UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ACCURACY AND REPEATABILITY ANALYSIS OF INDUSTRIAL ROBOT UNDER LOADED CONDITIONS AND VARIOUS DISTANCES

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Robotics and Automation) (Hons.)

by

MUHAMMAD AMMAR LUQMAN B. MOHD SALIM
B051310058
921223-01-5899

FACULTY OF MANUFACTURING ENGINEERING
2016

DECLARATION

I hereby declare that this report entitled **"ACCURACY AND REPEATABILITY ANALYSIS OF INDUSTRIAL ROBOT UNDER LOADED CONDITION AND VARIOUS DISTANCE"** is the result of my own research except as cited in the references.

Signature :

Authors's Name : **MUHAMMAD AMMAR LUQMAN B. MOHD SALIM**

Date : 23th June 2016

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering (Robotics and Automation) with Honours. The members of the supervisory committee are as follow:

Dr. Syamimi Binti Shamsuddin

(Supervisor)

ABSTRACT

This project analyses the performance of a six axis COMAU Smart NS industrial robot in terms of its accuracy and repeatability using dial gauge indicator. The dial gauge was choosen because it is the one economic way calibration method compared to laser interferometer and it is easy to set-up. This project also investigates how repeatability and accuracy of the industrial robot are affected by two variables which are varying load and distances. This project started by conducting literature research about the industrial robot and dial gauge indicator using online resources, books, manuals, journals and articles.. This project had obtained successful results to meet the objectives. The dial gauge indicator was able to give measurement values of the accuracy and repeatability with 360 number of experiment for each distance. The repeatability result is $\pm$ 0.004 mm and it is proved that the COMAU robot still has good repeatability and accuracy when compared to manufacturer specification. Furthermore, only accuracy against load factor that shows the relationship between each other with the model of equation. The results for this calibration may not accurate as using laser interferometer but this study are able to promote the use of dial gauge indicator as a simpler method to determine robot's performance for robotic laboratory exercises.

ABSTRAK

Projek ini menganalisis prestasi enam paksi Comau Smart NS robot industri dari segi ketepatan dan kebolehulangan menggunakan penunjuk tolok dail. Tolok dail telah dipilih secara rawak kerana ia adalah kaedah penentukuran sehala ekonomi berbanding laser interferometer dan ia adalah mudah untuk setup. Projek ini juga menyiasat bagaimana kebolehulangan dan ketepatan robot perindustrian dipengaruhi oleh dua pembolehubah yang berbeza-beza beban dan jarak. Projek ini bermula dengan menjalankan penyelidikan sastera mengenai robot perindustrian dan dail penunjuk tolok menggunakan talian sumber, buku, manual, jurnal dan artikel .. Projek ini telah mendapat keputusan yang berjaya untuk memenuhi objektif. Penunjuk tolok dail dapat memberi nilai pengukuran ketepatan dan ulangan nombor 360 eksperimen bagi setiap jarak. Hasil kebolehulangan adalah ± 0.004 mm dan ia membuktikan robot Comau masih mempunyai kebolehulangan yang baik dan ketepatan jika dibandingkan dengan spesifikasi pengilang. Tambahan pula, hanya ketepatan terhadap faktor muatan yang menunjukkan hubungan antara satu sama lain dengan model persamaan. Keputusan bagi penentukuran ini mungkin tidak tepat kerana menggunakan laser interferometer tetapi kajian ini dapat menggalakkan penggunaan penunjuk tolok dail sebagai kaedah yang lebih mudah untuk menentukan prestasi robot untuk latihan makmal robotik.

ACKNOWLEDGEMENTS

I would like to praise to ALLAH swt with His love and merciful I able to finish my Final Year Project (Projek Sarjana Muda). Besides that, I would like to give my thanks and gratitude to my supervisor Dr. Syamimi Binti Shamsuddin for her support and idea in helping me to complete the project successfully. My thanks and grateful also goes to Universiti Teknikal Malaysia Melaka (UTeM) which is place I completed my project and study. And also to other lectures who help me in completing the project.

Not to forget to my beloved family that supports me from start of my life until now. Without divided support makes me able to stand sturdily. Also, to my friends and peers who are good companions at times in need.

TABLE OF CONTENT

Abstract	i
Abstrak	ii
Acknowledgement	iii
Table of Content	iv
List of Table	viii
List of Figures	ix
CHAPTER 1: INTRODUCTION	
1.1 Introduction	1
1.2 Background	1
1.3 Problem Statement	3
1.4 Objectives	4
1.5 Scope and limitation	4
1.6 Summary	5
CHAPTER 2: LITERATURE REVIEW	
2.1 Introduction	6
2.2 Robotics Technology	6
2.3 Industrial Robot	10
2.3.1 Joints and Link	12
2.3.2 Robot Configurations	13
2.4 Calibrations Issues	15
2.4.1 Accuracy	15
2.4.2 Repeatability	17
2.5 ISO 9283	19
2.6 Calibration Method	20
2.6.1 Laser Tracker	20
2.6.2 Dial Gauge Indicator	23
2.7 Comparison Table of Past Studies	26

2.8 Summary 31

CHAPTER 3: METHODOLOGY

3.1 Introduction 32

3.2 Research Process 32

3.3 Project Tools 35

3.4 COMAU SMART NS Robot 36

3.5 Dial Gauge Indicator (0.01 mm) 38

3.6 Experimental Setup 40

3.6.1 COMAU Setup 41

3.6.2 COMAU's Programming 42

3.6.3 Dial Gauge Indicator Setup 45

3.6.4 Loads Setup 46

3.7 Experiment 48

3.8 Result 49

3.9 Summary 49

CHAPTER 4: EXPERIMENTAL SETUP

4.1 Introduction 50

4.2 Linear Accuracy 50

4.3 Linear Repeatability 52

4.4 Linear Accuracy against Load 52

4.5 Linear Accuracy against Distance 56

4.6 Linear Repeatability against Load 57

4.7 Linear Repeatability against Distance 59

4.8 Summary 63

CHAPTER 5: CONCLUSION

5.1 Conclusion 65

5.2 Recommendation 66

5.3 Sustainability 67

REFERENCES 68

APPENDICES
A Average from 360 set of data calculated value of accuracy and repeatability
B Correlation & Regression Analysis between Accuracy against Load
C Correlation & Regression Analysis between Accuracy against Distance
D Correlation & Regression Analysis between Repeatability against Load
E Correlation & Regression Analysis between Repeatability against Distance

LIST OF TABLES

2.1	Description of Asimov's Laws with the Alternative Laws of Robotic	7
2.2	Types of Robot Configuration	13
2.3	Review of Past Study	26
3.1	List of Project Tools	35
3.2	COMAU SMART NS Hand Characteristic and Performance	37
3.3	Sets of Experiment	41
4.1	Summary data of accuracy for linear motion	51
4.2	Summary data of repeatability for linear motion	52
4.3	Correlation & Linear Regression Analysis for Linear Accuracy against Load Factor	54
4.4	Correlation analysis linear accuracy against distance factor	56
4.5	Correlation Analysis & Linear Regression for Linear Repeatability against Load Factor	57
4.6	Correlation Analysis & Linear Regression for Linear Repeatability against Distance Factor	60
4.7	Summary of result experiment	63
4.8	Relationship between robot specification against load and distance	63
4.9	Table comparison between dial gauge indicator and laser interferometer	63

LIST OF FIGURES

1.1	UNIMATE Robot	2
2.1	Part of the Robots	8
2.2	Example of Six-Axis Articulated Welding Robot Reaching Into A Fixture To Weld	11
2.3	Joint-Link Method for Robot Manipulator	12
2.4	Types of Accuracy and Repeatability	15
2.5	Accuracy in Normal Distribution	17
2.6	Example of Representation of Resolution, Accuracy, and Repeatability of a Robot Arm	18
2.7	Types of Laser Tracker System	21
2.8	0.01mm Dial Faces Indicator	23
2.9	0.001mm Dial Faces Indicator	24
2.10	Dial Test Indicator	25
2.11	Example of Calibration of Robot Performance	25
3.1	Methodology Flow Chart	33
3.2	SMART NS	36
3.3	Dial Gauge Indicator with Magnetic Base	38
3.4	Illustrations of Using Dial Gauge in Experiment.	39
3.5	The Position of the Dial Gauge during Experiment	39
3.6	Experiment Flow	40
3.7	Illustrative Linear Movement of Robot	42
3.8	The Program in the Teach Pendant	43
3.9	COMAU Robot Programming for Distance of 500 mm	43
3.10	Program for Distance of 750 mm	44
3.11	Program for Distance of 1000 mm	45
3.12	Dial Gauge Indicator Alignment	46
3.13	The Load Position	47
3.14	Loads of 30 N and 50 N on the Robot.	47
3.15	The Step of the Robot Movement	48
4.1	Graphs of Linear Accuracy Error against Load	53

4.2	Graphs of Linear Accuracy Error against Distance	56
4.3	Graphs of Linear Repeatability Error against Load	57
4.4	Graphs of Linear Repeatability Error against Distance	60
5.1	The Example of Multidirectional Movement	66

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter describes the introduction of the research problem, objectives of the research, scope of the research and structure of dissertation.

1.2 Background

Robotics is a branch of mechanical engineering, electrical engineering, electronic engineering and computer science that deals with the design, construction, operation, and application of robots, as well as computer systems for their control, sensory feedback, and information processing.

In early 1954, the first industrial programmable robot which called UNIMATE was designed by George Devol, who coins the term Universal Automation. Thus, he shortens the name to Unimation which becomes the name of the first robot company in 1962. Figure 1.1 shows the UNIMATE robot which is originally used to automate the manufacturing of TV picture tubes [1].

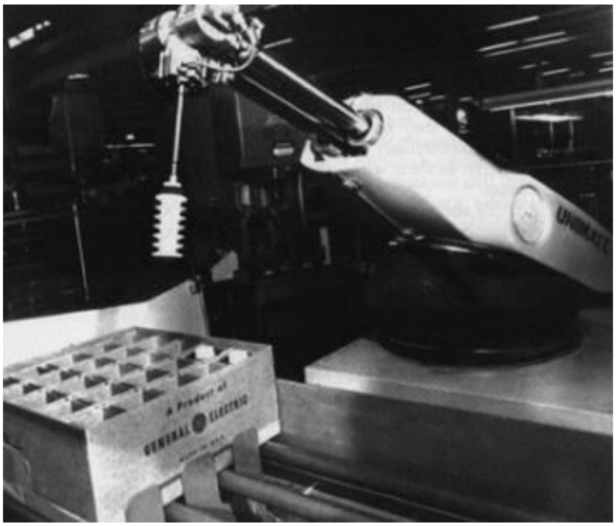

Figure 1.1: UNIMATE Robot [1]

Robot is a powerful element that is used to replace human work efficiently. There are several types of robot in these eras which are manipulator, legged robot, mobile robot, and etc. Generally, the purposes of robot are:

a) Able to repeat task for 24/7.
b) Does not have time break during operations.
c) Able to do dangerous task for humans.
d) Able to operate with higher precision than human.
e) The cost may be cheaper for the long term.
f) May be able to perform tasks that are impossible for humans

There are four types of robot configurations and it function industries which are Cartesian robot, cylindrical robot, spherical robot, jointed arm robot, and SCARA robot [2]. These types of robot have mechanical joint which are moved in different ways such as linear and rotational movement. The robot consists of joint which represent movement of the robot.

Generally, a robot consists of four main parts which are manipulator, pedestal, end effectors and power source. The manipulator of robot is the mimics of the human arm which consist of base and appendages such as shoulder, arm, and grippers. The pedestal can be representing as human wrist that used to supports the manipulator. It is also act as a counterbalance to the robot. In addition, the controller can be defined as the brain of the robot to give an instruction. It is also used to controls peripheral devices. The end effector can be defining as a human hand which consists of roll, pitch and yaw. Usually, the end effector of the robot can be changed based on the robot applications such as grippers, welding attachments and etc. Lastly, the power source is the source that used to move the robot. Basically, there are three types of power source of the robot which are electric, pneumatic and hydraulic. Hydraulic is used for heavyweight application, while pneumatic is source from the compressed air and it is suitable for lightweight application of the robot [2].

1.3 Problem Statement

An industrial robot is made to perform application in industries were done by human. However, the performance of the robot will decrease due to longer time usage. There are several factors that can affect the robot performance such as environment, human error, payload and distance.

Based on the ISO 9283 standard, the payload and distance are determined as the biggest factor affecting the robot performance. Usually, the biggest problem occur in robotics performance is positional error. It’s mean that the robot accuracy and repeatability is not follow the manufacturer specifications. To improve the robot performance, the positional error must be reduced.

The positional errors are occurred due to the factor of payload and distance. The payload may affect the robot movement when there vary load over from the manufacturer specifications. In addition, the distance may also give effect to the robot performance when the robots reach to outside of working envelope.

The calibration by robot itself has also gives inaccurate result. It’s mean that the calibration result of the robot is not same with the manufacturer specification. The external calibration is needed in order to determine the actual robot performance. Laser tracking system for calibration, is in high cost instrument but high precision. The new alternative which is more economical is needed in order to fulfil the requirement of calibration. The result of calibration will be compared with previous method using laser tracker system.

1.4 Objectives

The objectives of this research are:

a) To investigate the accuracy and repeatability of COMAU Smart NS industrial robot against load using dial gauge indicator method
b) To investigate the accuracy and repeatability of COMAU Smart NS industrial robot against distance using dial gauge indicator method
c) To compare the results on repeatability and accuracy from using dial gauge indicator with laser tracking system

1.5 Scope and Limitations

In this study, the COMAU SMART NS robot has choose which is located in Robotics Laboratory, Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka (UTeM). The parameter which is payload and distance will be used to determine the accuracy and repeatability of the robot. The payload must not exceed 16kg and the distance must within 1650 mm because it is the limitation of the robot. Within that range, the robot performance will be assumed well and gives the best result. The calibration will be done using dial gauge indicator. This is an economic way to fulfil the requirement of calibration. The repeatability of COMAU SMART NS robot is ± 0.05 mm and the dial gauge with 0.01 mm accuracy will be used to calibrate the robot. This study wants to approve that the dial gauge is also able to calibrate robot accuracy and repeatability. However, the result is might be not accurate as using laser tracker system because the dial gauge is only can measure until 0.01mm and the laser tracker can measure until 0.0001mm. This prove that the dial gauge also can be used as calibration method to measure performance COMAU SMART NS robot because the dial gauge accuracy is still under the manufacturing specification but not too accurate as a laser tracker system.

1.6 Summary

To conclude this chapter, the background is discussed about the robot technology. Furthermore, the problem statement has stated clearly to overcome the objectives in this study. In addition, the scope and limitation is identified by knowing the boundary of this study which is focusing on calibration of industrial robot.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides a review of the findings and methodology from previous related studies in the areas of performance of industrial robots.

2.2 Robotics Technology

Robots nowadays are powerful elements in the manufacturing industries. They are capable to perform several of task and operation accurately and do not require common safety and comfort elements humans need. Unfortunately, in order to make a robot function properly it requires many resources and much effort. Most companies of the mid-1980s that made robots are gone, with a few exceptions, only companies that make real industrial robots have remained in the market such as FANUC, ABB, PUMA Robot.

In robotics technology, there have law's that is used to applied for all types of robots. Asimov's law has been created on 1947 with based on functional morality, which assumes that robots have sufficient agency and cognition to make moral decisions. In order to address difficulties of applying Asimov's three laws to the current generation of robots while respecting the laws' general intent, the three laws of responsible robotics is suggested to fulfil law's goal [3]. Both of laws are listed in Table 2.1 below.

Table 2.1: Description of Asimov's Laws with the Alternative Laws of Robotic.

Asimov's laws	Alternative laws
1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.	A human may not organized a robot without the human–robot work system meeting the highest legal and professional standards of safety and ethics.
2. A robot must obey orders given to it by human beings, except where such orders would conflict with the first law	A robot must respond to humans as suitable for their roles.
3. A robot must protect its own existence as long as such protection does not conflict with the first or second law.	A robot must be able with sufficient situated autonomy to protect its own existence as long as such protection provides smooth transfer of control to other agents consistent the first and second laws.

Robots are very useful because it can replace the human work with efficient and unstoppable. Like human, robots can do certain things, but not others. As long as designed properly for the intended purposes, the robots are very useful and continue to be used. The robots can differently describe as crane which has robot and manipulator. The difference between this two is that the crane and the manipulator are controlled by human who operates and controls the actuators, whereas the robot manipulator is controlled by a computer that runs the program [4]. The differences between the two determine whether a device is a simple manipulator or a robot.

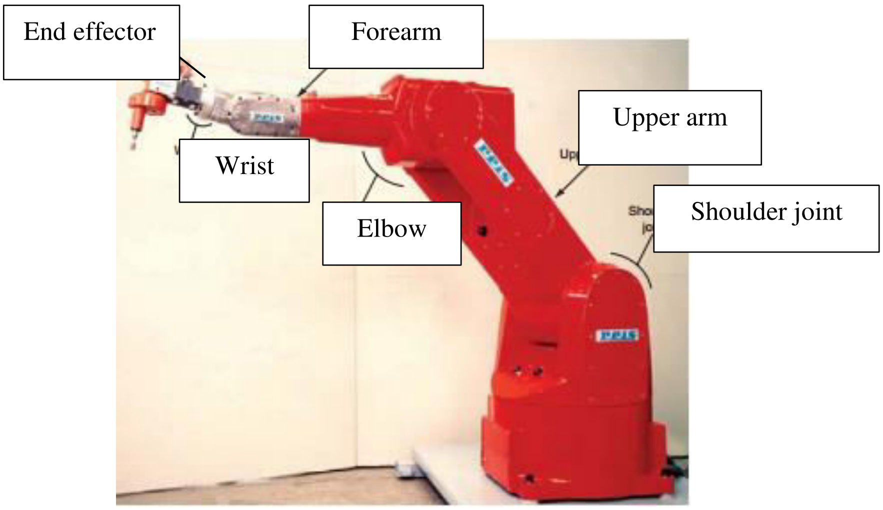

Figure 2.1: Part of the Robots [5]

The manipulator is main body of the robot and consists of the joints, links, and other structural elements of the robot. Generally, joints of manipulator can be divided into two which is revolute (rotary) and prismatic (linear). As a mechanical configuration is neglected, the manipulator defined as joint-link structure that includes three main elements as a human part which is the arm, wrist, and the end effector that shown in Figure 2.1 above [5]. From the figure above, the three main elements are same like human arms which have three joint clusters: the shoulder, the elbow and the wrist. The shoulder has 3 degrees of freedom since the upper arm or humerus can rotate in the sagittal plane, which is parallel to the mid-plane of the body, the coronal body which is a plane from shoulder to shoulder, and about the humerus. The elbow has 1 degree of freedom which it can only flex and extend about the elbow joint. The wrist also has 3 degree of freedom. It can abduct and adduct, flex and extend, and it can rotate longitudinally. [5]

Another part is end effector is a special tooling of robot that enables to perform a specific task. This part is never considered as one degree of freedom because all robots have this additional capability, which may appear to be similar to a degree of freedom. However, none movement of end effector are counted toward the robot's degrees of freedom [6]. Generally, there are two types of end effector which is grippers and tools. The gripper is used to grasp or manipulate parts such as pick and place operation for material handling. Another part which is tools is used to perform process such as spot welding and spray painting [7].

In general, robots are designed to be controlled by a computer or similar devices. The motion of the robot is controlled through a controller under the supervision of the computer which is running some type of program. Therefore, it can be reprogrammed immediately to change the action of the robot. All robots have their own advantages and disadvantages while performing task that has been programmed by the human through the controller. From that, the advantages and disadvantages of using robots are listed below [6]:

a) Robotics and automation can increase productivity, safety, efficiency, quality, and consistency of products.
b) Robots can work in hazardous environments such as radiation, darkness, hot and cold, space and etc.
c) Robots works continuously without tiring or fatigue or boredom.
d) Robots can be much more accurate than humans.
e) Robots can process multiple stimuli or tasks simultaneously.

On the other hand, disadvantages of using robot are as follows:

Robots lack capability to respond in emergencies if the situation response is not including to the system. Safety measures are required to ensure that all things around the robots are safe [8]. This includes:

a) Inappropriate or wrong responses
b) Lack of decision-making power
c) Loss of power
d) Damage to the robot and other devices
e) Injuries to human

2.3 Industrial Robot

An industrial robot is a general-purpose, programmable machine possessing certain anthropomorphic characteristics. The most obvious anthropomorphic characteristic of an industrial robot it its mechanical arm, which is used to perform various industrial tasks. Other human-like characteristics are the robot's capabilities to respond to sensory inputs, communicate with other machines, and make decisions. These capabilities allow robots to perform a variety of useful tasks. The development of robotics technology followed the development of numerical control which stated in the history of robotics.

The first inventors who made original contributions to the technology of industrial robotics was Cyril W.Kenward. A British inventor who devised a manipulator that moved on an x-y-z axis system. In 1954, Kenward applied for a British patent for his robotics device, and in 1957 the patent was issued.

The second inventor was an American which is George C. Devol. He is credited with two inventions related to robotics. The first was a device for magnetically recording electrical signals so that the signals can be played back to control operation of machinery. This device was invented around 1946, and U.S century patent was issued in 1952. The second invention was a robotic device developed in 1950s, which Devol called "Programmed Article Transfer". This device was intended for parts handling. The U.S patent was finally issued in 1961. It was a prototype for the hydraulically driven robots that were later built by Unimation, Inc [9] [10].

Both of the technologies involve coordinated control of multiple axes which are called joints in robotics terms. They both also use dedicated digital computers as controllers. Whereas NC machines are designed to perform specific processes such as machining, thermal cutting and sheet metal hole punching. Robots are designed for a wider variety of tasks. Typical production application of industrial robots include spot welding, material transfer, machine loading spray painting, and assembly.

Figure 2.2: Example of Six-Axis Articulated Welding Robot Reaching into a Fixture to Weld [11]

Industrial robots are commercially and technologically important because:

a) Robots are able to perform work in hazardous or uncomfortable work environments rather than human.
b) A robot performs their work cycle with a consistency and repeatability that cannot be achieved by humans.
c) Robots can be reprogrammed easily which means it the robot can stop immediately during operation and reprogrammed with another task to complete the operation.
d) Robots are controlled by computers and can therefore be connected to other computer system to achieve computer integrated manufacturing.

2.3.1 Joints and Link

The manipulator of an industrial robot consists of a series of joints and links. Different joints and links comprise the study of robot anatomy, as well as other aspects of the manipulator's physical construction. A robotic joint provides relative motion between two links of the robot. Each joint, or axis, provides a certain degree-of-freedom (dof) of motion. In most cases only one degree-off freedom is associated with each joint, so a robot's complexity can be classified according to the total number of degrees-of-freedom they possess [12].

Each joint is connected to two links which is an input link and an output link with the joint providing controlled relative movement between the input link and output link. A robotic link is the rigid component of the robot manipulator. Most robots are mounted on a stationary base, such as the floor. From this basis a joint-link numbering scheme may be recognised shown in Figure 2.3.

Figure 2.3: Joint-Link Method for Robot Manipulator [12]

The robotic base and its connection to the first joint has determine as link 0. Thus, the first joint in the sequence is joint 1 whereby the link 0 is the input link for the joint 1 and link 1 as an output links. Its same goes to the next output link which is