SMART ROBOTIC ARM IN MEDICINE ALLOCATION APPLICATION

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SMART ROBOTIC ARM IN MEDICINE ALLOCATION APPLICATION

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DECLARATION

I declare that this thesis entitled “SMART ROBOTIC ARM IN MEDICINE ALLOCATION APPLICATION” 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.

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Date :

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APPROVAL

I hereby declare that I have checked this report entitled "SMART ROBOTIC ARM IN MEDICINE ALLOCATION APPLICATION" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

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DEDICATIONS

To my beloved mother and father

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ABSTRACT

Medications are the most typical treatment intervention that used in healthcare to improve the health and well-being of patients. However, medication errors contain potential risk in affecting patient safety as well as treatment costs which then cause hazards for patients and their family. Hence, this project has proposed a Smart Robotic Arm in Medication Allocation Application in that to assits healthcare profession by reducing their tasks on medication dispensing. This project is developed by using TeraSoft 6 Degree of Freedom (DOF) Intelligent Technology Robot Arm System with code label based object recognition model. The inverse kinematic model is designed in Simulink Environment to control the position of Smart Robotic Arm for medication allocation. While, the code label based object recognition model is designed with Raspberry Pi Camera Module V2 and OpenCV ran in Raspberry Pi Model 2B for reading information of desired medication. The performance of the Smart Robotic Arm system is tested. The results have showed that the designed inverse kinematic model is capable in providing accurate solution after comparing with kinematic model that built in Peter Corke Robotics Toolbox. However, the designed robot controller has showed the limitation in optimizing the performance since the Smart Robotic Arm have experienced the steady-state error as well as vibration issue during positioning. Hence, the poor performance of robot controller has lead to the erroneous of Smart Robotic Arm in reaching the desired position in actual environment. Besides, the physical defecting in Smart Robotic Arm has also directed to the erroneous in reaching the desired position as well. Other than that, the code label based object recognition is built successfully and it has reached 100% accurate in detection and recognition of clear and blurred Quick Response (QR) code in 5cm between camera sensor and QR code image.

ABSTRAK

Ubat-ubatan adalah intervensi rawatan yang paling biasa yang digunakan dalam penjagaan kesihatan untuk memperbaiki kesihatan dan kesejahteraan pesakit. Walau bagaimanapun, kesilapan ubat mengandungi risiko untuk menjejaskan keselamatan pesakit serta kos rawatan yang menyebabkan kesusahan bagi pesakit dan keluarganya. Oleh itu, projek ini telah mencadangkan Lengan Robotik Pintar dalam Aplikas Pengambilan Ubat untuk membantu profesion penjagaan kesihatan dengan mengurangkan tugas mereka mengenai pengambilan ubat. Projek ini dibangunkan dengan menggunakan Sistem Lengan Robot Teknologi TeraSoft 6 Darjah Kebebasan (DOF) dengan model pengiktirafan objek berdasarkan label kod. Model kinematik songsang direka di Simulink untuk mengawal Sistem Lengan Robot dalam pengambilan ubat. Walaupun, model pengiktirafan objek berdasarkan label kod direka dengan Raspberry Pi Kamera Module V2 dan OpenCV beroperasi dalam Raspberry Pi Model 2B untuk membaca maklumat ubat yang dikehendaki. Prestasi sistem Lengan Robotik Pintar telah diuji. Hasilnya menunjukkan bahawa model kinematic inverse yang direka mampu memberikan penyelesaian yang tepat selepas membandingkan dengan model kinematik yang dibina di Peter Corke Peralatan Robotik. Walau bagaimanapun, sistem pengawal robotik yang direka menunjukkan kelemahan dalam mengoptimumkan prestasi kerana Lengan Robotik Pintar telah mengalami "*steady state error*" serta isu getaran semasa pergerakan. Justeru, kelemahan pretasi dalam sistem pengawal robotik telah menyebabkan Sistem Lengan Robot tidak dapat mencapai koordinat yang dikehendaki dalam persekitaran sebenar. Selain itu, kecacatan fizikal di Sistem Lengan Robot juga telah menyebabkan Sistem Lengan Robot tidak dapat dalam mencapai koordinat yang diinginkan juga. Selain itu, pengiktirafan objek berasaskan label kod dibina dan ia telah mencapai 100% tepat dalam pengesanan dan pengiktirafan kod "*Quick Response (QR)*" sama ada label kod yang jelas atau kabur dalam 5cm antara sensor kamera dan imej kod "*QR*".

TABLE OF CONTENTS

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

اونيورسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF TABLES

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF FIGURES

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF SYMBOLS AND ABBREVIATIONS

DOF	-	Degree of Freedom
QR Code	-	Quick Response Code
N/A	-	Not Available

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LIST OF APPENDICES

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 1

INTRODUCTION

1.1 Background

Medications are drugs that used in treatment to improve the health or treat disease. However, medication errors, a failure in treatment process will has potential risks to harm patient. Heavy duty of healthcare profession had increased their burden and hence it will make them unable to be distracted which may lead to medication errors to be occurred. In order to deal with this situation, a robotics system is needed to assist healthcare profession in that allowing them to pay attention to more important tasks.

1.2 Motivation

Medications are the most typical treatment intervention used in healthcare to improve the health and well-being of patients [1]. However, medication errors contain potential risk in affecting patient safety as well as treatment costs which then cause hazards for patients and their family. The National Coordinating Council for Medical Reporting and Prevention has defined medication error as any preventable event that may lead to inappropriate medication use or patient harm while the medication is in the control of the healthcare professional, patient or consumer [2]. In 2016 [3], a Johns Hopkins study has claimed that medical errors are the third leading cause of deaths in U.S which kills more than 250,000 people per year. Based on Patient Safety Unit of Health Ministry in 2014 to 2015 [4], they have received report of 3,526 medication errors and 248.307 near misses.

Typically, medication process has 5 stages which include prescribing, transcribing, dispensing, administering and monitoring [5]. Based on the studies in [6, 7], prescribing, the appropriate medication selection stage was the most common medication error which account more than 40% of medication errors. The studies also claimed that distraction is one of the main reasons for medication errors as about 75%

of medication errors have attributed to this reason. This is due to the healthcare profession have many duties in hospital or pharmacy and hence they are needed to complete the duties quickly in order to maintain hospital productivity. In the study of [8], percentage of errors was greater when only 1 pharmacist on duty compare to 2 pharmacists on duty which is 68% versus 29%. Hence, it is clearly showed that lack of adequate healthcare profession or pharmacist is one of the major reasons lead to medication errors.

However, robots nowadays are increasingly interacted and integrated into various working tasks to assists or replace humans due to their productivity, expert reliability and repeatability [9]. Besides, robot is capable to work around the clock without affecting the standard of quality and to perform rising range of 3D (dirty, dangerous and dull) tasks [10]. Moreover, the development of the artificial intelligence (AI) and machine learning in recent are believed will opening a door for robotic field to next revolution. As reasons, they have dealt with computer vision in that providing robots capability to see and identify the objects. So, this research has proposed a smart robotic arm with object recognition feature in medicine allocation application in that allowing the healthcare profession able to focus on more important tasks.

1.3 Problem Statement

Trajectory planning is a vital issue that needed to be considering in robotic application and automation[11, 12]. As reason that, an ineffective trajectory planning will directly influence the accuracy of controlling robot arm in complete the tasks. Based on the studies, kinematics and dynamics are constraints that commonly to be considered during trajectory planning. However, only kinematics which deal with position control of manipulator arm will be focused on this research due to increasing of computational efforts when involve dynamics.

Object recognition knows as a computer vision technique that identifying objects in digital videos or images. Deep learning and machine learning algorithms are the familiar approaches in object recognition. Regard to previous research, a lot of object recognition techniques able to identify and classify the objects with high accurate results based on the neural network training, feature extraction or colour detection. However, the erroneous in recognition still can be occurred especially between two look-alike objects [13]. With text recognition, the look-alike objects can be differentiated based on their item's details on imprinted text. However, the accuracy of text recognition is easily affected by front type, character-character spacing, noise in image and tilting [14]. Hence, an object recognition technique that able to differentiate the look alike sound like (LASA) medication is needed in this research so that to prevent medication errors espiacially in dispensing stages.

1.4 Objectives

This project embarks on achieving the following objectives upon its completion:

i) To develop a kinematic model for positioning control of a smart robotic arm in medication allocation application.

ii) To develop smart robotic arm with an object recognition feature for identifying medicine.

iii) To validate the smart robotics arm performance in term of kinematics positioning as well as recognize medicine.

1.5 Scope

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

In accomplishing the intended objectives stated above, the scope below must be considered:

i) The smart robotic arm is developed by using TeraSoft 6 DOF Intelligent Technology Robot Arm System with Raspberry Pi 8MP Camera Module V2.

ii) The kinematic model for positioning control of smart robotic arm is focused in this research and hence only geometry issues such position and orientation will be considered. Besides, this model is built by using Matlab Simulink software in personal computer and used in controlling smart robotic arm through Micro-Box 2000/2000C, a controller.

iii) The object recognition with code label is focused in this research and it is developed by using OpenCv in Raspberry Pi 2 Model B, a microprocessor.

iv) The smart robotic arm is working at a lighting condition.

v) There only one code label is presented in camera each time.

1.6 Thesis Outline

This research project is documented and structured as follows. Chapter 2 discuss the literature reviews based on previous researches and findings. Chapter 3 provides methodology used in this project in that to achieve the objectives mentioned above. The analysis and discussion on results of this project are included in Chapter 4. Lastly, the conclusion of entire research as well as recommendation for future work are presented in Chapter 5. All the references and appendices related to this research are attached at the end of the thesis.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discuss the theoretical background that relate to the project. Besides that, the researches review on journals and conference papers according to research scope also has included in this chapter. Then, a short summary is provided at the end of this chapter to conclude the research gap as well as the finding on literature reviews.

2.2 Robotic Arm

Robotic arm is also known as robot manipulator which commonly programmable with human-like arm function[15]. The rigid members of robotic arm are named as links and they are connected by the moveable components called joints in that allowing either rotational or translational motion between adjacent links. Thus, it is seen that a kinematics chain is created from the links of robotic arm. At the end of the kinematics chain of robotic arm, an end effector, a device or an actuator that designed to accomplish desired task such welding, spinning and grasping is attached. In generally, robotics arm made of 5 and more joints and hence made it to precisely carry out human works [15, 16]. Besides, the robotic arm can be either autonomous or controller manually as well as fixed or mobile in design. Based on the mechanical structure, the robotic arm can be then classified into 6 main types which include cartesian robot, cylindrical robot, spherical robot, articulated robot, selective compliance articulated robot arm (SCARA robot) and parallel robot.

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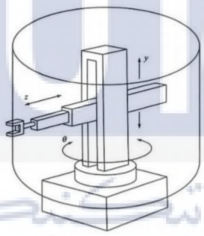
Cartesian robot as shown in Figure 2.1 is also known as linear or gantry robot. It is a robot with 3prismatic joints that coincide with cartesian coordinate axes.

Figure 2.1: Cartesian Robot [17]

Cylindrical robot as shown in Figure 2.2 is a robot which consist of at least one rotary joint at the base and one linear joint for links connection in that allowing it to work within a cylindrical workspace.



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 2.2: Cylinder Robot [17]

Spherical robot as shown in Figure 2.3 is also named as polar robot. It is a robot which generally included one linear joint with two rotary joints in that creating a polar coordinate system and workspace.

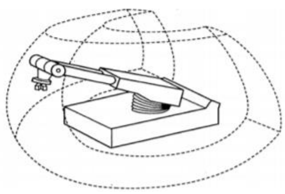


Figure 2.3: Spherical Robot [18]

Articulated robot as shown in Figure 2.4 is a robot that featured two rotary joints or more. In common, the links of arm are joined by rotary joints and arm is attached to the base with a twisting joint.

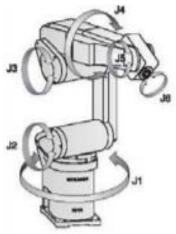


Figure 2.4: Articulated Robot [17]

SCARA robot as shown in Figure 2.5 is a robot that consist of two parallel rotary joints that provide it to move along the plane.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 2.5: Selective Compliance Articulated Robot Arm, SCARA Robot [17]

Parallel robot as shown in Figure 2.6 is also named as delta robot, a spider like robot. It is built by connecting the jointed parallelogram end effectors to a fixed base.

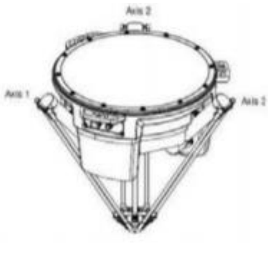


Figure 2.6: Parallel Robot [17]

2.3 Robotic Arm Trajectory Planning

Trajectory planning is one of most vital and fundamental topics in robotics field [12]. Trajectory planning consists in finding a temporal motion law over a specific geometric path based on goal that desired to be achieved by a robot. The kinematic and dynamic constraints are other inputs need to be considered during the trajectory planning. However, the robot dynamics are commonly ignored during the trajectory planning process to reducing computational efforts. While, the trajectory output will be the time function of the robot's moving path.

In general, the trajectory planning consists of two different sections which include joint space trajectory planning and cartesian space trajectory planning based on the elements that being controlled during the robotic motion control. For the joint space trajectory planning, each joint angle is controlled separately so that desired movement of manipulator in term of position and orientation is occurred through forward kinematics. On the other hand, the inverse kinematics provide the solution to cartesian space trajectory planning in determining the alteration of angle of joints based on the position and orientation of manipulator.

In [19], Zhao has studied the polynomial trajectory planning for 6 DOF robotics arm. The cubic polynomial interpolation and quantic polynomial interpolation methods for joint space trajectory planning are being compared in this paper. The motion planning of the manipulator from the starter point to the target point is realized by the cubic polynomial interpolation and the quantic polynomial interpolation method respectively. The angle, velocity, acceleration curve is also obtained in Matlab simulation. After comparing and analysing, the results show that the quantic polynomials method has more obvious effect on the trajectory planning of the 6-DOF robotic arm. The quantic method is proved that can make the robotic arm to run smoothly, reduce the occurrence of jitter and vibration, improve the stability of system, prolong the life of robotic arm.

L. Wu et al has proposed an iterative algorithm by applying the Levenberg-Marquardt (LM) in exacting inverse kinematics solution for a class of 7R 6-DOF robots with non-spherical wrist in [20]. By introducing a virtual wrist centre, an analytical solution is first presented and used as an estimation of exact solution as well as an initial data for further algorithms. From the product of exponentials (POE) formula obtained in analytical solution, the iterative algorithm is derived to solve the inverse kinematics solution with LM method. The performance of proposed algorithms is evaluated by comparing with traditional method using Matlab simulation. From simulation results, the proposed algorithm has showed its advantages in efficiency and accuracy.

In [21], Z.H Wang has proposed an inverse kinematics analysis and solution method toward a hybrid six degree of freedom industrial robot based on projective method of descriptive geometry. To prevent the singular pose, the six axes of the robot body is first divided into two categories. The descriptive geometry projection approach is applied to analysis and solve inverse kinematics of the first three axes. The descriptive geometry projection method has reduced the calculation complexity because of it has reducing the dimension by turning the multiple member space problem into a plane problem. For the latter three axes, the conformal geometric algebra, a strong geometric intuition is adopted to solve their inverse kinematic. Based on the minimum motion range and the minimum motion distance of the joints, the optimal solution is chosen from the multiple sets inverse solution. The proposed inverse kinematic solution is then simulated and validated with Matlab toward a series of six degree of freedom industrial robots. The results have showed the proposed solution is accurate and effective in real time performance.

In [22], Tarun has solved the inverse kinematic of 5 DOF redundant manipular by multiplying each inverse matrix of transformation matrices with general transformation matrix that represents the transformation of end effector relative to reference frame and then equalizing the corresponding elements of the equal matrices of both ends. Then, the inverse kinematic is solved by using algebraic method. The similar appoarch has used by B.T Hai Linh in [23]. However in [23], the transformation matrix desired orientaion of gripping is firstly defined and then used in elements comparison with the transformation matrix from forward kinematic. Then same as [22], the algebraic method is applied to solve inverse kinematic analysis. The designed inverse kinematic model has compared with inverse kinematic in ModelSim and results have showed the inverse kinematic model built is accurate in performance.

From literature did, it is clearly seen that the trajectory planning is able to be done accurately by using various appraoches. However, each approach has its advantages and disadvatages. Due to the simplicity in design process as well as capable to provide accurately solution, the inverse kinematic model that suggested by B.T Hai

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Kinh is chosen as the trajectory planning approach for positioning control of smart robotic arm in this project.

2.4 Robotic Arm with Object Recognition Feature

Recently, robotic arm has extensively applied in many field such as manufacturing, medication, education and so on. This is due to its repeatability, productivity and accuracy in performing the tasks. Hence, robotic arm became popular in a wide range of application to perform welding, assembly, packing, labelling, sorting, product testing and so on. Moreover, the integrating of computer vision with the robotic arm in recent has allowed them to become more intelligent, flexible as well as autonomous. This is because of computer vision capable to provide the robotic arm the ability to view and understand the environment, detect anf recognize objects and then make decision upon what they perceive. In short, computer vision has allowed the robotic arm to become more human-like as well as capable to perform mutliple tasks.

In [24], R.Szabo and L.Lie have succefully implemented colored object sorting robotic arm using blod filter with reference colours in computer palette in recognition colour of objects. However, the authors in [25] have extended the colour recognition by adding size detection in their model and then used in developing a lemon sorting system based on colour and size. By comparing the HSI colour values and estimated volume of captured image with the threshold volume and colour in database that built initially, the system has worked well in colour and size recognition. In [16], Md.Hazrat Ali et al have included the shape and size recognition in object sorting application using Matlab and Visual Basic. The size and shape is identified by calculating the area ratio or extent of object's bounding box that constructed during image-processing stage. The experimental results have showed that the system design is well functioning.

In [26], the convolutional neural network (CNN) with noise-aware training is used on RGBD images recognition and the results have showed this approach is effective and improve recognition accuracy on RGB-D images. While, the CNN with the deep-feature extraction is developed in recognition and classifying different type of objects in [27]. In [28], the authors have implemented a fast RCNN approach with the region proposal genaration and the VGG-16 model in object recognition and pose estimation. Based on the results, the proposed RCNN approach is capable to recognize

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objects as well as estimate its pose accurately even in a complex background. Hence, it is clearly seen that neural network approach able to recognize object accurately in most of cases. However, a complexity produce is involved when designing a neural network since it required a lot of training data so that achieve high accurate performance.

In [29], H.Tan et al has implemented a surgical tool sorting application using barcode reading as well as template matching in finding and sorting surgical tools from a cluttered scene. From [29], it is clearly showed that the look-alike surgical tools is able to be differentiated by identifiying the barcode label attached on it. While, N.Giannoccaro has proposed the Radio Frequency Identification (RFID) marker in recognizing and sorting objects in [30]. From the results in [30], the proposed RFID reader has achieved a high speed in recognition the object which is about 0.5 seconds.

From the literature reviews did, the code label based object recognition model is chosen to be implemented in this project. Since it has the feature in differentiating the look-alike objects with accuarate results and hence it is trusted that able to be applied to recognize the medicine which commonly look-alike in size, shape and colour.

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2.5 Type of Code Label

Barcode is a coding technology of Automatic Identification and Data Collection (AIDC) that used to represent the real time data [31]. Barcode has known as zebra technology as it is collection of vertical or graphical bar patterns colored in blanks and white spacing. It is generally used in grocery stores since 70’ and then in variety organization due to the rate and errorless in reading information. In general, barcode can be classified into two types which include linear barcode and two-dimensional (2D) barcode as shown in Figure 2.7. Linear barcode is composed of black vertical lines with white space while 2D barcode is composed of either stacked linear bars or matrix symbol shaped in black and white. 2D barcode able to keep larger amount of information than linear barcode, which regularly contain numerical data and limited data only.

Figure 2.7: Linear Barcode (Left) and 2-Dimensional Barcode (Right) [31]

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QR code as shown in Figure 2.8 is one kind of 2D matrix code that first created in 1994 for the automotive industry in Japan and. QR code is used to hold and provide additional information[31, 32]. It can hold a large amount of data and can be used anywhere. In addition, QR code has additional features such as speedy response, comprehensive reading and the portable offline application database. Moreover, it has increased efficiency of the character representation of other 2D barcode by 20%.

Figure 2.8: Quick Response (QR) Code [31]

The features comparison between the barcode and quick response (QR) code have showed in below.

Table 2.1: The Features Comparison between the Barcode and Quick Response (QR) Code [31, 33]

Barcode Type / Feature	Barcode	Quick Response (QR) Code
Accuracy and Effectiveness	Give accurate data	Give accurate data with fast response
Capacity	Low capacity - up to 10-20 digits	High capacity up to 7089 numeric digits
Language Supported	Support numeric & alphanumeric information only	Support variety of information such as numeric, alphanumeric, Kanji, Kana, URL, SMS
Cost	Low cost	Low cost
Space	10 digits numeric (approximation 50mm x 20mm)	40 digits numeric (approximation 5mm x 5mm)
Damage Resistance	Damaged barcode is impossible to read	Reading is possible upto 30% damaged
360º Reading	Only horizontal reading	Support 360º reading

Based on the Table 2.1, the QR code has advanced features over the barcode especially it is readable up to damage of 30% and 360º and hence it is recommended that QR code is used as visual label that storing the product information.

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2.6 Code Label Recognition

Barcode and QR code are defined as a visual representation of data in the term of black and white rectangular or square bars or dots [31, 34]. These allow the information can be retrieved more faster than regular process through scanners or readers. The process done by the scanner or reader is called barcode recognition [35]. In generally, the image pre-processing and barcode extraction are included in the barcode recognition process. The image pre-processing is a recommanded process in barcode recognition procedure due to the results of image pre-processing may have a significant impact on the barcode recognition rate.

In [36], Imran et. al has successfully designed a real time barcode recognition system which has worked with almost 98% accuracy by using National Instruments' LabView. He has used IMAQ read barcode VI for barcode image processing and then generating a duplicate digital image. The digital image data is then forwarded to the next loop for further classification and barcode data extraction. In order to evaluate the accuracy extraction, the string data of real time barcode processing is compared with string data of database barcode processing. This barcode recognition system has reached high accuracy. Besides, it able to detect slanted barcode with orientation from 0º to 360º, multiple barcodes from black & white, grayscale, palletized and color images and nearly six industrial barcode types. To obtain the higher accuracy and speed on barcode recognition, a proper lighting condition on barcode images is recommended.

To locate or detect the barcode, Priyanka et al has proposed the discrete curvelet transform and artificial neural network in [37]. The input image is first resized so that suit to the size of images used for training of neural network. Then blocking process is done to cut the image according to block size. The mean and standard deviation of curvelet feature statistics for each block are computed and simulated to the trained neural network. Once trained is done, the thresholding process is applied to remove the non-barcode image blocks. Then, morphological operation is used in getting logical image that used for localizing the barcode image. This method able to localize barcode region present in either vertical or horizontal direction.

In [38], Priyanka et al. has developed a 2D QR barcode recognition model using texture features and artificial neural network on Matlab platform. Based on the statistic features, the training of neural network is performed to train the barcode containing image blocks. To localize the barcode region, the barcode containing image blocks are converted into binary image. Then, the thresholding process is done to form boundary box for segmentation of barcode region. The extracted barcode is recognized by using open source library ZX-ing. The performance toward different barcode condition is tested and high accuracy results are showed.

In [39], Priyanka et. al has used Matlab platform in developing a QR code recognition model. The canny edge detection technique is used in order to identify the boundaries of QR code within the image. After extracting the barcode, an open source ZX-ing Library is applied to recognize barcode. Input binary 2D barcode image is masked by segmented image for extracting the barcode. The performance is evaluated with several different QR codes which include clear barcode, blurred barcode and damaged barcode and has showed satisfactory results.

In [40], Karaol et al. has proposed histogram analysis method in QR code detection. The model is tested with QR code from different resolution, different versions, variety illumination condition, variety geometric distortions, variety tilt angle as well as different proportional position in image. Some incorrectly marks are found but the overall results are considered good.

In [41], R.Madhumetha has used python and OpenCv in developing a barcode scanner with pyzbar library in python library. The barcode scanner has been tested and the results has showed the barcode scanner is functioning well.

After comparing the literature reviews, the python with OpenCv is chosen as the approach in developing the object recognition with code label since it is easily in implementation as it is an open source library as well as it has showed well functioning in barcode detection in [41].

2.7 Summary

In summarize, the research have done and the information obtained is then used as a reference when doing this research. The researches gap of this project have been set according to the literature review on journals and conference papers. Due to the complexity when considering dynamic issue in trajectory planning and hence there will only the kinematic will be involved in trajectory planning. Then, algebraic method is chosen to be applied in this research to developing inverse kinematic model for positioning control of smart robotic arm since it is simple in design procedure. Moreover, an code label based object recognition model is also will be implemented using python with OpenCv in that providing smart robotic arm with additional feature in object recognition.

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CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will provide a clear explanation on the methods that are used in this research in order to achieve objectives. This chapter has included the design and development of kinematic model for positioning control of smart robotic arm and code label based object recognition model. Beside that, a series of experiments are implemented to evaulate the performance of the proposed smart robotic arm system.

3.2 Architecture System of Positioning Control of Smart Robotic Arm

The block diagram in Figure 3.1 shows the overview architecture system for positioning control of smart robotic arm. The positioning control of smart robotic arm is performed so that the gripper of smart robotic arm able to reach the storage location of desired medication accurately. Inverse kinematic model is applied to solve the cartesian coordinates of desired medication location and obtain joints angle that positioning the smart robotic arm to desired medication location. The robot controller with encoder feebcack is included so that to ensure the smart robotic arm to reach the desired medical location.

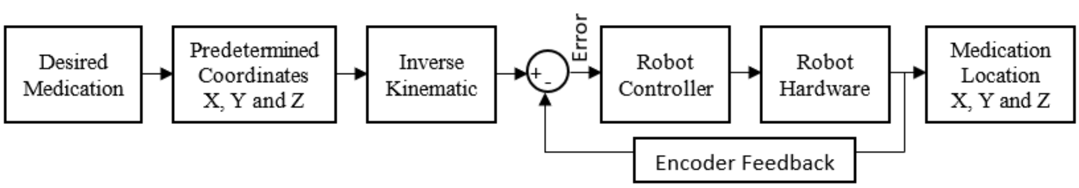

Figure 3.1: The Block Diagram for Positioning Control of Smart Robotic Arm

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3.2.1 Kinematic Modelling of Smart Robotic Arm

The 6 DOF smart robotic arm consists of 5 revolute joints and 1 gripper with 3 links. Kinematic model of a robotic arm has involved the transformation between joints angle and the tool or end-effector position and orientation. Forward kinematic has dealt with the transformation of the joints angle to position and orientation of end effector. While, inverse kinematic is opposite of the forward kinematic which involve the transformation of position and orientation of end effector to joints angle. In here, the inverse kinematic analysis is solved firstly by defining the desired orientation of end effector based on the reference coordinate system in its representative homogenous matrix and then follow by comparing the corresponding components of these homogenous matrix and forward kinematic homogenous matrix. Finally, the inverse kinematic solution is obtained by using algebraic approach. Hence, forward kinematic analysis is needed to be done first so that can be applied into inverse kinematic analysis.

3.2.1.1 Forward Kinematic

Forward kinematic analysis is done by applying Denavit-Hartenberg (DH) method. According to the Denavit-Hartenberg method, there are 2 basic rules that need to be considered when defining coordinate frame of each joints which are z-axis is in the direction of the joint axis and x-axis is parallel to the common normal.

Hence, the schematic diagram of smart robotic arm with the systems of axes that have defined by using DH method is showed in Figure 3.2.

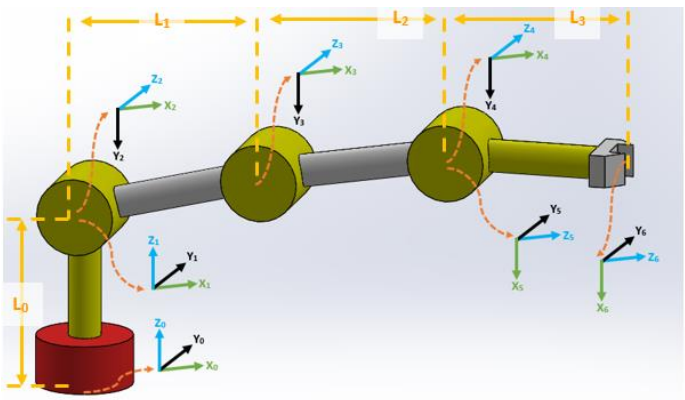

Figure 3.2: Schematic Diagram of Smart Robotic Arm

Then, the link parameters and joint parameters between two successive frames are obtained by applying the Denavit-Hartenberg (DH) parameters. There are 4 DH parameters which are defined as follow:

i) a_{i-1} is the distance from Z_i to Z_{i+1} measured along X_i

ii) α_{i-1} is the angle between Z_i to Z_{i+1} about along X_i

iii) d_i is the distance from X_{i-1} to X_i measured along Z_i

iv) θ_i is the angle between X_{i-1} to X_i measured about Z_i

Based on the schematic diagram of smart robotic arm in Figure 3.2, the corresponding DH parameters of smart robotic arm is obtained and presented in Table 3.1.

Table 3.1: DH Parameter of Smart Robotic Arm

i	a_{i-1}	α_{i-1}	d_i	θ_i
1	0	0	L_0	θ_1
2	-90°	0	0	θ_2
3	0	L_1	0	θ_3
4	0	L_2	0	θ_4
5	90°	0	0	θ_5
6	0	0	L_3	θ_6

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where:

L_0 = 92 mm;

L_1 = 146 mm;

L_2 = 187 mm;

L_3 = 100 mm.

Next, the transformation matrix of two successive frame can be computed by substituting the DH parameters into the homogenous transformation matrix which shows in (3:1).

$$ {}^{i-1}_{\;1}T = \begin{bmatrix} \cos\Theta_i & -\sin\Theta_i & 0 & a_{i-1} \\ \sin\Theta_i\cos\alpha_{i-1} & \cos\Theta_i\cos\alpha_{i-1} & -\sin\alpha_{i-1} & -\sin\alpha_{i-1}d_i \\ \sin\Theta_i\sin\alpha_{i-1} & \cos\Theta_i\sin\alpha_{i-1} & \cos\alpha_{i-1} & \cos\alpha_{i-1}\,d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (3:1) $$

In kinematic analysis, the following nomenclature has been considered.

$$c_1 = \cos\theta_1 \tag{3:2}$$
$$c_{12} = \cos(\theta_1 + \theta_2) \tag{3:3}$$
$$c_{123} = \cos(\theta_1 + \theta_2 + \theta_3) \tag{3:4}$$

Hence, the individual transformation matrix is computed by using the homogenous transformation matrix ${}^{i-1}_{1}T$ and DH parameters. All the individual transformation matrix is listed below.

$${}^{0}_{1}T = \begin{bmatrix} c_1 & -s_1 & 0 & 0 \\ s_1 & c_1 & 0 & 0 \\ 0 & 1 & 1 & L_0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3:5}$$
$${}^{1}_{2}T = \begin{bmatrix} c_2 & -s_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -s_2 & -c_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3:6}$$
$${}^{2}_{3}T = \begin{bmatrix} c_3 & -s_3 & 0 & L_1 \\ s_3 & c_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3:7}$$
$${}^{3}_{4}T = \begin{bmatrix} c_4 & -s_4 & 0 & L_2 \\ s_4 & c_4 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3:8}$$
$${}^{4}_{5}T = \begin{bmatrix} c_5 & -s_5 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ s_5 & c_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3:9}$$
$${}^{5}_{6}T = \begin{bmatrix} c_6 & -s_6 & 0 & 0 \\ s_6 & c_6 & 0 & 0 \\ 0 & 0 & 1 & L_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3:10}$$

The forward kinematic end effector with respect to the base frame is the total transformation between the base of smart robotic arm and the end effector which can be obtained by multiplying all the individual transformations.

$${}^{0}_{6}T = {}^{0}_{1}T \times {}^{1}_{2}T \times {}^{2}_{3}T \times {}^{3}_{4}T \times {}^{4}_{5}T \times {}^{5}_{6}T \tag{3:11}$$
$${}^{0}_{6}T = \begin{bmatrix} c_1c_{234}c_{56} - s_1s_{56} & c_1c_{234}s_{56} - s_1c_{56} & c_1c_{234} & c_1b \\ s_1c_{234}c_{56} + c_1s_{56} & s_1c_{234}s_{56} + c_1c_{56} & s_1s_{234} & s_1b \\ -s_{234}c_{56} & s_{234}s_{56} & c_{234} & a \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3:12}$$

where:

$b = s_{234}L_3 + c_{23}L_2 + c_2L_1$
$a = c_{234}L_3 - s_{23}L_2 - s_2L_1 + L_0$

3.2.1.2 Inverse Kinematic

The inverse kinematic is derived by comparing all the components in transformation matrix of desired orientation of end effector with forward kinematic. The transformation matrix for forward kinematic in (3:12) is postmultiplied transformation matrix. An equality representation of transformation matrix is given in (3:13).

$$ {}^{0}_{6}T = \begin{bmatrix} r_{xx} & r_{yx} & r_{zx} & P_x \\ r_{xy} & r_{yy} & r_{zy} & P_y \\ r_{xz} & r_{yz} & r_{zz} & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3:13} $$

where r (rotation) elements and P (position) elements are used for indicate orientatation and position elements relative to reference frame respectively.

In here, the desired orientation of the end effector of smart robotic arm is set to be awalys offset forward that means it will be parallel with the base surface at all times. Hence, the transformation matrix for these desired orientation of end effector is defined by substituting the calculated rotation elements of end effector relative to base frame.

The rotation of frame for end effector relative to base frame is described in Figure 3.3 based on schmetic diagram in Figure 3.2.

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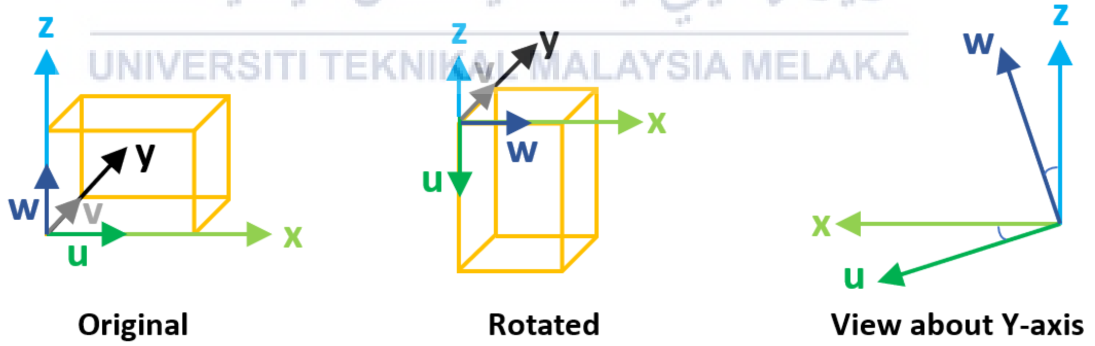

Figure 3.3: Frame Rotation of End Effector Relaive to Base Frame

Based on the Figure 3.3, it is cleary showed that the end effector frame is rotated 90 º (counterclockwise 90º) about Y-axis. By substituiting the rotating angle into rotation matrix inside transformation matrix in (3:13), transformation matrix with desired orientation of end effector of smart robotic arm is obtained as follow:

$$
{}^{0}_{6}T = \begin{bmatrix} \cos 90º & 0 & -\sin 90º & P_x \\ 0 & 1 & 0 & P_y \\ \sin 90º & 0 & \cos 90º & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (3:14)
$$

$$
{}^{0}_{6}T = \begin{bmatrix} 0 & 0 & -1 & P_x \\ 0 & 1 & 0 & P_y \\ 1 & 0 & 0 & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (3:15)
$$

Hence, the inverse kinematic analysis is solved by comparing the components in (3:12) and (3:15). By comparing of element in r_{zz},

$$c_{234} = 0 \qquad (3:16)$$
$$\theta_{234} = 90º \qquad (3:17)$$
$$s_{234} = 1 \qquad (3:18)$$

By comparing the elements of P_x, P_y and P_z, the following equations is obtained,

$$P_x = c_1 b \qquad (3:19)$$
$$P_y = s_1 b \qquad (3:20)$$
$$P_z = c_{234}L_3 - s_{23}L_2 - s_2L_1 + L_0 \qquad (3:21)$$

By dividing the (3:19) with (3:20), the joint angle 1, θ_1 is obtained as follow:

$$\theta_1 = \operatorname{artan}\frac{P_y}{P_x} \qquad (3:22)$$

The equation of b parameter can be obtained directly from (3:12) or summing the squared (3:12) and (3:15) and then substituting (3:18) into the respective equation. The both equation for b paramenter is shown in (3:23) and (3:24) .

$$b = s_{234}L_3 + c_{23}L_2 + c_2L_1 \qquad (3:23)$$
$$b = \pm\sqrt{{P_x}^2 + {P_y}^2} \qquad (3:24)$$

By summing the squared (3:21) and (3:23), the joint angle 3, θ_3 is obtained as follow:

$$\theta_3 = \arccos\frac{(L_0 - P_z)^2 + (\mathrm{b} - L_3)^2 - {L_1}^2 - {L_2}^2}{2L_1L_2} \qquad (3:25)$$

By solving (3:21) and (3:23) algebraic, the joint angle 2, θ_2 is obtained as follow:

$$\theta_2 = \operatorname{artan}\frac{(L_3 - \mathrm{b})(s_3L_2) + (L_0 - P_z)(c_3L_2 + L_1)}{-(P_z - L_0)(s_3L_2) + (\mathrm{b} - L_3)(c_3L_2 + L_1)} \qquad (3:26)$$

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From (3:17), the joint angle 4, θ_4 is obtained as follow:

$$\theta_4 = 90^{\circ} - \theta_2 - \theta_3 \quad (3:27)$$

In here, the joint angle 5, θ_5 and the joint angle 6, θ_6 has ingored in the inverse kinematic analysis that uses in positioning control of smart robotic arm. As reason, the the joint angle 5, θ_5 has dealt with the rotation of end effector while the joint angle 6, θ_6 is used in controlling open and closed condition of end effector. Hence, they does not affecting in positioning control of smart robotic arm.

The inverse kinematic model is then built in the Matlab Simulink software to control the smart robotic arm hardware through a Micro-box 2000/2000C.

3.2.2 Robot Controller

The 6 DOF smart robotic arm consits of 3 links and is controlled by 6 DC servo motor which shown in Figure 3.4. Each DC servo motor is used in controlling one degree of freedom of the smart robotic arm and each DC servo motor has a pontentioner encoder to indicate angular position. Hence, the multiple single input single output (SISO) system is applied in here to control the smart robotic arm position by controlling the angular position of each DC servo motor.

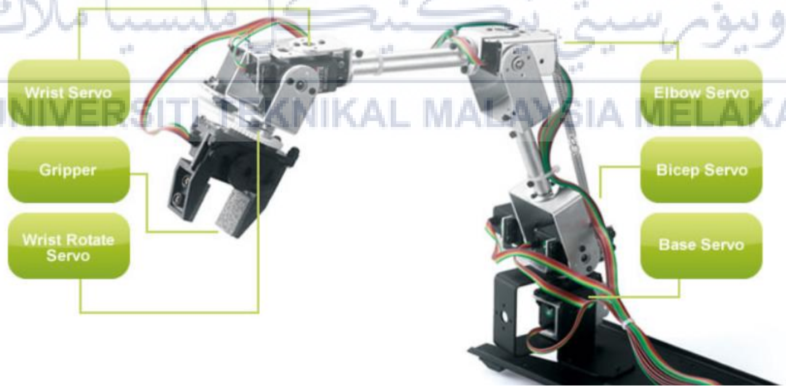

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Figure 3.4: 6 DOF Smart Robotic Arm with 6 DC Servo Motors

A DC servo motor is able to move in two direction which are forward and backward direction. Hence, a simple on off controller is built in Matlab Simulink to control the moving direction of DC servo motor according to the angular position of DC servo motor relative to the setpoint so that the DC servo can be turned to the desired angular position.

3.3 Architecture System of Object Recognition based on Code Label

In here, QR code is used as the code label to store information of medication. The block diagram in Figure 3.5 has illustrated the process of objection recognition based on code label. The Raspberry Pi Camera Module V2 is used as camera sensor to obtain the QR code while Raspberry Pi Model 2B is acted as a microprocessor to process the input and output information. OpenCv softwave is used to developing the objection recognition based on code label by using the ZBar libaray. The output information is then displayed out and uploaded manually to Smart Robotic Arm control system in Matlab to move the Smart Robotic Arm to the desired position.

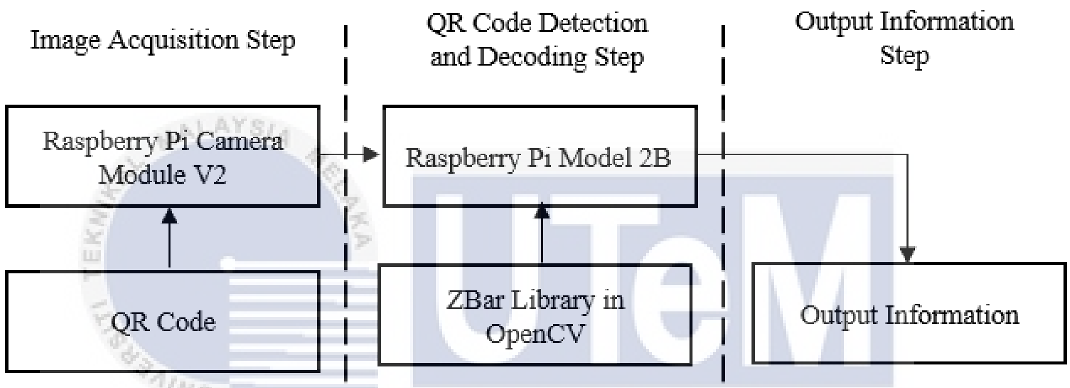

Figure 3.5: Block Diagram for Object Recognition Based on Code Label

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3.4 Performance Evaluation

A series of evaulation test will be conducted based on the objectives of this project to in that to strive for the objectives mentioned in Chapter 1. Hence, this section has explained and discussed the experiments that will be conducted in this project.

3.4.1 Positioning Control of Smart Robotic Arm

In order to evaluate the performance in positioning control of smart robotic arm, there have included three experiments to validate the different components in positioning control of smart robotic arm and the details of each expriment is provided in the sub-section below.

3.4.1.1 Evaluation of Inverse Kinematic Model

This evaluation aims to validate the designsed inverse kinmatic model in providing the correct inverse kinematic solution by comparing with the kinemtic model that built in the Peter Corke's Robotics Toolbox in Matlab based on the DH parameter in Table 3.1. A 10 random coordinates (x, y, z) is chosen and tested in the both kinematic model and then the corresponding joint angles generated by the both model will be recorded and compared. Since, the joint angles θ_5 and θ_6 does not affecting in positioning control of smart robotic arm and hence only the first four joints angle will be compared in this evaluation.

3.4.1.2 Evaluation of Robot Controller

This experiment aims to compare the performace of the on off controller with the setpoint of zero and setpoint of ±2 toward the motors on the smart robotic arm. This experiment will run in term of positioning of smart robotic arm using the designed inverse kinematic model. The pre-selected coordinates of initial position and final position are shown in Table 3.2. The experiment is firstly conducted toward the motors without load or before installing on to the smart robotic arm and then only procced toward motors that have installed on to the smart robotic arm. Then, the performance of both controller in first 4 motors in which are base servo, bicep servo, elbow servo and wrist servo referrring to Figure 3.4 for both of motors satges are recorded and analysed.

Table 3.2: Coordinate of Initial Position and Final Position

Coordinate	Initial Position (mm)	Final Position (mm)
X	280	0
Y	0	310
Z	300	300

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3.4.1.3 Evaluation of Performance in Positioning of Smart Robotic Arm

This experiment aims to check the performance of smart robotic arm with ±2 setpoint controller in reaching the desired coordinate. Same as previous experiment, the experiment will be carried out in term of positioning of smart robotic arm from the pre-selected initial position to final position using the designed inverse kinematic model. For the pre-selected coordinates, the same pre-selected coordinates of the previous experiment which shown in Table 3.2 will be applied. The grid board with marking label is used as aid to represent and visualise the target coordinate in real environment as shown in APPENDIX D. After that, the measuring tap and grid board are used to measure the deviation of actual coordinate reached by smart robotic arm from the desired coordinate that have selected initially. The experiment is repeated three times and all the data is then recorded and discussed.

3.4.2 Object Recognition based on Code Label

Besides from the performance test for positioning control of smart robotic arm, the performance of code label based recognition model is also tested and the details of the experiment have provided in the sub-chapter below.

3.4.2.1 Evaluation of Code Label Recognition Model Toward Difference Code Label Condition and Distance

This experiment is to test and verify the performace of code label based object recognition system toward different code label condition which include clear QR code and blurred QR code. 30 images that contain QR code in size of 1.5 cm X 1.5 cm for each code label condition are tested. This experiment will be ran repeatly three times with three different distance between QR code and camera sensor which are 15cm, 10cm and 5cm. The number of success detection and recognition are recorded and used in calculation the accurancy of detection and recognition respectively by using eqaution (3:28) and then the results are tabulated.

$$Accuracy = \frac{Number\ of\ Success}{Number\ of\ Tested}\ X\ 100\% \qquad (3:28)$$

3.5 Summary

This chapter has discussed the methodogy in developing system in both hardware and software. The performance evaluations are planned to check the performace of the system and all the results and discuss have presented in the next chapter.

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CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, all the experimental results will be presented in the form of table and graph in that provide better understanding towards parameters involved in each experiments.

4.2 Results and Discussions

All the analysis and discusion upon the experimental results will be recorded as follow in which the first section will be discussed evaluation performance of positioning control of smart robotic arm while next section will be focused on the evaluation performance of code label based object recognition model.

4.2.1 Positioning Control of Smart Robotic Arm

4.2.1.1 Evaluation of Inverse Kinematic Model

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The simulation testing for the inverse kinematic model is shown in Figure 4.1 in which left side showed kinematic model that built in Simulink while right side showed the kinematic model in GUI of Peter Corke Robotic Toolbox.

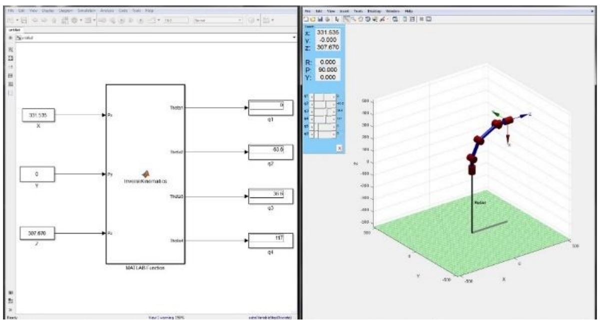

Figure 4.1: The Kinematic Model in the Simulink and the GUI of Peter Corke Robotic Toolbox

Then, both kinematic model is tested with 10 random coordinates, the corresponding joint angles results are recorded and tabulated as shown in Table 4.1.

Table 4.1: Simulation Results of Kinematic Model from Designed Simulink Model and Peter Corke Robotic Toolbox

Coordinate (x, y, z) / mm	Joint Angle (ϴ1, ϴ2, ϴ3, ϴ4) / º		
	Designed Simulink Model, S	**Peter Croke Robotic Toolbox, P**	**Angle Difference, D**
(331.535, 0, 307.670)	(0, -63.6 36.6 117)	(0, -63.6 36.6 117)	(0, 0, 0, 0)
(227.651, 227.651, 265.497)	(45, -75, 65, 100)	(45, -75, 65, 100)	(0, 0, 0, 0)
(279.950, 0, 300.071)	(0, -88.6, 69.2, 109.4)	(0, -88.6, 69.2, 109.4)	(0, 0, 0, 0)
(304.694, 0, 294.750)	(0, -79.2, 60.7, 108.5)	(0, -79.2, 60.7, 108.5)	(0, 0, 0, 0)
(243.856, 140.790, 316.243)	(30, -85.3, 60.4, 114.9)	(30, -85.3, 60.4, 114.9)	(0, 0, 0, 0)
(228.058, 228.058, 264.882)	(45, -74.8, 64.95, 99.85)	(45, -74.8, 64.95, 99.85)	(0, 0, 0, 0)
(157.033, -352.701, 164.968)	(-66, -45.8, 55.56, 80.24)	(-66, -45.8, 55.56, 80.24)	(0, 0, 0, 0)
(224.989, 210.026, 264.959)	(43.03, -80.93, 72.08, 98.85)	(43.03, -80.94, 72.07, 98.87)	(0, -0.001, -0.001, 0.002)
(102.701, 383.284, 126.940)	(75, -36.6, 52.78, 73.82)	(75, -36.6, 52.78, 73.82)	(0, 0, 0, 0)
(189.155, 327.625, 234.545)	(60, -50, 40.55, 99.45)	(60, -50, 40.55, 99.45)	(0, 0, 0, 0)

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Based on Table 4.1, it is cleary see that the inverse kinematic model which built in simulink model has performace well. This is because of the results have showed that difference in the computated joint angles for all cases are less 0.005º. Hence, the designed inverse kinematic model can be applied into the positioning control of smart robotic arm in that allowing the smart robotic arm in reaching the desired coordinate positions.

4.2.1.2 Evaluation of Robot Controller

The joint angles that correspond to the coordinate of initial position and final position in positioning control of smart robotic arm are shown in Table 4.2. The 4 joint angles have been controlled by 4 different servo motor. Figure 4.2 to Figure 4.9 have showed the performance of controller with zero setpoint and ±2 setpoint for each servo motor in pre-installed stage in response to the angles rotation over 5 second. While Figure 4.10 to Figure 4.17 have showed the performance of controller with zero setpoint and ±2 setpoint for each servo motor in already-installed stage in response to the angles rotation over 5 second.

Table 4.2: The Corresponded Joint Angles Toward Position of Smart Robotic Arm

Initial Position		Final Position	
Coordinate, (x, y, z) /mm	Joint Angle (Θ1, Θ2, Θ3, Θ4) / °	Coordinate, (x, y, z) /mm	Joint Angle (Θ1, Θ2, Θ3, Θ4) / °
(280, 0, 300)	(0, -88.59, 69.21, 109.4)	(0, 310, 300)	(90, -76.07, 55.31, 110.8)

The Figure 4.2 and Figure 4.3 have showed the step response of the motor 1 with the controller with zero setpoint and ±2 setpoint during the pre-installed stage.

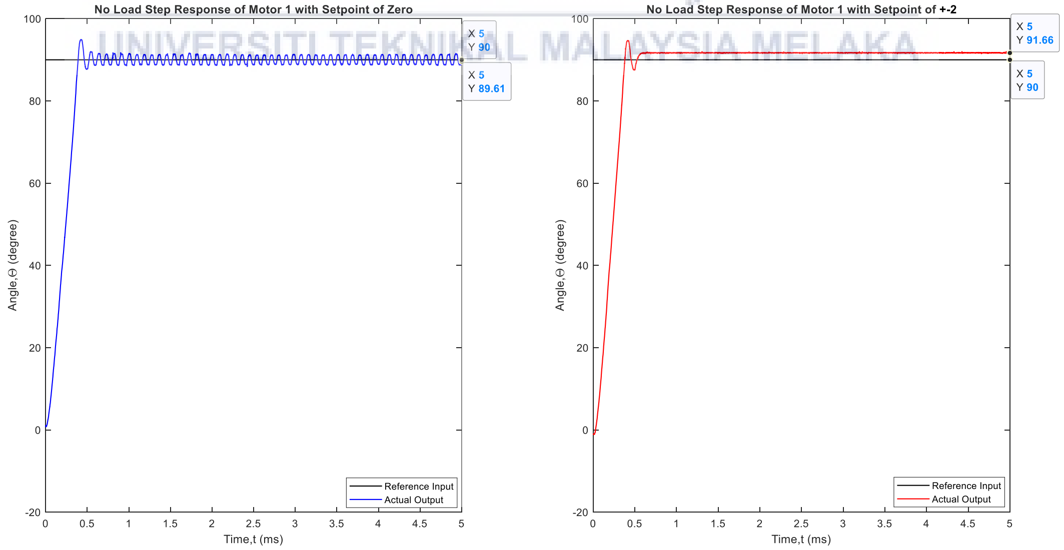

Figure 4.2: Side-by-Side Comparative Experimental Step Response of Motor 1 during Pre-Installed Stage

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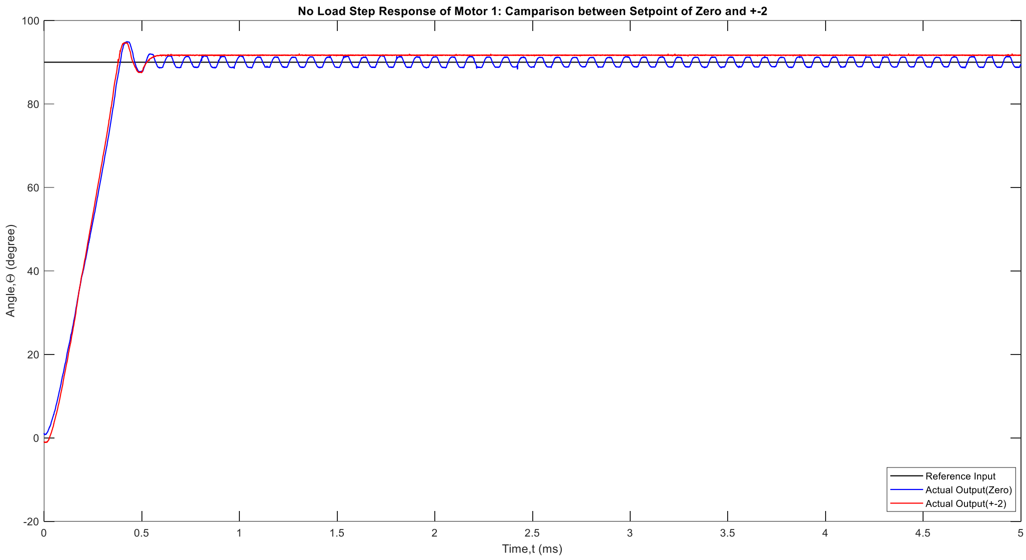

Figure 4.3: Comparative Experimental Step Response of Motor 1 during Pre-Installed Stage

The Figure 4.4 and Figure 4.5 have showed the step response of the motor 2 with the controller with zero setpoint and ±2 setpoint during Pre-Installed Stage.

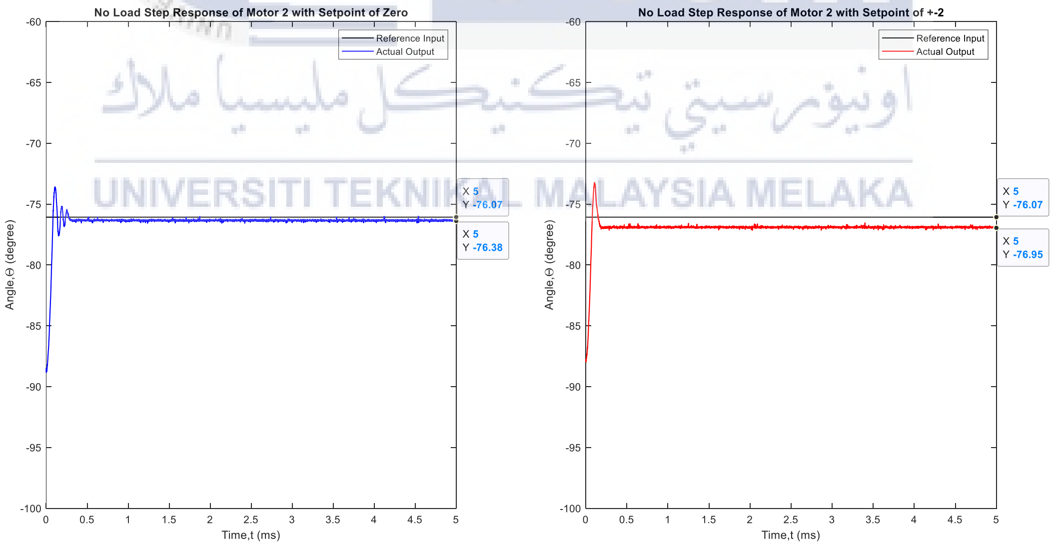

Figure 4.4: Side-by-Side Comparative Experimental Step Response of Motor 2 during Pre-Installed Stage

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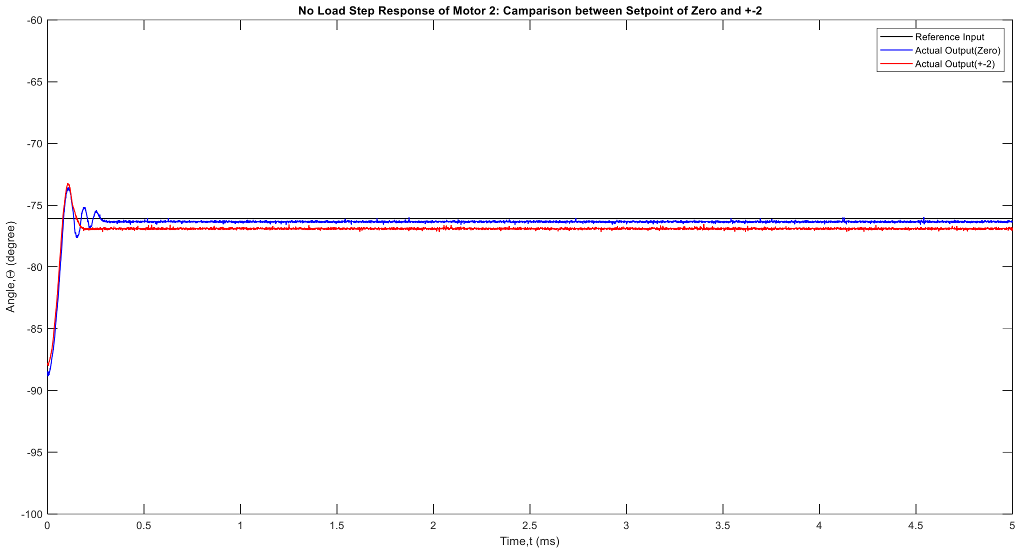

Figure 4.5: Comparative Experimental Step Response of Motor 2 during Pre-Installed Stage

The Figure 4.6 and Figure 4.7 have showed the step response of the motor 3 with the controller with zero setpoint and ±2 setpoint.

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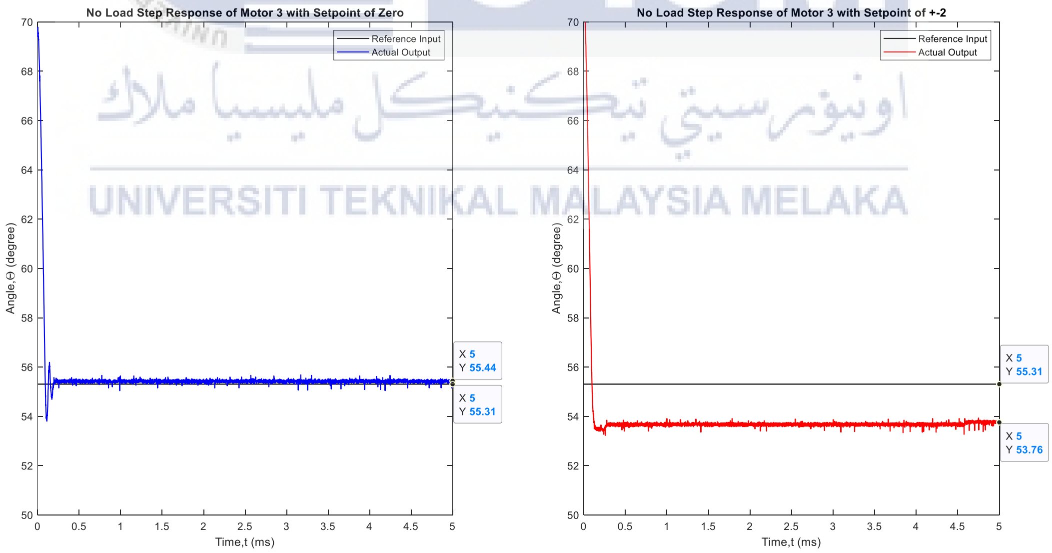

Figure 4.6: Side-by-Side Comparative Experimental Step Response of Motor 3 during Pre-Installed Stage

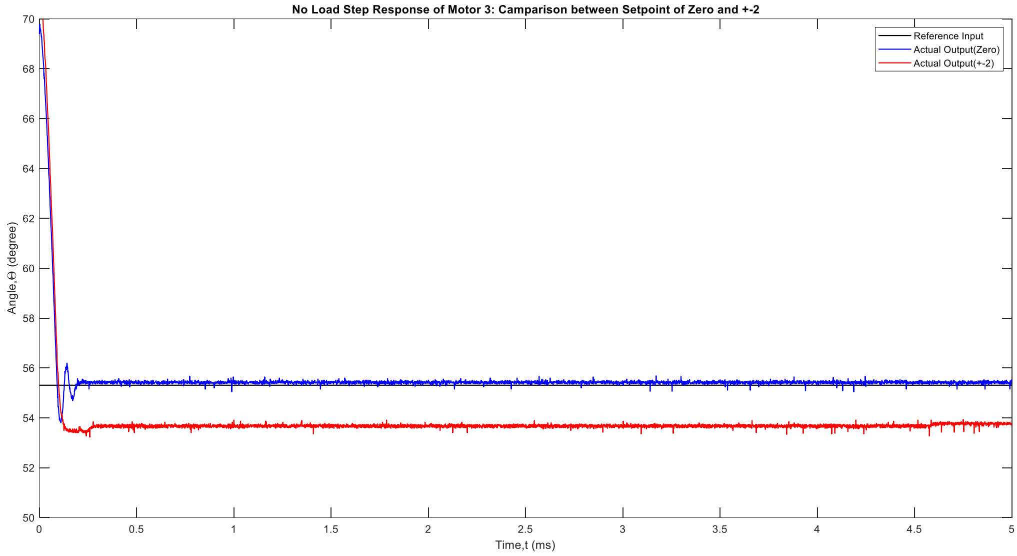

Figure 4.7: Comparative Experimental Step Response of Motor 3 during Pre-Installed Stage

The Figure 4.8 and Figure 4.9 have showed the step response of the motor 4 with the controller with zero setpoint and ±2 setpoint.

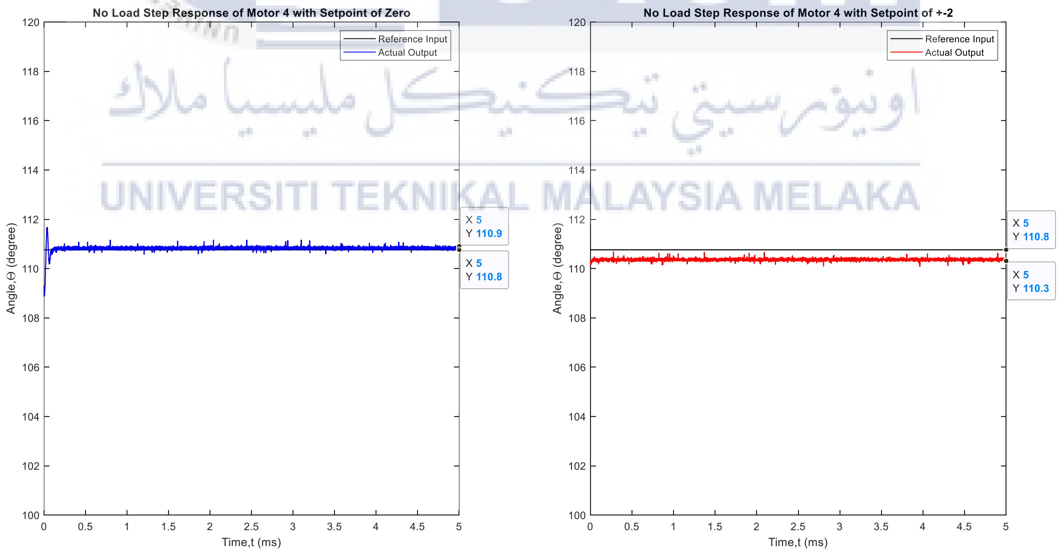

Figure 4.8: Side-by-Side Comparative Experimental Step Response of Motor 4 during Pre-Installed Stage

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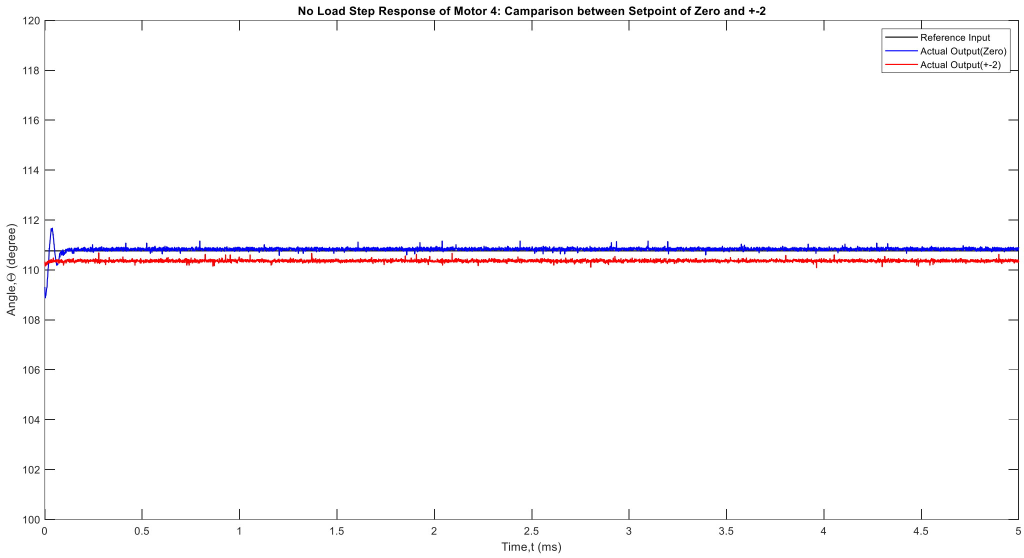

Figure 4.9: Comparative Experimental Step Response of Motor 4 during Pre-Installed Stage

The Figure 4.10 and Figure 4.11 have showed the step response of the motor 1 with the controller with zero setpoint and ±2 setpoint during already-installed stage.

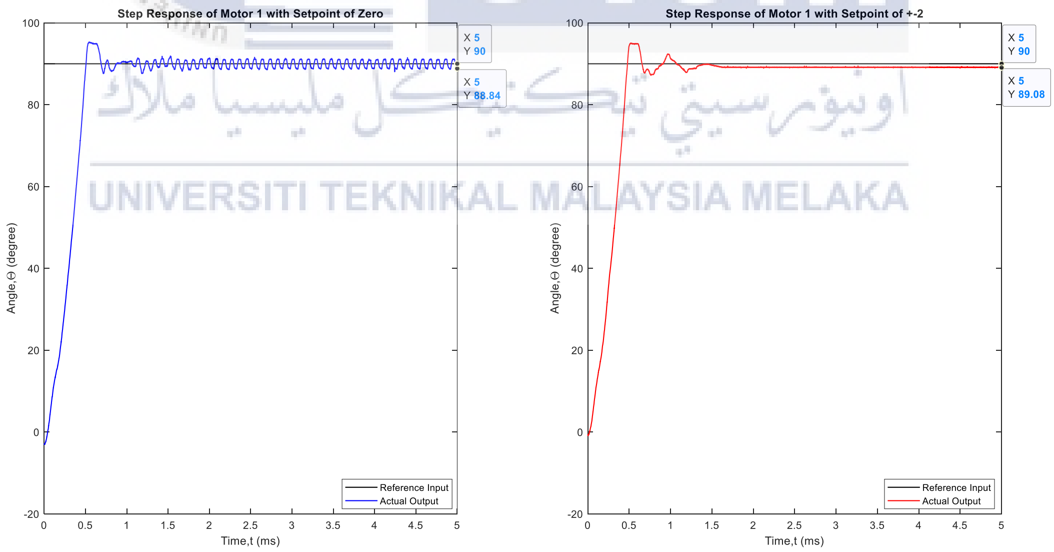

Figure 4.10: Side-by-Side Comparative Experimental Step Response of Motor 1 during already-installed stage

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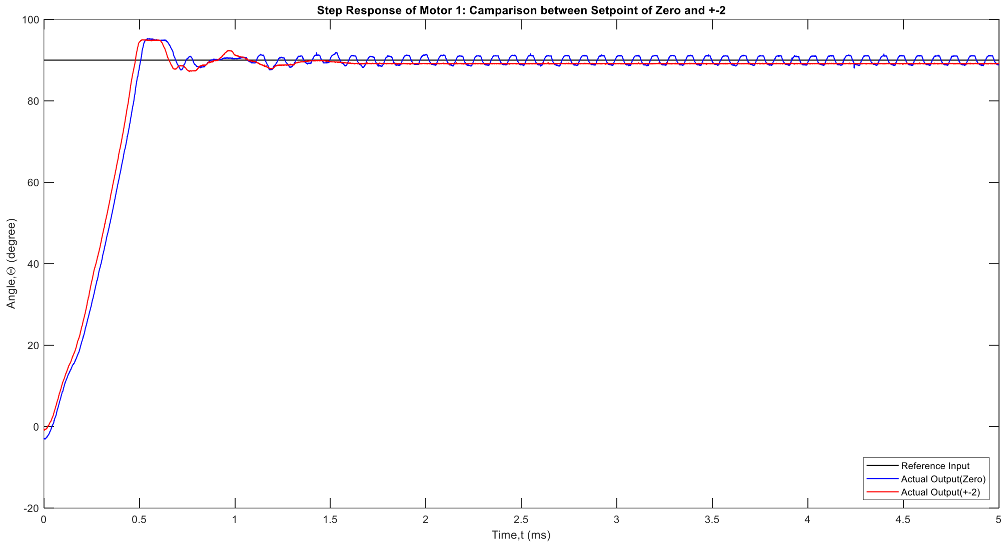

Figure 4.11: Comparative Experimental Step Response of Motor 1

The Figure 4.12 and Figure 4.13 have showed the step response of the motor 2 with the controller with zero setpoint and ±2 setpoint during already-installed stage.

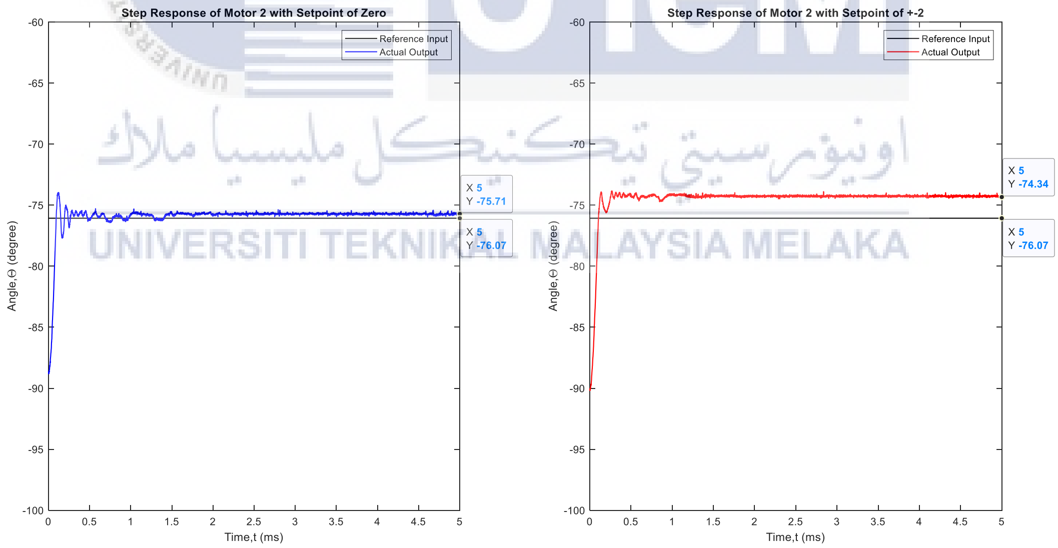

Figure 4.12: Side-by-Side Comparative Experimental Step Response of Motor 2 during already-installed stage

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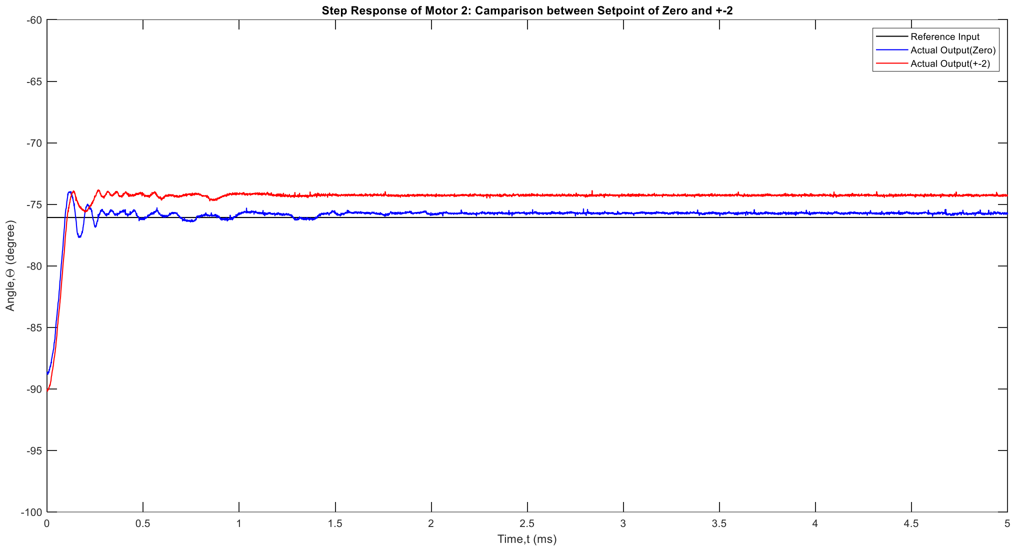

Figure 4.13: Comparative Experimental Step Response of Motor 2 during already-installed stage

The Figure 4.14 and Figure 4.15 have showed the step response of the motor 3 with the controller with zero setpoint and ±2 setpoint during already-installed stage.

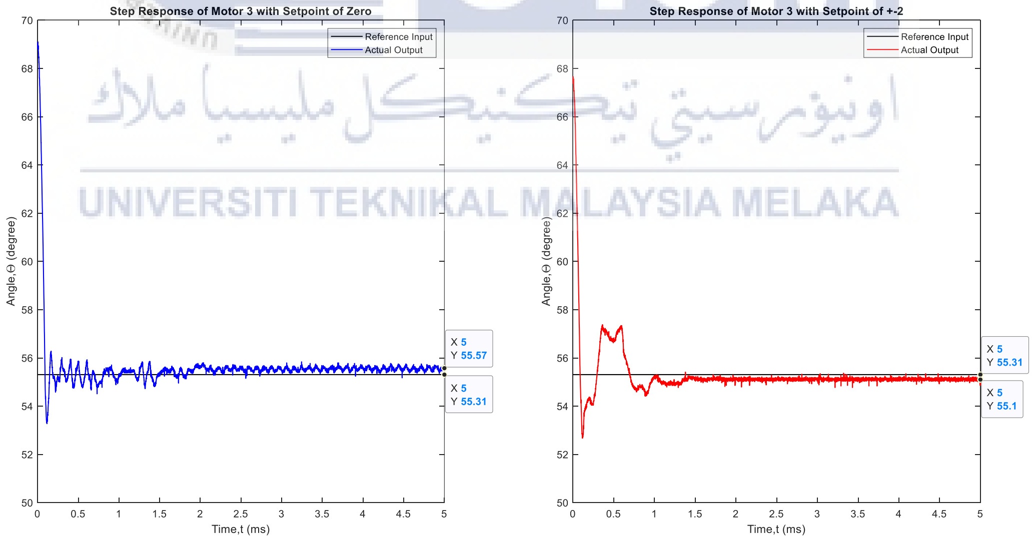

Figure 4.14: Side-by-Side Comparative Experimental Step Response of Motor 3 during already-installed stage

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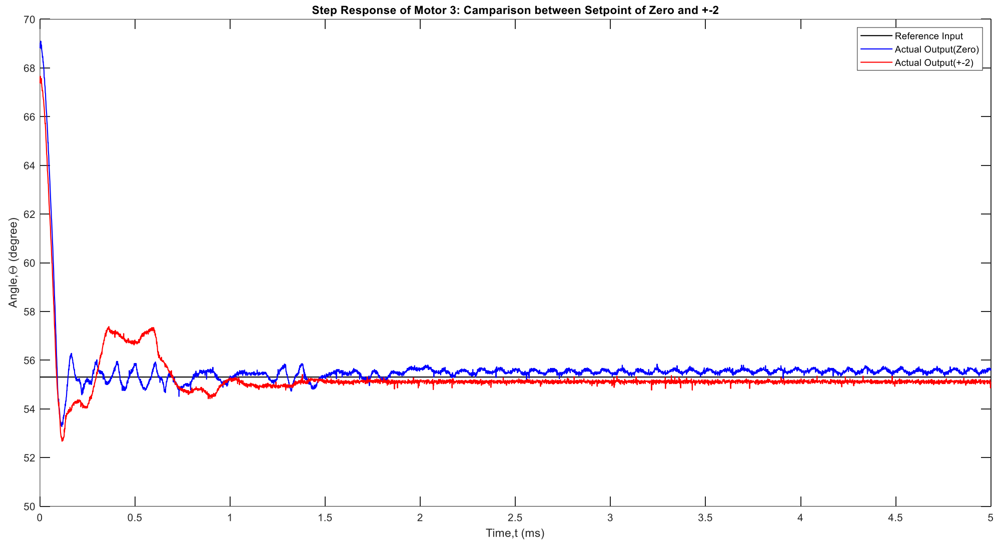

Figure 4.15: Comparative Experimental Step Response of Motor 3 during already-installed stage

The Figure 4.16 and Figure 4.17 have showed the step response of the motor 4 with the controller with zero setpoint and ±2 setpoint during already-installed stage.

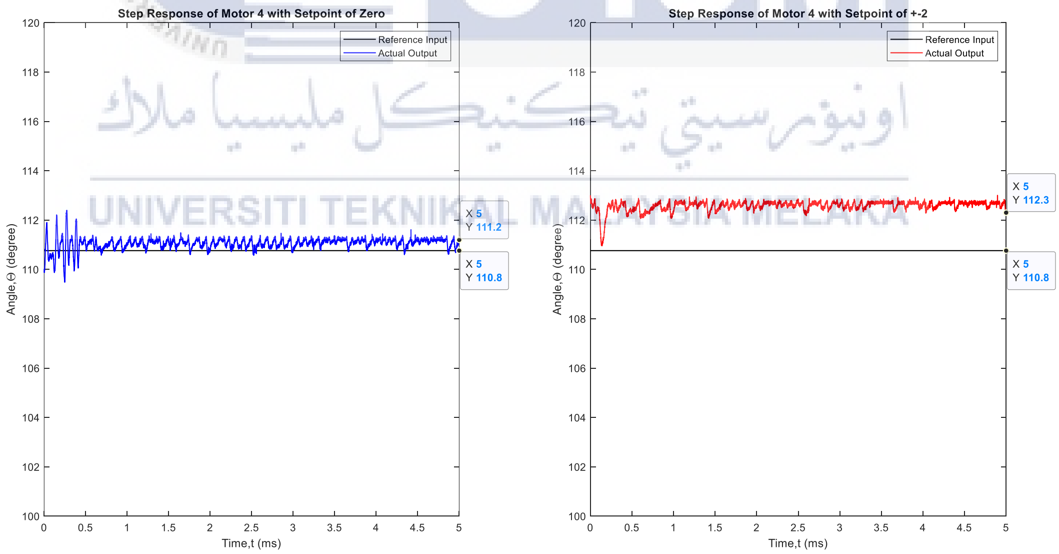

Figure 4.16: Side-by-Side Comparative Experimental Step Response of Motor 4 during already-installed stage

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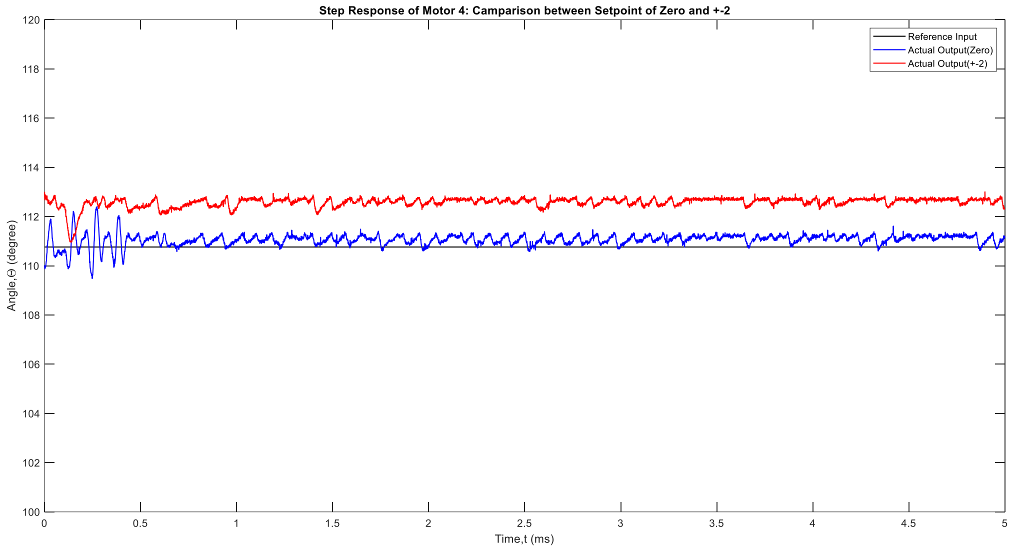

Figure 4.17: Comparative Experimental Step Response of Motor 4 during already-installed stage

The overshoot percentage in the trasient response of four motors in each case is obtained and recorded. Then, the error of angle in final value is also obtained from step response. Both the data have tabulated as shown in Table 4.3.

Table 4.3: Comparison between Performance of Controller with Setpoint of Zero and ±2 toward Different Motors Stage

Motor	Controller	Pre-Installed (No Load) Stage		Already-Installed Stage	
		Overshoot Percentage, OS /%	Final Angle Error, ΔΘ / °	Overshoot Percentage, OS /%	Final Angle Error, ΔΘ / °
Motor 1	Controller with Zero Setpoint	5.9495	0.39	7.272	1.16
	Controller with ±2 Setpoint	3.3073	1.66	6.666	1.92
Motor 2	Controller with Zero Setpoint	16.3021	0.31	17.294	0.36
	Controller with ±2 Setpoint	14.3179	0.88	21.327	1.73
Motor 3	Controller with Zero Setpoint	25.8706	0.13	24.339	0.26
	Controller with ±2 Setpoint	31.8937	1.55	22.7826	0.21
Motor 4	Controller with Zero Setpoint	0.6901	0.10	1.079	0.40
	Controller with ±2 Setpoint	0.3375	0.50	0.6263	1.50

where:

$$\Delta\theta = |\,Actual\ Output - Reference\ Input| \qquad (4:1)$$

Based on the Table 4.3, it is clearly seen that the overshoot percentage of each of the motors in both controller cases as well as both motors stages have showed slightly different only. Hence, the body weight of the smart robotic arm components have not bring much influence toward the overshoot percentage of each motor. On the other hand, the motors with zero setpoint controller have smaller final error as compare to motors with ±2 setpoint controller for both motor stages. According to Figure 4.2 to Figure 4.17, there is not significant vibration for all motors with both controller cases during the pre-installed stage expect for the motor 1 with zero set-point controller. However, the vibration in motors with zero setpoint controller have became larger after installed onto smart robotic arm while the vibration in motors with ±2 setpoint controller have not showed significant difference between both motors stages except for the motor 4 and hence it showed that ±2 setpoint controller have better in providing stability toward motors in smart robotic arm. Thus, it is cleary showed that the on off controller has limitation to optimize the performance of motors so that achieve higher stability, zero steady state error and better response time at the same time. Besides, the body weight of smart robotic arm components is also the reason that causing the vibration of motors in smart robotic arm as it acts as external force that affecting the motion of smart robotic arm. Therefore, it is needed to consider the body weight of smart robotic arm components when designing the robot controller.

4.2.1.3 Evaluation of Performance in Positioning of Smart Robotic Arm

The joints angle that correspond to the coordinate of pre-selected initial position and pre-selected final position in positioning control of smart robotic arm are shown in Table 4.2 in previous section. The Table 4.4 and Table 4.5 have recorded the result from the conducted experiment in term of coordinate and joint angle respectively. The desired output of coordinate is the coordinate of the pre-selected final position for smart robotic arm while desired output of joints angle are obtained from the inverse kinematic solution that displayed in simulink model. However, the actual output of coodinate is measured from hardware while the actual output of joints angle are taken from displayed output value in simulink model. The error between the desired and actual is calculated using (4:2).

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$$Error = \text{Actual Output} - \text{Desired Output} \tag{4:2}$$

Table 4.4: The Comparison between the Desired Output and Actual Output of Coordinate

Test	Coordinate, (x, y, z) / mm		
	Desired Output	Actual Output	Error
A	(0, 310, 300)	(40, 320,285)	(40, 10, -15)
B		(37, 320, 290)	(37, 10, -10)
C		(42, 320, 290)	(42, 10, -10)

Table 4.5: The Comparison between the Desired Output and Actual Output of Joints Angle

Test	Joint Angle, (ϴ1, ϴ2, ϴ3, ϴ4) / °		
	Desired Output	Actual Output	Error
A	(90, -76.0709, 55.3076, 110.7634)	(89.3677, -74.0709, 54.6831, 112.7572)	(-0.6323, 2.000, -0.6245, 1.9938)
B		(90.2334, -74.4386, 55.0097, 112.6382)	(0.2334, 1.6323, -0.2979, 1.8748)
C		(89.3168, -74.4326, 55.6224, 112.6434)	(-0.6832, 1.6383, 0.3148, 1.8800)

Based on the Table 4.4, the smart robotic arm has the errorneous up to 40mm in reaching the desired coordinate. There are serveral issues that lead to this condition to be happen. The errorneuos of the joints angle of smart robotic arm in reaching the respective desired joint angle as shown in theTable 4.5 is one of the major issue that cause to this problem according to the study of kinematic. In fact, the error in joints angle is caused by the poor performance of the desinged robot controller. Hence, a robustness controller is required in order to ensure the motors is able to reach the desired position accurately. Next, the defecting in body part of the smart robotic arm as show in APPENDIX E has caused the error of approximinately 30mm in the x-coordinate. To deal with this issue, the defecting in body part of smart robotic arm is needed to be considered when designing the kinematic model. Else, the well-built body part in smart robotic arm is required to prevent error to be happen.

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4.2.2 Object Recognition based on Code Label

4.2.2.1 Evaluation of Code Label Recognition Model Toward Difference Code Label Condition and Distance

The Figure 4.18 has showed the example of clear and blurred QR code that used in this experiment. While, the example of successfully recognizing QR code has showed in Figure 4.19.

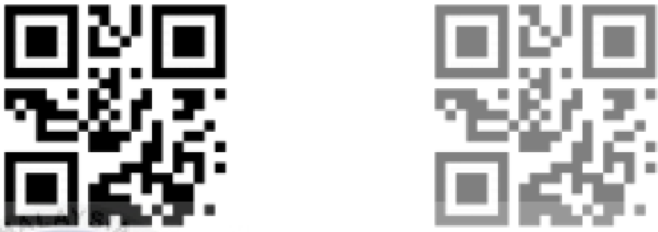

Figure 4.18: Clear QR Code (Left) versus Blurred QR Code (Right)

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Figure 4.19: Example of Successfully in Recognizing QR code

The Table 4.6 has recorded and tabulated all the results that obtained throughout the experiment. Then, a graph have been constructed as shown in Figure 4.20 to clearly visualize the experimental results. While, the term, N/A is used to represent the not available condition.

Table 4.6: Accuracy of QR Code Detection and Recognition toward Different QR Code Condition and Distance

Distance Between Camera Sensor and QR Code, / cm	QR Code Condition	No of Success Detection	Accuracy in Detection, / %	No of Success Recognition	Accuracy in Recognition, / %
15	Clear	29	96.67	29	96.67
	Blurred	N/A	N/A	N/A	N/A
10	Clear	30	100.00	30	100.00
	Blurred	26	86.67	26	86.67
5	Clear	30	100.00	30	100.00
	Blurred	30	100.00	30	100.00

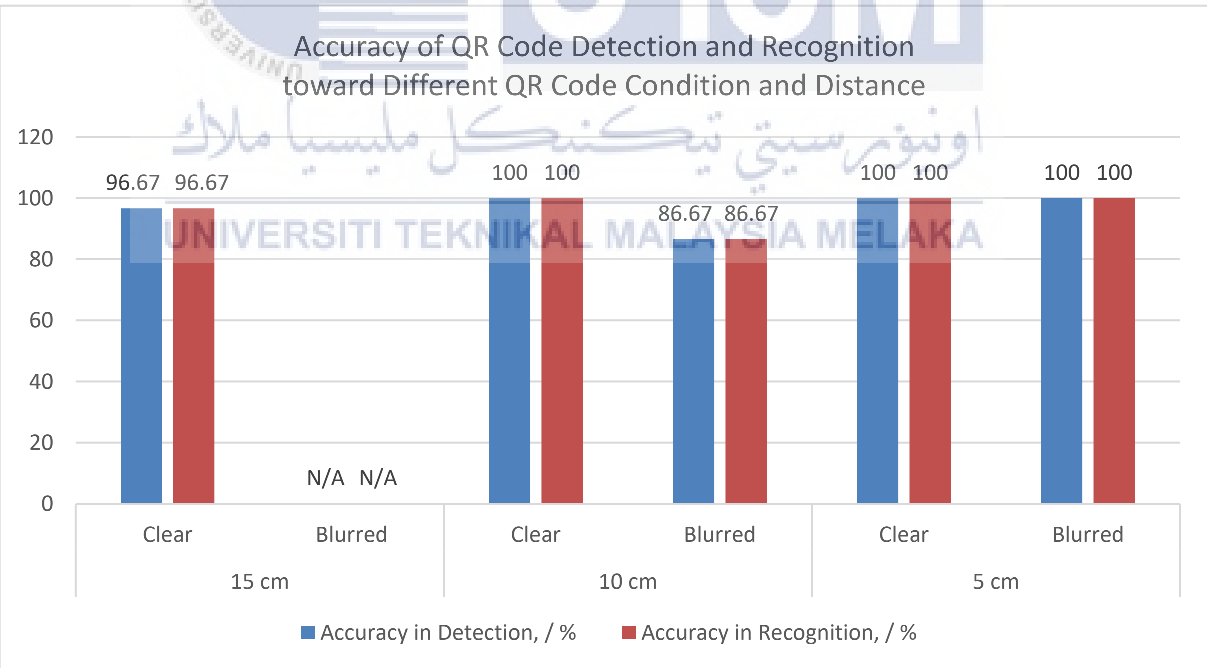

Figure 4.20: Accuracy of QR Code Detection and Recognition toward Different QR Code Condition and Distance

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According to the Table 4.6 and Figure 4.20, the QR code recognition model has achieved high accurancy in detecting and recognizing the clear QR code. There are several possible issues that lead to the undetectable in clear QR code. Firstly, the presentaing of the image noise and a variation of brightness in image when the camera captured the image. Next, the microprocessor experience lagging during exceution may also cause the QR code undetectable. A blurred QR code doesn't providing an enough contrast between the light and dark code element which will caused the QR code scanner unable to difference between the light and dark code elememts. Hence, it will lead to failure in detecting QR code. Besides, this condition can dramatically slow down decoding time of scanner as well as limit the distance at which a QR code can be read. Hence, this issue have possibility lead to the QR code recognition model unable to read QR code which placed 15 cm from camera sensor.

4.3 Summary

All the results of this research have been presented in Chapter 4. Several experiment have been carried out to evaluate the performance of system design. Analysis and discussion on the outputs obtained from total of 4 experiments are done with proper explanation on presented tables or figures. From the experiments, there are few issues which can affect the performance and effectiveness of the designed system. Firstly, the performance of on off controller in experiment 2 shows limitation in achieving the effective control system since it has contained steady state error as well as the vibration issue in its step repsonse. Hence, a robust controller such as proportional-integral-deriative (PID) controller and fuzzy logic controller can be implemented into the current control system in order to provide an optamized control system. Next, the experiment 3 has showed errorneous found when positioning smart robotic arm to desired coordinate. As reasons, defecting in smart robotic arm body in which the smart robotic arm is tilted from its base center. By designing an well body deisgn in smart robotic arm , the performance of existing smart robotic arm can be improved. Futhermore, the object recognition model is built and has showed a accurate performance. However, experiment 4 has showed that performance of object recognition model has a relation with the QR code condition. Thus, the image processing technique can be applied in order to enhance the quality of object recognition system. The next chapter concludes the project findings and recommend futher improvement.

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CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the all the objectives has been partially achieved where smart robotic arm for medication allocation application has been developed. The inverse kinematic model has been successfully constructed and able to provide the accurate inverse kinematic solution. The positioning control model of smart robotic arm is also built successfully in simulink environment and used in controlling smart robotic arm hardware through MicroBox 2000/2000C. However, the is minor error occurred due to imprefectly body of smart robotic arm. Besides, the code label object recognition model has been built using Raspberry Pi Camera Module V2 and OpenCV in Raspberry Pi Model 2B. However, the interfacing stage between the smart robotic arm with object recognition system is done manually to exchange data.

5.2 Future Works

In recommendation, a well built smart robotic arm is needed so that to prevent the errorenous due to the physical issues. Besides, it is highly recommended that a more powerful controller is required to replace the on off controller in that to enhance the performance of smart robotic arm in term of stability as well as accuracy. Moreover, the robotic dynamic is suggested to be considered when designing robot controller since it has dealt with the force issues in trajectory planning in robotics and hence to prevent the erroreous that leaded by dynamic issues. Lastly, an effective communication system between the smart robotic arm with object recognition model is necessary in order to increase the effeicency and autonomuos of smart robotic arm in medication allocation application.

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APPENDICES

APPENDIX A GNATT CHART OF FINAL YEAR PROJECT 1

No	Activity	Weeks														
		1	2	3	4	5	6	7	8	9	MB	10	11	12	13	14
Final Year Project (FYP) 1																
1	Title Registration	■														
2	FYP Talk	■	■	■	■	■	■									
3	Preparation of Logbook & Dicusssion with Supervisor		■	■	■	■	■	■	■	■	■	■	■	■	■	■
4	Library and Internet Research		■	■	■	■	■	■	■	■	■	■	■	■	■	■
5	Preparation of Draft Report									■	■	■	■	■	■	
6	Preparation Presentation Slide											■	■			
7	Seminar Presentation FYP 1												■			
8	Final Draft Report Submission														■	

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APPENDIX B GNATT CHART OF FINAL YEAR PROJECT 2

No	Activity	Weeks														
		1	2	3	4	5	6	7	MB	8	9	10	11	12	13	14
Final Year Project (FYP) 2																
	Objective 1															
1	Getting Start with MicroBox and Hardware Setup	■	■	■	■	■	■									
2	Designing of Robot Controller						■	■	■	■	■					
3	Designing of Inverse Kinematic Model										■	■	■	■		
	Objective 2															
1	Hardware Setup	■	■	■	■											
2	Designing of Object Recognition with Code Label									■	■	■	■	■		
	Objective 3															
1	Performance Evaulation of Smart Robotic Arm System													■	■	■
2	Performance Evaulation of Code Label Recognition													■	■	

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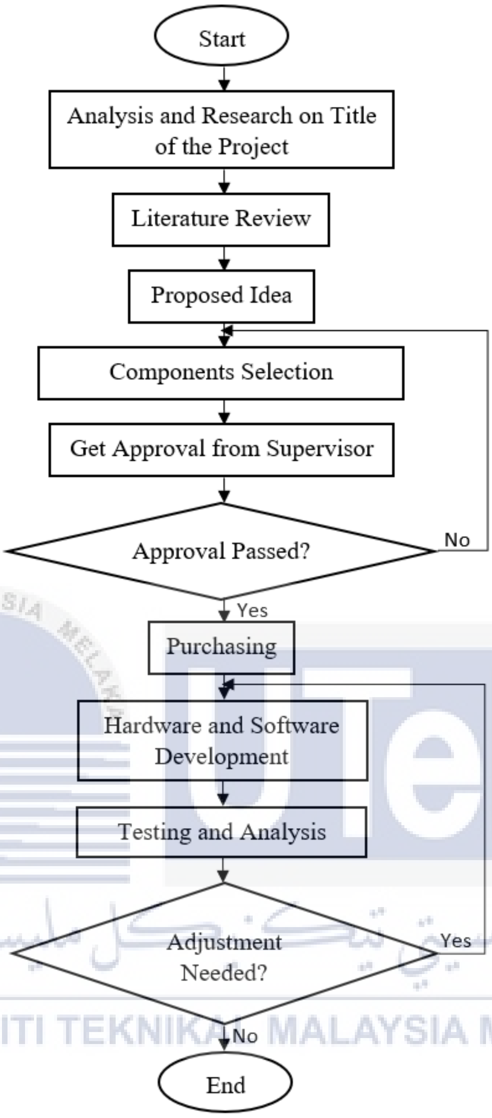
APPENDIX C PROJECT FLOW CHART



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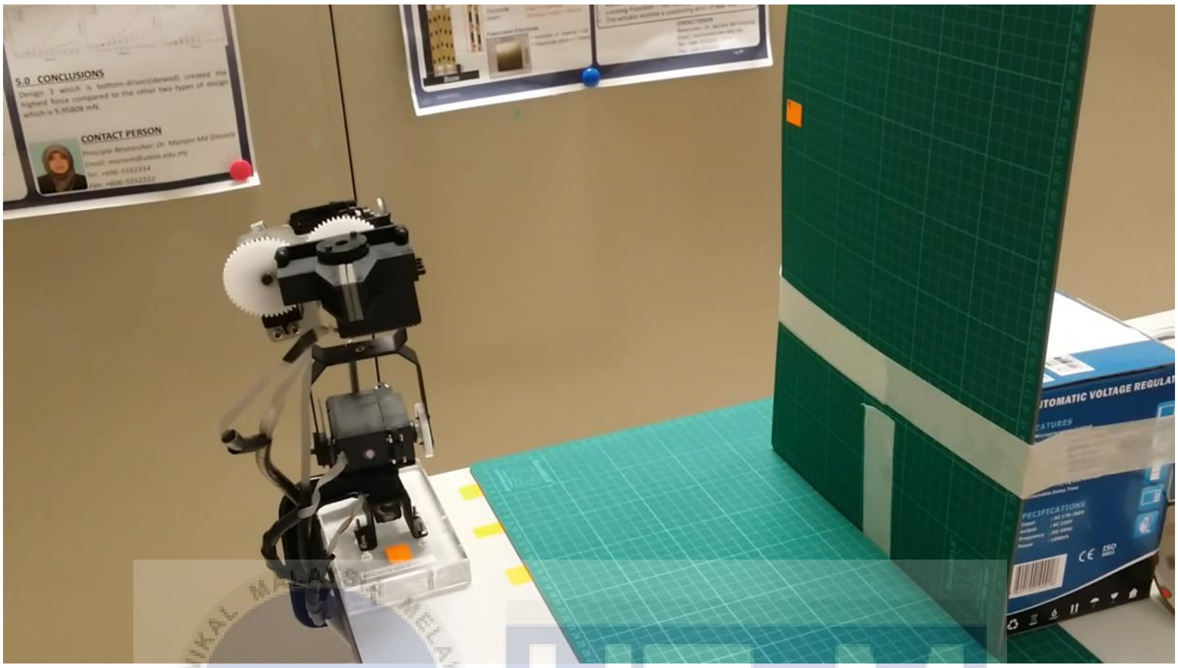
APPENDIX D EXPERIMENTAL SETUP



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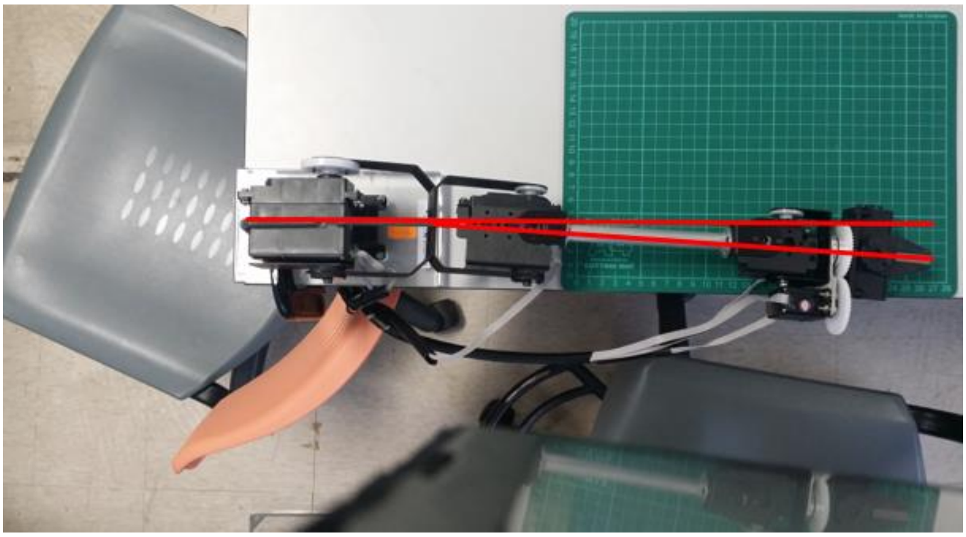
APPENDIX E SMART ROBOTIC ARM HARDWARE CONDITION



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