Electronics and Computer Science

Faculty of Engineering and Physical Sciences

University of Southampton

Yi Farn Lim

yfl1f18@soton.ac.uk

08/03/2022

Improving Robotic Grasping using Iterative Learning Control

Project supervisor: Professor Christopher Freeman

Second examiner: Doctor Nicolas Green

A project report submitted for the award of

MEng Electrical and Electronics Engineering

# Abstract

* Current needs on robotics assistance in industry
* Potential future needs that cant be fulfilled now
  + Grab water, food for physically challenged
  + Universal grip
* Issue with current gripper
  + Not able to grip diff objects
  + Do not learn from own mistakes (Current one only previous mistakes)
* How ILC can overcome issues
  + Grip different objects (mass)
  + Learn from all mistakes
  + Robust to external repeated disturbances
* Explain briefly the novelty
* Compare with Impedance control. Easy to implement with good results.

# Statement of Originality

I have acknowledged all sources, and identified any content taken from elsewhere.

I have not used any resources produced by anyone else.

I did all the work myself, or with my allocated group, and have not helped anyone else.

The material in the report is genuine, and I have included all my data/code/designs.

I have not submitted any part of this work for another assessment.

My work did not involve human participants, their cells or data, or animals

# Acknowledgements

I would like to thank…….

# Contents

[Abstract ii](#_Toc99054664)

[Statement of Originality iii](#_Toc99054665)

[Acknowledgements iv](#_Toc99054666)

[Contents v](#_Toc99054667)

[Report Structure vii](#_Toc99054668)

[1 Review of Robotic Gripping Controller 1](#_Toc99054669)

[1.1 Problem Analysis 1](#_Toc99054670)

[1.2 A History of Controllers for Robotic Gripping 1](#_Toc99054671)

[1.3 Importance of Simulation 1](#_Toc99054672)

[2 Detailed Specification 2](#_Toc99054673)

[2.1 Design Requirements 2](#_Toc99054674)

[3 Technical Background 3](#_Toc99054675)

[3.1 Overview of Impedance Control 3](#_Toc99054676)

[3.2 Overview of Iterative Learning Control 3](#_Toc99054677)

[4 Design Overview 4](#_Toc99054678)

[4.1 Simulation Environment 4](#_Toc99054679)

[4.2 Controller Specification 4](#_Toc99054680)

[4.3 Disturbance Scenarios 5](#_Toc99054681)

[5 Simulation Model 6](#_Toc99054682)

[5.1 Gantry Modelling 6](#_Toc99054683)

[5.1.1 Simulink and Simscape Modelling Object 6](#_Toc99054684)

[5.1.2 Gantry Model 6](#_Toc99054685)

[5.2 Contact Modelling 6](#_Toc99054686)

[6 Impedance Controller Design 7](#_Toc99054687)

[7 Norm Optimal ILC Controller Design 8](#_Toc99054688)

[7.1 Position Control 8](#_Toc99054689)

[7.1.1 Basic Position ILC Controller 8](#_Toc99054690)

[7.1.2 Advance Position ILC Controller 8](#_Toc99054691)

[7.2 Force Control 8](#_Toc99054692)

[7.3 Updating Controller Model 8](#_Toc99054693)

[8 Controller Disturbance Test 9](#_Toc99054694)

[8.1 Scenario 1 9](#_Toc99054695)

[8.2 Scenario 2 9](#_Toc99054696)

[8.3 Scenario 3 9](#_Toc99054697)

[9 Conclusions and Future Work 10](#_Toc99054698)

[Appendix A. Project management 12](#_Toc99054699)

[Contingency Planning, Minimising risk, reduce impact 12](#_Toc99054700)

[Work Planning 12](#_Toc99054701)

[Time Management 12](#_Toc99054702)

[Appendix B. Additional Graphs and Figures 13](#_Toc99054703)

[Appendix C. Simulink Model 14](#_Toc99054704)

[Appendix D. MATLAB Code 15](#_Toc99054705)

[Appendix E. Achieve File Overview 16](#_Toc99054706)

[Appendix F. Project Assumption 17](#_Toc99054707)

# Report Structure

* Shows a summary of what each chapter contains

Chapter 1:

# Review of Robotic Gripping Controller

Talk about why it is important

* Amazon have competition
* Grocery factory operates better
* Not tired, fatigue
* Does not make uncharacteristic mistakes
* Can find stats on number of robots use or projected industry value
* World around us custom for humans, where we have hands. So robot has to be able to grip also

## Problem Analysis

Talk about what is the current issue

* Robotic gripping is very slow
* Can only operate in a tight environment
* Can only operate on 1 specific item
* Not able to learn from previous mistakes since its repetitive

## A History of Controllers for Robotic Gripping

* Process of gripping. (Planning, trajection, etc)
* Different types of controller, their problems and advantages

## Importance of Simulation

Briefly talk about the importance

* Good way to verify controller behaviours
* Cost friendly
* Able to tune/change parameters/systems quickly
* Show the growing market of simulation

# Detailed Specification

* A quick review on diff controllers advantages and issues based on literature review
* Say the problem in problem statement is still present, although P and D ILC manage to solve abit
* Say a novel approach to solve is to use a better ILC algorithm and why.

## Design Requirements

Add more to explain each part and what this section is about

* Model in Simulation
  + DR1: Mimic real world system dynamics
  + DR2: Simulate real world interaction dynamics/forces
  + DR3: Able to visually see what is happening, easier when showcasing or just in general how the gripper would behave. Able to discover potentially ‘hidden’ issues, that might not be captured since it is unexpected. (Slipping)
* Grasping properties
  + DR4: Reach and grasp object **accurately** (Have position error of less than 1% to 5%, need to check with gripper accuracy again)
  + DR5: Reach and grasp object in a **short duration** (Complete trajectory within 5-7s)
  + DR6: Reach and grasp object with **least amount of Force** (Within 25% of access force from minimum force)
  + **DR7: Stable** reach and grasp operation for different object mass (100g to 2kg)
  + DR8: Converge as fast as possible (Within 8 Iterations when starting off)
  + DR9: Able to correct itself from repetitive disturbances. (Able to grab the object within 3 iterations after disturbance.)

# Technical Background

## Overview of Impedance Control

* Simple impedance control explanation
* Put related equations.
* Use simple integration method with PID. Back it up with papers showing that its good
* Explain in quite simple terms with help of pictures for robotic gripping
* Impedance will use Integration method. Include schematic and equation of update with it
* Explain meaning of each term

## Overview of Iterative Learning Control

* Difference between model and non-model based controller
* Say why ILC is good. Able to correct repetitive error etc
* Say which ILC algo has potential for gripping. Can review thesis to get some idea
* Explains the advantages of NORM-OP over other ILC

# Design Overview

Talk about how general approach of design and test will be

* The project can be split into 3 sections and talk about some general points so that the project would not wonder off course when building it
  + Model
  + Controllers
  + Disturbance
* Each sections should has its own initial plan, timeline, approach and contingency plan

## Simulation Environment

* Articles/papers about why MATLAB is a good simulation platform. Highlight the advantages of it (Simple, well established, user friendly, etc). Also mention the success of Simulink and Simscape
* DR1:
  + Decide which model to use (Mimic real world machines), robotics arms and gantry. Choose gantry since it is less complicated as each axis can be decoupled.
* DR2:
  + Explain some interaction force between robot and object and environment. (Gripping force, normal force, friction force, gravitational force)
* DR3:
  + Visualising requires not just numerical model but ‘physical’ model in the simulation environment.
* Talk about using Gantry. 3 axis are independent from each other, would be easier to design and test the controller and not deal with more complicated angles, etc from arm.
* Talk about splitting the model into X, Y, Z and gripper components. Test each one before continuing with the rest with some simple inputs so that it behaves as expected.
* Draw out a simple flow diagram on how the whole system is going to build. Like Z then Y then X then gripper.
* Talk about gripping requirements as well

## Controller Specification

* DR4:
  + To ensure it can grab object accurately. It should employ position feedback, so that the input can constantly adjust so that it can reach the final location.
* DR5:
  + Short duration means it has to have least amount of deadtime. Less ‘stop and go’ moment
  + Several position should move together.
* DR6:
  + Need force feedback, then from there it will adjust gripping to adjust force.
* DR7:
  + Able to grab diff mass means it should update the model with the object mass. If not it will introduce model inaccuracy and might cause undesirable outcome.
* DR8:
  + Need to balance the gain given to the controller, so that it can converge the fastest but not cause too much oscillation/overcorrection/unstable.
* DR9:
  + Able to correct previous errors requires controller that can utilise previous errors and modify input.
* Gives controller high level schematic. What type of feedbacks, how it is feed (input and output), plant etc.
* Justify the use of ILC after explaining DR. For position and force control. By highlighting the good of ILC like fast convergence, learning, robust (Able to allow some form of model inaccuracy).
* Explain the use of 2 ILC for gripper (Force and Position)
* Explain how the force will change in Y axis. Make some visual.

## Disturbance Scenarios

* Explains that the scenarios are commonly encountered.
* Can try and find some articles or papers highlighting some issues about robotics/gripping
* Say to fulfil DR9, controller will be subjected to the following tests. The tests can be to the gripper directly or indirectly via XYZ axis.
* DS1: Constant Initial Errors
  + Due to wear and tear
  + Incorrect initial alignments
  + Always have a constant error
* DS2: Sudden Impulsive Error
  + Bumping into object
  + Wear and tear at a certain area of the system
* DS3: Noise from Environment
  + Repetitive sine waves
  + Low frequency noise

# Simulation Model

Talk about translating modelling DR to actual system

## Gantry Modelling

### Simulink and Simscape Modelling Object

* Talk about (What, How, Why)
  + Prismatic joint (Follower and Base as well and the orientation)
  + Mass object
  + Translation

### Gantry Model

* Talk about the decision to use PID and mass and prismatic joint to mimic the dynamics of the actual system.
* Talk about using PID Tuner.
* Talk about issue of PID Tuner. (FVT shows always at 1)
* Talk about the trial of using script and PID at feedback. (FVT will have 1/kp, so unable to tune, need to have a gain)
* Talk about putting gain and tune X, Y, Z and gripper.
* Put Z axis graph. (Step input in Simulink then impulse for TF), then talk about using similar ways to do the rest.
* Show the final Simulink schematic as well as Explorer view.

## Contact Modelling

* Talk about (What, How Why)
  + Spatial contact force
  + Sphere
  + How Normal and friction force is calculated
  + How applied force is calculated and modelled
  + How to determine minimum force
* Talk about testing how MATLAB simulate the force with different testing scenario.
  + Diff contact points
  + Different distance
  + Different mass.
* Confirm the Y axis force changing scenario.
* Explain the choice of using 8 contact points (Wont tip, spin etc)

# Impedance Controller Design

* Position control using PID
* PID tune to get a fast response, so that it can correct any position error fast enough
* Impedance use non model based
* Tune the values manually. Show some examples and show the best result obtained.
* Put the force, position etc graphs and analyse it.
* Put error graph and analyse it as well.
* Explains the reference etc input to the system.

# Norm Optimal ILC Controller Design

## Position Control

### Basic Position ILC Controller

* Add the simple flowchart of a position feedback ILC Controller
* Talk about how trajectory generation. X1, Y1, Z1, G1.

#### Tuning controller using Numerical Evaluation

* Saves time as the evaluation is instant, Simulink takes longer. 40 iterations with 5s sequence equates to at least 200s.
* Talk about using normal Gain Norm ILC
* Change to one that is more complicated
* Use this to tune and roughly find the best value for the controller.
* Using lsim

#### Simulink Simulation Response

* To verify the response from above is desirable
* Realise that the response is different. Numerical is faster than Simulink. So have to retune slightly to ensure it fits DR.

### Advance Position ILC Controller

* Add flowchart of Z axis only starts gripping when X and Y are within X% of final position.
* Same for gripper on Z axis.
* Show some drawings on how to determine this and the maths to do so.
* This ensure it would not try to grip the object although it is far from it.
* This solves the issue of toppling/pushing etc of the object when it is near the final destination but still not within a decent bounding box to be safe to grip.
* Not able to determine if the object is firmly gripped, about to know if gripper is at the final position or not only. Solve by implementing Force Control.

## Force Control

* Talk about testing to grip object. (G1 and G2). Only when it is confident it has enough force to grip then only lift the object up. Ensures the object will not fall
* Show flow chart of the gripping algorithm
* Show the change of reference trajectory equations
* Talk about the new algorithms
* Check another doc to see the steps of implementing the flowchart step by step.
* Show the need to smooth out the change and the logic behind it
* Show that the gripping position is changing while trying to maintain constant force due to acceleration in Y axis directioin

## Updating Controller Model

* Show that without update, the Z axis can be weird. Vibrating is visible.
* Also the force oscillate less when update the model. Oscillate means bad and can drop the object. Part of model inaccuracy and can reduce the robustness of the controller.

# Controller Disturbance Test

## Scenario 1

## Scenario 2

## Scenario 3

# Conclusions and Future Work

* Concludes that ILC ensures that object can be gripped firmly even with disturbance. Although can take several iterations
* ILC is more robust generally speaking when there is disturbance in gripper and XYZ axis
* Impedance will have huge force applied in the beginning
* Impedance is able to tune so that most part reaches min force
* ILC able to remove any repetitive disturbance.

## Review against Design Requirement

* Make a review against DR

## Future Work

* Using conclusion and review deduce what can be investigate further.
* Would be good to add those 2 together
* Model update is important when the mass of object is large.
* Come up with a new update that takes into account minimising position and force error.
* Add slip detection so that it could adjust the reference force if the object slip.

References

# Project management

## Contingency Planning, Minimising risk, reduce impact

* Talk about the use of ready made model from matworks website. This is incase unable to build a model. Downside is that does not know the model of the model, hence challenging to use model based ILC
* Do the risk analysis thing
* Minimise is to get a simple model working, gantry instead of the more complicated arm manipulator

## Work Planning

* Come up with a list of work needed to be done and see which one correlates with the other and which is independent.
* Identify the longest path and most crucial component/path

## Time Management

* After planning the work use flowchart to map out the time
* Have some buffer time to catch up any delayed work
* Review the gantt chart for sem 2 at the end of sem 1 and adjust any plans

# Additional Graphs and Figures

* To put in any figures and graphs to support the analysis above but repetitive. Like X, Y and Z axis graphs for disturbance. Its similar but slightly different but uses the same way to analyse it.

# Simulink Model

* Show the full Simulink model, piece by piece. And some brief explanation. Some might not be important enough to put it into above, or its too much to put it on.

# MATLAB Code

* Quick guide to the MATLAB code for both ILC and Impedance.

# Achieve File Overview

* Shows what version does what and what file does what.
* Where is some simulation data stored so can plot easily

# Assumption

* X, Y, Z and gripper motor has enough Force to move it.
* Position and Force feedback are accurate
* Mass is known