VIETNAM NATIONAL UNIVERSITY, HO CHI MINH CITY
HO CHI MINH CITY UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING
DEPARTMENT OF MECHATRONICS

BACHELOR THESIS

ANALYSIS AND DEVELOPMENT OF A PARALLELOGRAM LINKAGE MANIPULATOR

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1. Overview

- Currently, robot with parallelogram linkages are widely used in automatic loading and unloading of crates and packages from the factory conveyor exit to pallets.

- This thesis aims to analyze and develop a compact parallelogram linkage 3-DOF robotic arm that can serve various purposes such as the needs of learning and research of students, industrial applications, or practicing needs of engineers. In the future, the capability to be mounted on AGVs to serve different purposes or installed in product-picking production lines is desired.

- This thesis will focus mainly on: developing a 3-DOF manipulator and an end-tool used for gripping objects.

An industrial palletizer

2. Conceptual design

Requirements for gripper:
- Object: rectangular carton box that weighs 0.2 kg.
- Not dropping the object while the robot is moving.
- Gripping force: in the range 0 – 1000 g.

Gripping mechanism: Parallel-finger gripper

Two fingers move parallel to each other thanks to the parallelogram linkages. Good for rectangular objects and can exert high gripping force.

Gripping force control: Closed-loop control with force feedback

Better at disturbance rejection compared to open-loop control. The force will be read by a force sensor and supplied to the controller.

Requirements for robot:
- Tool speed: can reach 1m/s.
- Joint accuracy: +/- 0.5°.
- Payload: 0.2 kg.

Main controller: Feedforward plus feedback control

While performance is guaranteed for both operations with load and disturbance rejection, implementation in the real world is moderately easy.

Supplement controller: Iterative learning control

Effective for robots doing a repetitive task. The implementation is quite convenient, because disturbances are not required to be known or measured.

The control system will be implemented on a STM32F411 MCU and a personal computer.

3. Mechanical design

- Minimum gripping force to resist gravitational force:
  $F_1 = 3.27\ N$
- Minimum gripping force to resist centrifugal force:
  $F_2 = 2.13\ N$
- Desired torque at the driving gear:
  $M = 54.60\ N.mm$

Actuator:

MG996R RC Servo
- Voltage: 4.8 – 7.2 V
- Current: 500 – 900 mA @ 4.8 V
- Torque: 922 N.mm @ 6V
- Speed: 353°/s @ 4.8 V

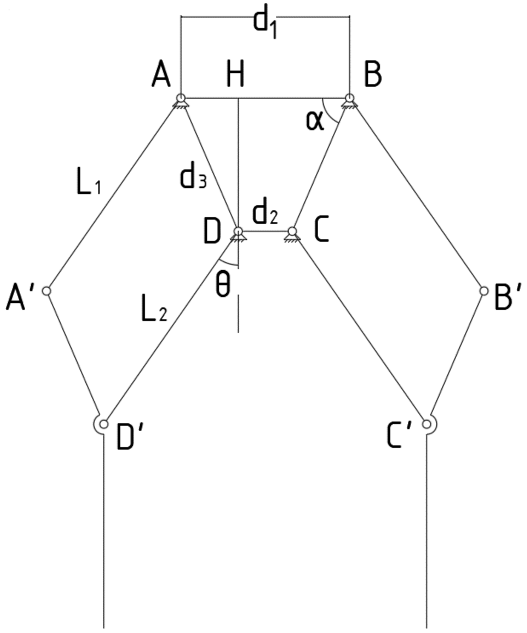
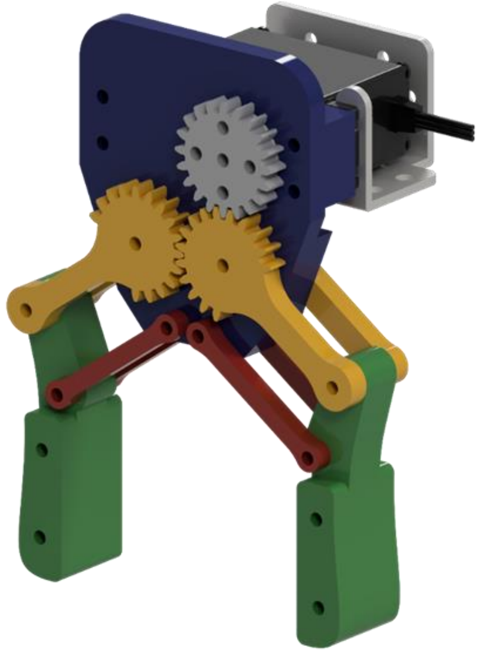
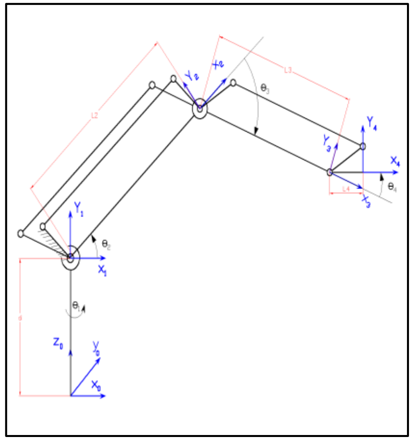


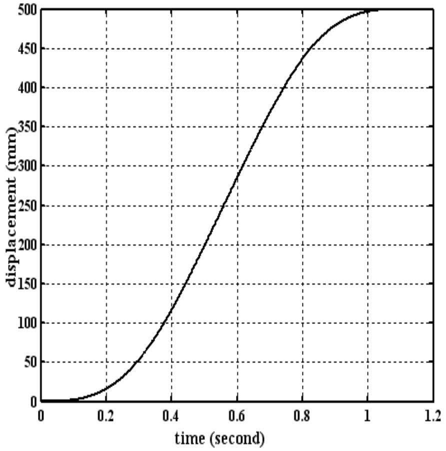
Diagram of the gripper

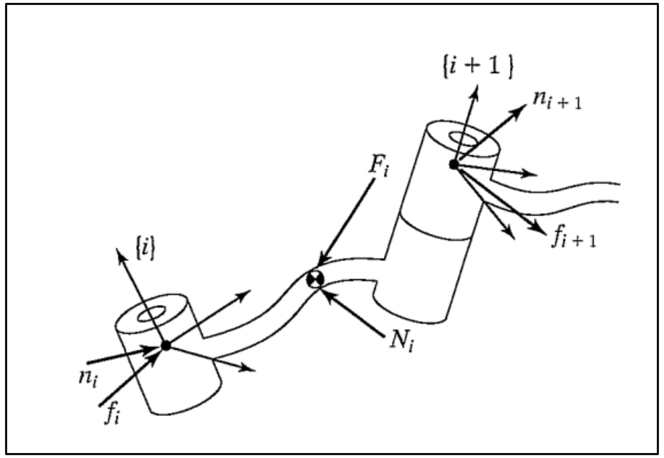


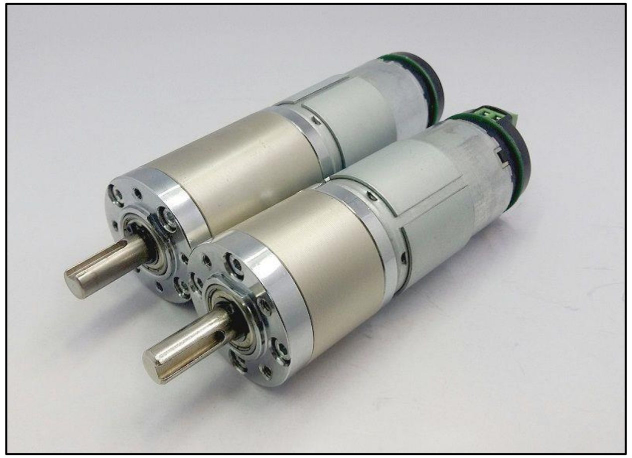
3D model of the gripper

4. Theory and system modelling









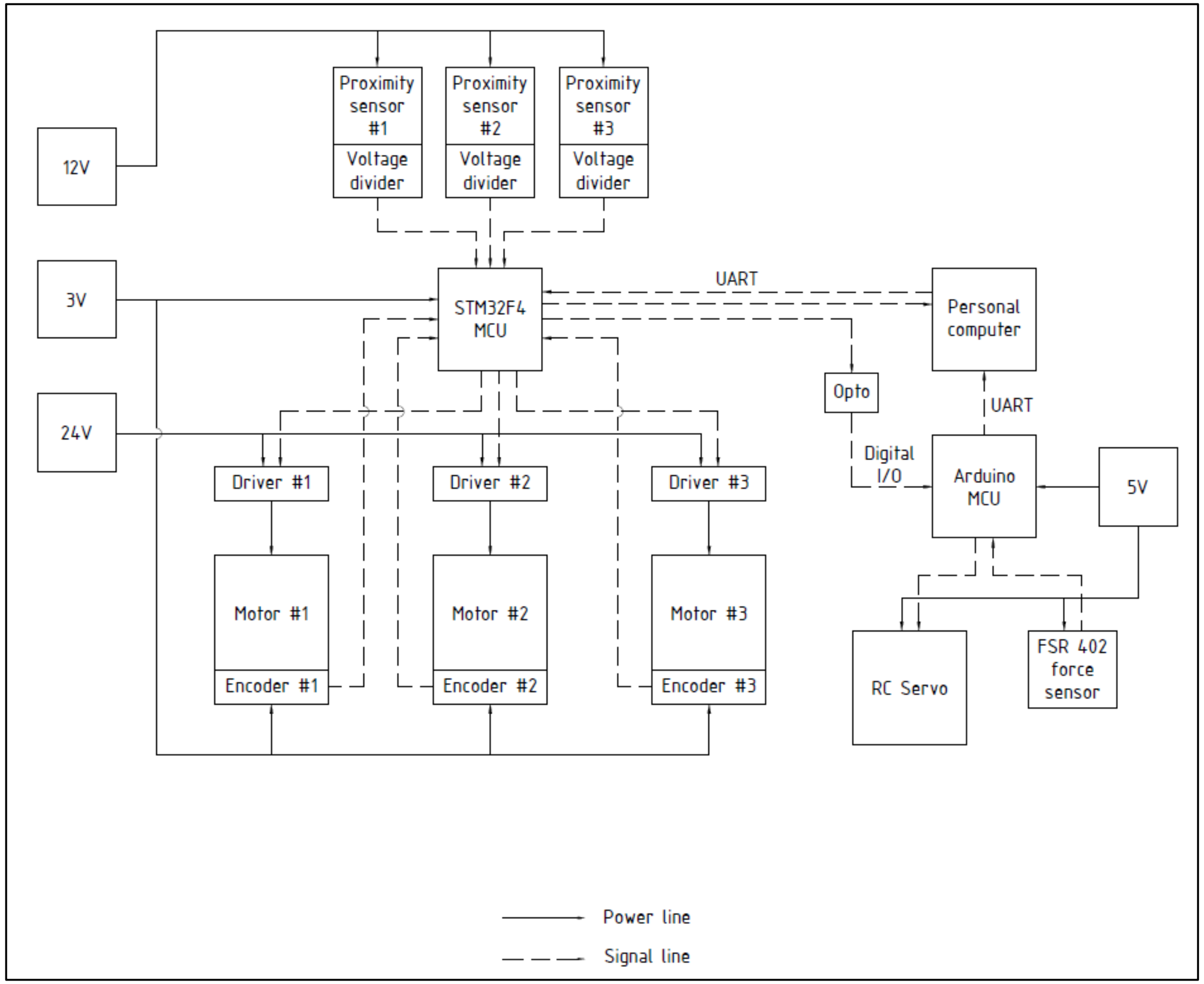
Kinematics
Derive the equations for forward kinematics, inverse kinematics, and velocity Jacobian.

Trajectory planning
In this thesis, S-Curve trajectories are used for each joint to reduce jerk and vibration, while still optimize the travel time.

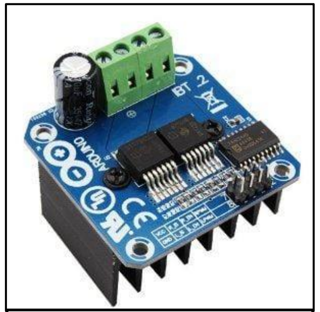
Dynamics
The dynamical model provides prior knowledge of load to the controller, which improves tracking performance. The method used is Newton – Euler inverse dynamics.

Actuator modelling
A DC motor can be controlled by varying the input voltage, commonly by means of changing the PWM duty cycle. In this thesis, to control the output torque, mathematical model of each DC motor is determined.

5. Electrical design

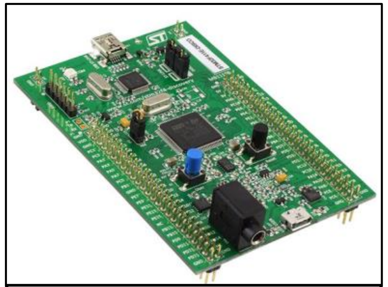


Electrical block diagram



BTS7960
DC motor driver

Switching power supply
24V, 12V and 5V



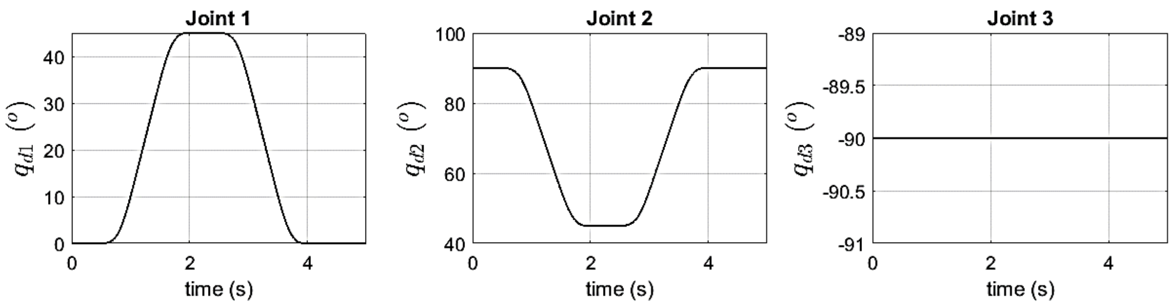
STM32F411
Robot control unit

Arduino Nano
Gripper control unit

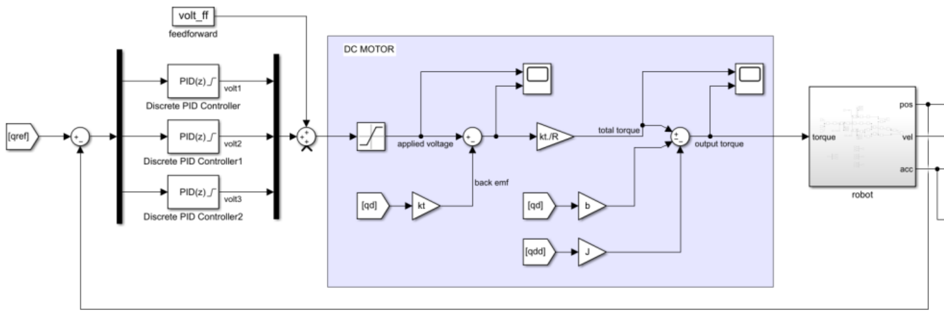
FSR 402
Force-sensitive resistor

The device is calibrated, and the final force can be calculated from the analog signal.

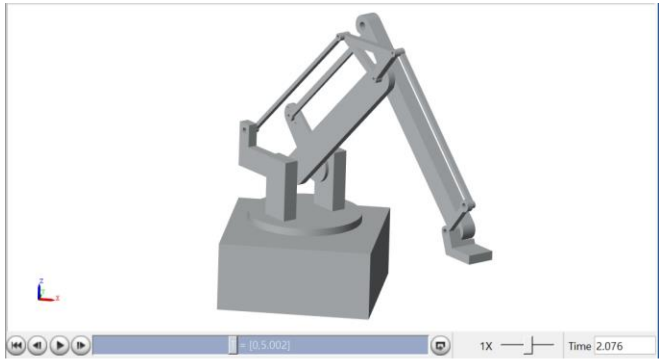
6. Controller design

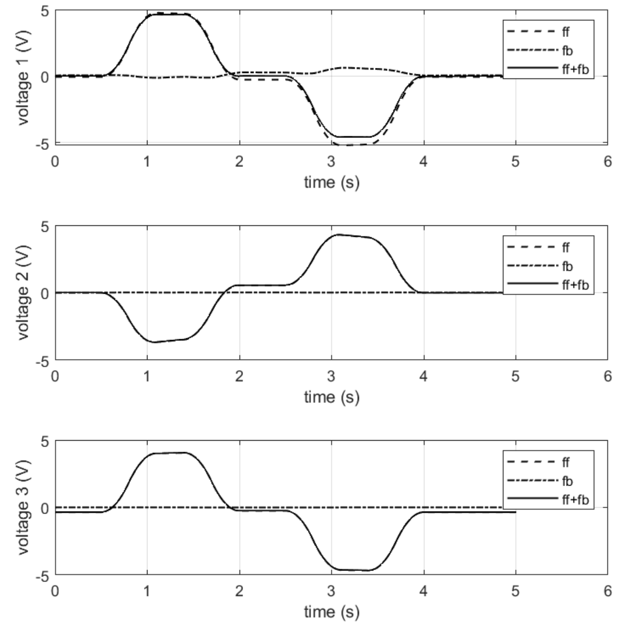


Joint trajectories (in degree)

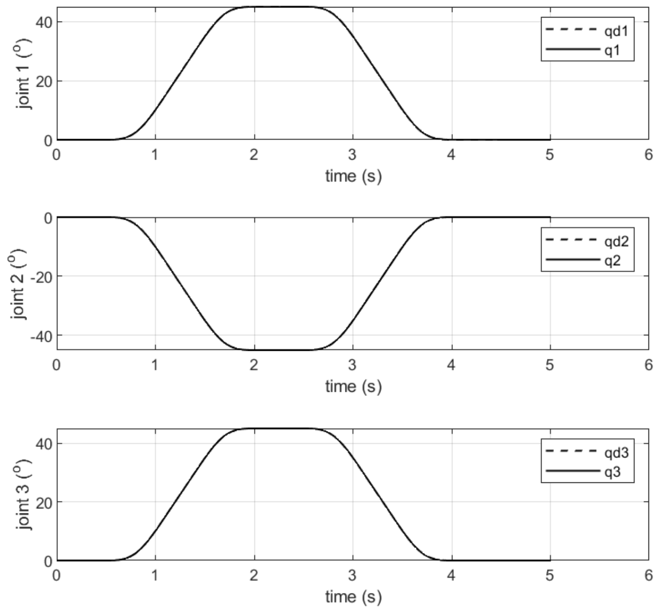


Implementation in MATLAB/Simulink

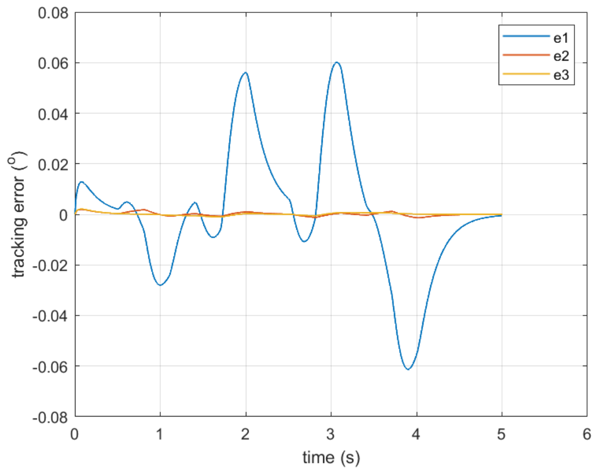




Control input of feedforward, feedback, and total



Reference tracking result of 3 joints



Tracking error of 3 joints

6. Controller design

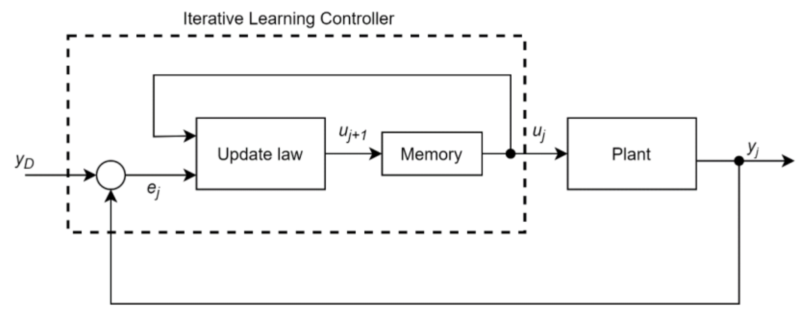
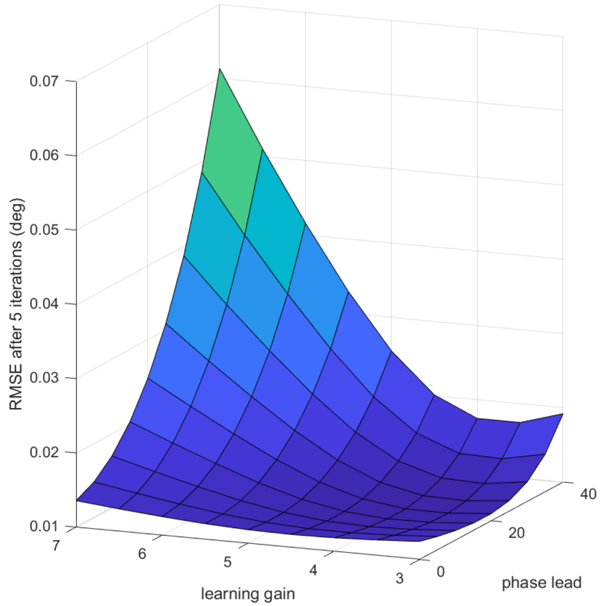


Diagram of an iterative learning controller (ILC)



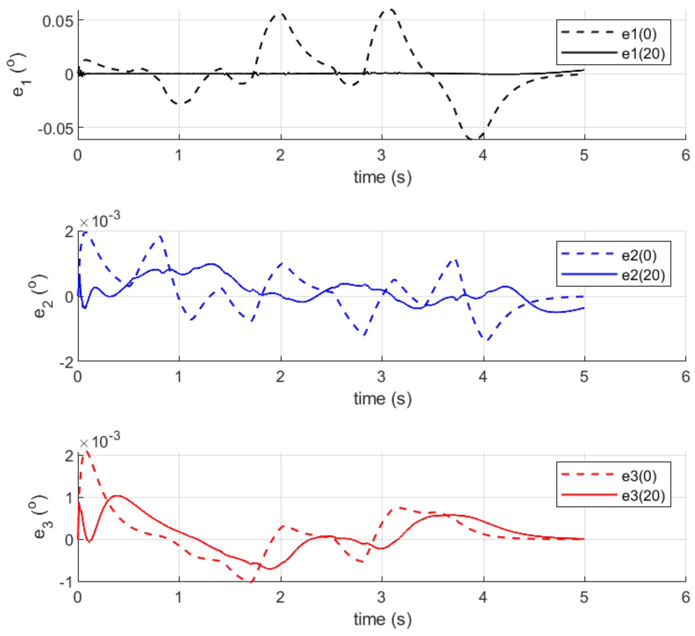
The control law:

$$u_{j+1}(k) = u_j(k) + \Phi e_j(k+l)$$

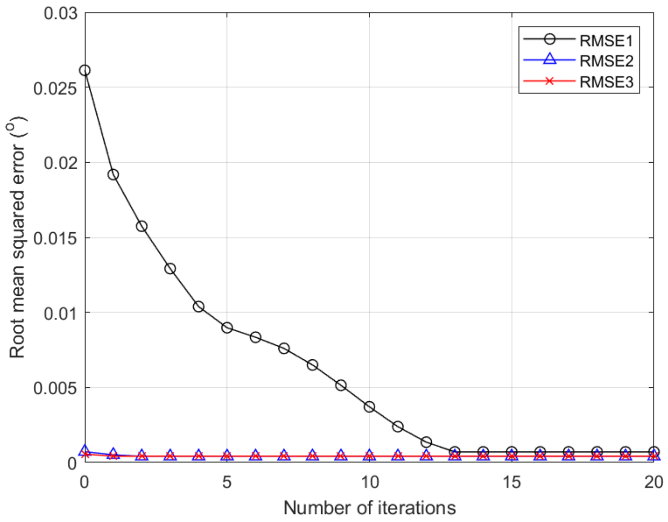
According to parameters tuning in simulation, select:

- Learning gain $\Phi = [4.5\ 4.5\ 4.5]^{\mathrm{T}}$
- Phase lead $l = 10$

With these values, the best error convergence property is achieved with the decrease of RMS error from 0.0274° to 0.0105° after 5 iterations.



Tracking error before and after 20 iterations

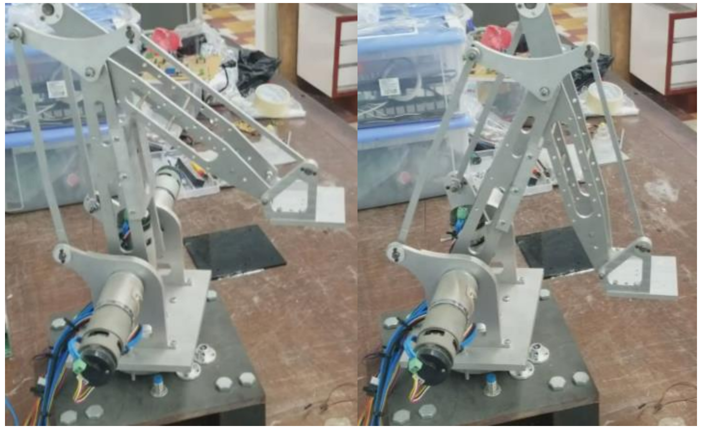


RMS error of 3 joints after 20 iterations

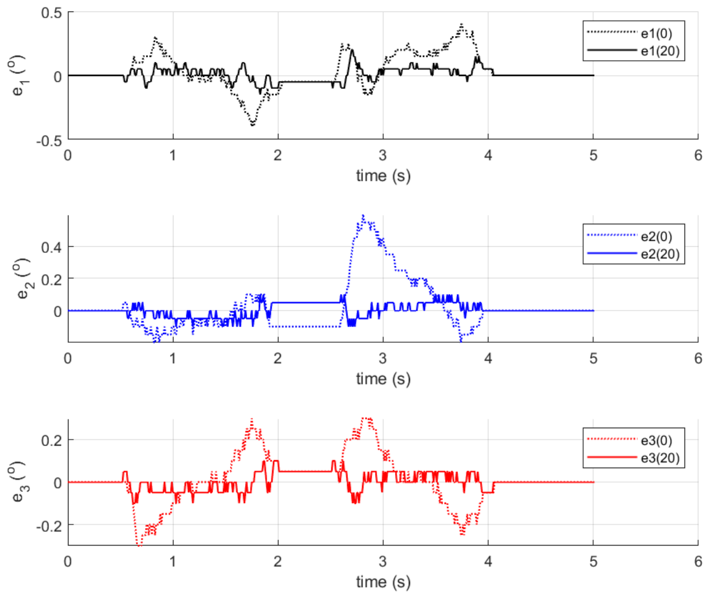
Overall, all three joints' results follow a typical trend: The tracking error is:

- Highest for feedforward control alone.
- A little lower for feedback control alone.
- Much lower for feedforward plus feedback control.
- Lowest for feedforward plus feedback plus ILC.

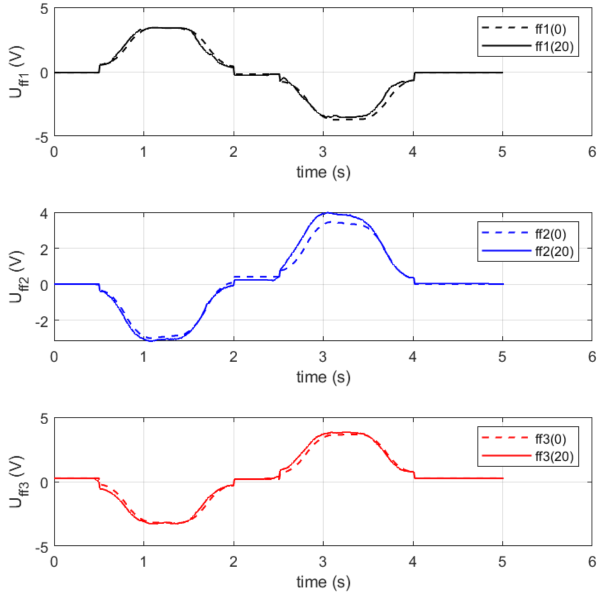
7. Experimental result and future works



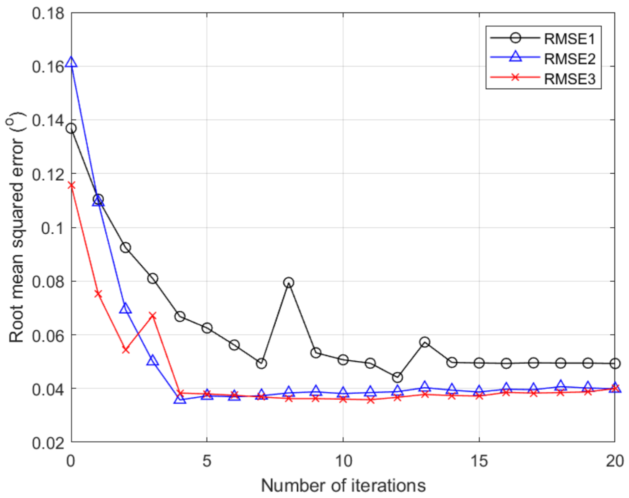
The robot in operation



Tracking error before and after 20 iterations



Feedforward voltage before and after 20 iterations

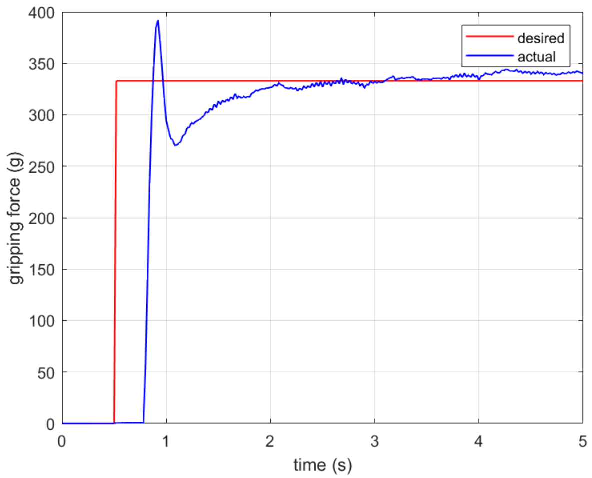


RMS error after 20 iterations

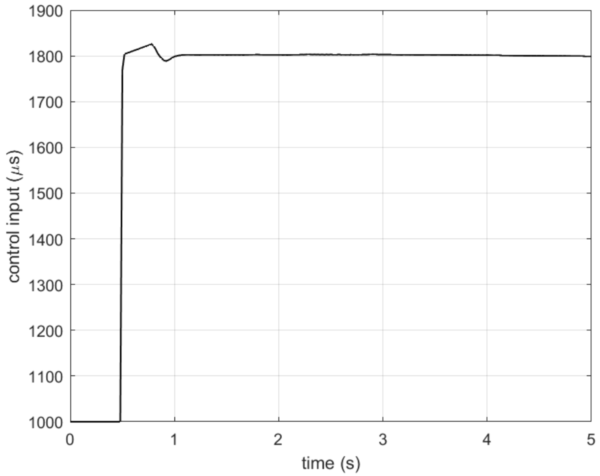
Overall, the tracking error as well as RMS error in experiment are always several times higher than that in simulation. However, in both simulation and experiment, the characteristics of the controllers are still presented clearly:

- Feedforward control is vulnerable to modelling errors and uncertainties.
- Feedback control is more robust.
- Feedforward plus feedback control is better than the two alone in terms of reducing tracking error.
- ILC suggests a simple but effective linear learning scheme that helps reducing tracking errors in a repeated operation.

7. Experimental result and future works



Force exert by the gripper



Control signal supplied to RC servo

Gripper experiment

- A PD controller is used to control the RC servo motor to achieve a desired gripping force value.
- The force settling time is roughly 1.5 second and the overshoot is roughly 17%.
- The 17% force overshoot can be high when the grasped object is fragile; however, for a rigid carton box, this value is acceptable.

Future works

Mechanical developments
- Improve the robot's rigidity.
- Improve the gripper's rigidity.

Controller developments
- Improve robot's performance with heavy load.
- Mathematical model of the gripper.

Electrical system developments
- Improve interaction with humans as well as ease of operation.

Applications of this thesis
- Can be easily mounted on AGVs to perform various operations.
- Can be installed in conveyor systems to pick and place objects.
- Force/torque control and collision detection.
- Visual inputs for pick and place operations, obstacle avoidance, etc.

For video clips of experiment, please visit:

https://youtube.com/playlist?list=PLajm7YJirzJ334udtLeGmeRIFjYgx3YuV

Or scan the following QR Code: