BK - OISP

Analysis and development of a parallelogram linkage manipulator

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INTRODUCTION

In this paper, a control system integrating feedforward, feedback, and iterative learning control (ILC) law is designed for a 3-DOF parallelogram linkage robot. Firstly, the dynamic model is obtained using Newton – Euler formulation, which is then used to calculate the feedforward control signal. The feedback control is designed independently of the feedback control. Subsequently, a passivity-based controller, which is a combination of the two aforementioned, is proposed and compared to the feedforward and feedback alone. Finally, an ILC algorithm is proposed and adjusted according to simulation result to decrease the remaining tracking errors. The performance of four controllers is analyzed and compared in simulation environment based on their tracking process of a reference trajectory.

***Acknowledgement**: This research is funded by Office for International Study Programs (OISP), Ho Chi Minh City University of Technology (HCMUT), VNU-HCM under grant number* **(SVOISP-2021-CK-45)**. *We acknowledge the support of time and facilities from HCMUT, VNU-HCM for this study.*

METHODS AND IMPLEMENTATION

A controller will be designed to help the 3-DOF parallelogram linkage robot (Figure 1) track a reference S-Curve trajectory whose position, velocity and acceleration are shown in Figure 2.

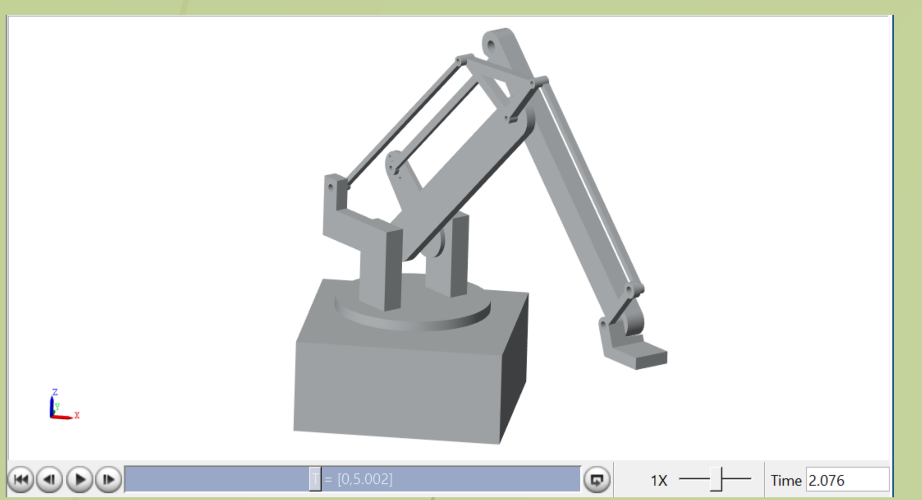

Figure 1 Robot model in Simulink

The controller will be designed and evaluated in simulation environment (Simulink) using the imported dynamic model from Solidworks.

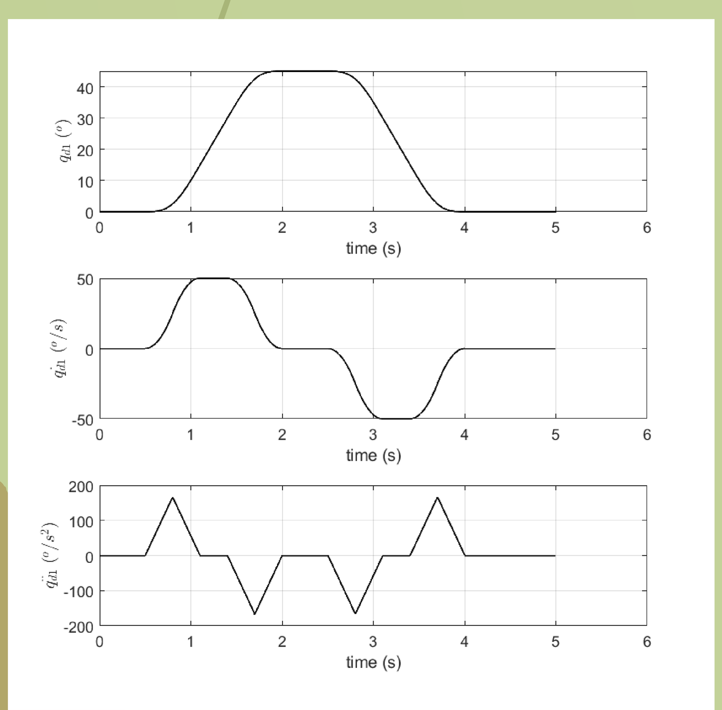

Figure 2 Reference joint trajectory

The robot system (Figure 3) will be tested with four different controllers: feedforward, feedback, integrated (feedforward plus feedback), integrated with Iterative Learning Control (ILC).

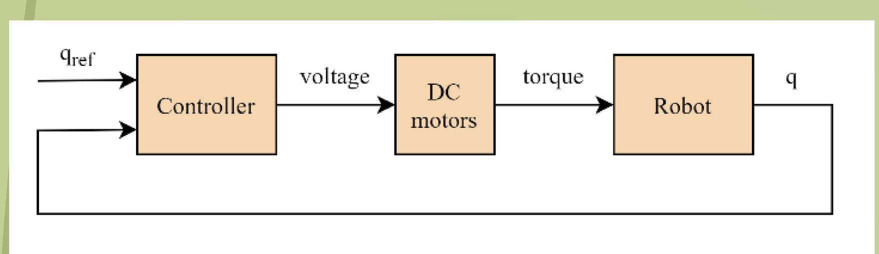

Figure 3 Robot system

The evaluation of the tracking error can be done by mean of root mean squared (RMS) error criteria defined for single actuators as:

$$RMSE = \sqrt{\frac{1}{N}\sum_{k=1}^{N}(q_D(k) - q(k))^2}$$

and for the complete system as:

$$RMSE = \sum_{i=1}^{3}\left(\sqrt{\frac{1}{N}\sum_{k=1}^{N}(q_{Di}(k) - q_i(k))^2}\right)$$

SIMULATION AND EXPERIEMENTAL RESULTS

Figure 4 shows the tracking errors of three joints for a feedforward plus feedback control system. Maximum tracking error for three joints: 0.06°, 0.002°, 0.002°, respectively. RMS errors for three joints: 0.026°, 0.001°, 0.001°, respectively.

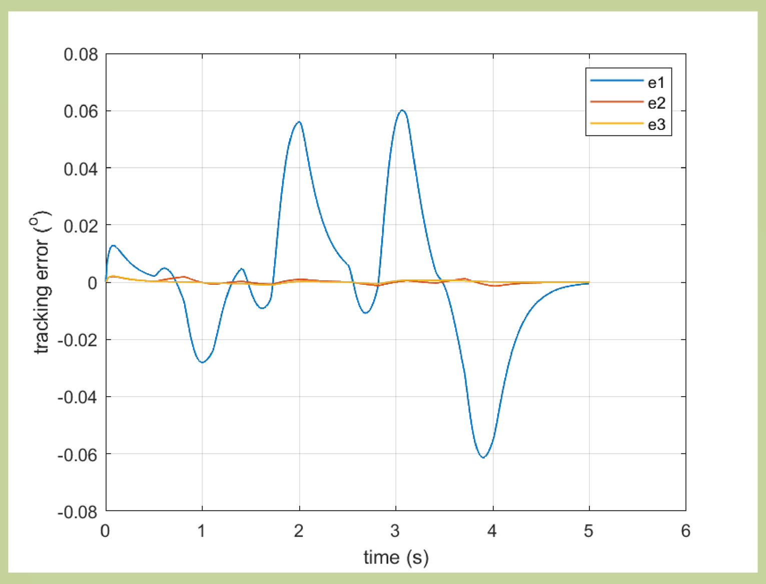

Figure 4 Tracking errors (ff+fb)

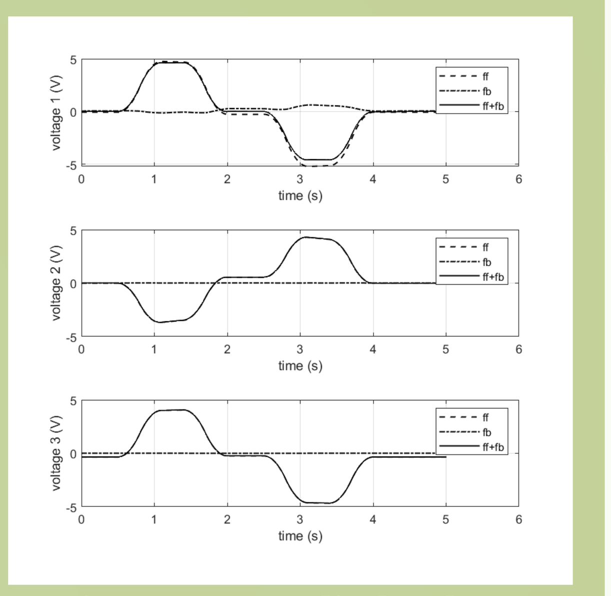

Figure 5 Supplied voltage

Figure 5 shows the control signal supplied to the actuators by the feedforward control (ff), feedback control (fb), and the total voltage (ff+fb). The integrated controller yields better tracking than either feedforward or feedback alone, with less control effort than feedback alone.

Figure 6 presents the effect of two parameters on the performance of ILC. The parameters are chosen as: learning gain $\Phi = [4.5 \quad 4.5 \quad 4.5]^T$, phase lead $l = 10$.

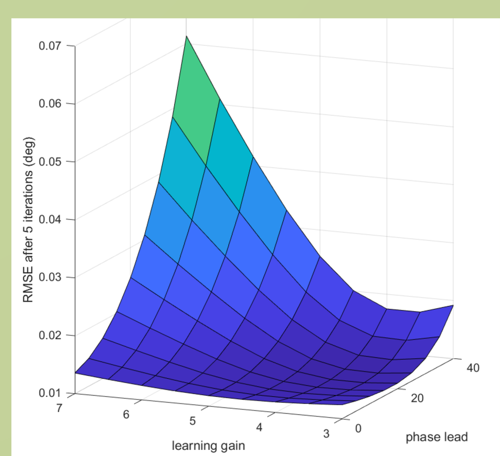

Figure 6 ILC parameters

Figure 7 shows the RMS error of three joints after 20 iterations:

- Joint 1: 0.0261° to 0.0007° after 13 iterations.
- Joint 2: 0.0007° to 0.0004° after 2 iterations.
- Joint 3: 0.0005° to 0.0004° after 1 iteration.

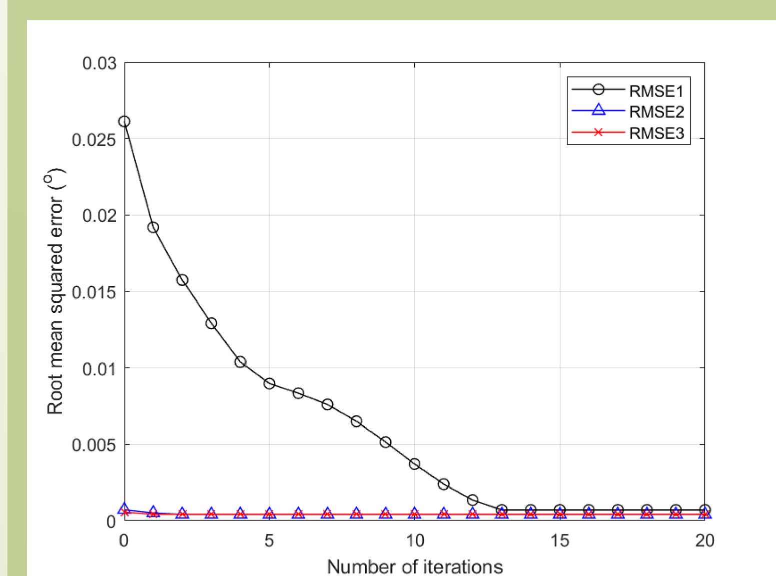

Figure 7 RMS error

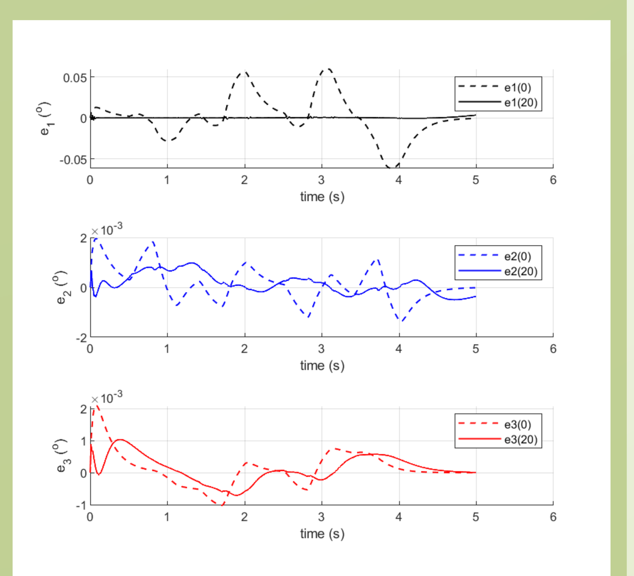

Figure 8 Tracking errors (with ILC)

Figure 8 shows the tracking errors of three joints before (dashed line) and after (solid line) 20 iterations. The errors are reduced by ILC until a desired value of RMS error is reached.

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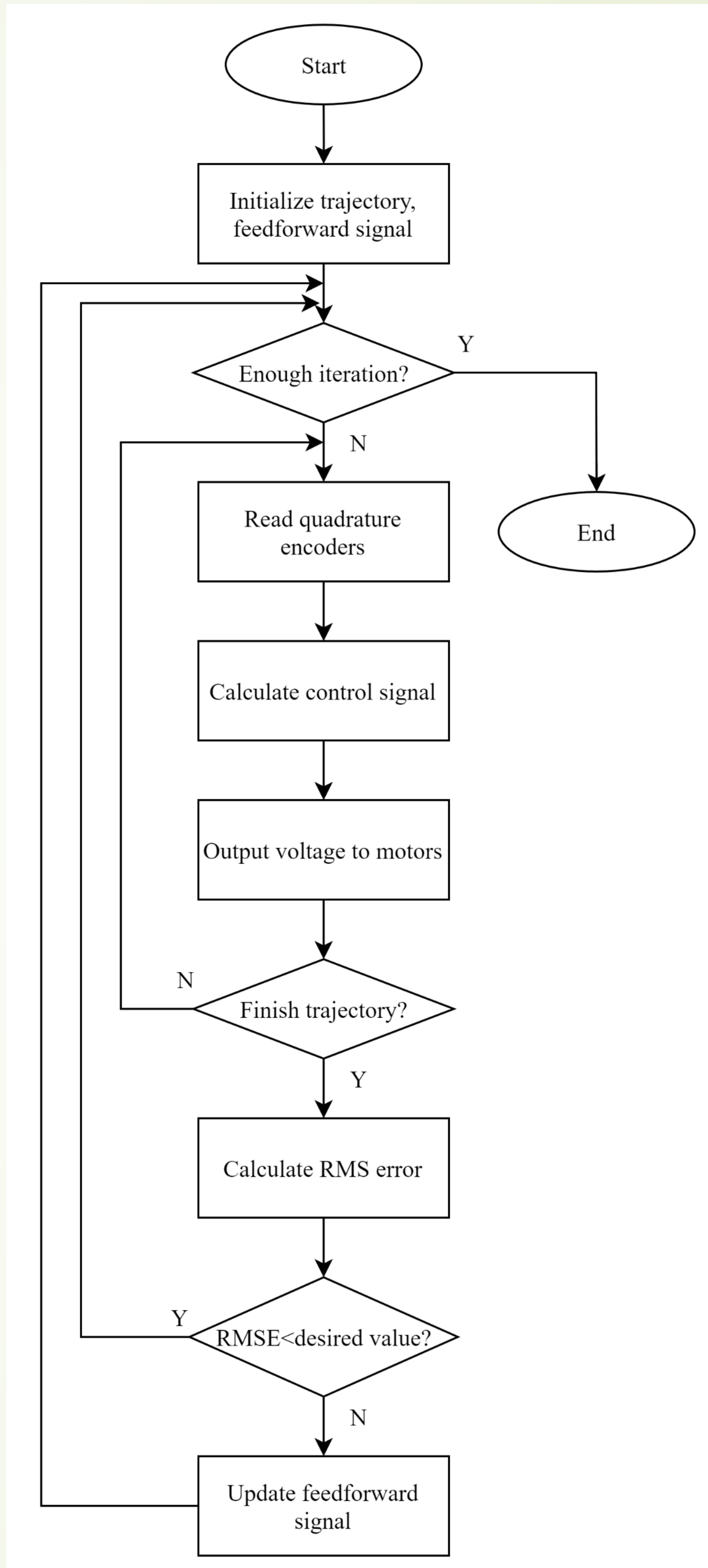

CONCLUSION

To increase the accuracy of parallelogram linkage manipulators, Iterative Learning Control (ILC) has been implemented in a control system integrating feedforward and feedback control. The feedforward and feedback control are first designed and tested individually, and later integrated in the same system. The results are very promising since all algorithms yield an important improvement of accuracy and a bettering of tracking performance. The use of additional learning techniques has allowed the application of simple and efficient linear learning methods.