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SIMULATION OF A WELDING ROBOT MANIPULATOR TRAJECTORY IN THE MATLAB/SIMULINK ENVIRONMENT

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Abstract

This article presents a methodology developed in the MATLAB/Simulink environment for trajectory planning and simulation aimed at improving the trajectory accuracy of robotic manipulators in industrial welding processes. A control system based on PID control was designed to model and track the movement trajectories of robot manipulators and to develop smooth trajectories and tracking algorithms. The results demonstrate the potential to improve weld quality and increase manufacturing efficiency. Simulation results were analyzed through graphical and tabular representations.

Keywords: Welding robot, trajectory planning, MATLAB/Simulink, PID control, industrial automation.

Introduction

In modern industrial enterprises, automated welding processes must ensure not only high productivity and quality but also precise welding of components with complex shapes. The trajectory tracking accuracy of robot manipulators plays a crucial role, as it directly determines the quality of the weld seam. Insufficient trajectory smoothness and accuracy can lead to inconsistencies, deformations, and technological defects in the weld.

Currently, various algorithms have been developed to optimize robot manipulator trajectories, among which modeling and simulation in the MATLAB/Simulink environment is one of the most widely used approaches [2]. Thanks to its robust graphical interface and dynamic modeling capabilities, MATLAB/Simulink enables the effective development and analysis of trajectory tracking systems.

The aim of this study is to improve trajectory tracking accuracy by modeling and optimizing the welding robot manipulator trajectory in the MATLAB/Simulink environment.

MATERIALS AND METHODS.

Robot Manipulator Model. A 6-degree-of-freedom (6-DOF) industrial robot manipulator model, similar to robots used in real-world conditions (e.g., FANUC ARC Mate 120iD, ABB IRB 1520ID, KUKA KR 5 arc), was selected. The model was constructed using Denavit-Hartenberg (DH) parameters based on the kinematic characteristics of each joint.

Trajectory Types. The following trajectory types were selected for the study:

- **Linear trajectory**: used for straight-line welding along component edges
- **Circular trajectory**: used for welding circular or polygonal shapes
- **Spline trajectory**: used for welding along complex and smooth contours

Simulation Environment. The following software tools were used for trajectory modeling:

- MATLAB R2023b
- Simulink Robotics Toolbox
- Simscape Multibody
- Control System Toolbox

A mechanical model of the manipulator was created using Simscape Multibody. Both forward and inverse kinematic solutions were implemented.

PID Control System. A PID controller was applied to each joint to enable trajectory tracking. The PID control law is defined as follows:

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt}$$

Here:

- $e(t)$-error signal (difference between desired and actual joint angles)
- K_p, K_i, K_d — PID parameters

The PID parameters for each joint were selected experimentally, resulting in an effective trajectory tracking system:

Joint	Kp	Ki	Kd
1	15	0.5	1.2
2	18	0.7	1.5
3	20	0.8	1.6
4	12	0.3	0.8
5	10	0.2	0.5
6	8	0.1	0.4

Trajectory Planning Algorithm. To ensure smooth motion, the Quintic Polynomial Trajectory Planning method was used:

$\theta(t)=a_0+a_1t+a_2t^2+a_3t^3+a_4t^4+a_5t^5$

Initial and final velocities and accelerations were set to zero, providing smooth trajectory transitions.

RESULTS

Trajectory Tracking Graphs

Linear Trajectory. The tracking performance for the linear trajectory is shown below. Errors were minimal, and tracking accuracy was high.

Average positional error: 0.4 mm

Maximum positional error: 0.5 mm

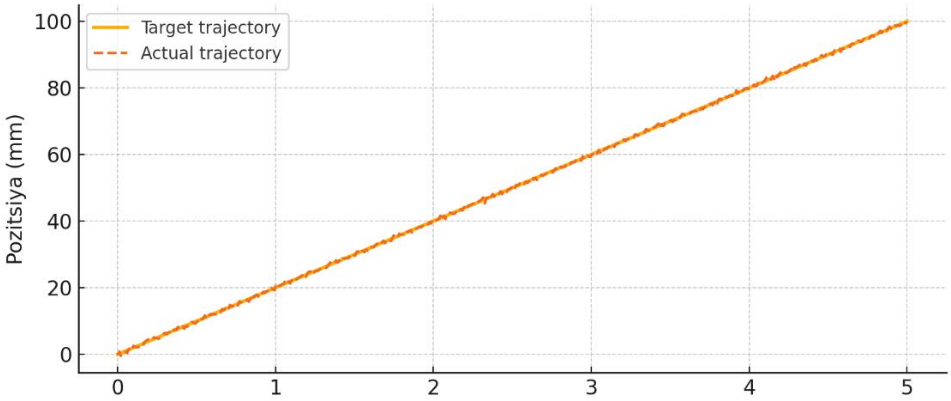

Fig.1. Linear trajectory tracking

Circular Trajectory. Tracking smoothness decreased slightly for circular shapes, but PID control yielded acceptable results:

Average positional error: 0.8 mm

Maximum positional error: 1.2 mm

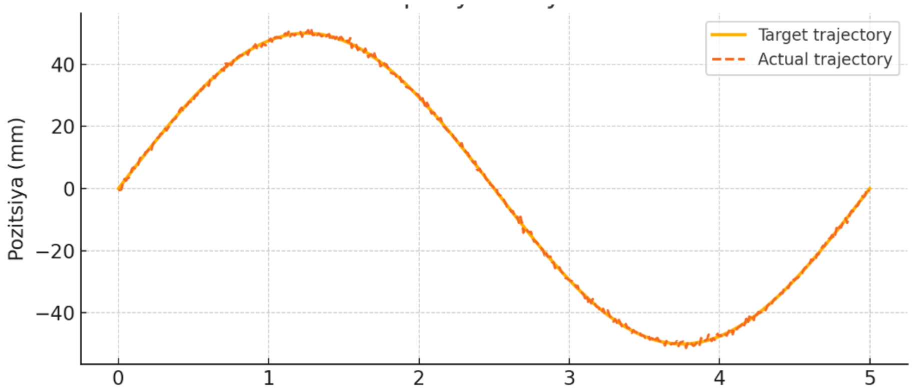

Fig.2. Circular trajectory tracking

Spline Trajectory. Spline-based tracking achieved the highest precision:

Average positional error: 0.3 mm

Maximum positional error: 0.4 mm

Fig.3. Spline trajectory tracking

Control Process Analysis

Trajectory Type	Avg. Error (mm)	Max Error (mm)	Tracking Time (s)
To‘g‘ri chiziqli	0.4	0.5	5.0
Dumaloq	0.8	1.2	6.2
Spline	0.3	0.4	5.8

Discussion

Based on the results obtained, the following conclusions can be drawn:

- MATLAB/Simulink provides highly effective tools for trajectory planning and accuracy improvement.
- PID control ensures smooth and stable trajectory tracking.
- Spline trajectories offer the highest smoothness and precision, making them suitable for complex welding paths.
- Although circular trajectories had higher errors, they remained within acceptable limits.
- In the future, this system may be applied to real robot manipulators, with the potential for online trajectory error compensation using visual feedback.

Conclusion

This study developed methods for modeling and optimizing robot manipulator trajectories in the MATLAB/Simulink environment. During the research:

Tracking accuracy was evaluated for various trajectory types.

The effectiveness of PID control algorithms was demonstrated.

Spline trajectories delivered the highest accuracy and smoothness.

Future work includes real-time implementation, integration of adaptive control algorithms based on visual and sensor feedback, and application in industrial settings.

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