UNIVERSITI TEKNIKAL MALAYSIA MELAKA

INVESTIGATING THE REPEATABILITY PERFORMANCE OF PARALLEL ROBOT

Thesis submitted in accordance with the partial requirements of the Universiti Teknikal Malaysia Melaka for Bachelor of Manufacturing Engineering (Robotic and Automation)

By

Nurdzila Binti Jaini

Faculty of Manufacturing Engineering

May 2007

APPROVAL

This thesis submitted to the senate of UTeM and has been accepted as fulfillment of the requirement for the degree of Bachelor of Manufacturing Engineering (Robotic and Automation). The members of the supervisory committee are as follows:

……………………………………..

(MR. Khairol Anuar Bin Rakiman)

Main supervisor

Faculty of Manufacturing Engineering

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Pensyarah
Fakulti Kejuruteraan Pembuatan
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ABSTRAK

Projek ini menerangkan berkenaan dengan pertunjukan pengulangan oleh robot selari kerana mempunyai kebolehan untuk bergerak dalam halaju yang tinggi. Berdasarkan kepada kenyataan itu, tujuan projek ini adalah untuk menganalisa pertunjukan pengulangan oleh robot selari dalam kebolehan yang ada. Terdapat dua alat yang direka khas untuk menganalisa kebolehan robot selari ini iaitu pemegang pen dan meja boleh laras yang setiap satu digunakan bersama sepanjang projek ini. Melalui projek ini, kaedah yang digunakan untuk mendapatkan keputusan termasuklah percubaan, pengaturcaraan, and menganalisis data. Tatacara untuk menganalisis bukanlah bergantung kepada buku manual tetapi ianya di buat sebelum percubaan ini dijalankan. Daripada keputusan yang diterima, beberapa jenis bentuk dilukis di atas kertas graf untuk dianalisis. Daripada graf maka analisis dapat dilakukan berkaitan dengan pengkajian robot selari dalam aspek pertunjukan pengulangan dan ketepatan untuk bergerak. Daripada keputusan yang diperolehi juga, robot selari ini dapat di nilai.

ABSTRACT

This project presents the repeatability performance of a parallel robot because the capability in movement and its ability to move in high speed. Regarding that, the project purpose is to analyze the repeatability performance of parallel robot in their tasking capability. There are two special devices that have been designed to perform the task analysis which are pen gripper and adjustable table and each device are function together during the testing. Through the project, the methods that are used to get the result include testing, programming, and analysis data. The procedure of the task analysis are not supported by the robot's manual book but it is been made and created during and before the task begin. From the result achieved, various types of graph can be performed and many analyses can able to be made. From there an assumption can be made regarding the repeatability and accuracy of the robot. Regarding to the result that obtained also, the repeatability of the parallel robot can be evaluated.

DEDICATION

For My parents, supervisor and friends.

ACKNOWLEDGEMENTS

In the name of Allah, the most Compassionate, the most Merciful. Alhamdulillahirabbil'alamin....

With His permission and His help, I can finish my final graduation project "The Investigating the Repeatability Performance of Parallel Robot". I would like to thank to my beloved family especially my parents, Mr. Jaini bin Bibet and Mrs. Kartini binti Taarol for their support and advice. For my supervisor Mr. Khairol bin Rakiman, truly without his guidance I would have been lost. Also thank to Mr. Nizamul for his support and help during doing this project. My warm regards to Mr Faizal who gave me a lot of assistance in managing this project. Also, many thanks to all my lecturers for their support and high spirit in helping to finish my project.

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LIST OF ABBREVIATIONS, SYMBOLS, SPECIALIZED NOMENCLATURE

$\varnothing$	-	Diameter
θ	-	Angle
P	-	Platform Coordinate
O	-	Base Frame
R	-	Rotation Matrix
C	-	Spherical Joint Center
L	-	Length
κ	-	Parameter
r	-	Radius
$\Delta\theta$	-	Joint Angle
ΔX	-	Positioning Error
A_{tra}	-	Translational Accuracy
A_{rot}	-	Rotational Accuracy
S	-	Standard Deviation

CHAPTER 1

INTRODUCTION

1.1 Project Background

Parallel robot is a closed loop mechanism in which the mobile plateform is connected to the base. This robot has 4 *dof* (degree of freedom) that are adapted to pick and place tasks which is 3 translations to carry an object from one point to another and 1 rotation about a given axis in world coordinates for the orientation. Indeed, the parallel robot is well capable of performing many different task and operations precisely. Besides that, this is due that actuators are fixed on the base and also have close kinematic chains design. ***R****UPUR* kinematic chain that is located at center leg is used to transmit the rotational motion from a revolute actuator fixed on the frame to the effector may become a weak point. ***R*** stands for actuated joint, *U* for universal, *P* for prismatic, and *R* for revolute. (Krut, S *et al*, 2003)

Parallel robot is capable of performing many different task and operation precisely. This type of parallel robot composed of four different part. These parts are the moving plateform, the following rods, the actuated arms, and the base. This part can be separated to the small part which is revolute actuator, forearm, spatial Parallelogram, and traveling part. The traveling part can be separated to linear guideway, pulley, and also cable. All of these types have different kinematic characteristic and dynamic behaviour. The moving plateform is articulated and does not require the kinematic chain transmitting the rotational motion to the effector. It is composed of two different parts (while the machine in utilizes a three part moving plateform) linked together by a prismatic guide, plus a pulley cable system which transforms the relative translation of both parts into the desired rotation.

In this project, pick and place are the characteristic of this robot. The performance of the repeatability is the main point to make a research. Thus, the performance of the repeatability is analyzed by the experiment setup for several paths such as linear path, circular path, rectangular path, and so on. After that, the parallel robot's performance can be evaluated by using graph and looking their accuracy and repeatability either there is poor accuracy and repeatability, poor accuracy but good repeatability, good accuracy but poor repeatability or good accuracy and repeatability.

However, in this research of the robot parallel there are to comprehensively realize the performance of the parallel robot, the forward kinematics, inverse kinematics, and Jacobian. The singularity is theoretically derived for the application of quantified and graphical performance synthesis tools.

1.2 Problem Statement

Parallel robot is a fully parallel robot, 3 axes 4 *dof* with three translational degrees of freedom and one rotational degree of freedom. By using parallel robot, objects need to be moved quickly and precisely, one at a time, from one location to another because is equipped with an integrated vacuum system capable of rapid pick and release of objects. The movement to pick and place and also the performance of repeatability is measured according to the capability to pick and place load. The movement is very fast for short cycle times and it also can develop for optimized short pick and place cycles.

Because of that, experiment setup is very important in this project to detect the different point of the repeatability performance. The repeatability is measured by analyzing the plotted graph for different speed and different path looking to the performance of pick and place. From that, plotted graph is analyzed because to see the accuracy and repeatability of the movement. After the theoretical aspects of the method, simulations are presented and compared to the experiment result.

1.3 Objectives

There are two objectives that should be achieved in this project. The objectives are as following:

(a) To analyze the repeatability performance of the parallel robot for their capabilities.
(b) To familiarize with the equipments setting and configurations.

1.4 Scope

The scopes for this project are as below:

(a) Machine familiarization.
(b) Do experimental work.
(c) Do comparative study in the collected data.

CHAPTER 2

LITERATURE REVIEW

2.1 Robot Theory

Robots can be found in the manufacturing industry, the military, space exploration, transportation, and medical applications. Typical industrial robots do jobs that are difficult, dangerous or dull. They lift heavy objects, paint, handle chemicals, and perform assembly work. They perform the same job hour after hour, day after day with precision. They do not get tired and they do not make errors associated with fatigue and so are ideally suited to performing repetitive tasks. There are several categories of industrial robots by mechanical structure such as Cartesian robots, Cylindrical robots, Spherical robots, SCARA robots, articulated robots, and Parallel robots. These robots have their own particular especially in the effectiveness.

For the Parallel robots there is one of the robots that use is a mobile platform handling cockpit flight simulators. It's a robot whose arms have concurrent prismatic or rotary joints as shown in figure 2.1.

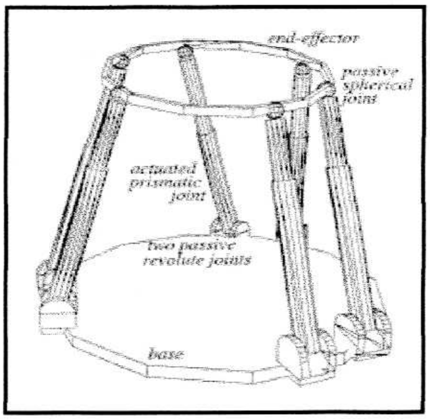


Figure 2.1: Parallel Robot

In this century, there are several robots in industrial that perform the operation related to the industry. Thus, robots have their own kinematic structure according to the robot principle and also perform the workspace as shown in figure 2.2.

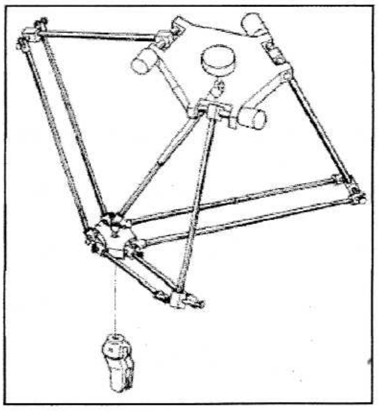


Figure 2.2: Kinematic Structure

Krut, S *et al*, 2003 ***R**UPUR* kinematic chain that is located at center leg is used to transmit the rotational motion from a revolute actuator fixed on the frame to the effector may become a weak point. ***R*** stands for actuated joint, *U* for universal, *P* for prismatic, and *R* for revolute. Even more recently, a machine with a moving platform including passive prismatic joints and a "Translation-to-Rotation" transformation system shows specific design which is four linear motors in the same plane and aligned on the same direction and a three-part moving platform. Therefore, the workspace is spherical volume as shown in figure 2.3.

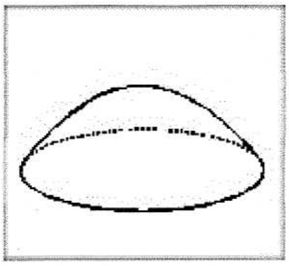


Figure 2.3: The workspace of a parallel robot

2.1.1 Planar Robot

One way to increase the number of joints of a robot without increasing its weight is to introduce passive joints. If robots with passive joints can couple with each other to form a parallel robot, it may be able to have the same number of actuators as its degrees of freedom (DOFs). Then it can be used for tasks of exerting a force. If they can couple differently, they can constitute a reconfigurable parallel robot. (Mori,0 and Omata,T (2002)).

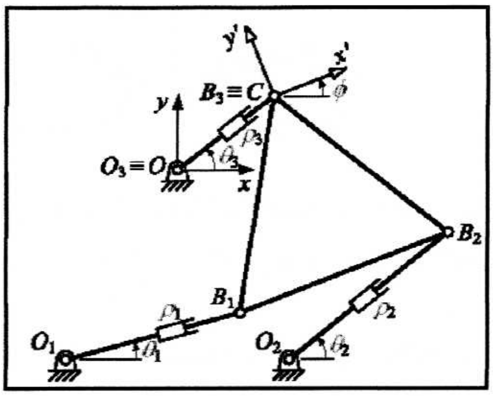


Figure 2.4: 3-RPR planar parallel robot with congruent equilateral base and platform

Regarding to Damien Chablat *et al*, it show the special 3-RPR planar parallel robot. Figure 2.4 represent its mobile platform and base form congruent equilateral triangles. From that figure it denotes with O_i and B_i (i = 1, 2, 3) the centers of the base and platform revolute joints, respectively. Then, let *Oxy* and *Cx'y'* be the base and mobile reference frames, respectively. The generalized coordinates locating the mobile platform, i.e., the mobile frame *Cx'y'*, in the base frame *Oxy* will be denoted by x, y, and $Ø$. There define each active-joint variable $Ø_i$ as the angle between the x-axis and a unit vector $\boldsymbol{v}_i$ that defines the direction of the prismatic joint of leg i, measured in counter-clockwise sense. Finally, the directed distance from point O_i to point B_i along vector $\boldsymbol{v}_i$ is denoted by $Ø_i$.

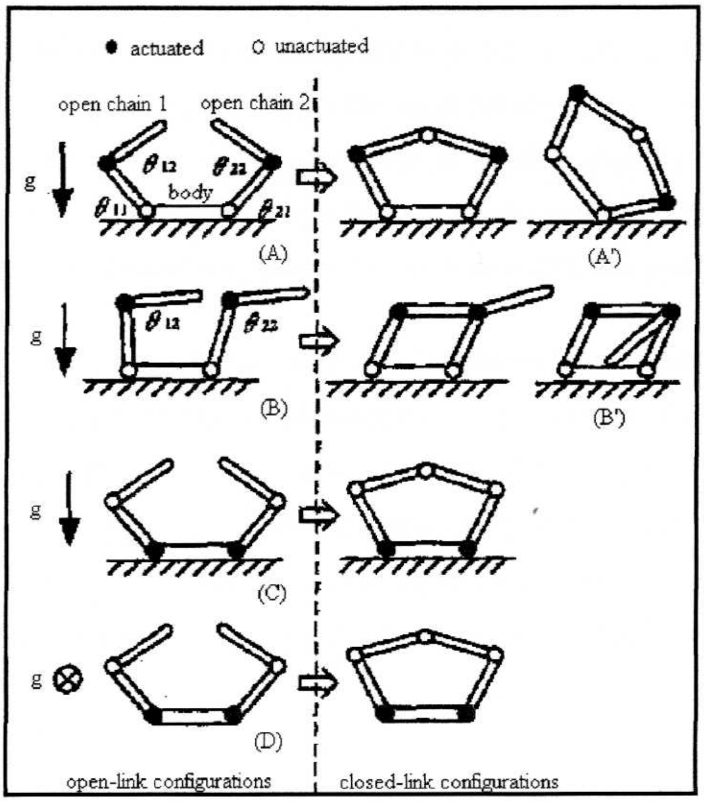
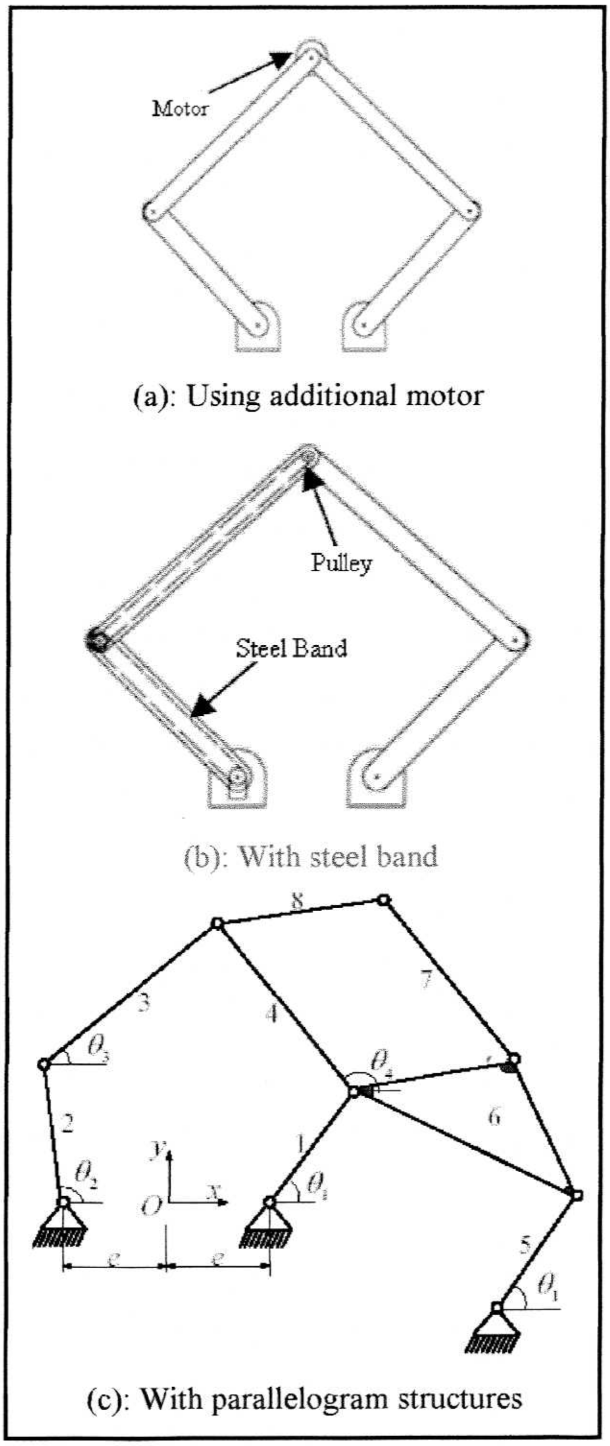


Figure 2.5: 2R open kinematic chains with a passive joint forming parallel robots

Figure 2.5 that show examples of reconfigurations to parallel robots from two 2R open kinematic chains with a passive joint. The left and right 2R open kinematic chains are referred to as open chains 1 and 2, respectively. For simplicity we assume that they are identical. In (A), the second joints θ_{12} and θ_{22} are actuated, and the first ones θ_{11}, θ_{21} are passive. Open chains 1 and 2 reconfigure to a 5R closed kinematic chain by coupling their end-points which constitute a passive joint. This 5R closed kinematic chain can be used as a two *dof* parallel manipulator. Another possibility is that it can move by rolling as shown in (A') if its base is not k e d on the floor. (B) shows a 4R closed kinematic chain formed from the same two 2R open kinematic chains. Only one actuator for joint θ_{12} is enough to control the 4R closed kinematic chain since it has one *dof.* The actuator for joint θ_{22} does not belong to the 4R closed kinematic chain but it drives the second link of open chain 2, which is added to the 4R closed kinematic chain. Thus (B) can be regarded as a 2 *dof* parallel manipulator different from (A). It can also form a rigid truss structure as shown in (B'). It is useful when it supports a heavy object. (C) shows a 5R closed kinematic chain formed from a different type of two 2R open kinematic chains. Their second joints are passive. (D) shows the same 5R closed kinematic chain but on a horizontal plane. The motion of a robot with a passive joint(s) is quite different depending on which joint is passive and whether or not gravity is a factor. We need to devise a coupling sequence and mechanism for *each* case. (Mori,0 and Omata,T, 2002)

A linkage mechanism for a pick and place robot includes two rotatable drive members mounted on a base and connected to a platform by a respective two element linkage. The mid point of the two element linkage has a bell crank, the arms of which are connected to first and second location links anchored respectively at the base and platform. The platform may be configured to carry various implements, and the mechanism permits movement thereof in two dimensions by selective motion of the drive members. (Huang, T *et al* 2006)

The main structure of the robot is a revolute-jointed five bars linkage and driven by two rotational motors. The position of the end effectors is incorporated determined by two rotary joints' position. Three possible kinematic have symmetrical rotary drives are possible to achieve translational moving capability in the motion plane as shown in figure 2.6 (a).



(a): Using additional motor

(b): With steel band

(c): With parallelogram structures

Figure 2.6: Two possible kinematic candidate

From the figure 2.6 (a) shows that the most direct way is using another actuator to control the orientation of end effector, which controls the orientation of the end effector.

The motor at the end point become the payload of linkage in the scheme so links must be more to provide enough stiffness. Another way is to guarantee the orientation of end effector by steel band as shown in figure 2.6 (b). One pulley is fixed on the base and another are mounted on the passive joint, and fixed on the effector, the steel band keeps the end effector always parallel to a fixed line on the base. Besides, the pulleys and steel belt make joints' design over strong.

The calibration of a novel planar parallel robot with parallelogram structures shows that is more effectiveness. Figure 2.6(c) show the combination of five bars linkage with two parallelogram linkages. The movable plateform 8 together with two adjacent links 4 and 7 and the triangle part 6 involve a parallelogram linked by four revolute joints. These two parallelogram structures keep the movable patform always parallel to a fixed on the base of the actuators. The advantage of multi closed loop structure is that the stiffness of robot is increased and the error from every branch chains on the end effector is decreased too. (Ding, Q, 2000)

2.1.2 Component of Parallel Robot

Parallel robots have the fast movement with high speed along trajectories about 200 mm long. Its fully parallel structure complies with this kind of applications. A simplified view is show in figure 2.7.

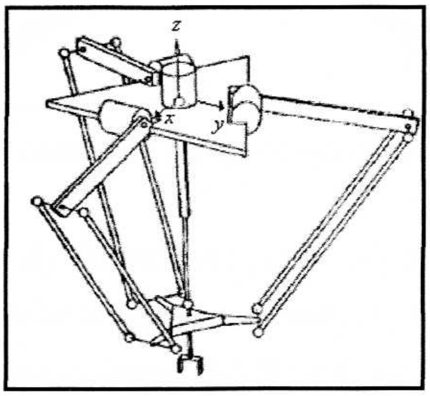


Figure 2.7: The robot Delta 4