Faculty of Electrical Engineering

REDUCTION OF ENERGY CONSUMPTION IN ARTICULATED ROBOT

Kamarul Syaffiq bin Mohamad Isa

Master of Science in Electrical Engineering

2018

REDUCTION OF ENERGY CONSUMPTION IN ARTICULATED ROBOT

KAMARUL SYAFFIQ BIN MOHAMAD ISA

A thesis submitted
in fulfilment of the requirements for the award of the degree of Master of Science in Electrical Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that this thesis entitled “Reduction of Energy Consumption in Articulated Robot” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	…………………………………………..
Name	:	…………………………………………..
Date	:	…………………………………………..

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electrical Engineering.

Signature	:	…………………………………………..
Supervisor Name	:	…………………………………………..
Date	:	…………………………………………..

DEDICATION

Specially dedicated to my beloved mother, father and sister.

ABSTRACT

Optimization is a process of finding an alternative with the highest achievable performance or the most cost effective under the given constraints, by minimizing undesired ones and maximizing desired factors. In this research, a study for optimal energy consumption in KUKA KR 16 articulated robot for pick-and-place task was done. In order to achieve the optimal energy consumption, an improve trajectory planning is required. Essentially, trajectory planning encompasses path planning in addition to planning how to move based on velocity, time, and kinematics. Trajectory planning gives a path from a starting configuration to a goal configuration by avoiding collisions in a 2D or 3D space. A configuration is the pose of a robot describing its position. Thus, the objective of this thesis is to study and analyze the PTP motion and Linear motion in order to determine which is the best motion that can improve the trajectory planning. This thesis proposed different method to achieve optimal energy consumption that is minimizing the movement for the first three main axes. The first three main axes are chosen because there are three big motors used to drive the axes. Unlike other optimization method, this method is much simpler in terms of development process and did not require any additional hardware to be install to the robot's system. This will eventually be a cost effective optimization method. The scope of this research is to focus on the experiment process for pick-and-place task only. Two robots will be use in this research. KUKA KR 5 sixx R650 is use to study and analyze PTP and Linear motion while KUKA KR 16 is use to study the optimal energy consumption. The energy performance is measures with respect to two categories of movements known as Default and Optimal movement which do the same task repetitively within specific time. The result for PTP and Linear motion shows that PTP motion consumed 6% more energy than Linear motion but completed 773 cycles within one hour whereas Linear motion only completed 492 cycles.Energy performance between Default and Optimal movement shows that Optimal movement recorded 21.8% less energy usage when compared to Default movement although the total cycles completed for both movement almost the same.

ABSTRAK

Pengoptimuman adalah proses untuk mencari pilihan yang mencapai prestasi paling tinggi atau kos yang paling berkesan berdasarkan kekangan yang diberi, dengan meminimumkan factor yang tidak diingini dan memaksimumkan factor dikehendaki. Dalam kajian ini, satu pembelajaran untuk penggunaan tenaga yang optimum untuk KUKA KR 16 robot bersendi bagi tugas angkat-dan-letak telah dilakukan. Dalam usaha untuk mencapai penggunaan tenaga yang optimum, penambahbaikkan perancangan trajektori diperlukan. Pada dasarnya, perancangan trajektori merangkumi perancangan laluan di samping merancang bagaimana untuk bergerak berdasarkan halaju, masa, dan kinematic. Perancangan trajektori memberikan laluan dari konfigurasi mula ke konfigurasi matlamat dengan mengelak perlanggaran dalam ruang 2D atau 3D. Tetapan adalah keadaan robot menggambarkan kedudukannya. Oleh itu, objektif tesis ini adalah untuk mengkaji dan menganalisis gerakan PTP dan gerakan linear untuk menentukan gerakan manakah adalah yang terbaik yang boleh menambah baik perancangan trajektori. Tesis ini mencadangkan kaedah yang berbeza untuk mencapai penggunaan tenaga yang optimum dengan meminimumkan pergerakan tiga paksi utama yang pertama. Ketiga-tiga paksi utama yang pertama dipilih kerana terdapat tiga motor besar yang digunakan untuk memacu paksi. Berbeza dengan kaedah pengoptimuman yang lain, kaedah ini adalah lebih mudah dari segi proses pembangunan dan tidak memerlukan apa-apa perkakasan tambahan yang perlu dipasang kepada sistem robot. Hal ini pada akhirnya akan menjadi satu kaedah pengoptimuman dengan kos paling berkesan. Skop kajian ini memberi tumpuan kepada proses ujikaji terhadap tugas angkat-dan-letak sahaja. Dua robot akan digunakan dalam kajian ini. KUKA KR 5 Sixx R650 digunakan untuk mengkaji dan menganalisis gerakan PTP dan gerakan linear manakala KUKA KR 16 digunakan untuk mengkaji penggunaan tenaga yang optimum. Prestasi tenaga diukur berdasarkan dua kategori pergerakan dikenali sebagai Rujukan dan Tetap yang melakukan tugas yang sama secara berulang-ulang dalam tempoh masa tertentu. Hasil keputusan bagi gerakan PTP dan gerakan Linear menunjukkan bahawa gerakan PTP menggunakan 6% lebih tenaga daripada gerakan linear tetapi melengkapkan 773 kitaran dalam masa satu jam manakala gerakan linear hanya melengkapkan 492 kitaran. Prestasi tenaga antara pergerakan Rujukan dan pergerakan Tetap menunjukkan bahawa pergerakan Tetap mencatatkan 21.8% kurang penggunaan tenaga berbanding pergerakan Rujukan walaupun jumlah kitaran untuk kedua-dua pergerakan hampir sama.

ACKNOWLEDGEMENTS

First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor Engr. Prof. Dr. Marizan bin Sulaiman from the Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for his essential supervision, support and encouragement towards the completion of this thesis.

I would also like to express my greatest gratitude to Mr. Hairol Nizam bin Mohd Shah and Mohamed Azmi bin Said from Faculty of Electrical Engineering, co-supervisor of this research for their advices and suggestions. Particularly, I would also like to express my deepest gratitude to UTeM research grant MTUN/2012/UTeM-FKE/3 M00011 for the financial support throughout this project.

Special thanks to my beloved mother, father and sister for their moral support in completing this degree. Also I would like to thank all of my colleagues especially Lab Ceria members for their support and time, their discussions of news and gossips always manage to lighten my stress and cheer me up. Lastly, thank you to everyone who had been associated to the crucial parts of realization of this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

GDP	-	Gross Domestic Product
GUI	-	Graphical User Interface
DOF	-	Degree of Freedom
D-H	-	Denavit-Hartenberg
PTP	-	Point-to-point
kWh	-	Kilowatt hour
Wh	-	Watt hour
W	-	Watt
A	-	Ampere
s	-	Seconds
J	-	Joule
Nm	-	Newton meter
CPU	-	Central Processing Unit
FL	-	Fuzzy Logic
GA	-	Genetic Algorithm
3D	-	Three dimension
CCD	-	Charge-coupled Device

LIST OF PUBLICATIONS

Sulaiman, Marizan and Syaffiq, M.I.K., Shah, H.N.M. and Fakhzan, M.N., 2013.**Simulation and Experimental Work of Kinematic Problems for KUKA KR5 Sixx R650 Articulated Robot**. *International Journal of Energy and Power Engineering Research (IJEPER),* vol. 1. pp. 6-9. ISSN: 2289-5620.

Sulaiman,Marizan and Syaffiq, M.I.K., Shah, H.N.M. and Fakhzan, M.N., 2014. **Measurement of Energy Consumption for KUKA KR5 Sixx R650.**In: *Proceedings the 2nd Power and Energy Conversion Symposium (PECS 2014), UTeM, Melaka, Malaysia,* 12 May 2014. ISBN: 978-967-0257-37-2.

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter will explain the background, motivation of research, problem statement, objectives of research, scope of research, contribution of research and organization of this thesis.

1.2 Background

A robot is a mechanical or virtual artificial agent. It is usually a system, which, by its appearance or movements, conveys a sense that it has intent or agency of its own. The word *robot* can refer to both physical robots and virtual software models. However, the virtual software models are usually referred to as *bots* to differentiate them. There are no definite definitions of robots but the most widely accepted industry standard is defined by the Robotics Institute of America (RIA). According to Robotics Industries Association, a robot is a reprogrammable, multifunctional machine designed to manipulate materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety task.

There are four (4) classes of robot classification system defined by the Association Francaise de Robotique (AFR) whereas the Japanese Robot Association (JARA) classifies robots into six (6) classes. On the other hand, the Robotics Institution of America (RIA) does not consider two classes from Japanese Robot Association (JARA) lists to be robots. Table 1.1 shows the details of robot classification according to these organizations.

Table 1.1: Robot Classification by Specific Organization

Organization	Robot Classification
Association Francaise de Robotique (AFR)	**Type A:** Manually controlled handling devices. **Type B:** Automatic handling devices with predetermined cycles. **Type C:** Servo controlled robots with programmable trajectories. **Type D:** Same as type C but able to respond to their environment.
Japanese Robot Association (JARA)	**Class 1:** Manual handling devices which actuated by an operator. **Class 2:** Fixed sequence robot. **Class 3:** Variable sequence robot with easily modified sequence of control. **Class 4:** Playback robot which can record a sequence of actions for later playback. **Class 5:** Numerical control robots with a movement program which it receives in the form of numerical data. **Class 6:** Intelligent robot that can understand its environment and able to complete the task despite changes in the operation conditions.

Robotics Institution of America (RIA)	**Class 1:** Variable sequence robot. **Class 2:** Playback robot. **Class 3:** Numerical control robot. **Class 4:** Intelligent robot.

Although there is still discussion about which machines qualify as robots, a typical robot will have several but not necessarily all of the following characteristics. A robot is not naturally exist which mean it is artificially created and programmable. A robot able to sense its environment and manipulate or interact with it. It also has some ability to make choices based on the environment and often using automatic control or a preprogrammed sequence. Basically a robot moves with one or more axes of rotation or translation and capable to make dexterous coordinated movements. The last characteristic is that a robot appears to have purpose or effect when it was invented.

The word *robot* was first popularised by Czech's writer, Karel Capek. The word is derived from the Czech's word, *robota* which translates as work with an implication of forced labor. The term *robotics* refers to the study and use of robots was first used by the Rusian-born American scientist and writer, Isaac Asimov. The first industrial modern robots were the Unimates developed by George Devol and Joe Engelberger in the late 50's and early 60's. The first patents were created by Devol for parts transfer machines. Engelberger formed Unimation and was the first to market robots. As a result, Engelberger has been called the 'Father of Robotics'.

1.2.1 Robot Joints and Degree of Freedom (DOF)

There are different types of joints available in robots such as linear, sliding, rotary or spherical. In general, spherical joints possess multiple degree of freedom and this make them difficult to control. Thus, most robots have either a linear (prismatic) joint or a rotary (revolute) joint. Prismatic joints are either hydraulic or pneumatics cylinders or they are linear electric actuators. Most of rotary joints are electrically driven, either by stepper motor or servomotors.

The number of Degree of Freedom (DOF) that a manipulator possesses is the number of independent position variables that would have to be specified in order to locate all parts of the mechanism. In other words, it refers to the number of different ways in which a robot arm can move. In the case of typical industrial robots, a manipulator is usually an open kinematic chain and because each joint position is usually defined with a single variable, the number of joints equals the number of degree of freedom.

1.2.2 Types of Robot Arm

Robots arm are usually characterized by the design of the mechanical system. Generally there are five recognizable robot arm configurations; Cartesian Coordinate Robots, Cylindrical Coordinate Robots, Spherical Coordinate Robots, Articulated Robot (Jointed-Arm) and SCARA Robots. The degrees of freedom are the axes around which it is free to move and the area a robot arm can reach is its working envelope. The following are brief explanations for five robot configurations and the examples of five types of robot arm are shown in Figure 1.2.

Cartesian Coordinate Robots

Cartesian coordinate robots are highly configurable, rectilinear robot systems which in a basic configuration include an X and Y axis. Three axis Cartesian coordinate robots, incorporating an X, Y and Z axis are also common for positioning tools such as dispensers, cutters, drivers and routers. Each of the axis lengths is selectable with the ability to attach different types of Z-heads.

Payloads and speeds vary based on axis length and support structures. Cartesian coordinate robots are also typically very repeatable, have better inherent accuracy than a SCARA or joined arm, and perform 3D path-dependent motions with relative ease. However, the Cartesian coordinate robots key feature is it configurability.

Cylindrical Coordinate Robots

A cylindrical coordinate robot has two linear axes and one rotary axis. The robot derives its name from the operating envelope. The Z axis is located inside the base, resulting in a compact end-of-arm design that allows the robot to “reach” into tight work envelopes without sacrificing speed or repeatability.

Spherical Coordinate Robots

A spherical robot has one linear axis and two rotary axes. Spherical robots are used in a variety of industrial task such as welding and material handling.

Articulated Robot (Jointed-Arm)

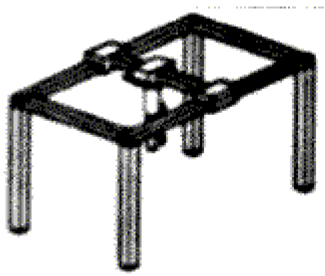
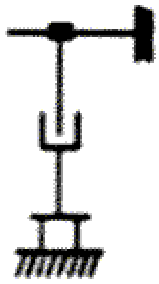
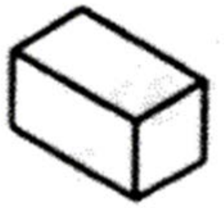
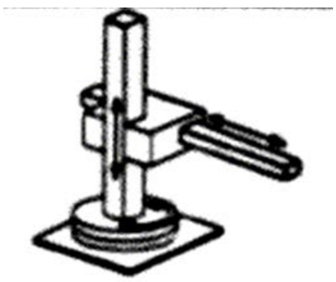
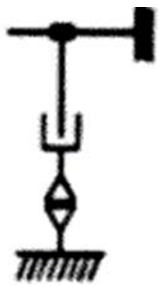
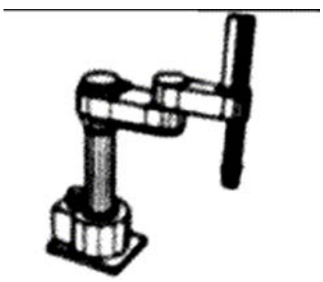
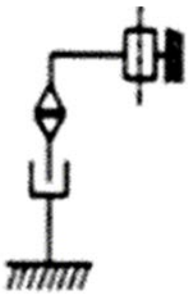
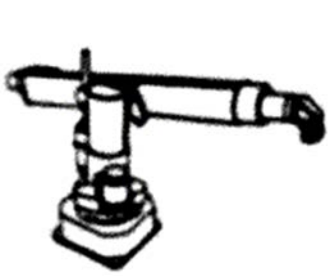
An Articulated robot, also known as Jointed Arm robot has three rotational axes connecting three rigid links and a base. An articulated robot is frequently called an anthropomorphic arm because it closely resembles a human arm. The first joint above the base is referred to as the shoulder. The shoulder joint is connected to the upper arm which is connected at the elbow joint. Articulated robots are suitable for a wide variety of industrial tasks, ranging from welding to assembly.

SCARA Robots

One style of robot that has recently become quite popular is a combination of the articulated arm and cylindrical robot. This robot has more than three axes and is called a SCARA robot. It is used widely in electronic assembly. The rotary axes are mounted vertically rather than horizontally. This configuration minimizes the robot's deflection when it carries an object while moving at a programmed speed.

The acronym SCARA stands for *Selective Compliance Assembly Robot Arm*, a particular design developed in the late 1970's in the laboratory of Professor Hiroshi Makino of Yamanashi University, located in Kofu, Japan. The basic configuration of a SCARA is a four degree-of-freedom robot with horizontal positioning accomplished by a combined Theta 1 and Theta 2 motion, much like a shoulder and elbow held perfectly parallel to the ground.

SCARA robot known for its cycle times, excellent repeatability, good payload capacity and a large workspace. SCARA robot also feature sophisticated motion control with full programmability. With its torso-based, one arm design, the SCARA integrates easily into most applications.

Principle	Kinematic Structure	Workspace
 Cartesian Robot		
 Cylindrical Robot		
 SCARA Robot		
 Spherical Robot