COMPUTATIONAL INTELLIGENCE METHOD FOR OPTIMAL ROTARY DESIGN SYSTEM

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Especially dedicated to:
Wife, Amma, Brother, Sister,
And Friends

My love for you all remains forever.....

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ABSTRACT

The application of computational intelligence techniques to the field of industrial robot control is discussed. The core ideas behind using computation, evolutionary computation and fuzzy logic techniques are presented, along with a selection of specific real-world applications. The practical advantages and disadvantages relative to more traditional approaches are made clear. The objective of this project was to investigate and compare different algorithms for the calculation of velocity from position information. The best algorithm was applied to a small robot arm system which consists of a controller (PC software), analog-to-digital and digital-to-analog converter PC card, power amplifier, DC motor, gear train and external load. Generally in robotic systems a velocity calculation is difficult or impossible to implement because of noise. Here in the project, fuzzy logic will be used to filter the noise from the position data before calculating velocity. The purpose of this research is to design fuzzy logic feedback controller to position the rotational system with one flexible joint. The system produces oscillations that need to be dampen. Here the PD (without) controller, ON-OFF controller, Linear Quadratic Regulator controller (LQR) and Fuzzy Logic controller (sugeno method) are being used to solve the mentioned oscillatory problem. In order to control the overall Rotary Flexible Joint System, the Fuzzy Logic controller (FLC) is designed base upon the coefficients of the existing LQR controller. Comparison between four controllers was being made through simulation and experiment and the results showed that the fuzzy controller performed better than the other controllers.

ABSTRAK

Aplikasi teknik pengiraan pintar di dalam bidang kawalan robotik industri telah dibincangkan. Idea asas sebalik penggunaan pengiraan, pengiraan persifat evolusi dan teknik logik kabur yang dibentangkan bersamaan dengan pemilihan yang tepat dan khusus bagi aplikasi dunia sebenar. Kebaikan dan keburukan praktikal adalah lebih kepada pendekatan tradisional yang nyata. Objektif projek ini adalah untuk menyelidiki dan membandingkan antara algoritma untuk pengiraan kelajuan dari segi posisi informasi. Algoritma yang terbaik telah diaplikasikan pada lengan robot yang mengandungi bahagian kawalan computer (perisian komputer), analog kepada digital dan digital kepada analog, pengubah kad perisian komputer, amplifier kuasa, motor a.t, gear dan beban luaran. Dalam sistem robotik pengiraan kelajuan adalah rumit untuk dilaksanakan kerana gangguan. Kawalan logik kabur telah digunakan untuk menapis gangguan dari segi data posisi sebelum pengiraan kelajuan dibuat. Kajian ini dijalankan untuk mereka bentuk sistem kawalan suap balik logik kabur untuk memposisikan semula suatu sistem putaran yang disambungkan kepada suatu sambungan fleksibel. Sistem ini menghasilkan ayunan yang perlu dikurangkan. Disini kawalan PD, kawalan '*ON –OFF*', kawalan pengatur kuadratik datar dan kawalan (kaedah sugeno) yang telah digunakan untuk menyelesaikan masalah ayunan tersebut. Bagi mengawal keseluruhan '*Rotary Flexible Joint System*', kawalan logik kabur telah direka dengan berdasarkan angkali pengawal pengatur kuadratik datar. Perbandingan antara keempat-empat kawalan telah dibuat melalui simulasi dan eksperimen. Keputusan menunjukkan pengawal logik kabur berfungsi licik daripada kawalan-kawalan yang lain.

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CHAPTER I

INTRODUCTION

1.0 Introduction

Rotary Flexible Joint Module which acts as robot is playing an increasingly important role in industry to meet the high demands of automated systems. They are expected to have a capability to sense environmental information process that information and perform appropriate actions for a wide range of tasks. A major challenge for these robots is that traditional control techniques generally require an accurate mathematical model of the system and its environment thus any inaccurate modeling will naturally have a direct negative effect on their performance. For this reason, computational intelligence techniques are now regularly being employed, particularly neural computation (Miller, et al., 1990, Lewis et al., 1998), evolutionary computation (Davidor, 1991) and fuzzy logic (Lee, 1990), since they provide powerful tools for the realization of better and more efficient control systems without the need for accurate models. These techniques all employ a general control framework, with associated parameters that are adapted to optimize the relevant performance measures. These measures can cover the obvious requirements of speed and accuracy, as well as other important requirements such as stability, reliability and safety. There is already an enormous literature on this subject. In this thesis the general principles involved will be explain with particular reference to existing applications of these techniques in industrial robotics and any other research in this area. Throughout the thesis the advantages and disadvantages of each technique compared with other approaches will be identify.

Quanser Rotary Flexible Joint System module was used in the project. The modules included a track, one mass with a DC motor and one empowered mass, a teeter-totter that the track can be placed on, a spring for connecting the masses, a pendulum rod, a power amplifier, an ISA or PCI computer interface board and the Wincon software that interfaces with SIMULINK. The Quanser systems also had an interface with MATLAB, which allowed implementing real-time controller designs in SIMULINK with ease. Develop a state space representation of a rigid-link, flexible joint robotic manipulator actuated by a DC motor, identify system parameter values of the actual system, evaluate the simulation vs. experiment results, critique the proposed simulation model and then augment the model in an effort to improve simulation accuracy. The utilization of the WinCon real-time interface is to actuate the robotic link and to collect measurements from the numerous sensors embedded on the physical plant.

1.1 Background

In the computational world, there are two broad areas of logic: crisp logic and fuzzy logic. Crisp logic arises out of the fundamental concepts of such people as Aristotle and Pythagoras who based their work on the idea that everything in the universe can be described by numerical formulae and relationships. Crisp logic is best known as Boolean logic. In Boolean logic, problems are simplified by reducing the possible states into variable which have, e.g. *1* or *0*, *on* or *off*, *true* or *false*. Since the eighteenth century, however, there has been some debate as to the introduction of vagueness into the realm of control theory. This came about initially through the work of philosophers. David Hume, for example, sought to involve common sense and the reasoning based on the knowledge that people gather in making future decisions. The German philosopher Immanuel Kant saw a flaw in conventional mathematics and set theory and thought that mathematics could only provide clean definitions, whilst leaving contradictory principles unresolved.

The original *0*, *1* or binary set theory was invented by the nineteenth century German mathematician Georg Cantor. The Polish philosopher Jan Lukasiewicz developed the first logic of vagueness in 1920 when he created sets with possible membership values of *0*, *1/2*, and *1*. Albert Einstein and his theory of relativity as well as Werner Heisenberg and his theory of uncertainty further questioned the logic of crisp logic. The concept of fuzzy logic as we know it today was invented in the 1960's by Lotfi Zadeh. It is an extension of Boolean logic where members of the set can have varying degrees of three memberships. Fuzzy Logic is an approach to handle vagueness or uncertainty and, in particular, linguistic variables. Classical set theory allows for an object to be either a member of the set or excluded from the set. Fuzzy Logic is a multi-valued type of logic that allows intermediate values to be defined between conventional threshold values. Notions like rather warm or pretty cold can be formulated mathematically using fuzzy logic and processed by computers.

Fuzzy Logic words can be organized under several headings. *Quantification* includes the terms All, Most, Many, About Half, Few and No. *Equality* includes always, frequently, often, occasionally, seldom and never. *Likelihood* terms are certain, likely uncertain, unlikely and certainly not. Fuzzy systems are used for estimating, decision making and in mechanical control systems such as air conditioning, automobile controls and subway systems. Since 1987 the subway system in the city of Sendai, Japan has been using a fuzzy system to keep the trains rolling, braking and accelerating without losing a second or jarring a passenger.

1.2 Project Aims and Objectives

The objective in this project is to design a of a fuzzy logic controller for a Rotary Flexible Joint system. The objective of the controller is to drive the manipulator through a desired trajectory without exciting vibration. The design of a fuzzy logic controller deals with the following:

i) Identifying the variables and structure of the controller.
ii) Choosing fuzzy inference rules that the controller uses.
iii) Modeling the Rotary Flexible Joint in Fuzzy Logic Toolbox
iv) Designing closed-loop (feedback) controller to dampen the arm vibrations using Fuzzy Logic Controller
v) Compare LQR controller and Fuzzy Logic Controller.
vi) Evaluating the performance of the controller to determine if any of the above elements, such as the number of membership functions that describe a variable, should be modified.

1.3 Scopes of Project

The scope of the project is to develop a state space representation of a rigid-link, flexible joint robotic manipulator actuated by a DC motor, identify system parameter values of the actual system and evaluate the difference between LQR controller and fuzzy logic controller. The utilization of the WinCon real-time interface to actuate the robotic link and to collect measurements from the numerous sensors embedded on the Rotary Flexible Joint System.

1.4 Problem Statement

Perhaps the obvious process for programming robot controllers would be to build a model of the system and its environment and then uses appropriate planning techniques to design a program for the controller which can perfectly carry out the desired tasks in the fixed environment. Typically this would involve controlling the position of and forces exerted by a robot manipulator with constraints on the paths traveled and smoothness of movements. Clearly such *model-based* methods will not be well suited to autonomous robots that work in dynamical environments with unknown details and have to cope with factors such as unpredictable payload variations, plant degradation and so on. To overcome this limitation, a *sensor-based* approach is a natural alternative. The damping constant of the link proved to be the most difficult parameter to estimate because the damping is nonlinear and very small. In particular, they should evaluate which system identification method produced parameters that would yield a more accurate simulation of the motor behavior. In essence, we need to reinforce the validation process through repetition. The gear ratios, internal and external, that were not emphasized within this project. The LQR controller was using a mathematical modeling which is more difficult and complex. In particular, the open ended nature of the model refinement step, which involved adding a friction term in the simulation, seemed time consuming.

1.5 Project Overview

The objective of this project is to construct accurate mathematical models, such as transfer functions and state space representations of complex dynamic systems for the classical control development and analysis. Without a suitable model of a physical plant, many of the classical approaches for compensator design and stability analysis are rendered ineffective. While the discipline of modeling is deeply rooted in physics, the process of constructing representative models can often be as much of an art as a science. Identifying system parameters, utilizing simplifying assumptions, and judging the validity of the resulting simulation results are very difficult topics to convey. In order to fully validate the system model, an experimental test must be performed on the target plant with all pertinent data collected and stored for comparison to the corresponding simulation results. Without such feedback it is extremely difficult to comprehend the impact of modeling assumptions, to observe measurement errors or to locate possible modeling mistakes. Due to this need, a hardware interface system must be utilized that can interact

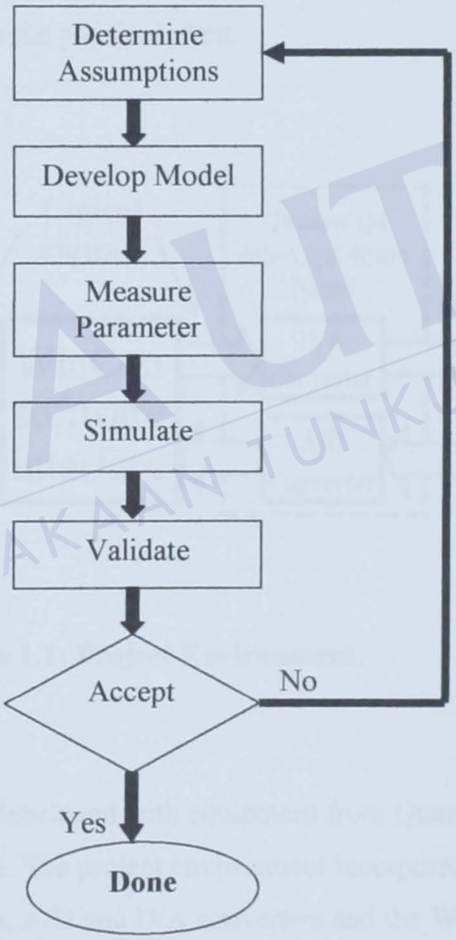

Figure 1.0: The Modeling Process

with the physical plant and sensors such that the experimental test can be realized. Currently, employing the WinCon real-time interface with SIMULINK for Quanser

Inc. figure 1.0 modeling process show the hardware interface alternatives have been successfully employed at the undergraduate or graduate level.

This project is to develop a state space representation of a rigid-link, flexible joint robotic manipulator actuated by a DC motor, identify system parameter values of the actual system, evaluate the simulation vs. experiment results, critique the proposed simulation model, and then augment the model in an effort to improve simulation accuracy. In each component of the project, can utilized the WinCon real-time interface to actuate the robotic link and to collect measurements from the numerous sensors embedded on the physical plant.

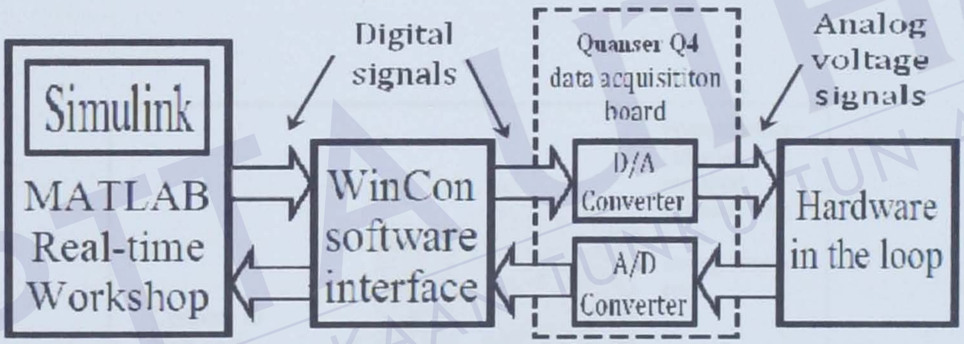

Figure 1.1: Project Environment

This project have been developed with equipment from Quanser, Incorporated serving as the core. The project environment incorporates a physical plant, analog and digital sensors, A/D and D/A converters and the WinCon real-time interface with SIMULINK as shown in figure 1.1 above. A power module manages the flow of power and information to and from the DC motor. The power module also contains the power electronics required to drive the DC motor. A terminal board connects the WinCon software interface to the hardware. The I/O board is equipped with sixteen A/D channels, four D/A channels and six encoders.

The Quanser DC motor is shown in figure 1.2 below. The motor is equipped with a potentiometer and a digital encoder to measure the angular position of the output shaft and a tachometer to measure the angular velocity of the output shaft. The motor shaft is rigidly coupled to the hub of the robotic link. This hub is coupled to a robotic arm through a spring-loaded rotary flexible joint. The angle of the arm relative to the hub is measured via a digital encoder. The entire arrangement is referred to as the flexible joint robotic arm. Obviously, it is not standard practice to connect robotic arms with springs. However, all joints have some compliance and this compliance can be approximated as a rotational spring. In a typical industrial robot however, the stiffness of the rotational spring is sufficient to have minimal impact on performance and stability. This was due to the long length (and consequently large inertia) of the arm and the succession of gear stages required to drive this large inertia.

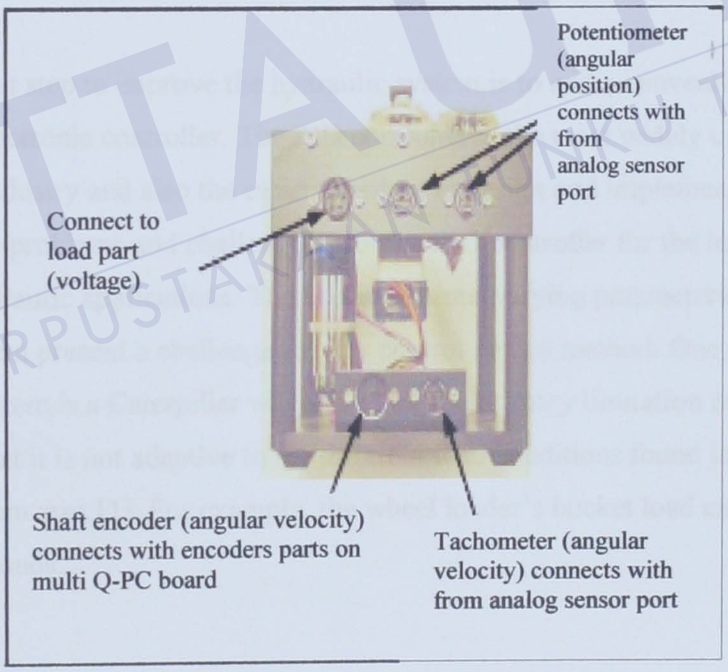

Figure 1.2: Quanser DC Motor

1.6 Significance of Research

The hydraulic systems area is one of the more challenging areas for closed-loop control especially in the large machinery area. Hydraulic systems are expensive and require large laboratory space. Control algorithms are investigated on smaller systems such as robot arms. Our robot arm system exhibits dynamics (mathematics) similar to a hydraulic actuated system. The predominant method used in industry is human control. Many product parameters cannot even be specified because they rely on the person's experience and training. Automatic electronic controllers can eliminate the repetitive tasks performed by the human controllers as well as achieving better performance such as final position accuracy. Final positioning accuracy has only become a concern in the last several years. Good accuracy is difficult to obtain with conventional controllers.

The first step to improve the hydraulic system is to add a conventional closed-loop electronic controller. The PID controller is the most widely used controller in industry and also the easiest method to design and implement. However, there are many problems and challenges with the PID controller for the large machinery hydraulic applications. The nonlinear time-varying parameters of the hydraulic system present a challenge for this control design method. One example of a hydraulic system is a Caterpillar wheel loader. The primary limitation of the PID controller is that it is not adaptive to the different load conditions found in the large hydraulic system area [1]. For example, the wheel loader's bucket load can vary from 0 to 33,000 pounds.

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