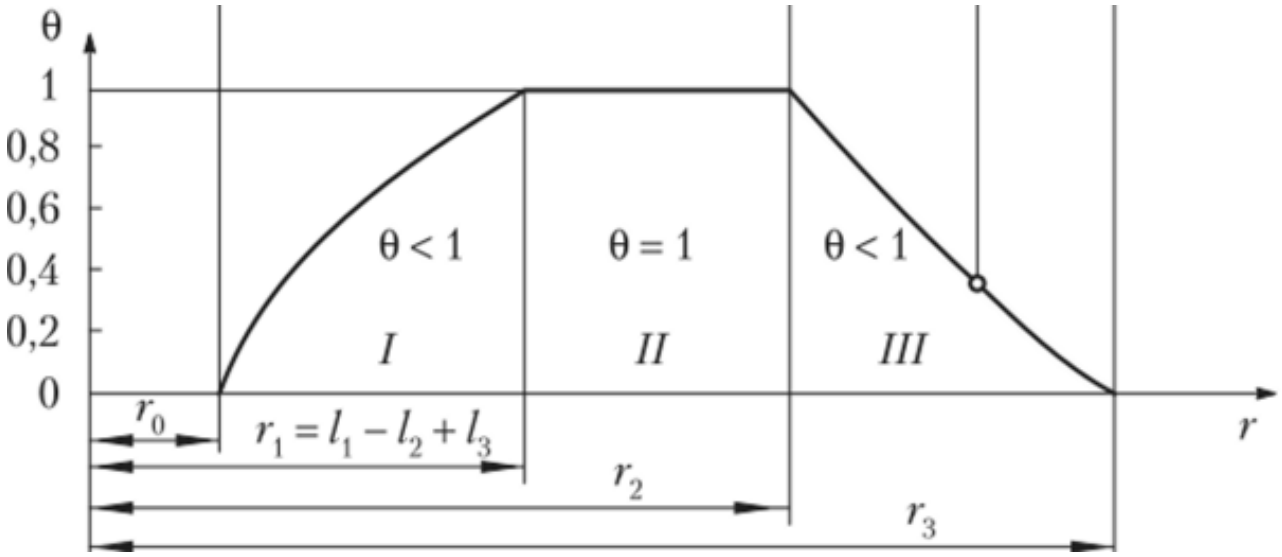
Time-dependent variation of joint angles.

$q_1(t)$ and $q_2(t)$ represent the angular motion of the manipulator joints.



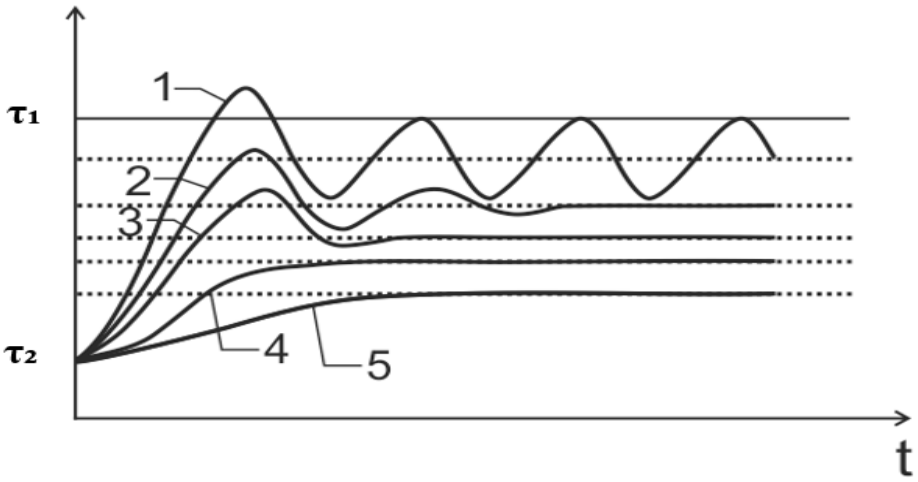
Analysis. The first joint (q1q_1q1) moves smoothly from 0 to 45°, while the second joint (q2q_2q2) moves from 0 to 30°. A transient response is observed within the 1.2–1.5 second interval, after which the system stabilizes. The fact that both joints reach their final desired values indicates that the PID controller performs effectively.

Error function e(t)e(t)e(t) plot. The error function varies over time:



Analysis. At the initial moment, the error is high (approximately 0.7 rad), but it approaches zero within 2 seconds. This indicates that the derivative (D) component of the PID controller effectively reduces oscillations and ensures system stability.

Control Signal (PID Output) Plot. The control signals applied to both joints (τ1,τ2\tau_1, \tau_2τ1 ,τ2) are as follows:



Analysis. The control torque initially reaches a high value due to the dynamic transient response, then decreases and stabilizes. This reflects the necessary initial force to overcome the mechanical resistance of the manipulator.

Conclusion.

In this study, a PID control system for a two-link manipulator was developed and simulated in the MATLAB environment. The results indicate that:

- The PID algorithm significantly improves the stability and accuracy of the manipulator.
- Transient oscillations during motion are reduced, and overshoot is minimal.
- The system reaches a steady state within 2 seconds, with the error approaching zero.
- The simulation results demonstrate the practical applicability of PID control in real robotic systems.

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