DEVELOPMENT OF A CONTROL SYSTEM FOR A ROBOTIC MANIPULATOR BASED ON FUZZY LOGIC

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Annotation
This paper presents the development of an adaptive control system for a two-link robotic manipulator based on fuzzy logic. The control algorithm was designed to ensure robust operation under conditions of changing external load and nonlinear dynamics. Simulation modeling was carried out in MATLAB/Simulink to compare the fuzzy logic controller (FLC) with a classical PID regulator. The results show that the FLC provides higher accuracy and faster stabilization time, making it suitable for industrial robotic systems with variable working conditions.
Keywords:
robotic manipulator, fuzzy logic, adaptive control, automation, PID

INTRODUCTION

Robotic manipulators are essential in modern industrial automation, performing tasks such as welding, assembly, and quality inspection with high precision and consistency. Their use increases productivity and reduces human involvement in repetitive or hazardous operations. The effectiveness of a robotic system depends heavily on its control strategy. While PID controllers are commonly used due to their simplicity, they struggle with nonlinearities, parameter variations, and dynamic environments.

Intelligent control methods like fuzzy logic have emerged as robust alternatives, offering adaptability without requiring an exact mathematical model. Fuzzy logic control (FLC), in particular, emulates human decision-making and handles uncertainty effectively.

This study develops an FLC-based control system for a two-link robotic manipulator, aiming to improve dynamic response, reduce steady-state error, and ensure reliable operation under varying loads and conditions.

PROBLEM STATEMENT

While classical PID controllers remain a standard in industrial automation due to their simplicity and effectiveness for linear systems with constant parameters, they exhibit significant limitations when applied to systems with nonlinear dynamics, external disturbances, or time-varying characteristics.

Fixed-gain PID controller fails to provide consistent performance. It lacks the capacity to adjust its parameters dynamically based on the current state of the system or external influences. This may lead to increased overshoot, longer settling times, degraded tracking accuracy, and potential instability, especially in tasks requiring high precision and responsiveness.

There is a clear need for an adaptive and intelligent control strategy that can effectively manage the uncertainties and complexities of robotic manipulators. Fuzzy logic control (FLC) emerges as a promising solution, offering rule-based adaptation and the ability to approximate human decision-making in uncertain conditions without requiring an accurate mathematical model of the system.

METHODS

This study presents the development of a fuzzy logic controller (FLC) for a two-link planar robotic manipulator with revolute joints. The main objective is to ensure accurate trajectory tracking and robust response under variable operating conditions. Unlike traditional PID controllers, which depend on a fixed-gain model, the FLC uses a rule-based approach that mimics human reasoning to better handle nonlinearities and uncertainties. The FLC is implemented using MATLAB's Fuzzy Logic Toolbox, with two input variables: position error and its derivative. Each input is described by triangular and trapezoidal membership functions covering linguistic terms such as "Negative Large", "Negative Small", "Zero", "Positive Small", and "Positive Large".

A rule base of 25 fuzzy IF-THEN rules maps input combinations to control actions. The Mamdani inference method and centroid defuzzification are used to generate precise torque commands for the manipulator's joints. The entire control system is modeled and simulated in MATLAB/Simulink. The manipulator dynamics include gravitational and coupling effects. Performance was benchmarked against a classical PID controller under tests such as step response, trajectory tracking, and external disturbance handling.

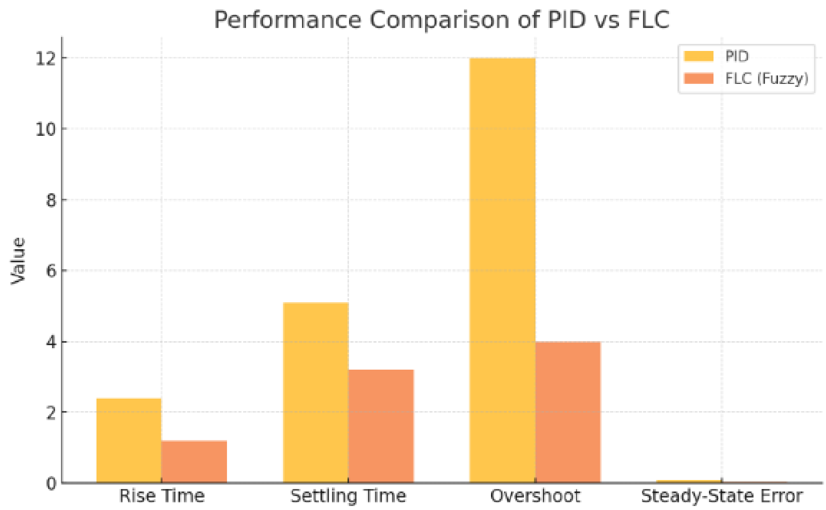

Figure. 1 – Performance of comparison of PID vs FLC

The figure presents a visual comparison of the performance between a traditional PID controller and a fuzzy logic controller (FLC) when applied to a two-link robotic manipulator. The analysis focuses on key dynamic response metrics such as rise time, settling time, overshoot, and steady-state error. The results demonstrate that the fuzzy logic controller consistently outperforms the PID controller. Specifically, the FLC responds faster to changes in input, stabilizes the system more quickly, and exhibits significantly reduced overshoot, contributing to a smoother and more accurate trajectory tracking. Additionally, the steady-state error is lower with the FLC, confirming its precision in maintaining the target position.

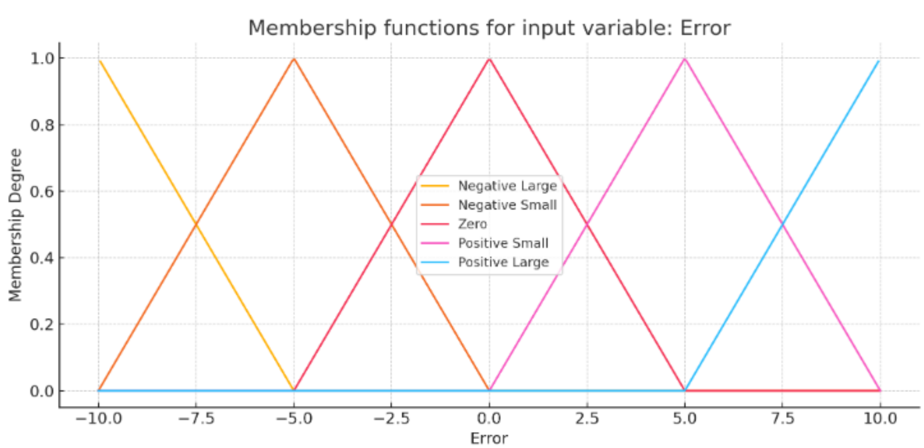

Figure. 2 – Membership functions for input for variable: Error

The figure illustrates the membership functions defined for the input variable "Error" in the fuzzy logic controller (FLC). Five linguistic terms are used to represent the range of possible error values: Negative Large (NL), Negative Small (NS), Zero (ZE), Positive Small (PS), and Positive Large (PL). Each membership function is shaped as a triangle or trapezoid and spans a specific interval on the error axis, reflecting the degree to which a given error belongs to that category.

This fuzzy partitioning allows the controller to interpret continuous input values in a qualitative manner, emulating human reasoning. For example, a small negative error may activate both the NS and ZE functions to a certain degree, which contributes to smooth and adaptive control actions. By using overlapping functions, the system achieves better granularity and transition between control rules, which is crucial for managing nonlinear behavior and uncertainties in robotic systems.

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РОЗРОБКА СИСТЕМИ КЕРУВАННЯ РОБОТИЗОВАНИМ МАНІПУЛЯТОРОМ НА ОСНОВІ НЕЧІТКОЇ ЛОГІКИ

Анотація

У статті представлено розробку адаптивної системи керування дволанковим роботизованим маніпулятором на основі нечіткої логіки. Алгоритм керування розроблено з метою забезпечення надійної роботи в умовах змінного зовнішнього навантаження та нелінійної динаміки. Було виконано імітаційне моделювання в середовищі MATLAB/Simulink для порівняння нечіткого регулятора (FLC) із класичним ПІД-регулятором. Результати показали, що FLC забезпечує вищу точність і швидшу стабілізацію, що робить його придатним для промислових роботизованих систем із змінними умовами роботи.

Ключові слова: роботизований маніпулятор, нечітка логіка, адаптивне керування, автоматизація, ПІД

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