"I hereby declare read through this report entitle "Controller Design of Dual-limb Robotic Arm" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronic Engineering"

Signature : ……………………………………………

Supervisor's Name : ……………………………………………

Date : ……………………………………………

CONTROLLER DESIGN OF DUAL-LIMB ROBOTIC ARM

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A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Mechatronic Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

I declare that this report entitle "Controller Design of Dual-Limb Robotic Arm" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………………………………………

Name : ……………………………………………

Date : ……………………………………………

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ABSTRACT

Robotic becomes one of the most advancing technologies where it replaces countless human labors into a more tough and efficient mechanical body, regardless of working environment. Normally, robotic arm is designed based on the purpose and the usage of the robotic in different field. Multiple solutions are proposed to learn signal trajectory given to the robotic arm and control it for accomplished specified task. Previous research had analyzed and controlled signal trajectory of a 1-DOF robotic arm to minimize error and improve system performance. In this project, the focus is on developing and fabricating upper dual-limb robotic arm which are able to move in parallel motion. The experimental data is obtained through open loop test for the robotic arm model. It is aim to determine the characteristic of robotic arm model. By using system identification method, the determination of system model of robotic arm can be done via experimental data. Proportional, Integral and Derivative (PID) controller is introduced to control the signal trajectory of the robotic arm. After comparing each controller, Proportional and Derivative (PD) controller is found suitable to control robotic arm with proportional gain $K_p = 169$ and derivative gain $K_D = 1.1412$. For controlling the signal trajectory, closed loop control system is developed with designed PD controller as control system. The closed loop test and signal tracking test are performed for the verification of the robustness of the PD controller. It shows that the motion of robotic arm can track and follow the input trajectory with error of 10%. Both robotic arms are expected to move synchronous and accurately with respect to desired input.

ABSTRAK

Robot telah menjadi salah satu alat teknologi yang canggih pada masa kini dan dapat mengganti tenaga manusia dengan tubuh badan mekanikal robot yang tegak dan effisien tanpa mengira suasana operasi robot. Kebiasaanya, reka bentuk robot adalah berdasarkan tujuan dan cara penggunaannya. Oleh itu, terdapat beberapa cara penyelesaian telah dicadangkan untuk mempelajari reka bentuk robot dan isyarat laluan yang diberikan kepada robot untuk menjalankan tugasan yang diberi. Berdasarkan penyelidikan sebelum ini, isyarat laluan sebuah lengan robot yang mempunyai satu darjah kebebasan telah dianalisasi dan dikawal dengan meminimumkan ralatnya dan menambahbaikan prestasi sistem. Dalam projek ini, fokus projek adalah mereka dan menghasilkan kedua-dua lengan robot yang bergerak secara selari antara satu sama lain. Data eksperimen boleh didapati melalui eksperimen gelung buka terhadap model lengan robot. Tujuannya adalah untuk mengenal pasti ciri-ciri model lengan robot. Dengan mengguna sistem identifikasi, rangkap pindah lengan robot dapat diketahui melalui data eksperimen. Selain itu, pengawal PID telah digunakan untuk mengawal isyarat laluan terhadap model lengan robot. Selepas analisis data eksperimen dengan menggunakan pengawal yang berbeza, ia didapati bahawa pengawal PD dengan nilai $K_p = 169$ dan $K_D = 1.1412$. Akhirnya, eksperimen gelung tutup dan ujian system isyarat penjejakan dijalankan untuk memastikan prestasi pengawal PD tersebut terjamin. Daripada ujian tersebut, ia menunjukkan bahawa pergerakan lengan robot dapat menjejak dan mengikut isyarat masukan yang ditetapkan dengan ralat sebanyak 10%. Kedua-dua model lengan robot dijangka bergerak selari dan tepat pada posisi yang ditetapkan.

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Nowadays, technologies have advanced to a stage where robotic field has become part and parcel in educational, medical and industrial sector. Research and development of robotic arm had greatly decreases the dependency of labor workforce and increase of high quality product in industrial sector. With the high precision, repeatability and flexibility of robotic arm, errors occurred like human error and random error are minimized and produce high quality work.

Apart from that, robotic arm also can perform activities under extreme condition such as hazardous or radioactive. This breakthrough had lead to a safer and less hazardous exposure environment to workers. According to Sellafield, a nuclear decommissioning company in England stated that the use of Powered Remote Manipulator Arm (PRM) in decommissioning high hazard plants is a success. They added, the precision of PRM had help in securing the environment by sealing leaked concrete and pipeline before workforce is allowed to continue decommission.

In 11st March 2011, a nuclear disaster happened in Fukushima Nuclear Power Plant when earthquake and tsunami hit Tohoku. It was followed by 3 nuclear meltdowns and released of radioactive materials due to coolant system failure. The event was announced as a Level 7 event classification of the International Nuclear Event Scale. Thus, a nuclear reactor repair plan was carried out to fix Fukushima reactor. In summer 2014, Kurion, California-headquartered nuclear waste management firm had deployed 3 remotely-operated robots to determine leaks and their cause. The Fukushima Inspection Manipulator (FIM) robots scanned the leaks and cracks which will be the information needed for actual repair phase. It is expected that advanced robotic arm, Fukushima Repair Manipulator (FRM) will be deployed to repair Reactor 2 of Fukushima Daiichi Nuclear Power Plant by mid 2016. With the aid from FRM and FIM, field inspection can be done in a more accurate way where workers can control it remotely and risk-reduced working environment.

In conjunction to global population growth in the coming decades, it becomes a demand for increasing the rate of production in agriculture. United Nations' Food and Agriculture Organization (FAO) forecasted that global demand for food is increased by 70% in 2050. Thus, robotics as mechanical labors are chose as a potential way to increase their productivity. For instances, a LettuceBot can identify the condition of lettuce, keeping healthy plants and eliminating unwanted plants to optimize the yield. A robotic strawberry harvester utilizes AGvision, an artificial vision system that can identify and pick the ripest berries based on color and size. These examples are significantly improving and assisting in agricultural world.

In short, the development of robotics had established a more promising future as it helps human being in many different way.

1.2 Problem Statement

Under most of extreme environments in working places which are unfavorable to human body, robots as a substitute of us should be implemented so that work can be done without harmful effect on human body. Besides that, random errors always a concern in working places due to possibilities of triggering a disaster accident. However, controlling a robot requires arranged and well developed programming and multi-functional controller in order to perform variety of tasks accurately and efficiently. The purpose of this project is to design and develop controller for 1-DOF dual-limb robotic arm which can move in parallel motion.

Previous research on the development of an upper limb robotic arm and its controller had been succeeded. The project is continued by developing an upper dual-limb robotic arm and its controller for position control. A dual-limb robotic arm is able to expand its original workspace and ease operation that requires both arms.

A robotic arm model's transfer function plays a key role in developing a closed-loop controller and it is differ from other robotic arm model, depending on the material used, shape, weight, and dimension of model. With time-bounded, system identification method is used to identify the most suitable transfer function for the specific robotic arm model. It is merely a grey box model where a few of unknown parameters can be estimated based on the experimental data from this robotic arm model. After obtaining its transfer function, a closed-loop controller is developed to control the movement of 1-DOF robotic arm. The developed controller should have the characteristic of accurate, fast response time and robust.

In a nutshell, this project is to propose a suitable controller for upper dual-limb robotic arm that can be controlled simultaneously and move in parallel. Furthermore, increasing the load of robotic arm can verify the robustness of the controller.

1.3 Objective

By the end of this project, there are numerous objectives needed to be achieved. The objectives of this project are:

i. To design and fabricate the upper dual-limb robotic arm.
ii. To evaluate the open-loop characteristics of the robotic arm.
iii. To design the controller for parallel motion and position tracking control for robotic arms.

1.4 Scope

The scopes of this project are:

i. Develop a 1-DOF upper dual-limb robotic arm.
ii. The robotic arm is fabricated by using 3D printer.
iii. Micro-Box 2000 is selected as microcontroller of the robotic arm.
iv. Proportional, Integral and Derivative (PID) is chose as controller for dual-limb robotic arm.
v. DC geared motor with encoder SPG30E-300K is used as actuator of robotic arm.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview and project background

A robotic arm, by definition is a mimic of human arms' mechanisms that had been developed in a mechanical structure and linked by programmable joint. Manipulators that are connected with joints have allow motion in either rotational (revolute) or translational (prismatic) with a number of Degree of Freedom (DOF). In such design, robotic arms usually help in conducting activities where environment is hazardous or dangerous to human and activities that required high accuracy and repeatability.

In industrial sector, robotic arms with high reliability are chose as a medium to conduct repetitive and high precision work such as pick and place, welding, painting and assembly of machine's component. Rhino robotic systems are one of the articulated robotic arms that can perform up to 6 DOF as shown in Figure 2.1.

Figure 2.1: Rhino XR-3 robotic arm in Robotic and Automation Lab of UTeM

Despite of performing high accuracy and repeatability activities, robotic arms also can operate under hazardous condition especially material handling process where hazardous substances are by-product in the manufacturing process. Handling chemical or hazardous materials by robotic arms will definitely reducing worker exposure. In short, robotic arms not only help human in performing activities that required high precision and repeatability, it also help human to avoid a direct exposure to hazardous environment.

2.2 Methods of controlling robotic arm

Alavandar and Nigam had proposed ANFIS (Adaptive Neuro-Fuzzy Inference System) as an approach to learn the training data of desired position of robotic arms [1]. In their paper, ANFIS is defined as an implementation of a representative fuzzy inference system using a BP (Back Propagation) neural network-like structure, with limited mathematical representation of the system. Computer simulation shows that the difference in theta deduced and predicted data by ANFIS of 2 and 3 DOF is ranging from 0.1 to 0.15 degree.

Guez and Ahmad had developed a solution (neural solution) to the inverse kinematic problem of a robot [2]. Neural solution provides a good initial guess of iteration, in this case better than Newton Raphson method's fixed value. It was found that the accuracy of neural network solution is depends on the size of network / training time. A good initial guess by neural network results in minimal processing within each control cycle, hence, enable real time robot control. The back error propagation or BP algorithm that simulates a 3 layer perceptron and symmetric sigmoidal nonlinearity was used to solve this problem.

Karlik et al. had developed improved ANN to the solution of inverse kinematics problems for robotic arms [3]. In their paper, ANN was used for the solution of kinematics for a 6 DOF robotic arm. Two different configurations of ANN were used to study the relationship of ANN structures and its accuracy. There are 12 input neurons, 12 hidden neurons and 6 output neurons in first configuration. There are 12 input neurons, 12 neurons in first hidden layer, 12 neurons in second hidden layer and 1 output neuron. Back propagation algorithm was used for learning equations in constructing neural network model. Borland C++ language was used for the ANN architectures and 6000 iterations were used for teaching the ANN. It was found that second configuration of ANN gives better results (lower total error of the output) for this robotic arm.

P.Jha had investigated the novel artificial neural network application for prediction of inverse kinematics of robotic arm [4]. The author had tested 2 modeling methods, multilayer perceptrons (MLP) and polynomial poly-processor neural network (PPN) of ANN in predicting the joint variables by inverse kinematics. Back propagation algorithm was used for training and updating the desired weights. It was found that MLP gives better results than PPN for inverse kinematics problem.

Anh et al. proposed novel adaptive forward neural MIMO NARX (nonlinear auto-regressive exogenous input) model for the identification of industrial 3 DOF robotic arm kinematics [5]. The modeling and identifying the kinematics of a 3 DOF robotic arm system was done by the hybrid of forward kinematics and adaptive neural MIMO NARX (FNMN). Experimental input-output training data was used to model the industrial robotic arm based on the forward adaptive neural NARX model-based identification process. The FMNM model is generated by back propagation algorithm. It was found that proposed FNMN gives outstanding performance and high accuracy.

Jiang et al. had developed a fuzzy hybrid force-position control for robotic arm (pneumatic muscles) [6]. They used fuzzy logic (FL) and PI as controller for a 9 DOF robotic arm and compared their performance towards position and force / torque control. A 49 inference rule table of FL controller is formed while PI controller's constant is set to be $K_p = 0.00285$ and $K_i = 0.00175$ for angular position control; $K_p = 0.00175$ and $K_i = 0.0025$ for torque control. It was found that FL controller is better performance than conventional PI controller where FL had faster response time and small overshoot. In addition, FL controller is more stable when dealing with coupling between 2 pneumatic muscles.

Ketata R. et al had developed an experiment on robotic test-rig with fuzzy logic controllers [7]. They had developed 2 types of controller for the experiment: fuzzy logic controller and conventional PID controller. In their research, they found that there are more advantages and disadvantages of fuzzy logic control over PID control. Fuzzy logic can result a faster rise time of the system, process of mathematical modeling is unnecessary and easier to design and implement. However, there is a risk on an oscillatory response during the steady-state response of the system.

Heidar A. Malki et al had developed an uncertainties and flexible joint robot arm with combination of fuzzy PID control [8]. There are a few advantages of fuzzy PID compare to fuzzy and non-fuzzy PID. Firstly, fuzzy PID control adapts the linear structure yet non-constant gain of PID which has the capability of self-tuned in set-point tracking performance. Besides that, control-rule base and deffuzification are embedded in the fuzzy control law which will ease the process of fuzzification without using look-up tables.

2.2.1 Summary for methods of controlling robotic arm

Control of robotic arm of 2 or more DOF involves calculation of either forward kinematics or inverse kinematics. Kinematic is the science of motion which treats motion (position, velocity, force) without regard to the force causing it [10]. Forward kinematics is the use of kinematic equation of a robot to calculate the position and orientation of an end-effector from specified joint variables such as joint angle and length of linked joint. In contrast, inverse kinematics is the use of kinematics equations of a robot to calculate the joint variables from a desired position and orientation of an end-effector. Figure 2.2 shows the interrelation of forward kinematics and inverse kinematics.

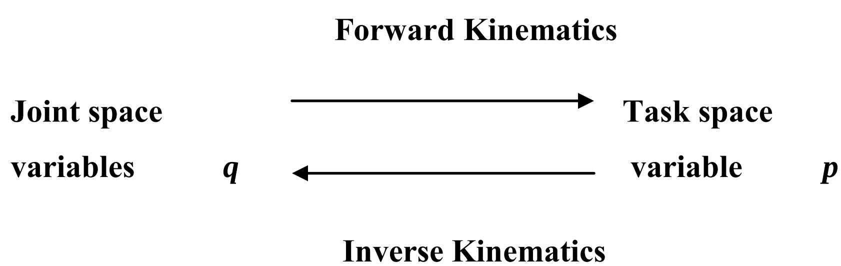
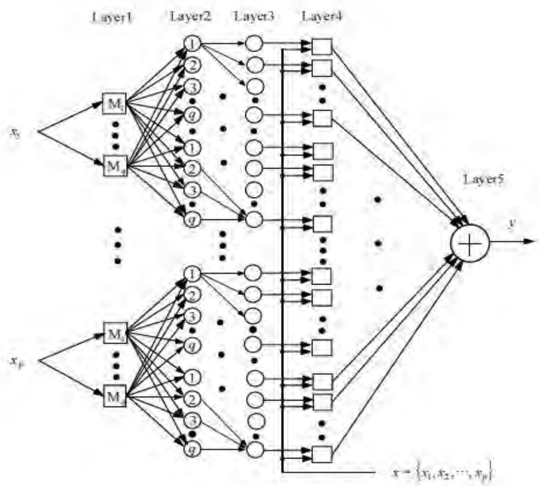
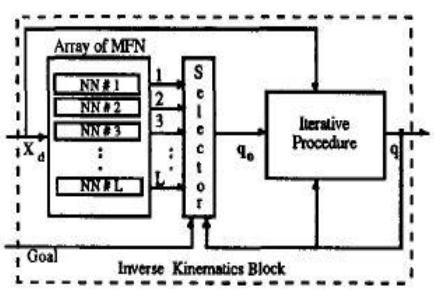
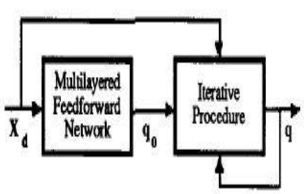


Figure 2.2: Interrelation of Forward and Inverse Kinematics

Each approaches used by previous researchers have pros and cons. Table 2.1 shows the comparison of each method used.

Table 2.1: Comparison of Each Method

Methods	Structure of Methods	Description
ANFIS [1]		• ANFIS is the hybrid of the learning capabilities of neural network and fuzzy inference system. • It is used to model nonlinear function, determine nonlinear components online in a control system, and predict a chaotic time series. • It is suitable for analyzing low DOF robotic arm. Higher DOF results in greater errors occurred.
Neural Solution [2]		• It is the hybrid of neural solution and iterative procedure which provide the final solution with specified tolerance. • It is simple to use and not restricted to any type of robotic arms.