"I hereby declare that I have read through this report entitle "**Sensor based Collision Avoidance Manipulator**" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Mechatronics Engineering.

Signature : .....

Supervisor's Name : DR. AHAMD ZAKI BIN HJ SHUKOR

Date : .....

© Universiti Teknikal Malaysia Melaka

SENSOR BASED COLLISION AVOIDANCE MANIPULATOR

NG JACK KII

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

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

© Universiti Teknikal Malaysia Melaka

I declare that this report entitle "**Sensor based Collision Avoidance Manipulator**" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : NG JACK KII

Date : .....

© Universiti Teknikal Malaysia Melaka

To my beloved mother and father

© Universiti Teknikal Malaysia Melaka

ACKNOWLEDGEMENT

First and foremost, I wish to express my sincere appreciation to my FYP supervisor, Dr Ahmad Zaki Bin Haji Shukor, for constantly guiding and encouraging me throughout the development of FYP1. Thanks a lot for giving me an opportunity, advice and suggestion to bring this report to its final form. Without his support and interest, this project would not have been the same as presented here. I am very grateful to him for his patience and his constructive comments that enriched this

I would also like to acknowledge with much appreciation the crucial role of the tutor and the technician central rotating group, for their valuable comments, sharing their time and knowledge related to the project and giving a permission to use all the necessary tools in the laboratory. They have contributed towards my understanding and thoughts. And last but not least, thanks to my family for their continuous support and confidence in my efforts.

© Universiti Teknikal Malaysia Melaka

ABSTRACT

According to the 2013 Social Security Organization (SOCSO) Annual Report[1], from the total number of accident cases that reported in year 2013, there were more than half of the accident was occurring in the workspace. One of the reasons behind the fact is that worker nowadays needs to frequently undergoes human-robot interaction (HRI) in a robot workspace. In industrial environments where humans and robot manipulators co-exist, it is always a risk that humans get injured while operating alongside robot manipulators in its workspace. In fact, this kind of accidents do occur and in some cases, results in fatalities. Reasons include the negligence of the safety procedures from the human worker or any form of carelessness when the human operator is inside the manipulator's workspace. Industrial robots are rigid, performance-based machines, but can be equipped with sensors and algorithms to accommodate human presence in the work envelop. Hence, safety industrial robot which can perform its primary task, but at the same time take consideration about the worker safety is introduced to compromise and reduce the industrial accident. The objective of this paper is to propose a pre-contact sensor-based collision avoidance manipulator that adjusts its motion when a human presence is detected by using proximity sensors placed at different locations of the manipulator. The system performance is then analyzed in terms of sensor positioning for both simulation and hardware prototype. For the system design process, V-Rep robot simulator software is used. Through the simulation results, a system that covered the interfaces process between sensor and manipulator with collision avoidance function is being done. Ultrasonic sensor which under the category of proximity sensor is used in both platforms for the approaching obstacle detection purpose. While for the system performance test, two different position of sensors are being considered and results are compared between both platforms. The results obtained from the experiments indicate that although there are differences between simulation and hardware prototype, but the overall system performance is well-function by following the process flow chart.

.

© Universiti Teknikal Malaysia Melaka

ABSTRAK

Menurut kepada laporan tahunan 2013 daripada Pertubuhan Keselamatan Social (PERKESO)[1], daripda jumlah bilangan kes kemalangan yang dilaporkan pada tahun 2013, lebih daripada separuh kemalangan itu berlaku di ruang kerja. Salah satu faktor yang berkaitan dengan hakitatnya adalah bahawa pekerja pada masa kini perlu kerap menjalani kerja yang melibatkan interaksi antara manusia dengan robot di dalam ruang kerja robot. Malah, beberapa kes kemalangan industri telah berlaku dan menyebabkan kematian terhadap pekerja. Faktor terhadap isu ini adalah seperti kecuaian prosedur keselamatan daripada pekerja atau apa-apa bentuk kecuaian apabila pengendali manusia di dalam ruang kerja manipulator robot. Robot industry yang tegar, mesin berasaskan prestasi, tetapi boleh dilengkapi dengan pengesan dan algoritma untuk menampung kehadiran manusia dalam kawasan ruang kerja. Oleh itu, robot industry yang boleh melaksanakan tugas utamanya tetapi pada masa yang sama mengambil kira tentang keselamatan pekerja telah diperkenalkan untuk berkompromi dan mengurangkan kemalangan di sector perindustrian. Oleh itu, objektif kertas kerja ini adalah untuk mencadangkan satu manipulator robot yang boleh mengelakkan perlanggaran dengan menggunakan pengesan jarak yang diletakkan di beberapa lokasi di manipulator robot untuk mengesan gerakan menghampiri oleh manusia. Sistem ini kemudian dianalisis dari segi kedudukan sensor. Untuk proses reka bentuk sistem , V- Rep perisian robot simulator digunakan. Melalui keputusan simulasi , satu sistem yang meliputi proses interaksi antara pengesan dan manipulator dengan fungsi mengelakkan perlanggaran yang sedang dilakukan.Pengesna ultrasonik yang di bawah kategori pengesan jarak digunakan dalam simulasi dan perkakasan prototaip untuk tujuan mengesan halangan menghampiri. Manakala bagi ujian prestasi sistem, dua kedudukan yang berbeza untuk pengesan dipertimbangkan dan keputusannya dibandingkan. Keputusan yang diperolehi dari eksperimen menunjukkan bahawa walaupun terdapat perbezaan antara simulasi dan perkakasan prototaip, tetapi prestasi keseluruhan sistem adalah baik -fungsi dengan mengikuti carta aliran proses .

© Universiti Teknikal Malaysia Melaka

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	ACKNOWLEDGEMENT	**v**
	ABSTRACT	**vi**
	ABSTRAK	**vii**
	TABLE OF CONTENTS	**viii**
	LIST OF TABLES	**xi**
	LIST OF FIGURES	**xii**
	LIST OF SYMBOLS	**xvii**
	LIST OF APPENDICES	**xviii**
	CHAPTER 1	
	INTRODUCTION	**1**
	1.1 Motivation	1
	1.2 Problem Statement	4
	1.3 Objectives	5
	1.4 Scopes	6
	1.5 Thesis Organization	6
	CHAPTER 2	
	LITERATURE REVIEW	**7**
	2.1 Sensor System	7
	2.1.1 Projection-based Sensor System	7
	2.1.2 Vision Based Sensor System	10

© Universiti Teknikal Malaysia Melaka

2.1.3 Proximity Based Sensor System 13

2.1.4 Summary 17

2.1.5 Analysis of Sensor System 20

2.2 Collision Avoidance Strategy 21

2.2.1 Summary 25

2.2.2 Analysis of Collision Avoidance Strategy 28

2.3 Overall Summary 30

CHAPTER 3

METHODOLOGY 31

3.1 Introduction 31

3.2 The Process Flow Diagram 33

3.3 Hardware Selection 34

3.3.1 Arduino Mega 34

3.3.2 Ultrasonic Sensor 35

3.3.3 DC Geared Motor with Encoder 36

3.4 Process flow chart 38

3.5 Control Arduino with Simulink 40

3.6 Experiment Setup 41

3.6.1 Category 1: Manipulator and System Design 41

3.6.3 Workspace of a two links planar manipulator 46

3.6.2 Category 2: Performance Test 47

CHAPTER 4

RESULT AND DISCUSSION 53

4.1 Introduction 53

4.2 Simulation Result 54

4.2.1 System configuration 54

© Universiti Teknikal Malaysia Melaka

4.2.2 When no obstacle detected, manipulator run in normal mode. 55

4.2.3 When obstacle is detected in green region, manipulator run in limit speed. 57

4.2.4 When obstacle detected in yellow region, manipulator stop operation. 60

4.2.5 Discussion 62

4.3 Results from performance test 63

4.3.1 Workspace of the prototype two links planar manipulator 63

4.3.2 Position 1 (Near the end effector) 65

4.3.3 Position 2 (Top surface of the manipulator) 75

4.3.4 Discussion 88

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS 89

5.1 Conclusion and Recommendations 89

5.2 Recommendation 90

REFERENCES 92

© Universiti Teknikal Malaysia Melaka

LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1:	List of detail of the sensor used from previous study.	17
Table 2.2:	List of collision avoidance strategy from previous study.	25
Table 2.3:	Advantage and disadvantage of each collision avoidance strategy.	28
Table 3.1:	Physical characteristics of Arduino Mega.	34
Table 3.2:	Physical characteristics of ultrasonic sensor HC-SR04	36
Table 3.2:	Specifications of DC Geared Motor with Encoder SPG30E-60K	37

© Universiti Teknikal Malaysia Melaka

LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 1.1:	Occupational accidents by sector until August 2015 [1]	2
Figure 1.2:	Number accident reported, Malaysia, 2009-2013 [2]	3
Figure 2.1:	Internal robot model consisting of simple primitives like spheres, cylinders and cubes (red wired). [6]	8
Figure 2.2:	Processing scheme of the entire detection process.[5]	9
Figure 2.3:	Triple stereo vision with three camera system [7]	10
Figure 2.4:	Camera view with tracking positions [7].	11
Figure 2.5:	Obstacle detection result [9]	12
Figure 2.6:	WHAP Geometry and Electric Model. [10]	13
Figure 2.7:	Sensor and Brain Stem module mounted on the elbow of the arm [13].	15
Figure 2.8:	(Left) Schematic description of the whole sensor and (Right) scheme of system developed in [14].	16
Figure 2.9:	Definition of the distance value for each cell [17].	21
Figure 2.10:	Definition of the distance value for each cell [17].	22
Figure 2.11:	A framework of novel hybrid safety control strategy [16]	23
Figure 2.12:	Overall framework of the presented fuzzy based force feedback method for obstacle collision avoidance [19].	24
Figure 3.1:	Design cycle of a control system using HIL simulation	31

© Universiti Teknikal Malaysia Melaka

Figure 3.2:	Flow chart of overall process of project	33
Figure 3.3:	Arduino Mega	35
Figure 3.4:	Ultrasonic sensor.	36
Figure 3.5:	DC Geared Motor with Encoder SPG30E-60K	37
Figure 3.6:	Process flow chart	38
Figure 3.7:	(Left) User interface of Simulink; (Right) Arduino common blocks.	40
Figure 3.8:	The robot simulator, V-Rep.	41
Figure 3.9:	User interfaces of V-Rep.	42
Figure 3.10:	MTB robot.	42
Figure 3.11:	MTB robot properties dialog.	43
Figure 3.12:	The commands that supported by MTB robot.	43
Figure 3.13:	Custom user interface.	44
Figure 3.14:	(Left) Conical beam pattern; (Right) Cone type proximity sensor.	44
Figure 3.15:	Non-threaded child script.	45
Figure 3.16:	Illustration showing the two joint robotic arm with the two angles.	48
Figure 3.17:	Experiment 1 setup for position 1 (near the end effector).	48
Figure 3.18:	Experiment 1 setup for position 2 (top surface of manipulator links)	48
Figure 3.19:	The Scrip Parameter in V-Rep simulator that is able to change the walking speed of obstacle.	49
Figure 3.20:	The detection distance versus time graphs are plotted	49
Figure 3.21:	(Left) Position 1 (near the end effector); (Right) Position 2 (top surface of manipulator links).	50
Figure 3.22:	Experiment 1 setup.	50

© Universiti Teknikal Malaysia Melaka

Figure 3.23: (Left) Android application for Bluetooth controlled Arduino RC car; (Right) Speed measurement for Bluetooth controlled Arduino RC car. 51

Figure 3.24: Simulink model for system designed. 51

Figure 3.25: Signal monitoring using Simulink. 52

Figure 4.1: System configuration 54

Figure 4.2: Illustration of the obstacle is out of the range of detection. 55

Figure 4.3: The revolute joint 1 position (degree) versus time graph. 55

Figure 4.4: The revolute joint 1 angular velocity (degree/second) versus time graph. 56

Figure 4.5: The X-Y graph shows the trajectory of end effector 56

Figure 4.6: Illustration of the obstacle detected in green region. 57

Figure 4.7: The revolute joint 1 position (degrees) versus time graph when detecting obstacle in green region. 57

Figure 4.8: The revolute joint 1 angular velocity (degree/second) versus time graph when detecting obstacle in green region. 58

Figure 4.9: The distance of obstacle detected by the sensor (meter) versus time graph. 59

Figure 4.10: Illustration of the obstacle detected in yellow region. 60

Figure 4.11: The revolute joint 1 position (degree) versus time graph when detected obstacle in yellow region. 60

Figure 4.12: The revolute joint 1 angular velocity (degree/second) versus time graph when detected obstacle in yellow region. 61

Figure 4.13: The distance of obstacle detected by the sensor (meter) versus time graph. 61

Figure 4.14: Matlab code to generate data for the end-effector position. 63

© Universiti Teknikal Malaysia Melaka

Figure 4.15: The X-Y coordinates generated for all theta 1 and theta 2 combinations using forward kinematics formula. 64

Figure 4.16: Labelling of each sensor. 65

Figure 4.17: Left sensor reading from simulation. 66

Figure 4.18: Middle sensor reading from simulation. 67

Figure 4.19: The joint 1 position (degree) versus time graph. 68

Figure 4.20: The joint 1 angular velocity (degree/second) versus time graph. 68

Figure 4.21: Middle sensor reading from prototype. 70

Figure 4.22: Left sensor reading from prototype. 71

Figure 4.23: Right sensor reading from prototype. 72

Figure 4.24: The joint 1 position (degree) versus time graph.. 73

Figure 4.25: The joint 1 angular velocity (radian/second) versus time graph. 73

Figure 4.26: Labelling of each sensor. 75

Figure 4.27: The first right sensor reading from simulation. 76

Figure 4.28: The second right sensor reading from simulation. 77

Figure 4.29: The first left sensor reading from simulation. 78

Figure 4.30: The second left sensor reading from simulation. 79

Figure 4.31: The joint 1 position (degree) versus time graph. 80

Figure 4.32: The joint 1 angular velocity (degree/second) versus time graph. 80

Figure 4.33: The second left sensor reading from prototype. 82

Figure 4.34: The first right sensor reading from prototype. 83

Figure 4.35: The second left sensor reading from prototype. 84

Figure 4.36: The first left sensor reading from prototype. 85

© Universiti Teknikal Malaysia Melaka

Figure 4.37: The joint 1 position (degree) versus time graph. 86

Figure 4.38: The joint 1 angular velocity (radian/second) versus time graph. 86

© Universiti Teknikal Malaysia Melaka

LIST OF SYMBOLS

© Universiti Teknikal Malaysia Melaka

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
APPENDIX A	Gantt chart for FYP1	95
APPENDIX B	Gantt chart for FYP2	96

© Universiti Teknikal Malaysia Melaka

CHAPTER 1

INTRODUCTION

Motivation, problem statement, objective and the scope of the project will be covered in this chapter.

1.1 Motivation

On nowadays, the uses of automation robots in industrial sector become more common in order replace human workers in performing risky, tedious, difficult and monotonous tasks[2]. Sometimes, human workers also need to work in close cooperation with robots. In the resulting situations, human-robot interaction (HRI) becomes more frequent and unavoidable while at the same time creates the possibilities for an accident.

In Malaysia, the number of occupational accident took place in the manufacturing sector had recorded the highest number of victims in both non-permanent disability and permanent disability categories in the year 2015. However, based on the occupational accident statistics [3] by Department of Occupational Safety and Health (DOSH), Malaysia, other sector which contributed to the largest economic growth, such as construction, agriculture, forestry, logging and fishing also gave a higher number of accidents which caused death, non-

© Universiti Teknikal Malaysia Melaka

permanent disability and permanent disability. The reason behind all these occupational accidents occurred are mainly due to the lack of level of awareness toward safety and health among the workers which involve in the machinery handling operation. Moreover, human errors or known as unsafe act of a person that could potentially cause accident also must be considered as one of the factors.

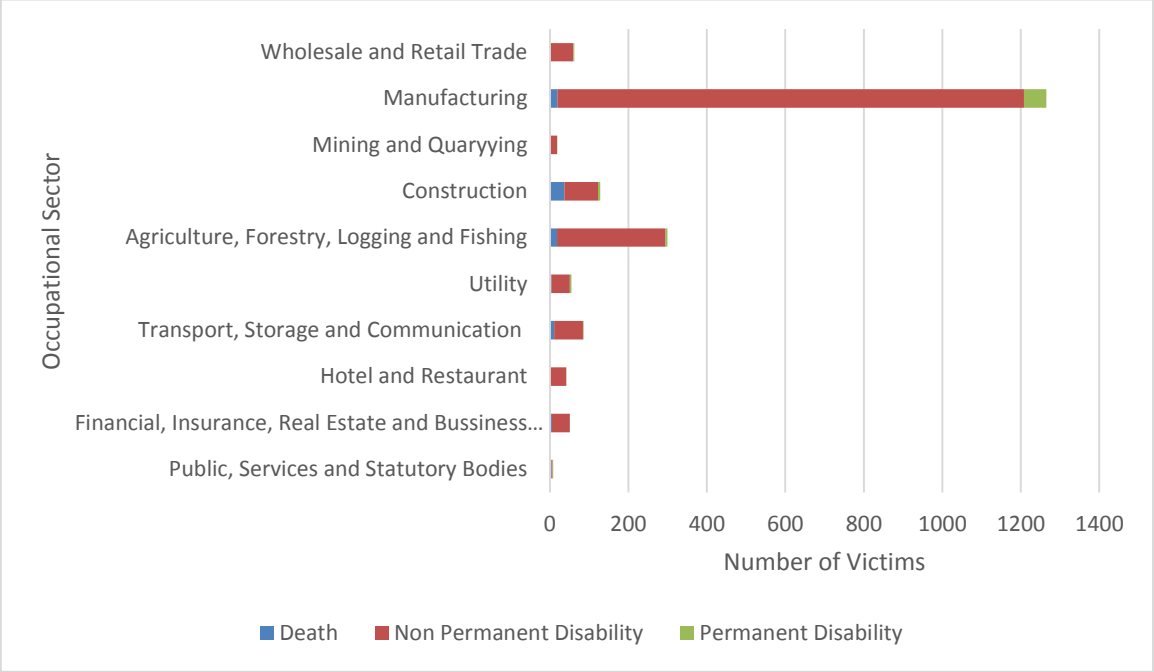

Figure 1.1: Occupational accidents by sector until August 2015 [1]

© Universiti Teknikal Malaysia Melaka

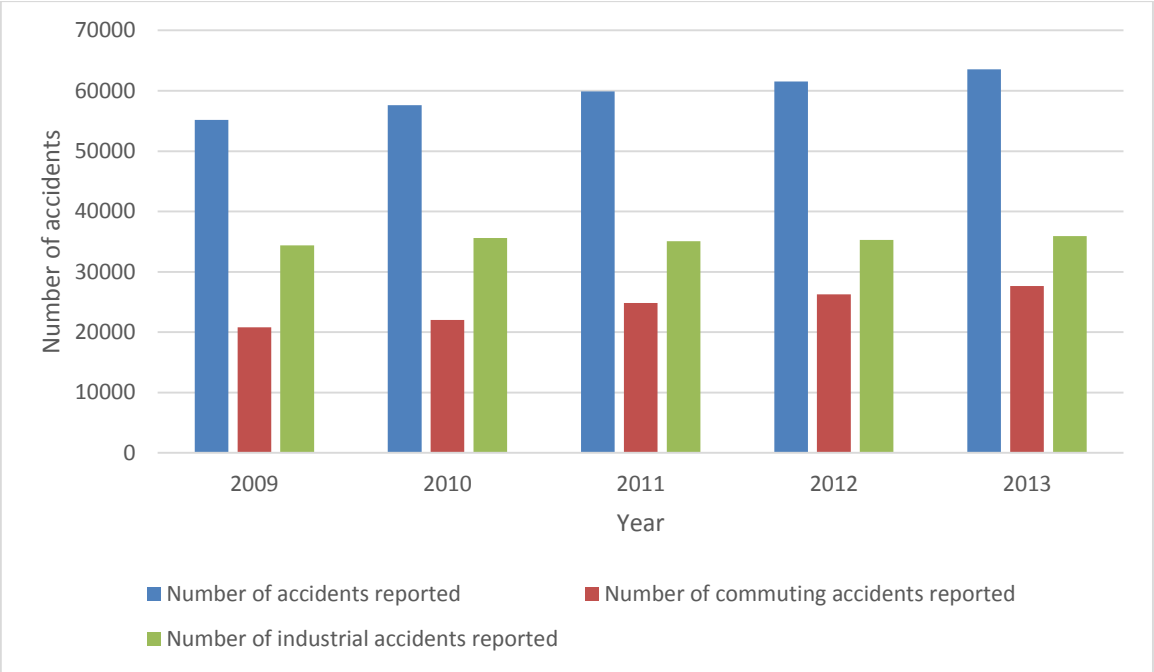

Figure 1.2: Number accident reported, Malaysia, 2009-2013 [2]

In addition, according to the 2013 Social Security Organization (SOCSO) Annual Report [2], a total of 63557 accident cases was reported in year 2013, there was an increased trend in the number of accidents reported from year 2009 (55186) to 2013 (63557). Of this total, 56.48 per cent accidents occurred in the workplace and the remaining 43.52 percent took place while travelling directly connected to the employment in year 2013. Industrial accidents in Malaysia have a fluctuate result from year 2009 to 2013 which inclined 1227 cases for the period of 2009 to 2010 then after 2010, there was a 1.44 per cent decrease of the number of industrial accidents to 35088 cases compared to 35603 cases in 2010. When the year 2012, the number of accident increase 1.71 per cent from 35296 cases to 35898 cases in year 2013 while for commuting accidents reported, the result shown an inclined trend by 32.91 per cent from 20810 cases in 2009 as compared to 27659 cases in 2010.

On 2nd July 2015, there was an industrial accident that involved a 22 year old contractor who works at a Volkswagen factory in Germany was killed by a stationary robot when he was trying to set it up [4]. According to the citing company spokesman, the death of a worker was mainly due to human error, but not because of a technical problem with the robot. The robot involved in the incident needs to perform various tasks in the assembly

© Universiti Teknikal Malaysia Melaka

process and normally operates within a restricted area at the factory. On that day, the worker was grabbed by robot and crushed him against a metal plate when he was standing in the safety cage. According to US government data, the fatality rate in the US in the years 2013 was about 2.1 for every 100,000 full time equivalent employees in manufacturing, while for the transportation equipment industry the fatality rate was just 0.9 per 100,000 employees which shown that it is more dangerous to work in the manufacturing area [2].

At last, from the statistic data given above and the Volkswagen incident which occurred a few month ago, its prove that although the development of technology is so rapid nowadays but without the safety control strategy or precaution for a certain technology, there still have a risk where it can causes harm in term of physically or mentally to the users and the workers involve. As we know, prevention is better than cure, rather than avoid any accidental contact with human by keeping a heavy robot behind safety cages, an improved safety strategy must be introduced to handle or manage the human-robot interaction process to become more secure and to avoid the issue of industrial accident.

1.2 Problem Statement

Exhaustion, distraction and in observance of hoarding procedures, lack of experience or following the wrong instructions for the initial robot start-up are considered as human mistakes and also one of the factors of industrial accident. Human mistakes are more controllable if compare with engineering error (Programming bugs, faulty electronics, defective algorithm of controller) and environmental factors (poor sensing due to haze or lighting condition, high temperature).

In reality, it is a complex task to build a robot which has a balance between performance and safety. Machines that have to perform heavy tasks like welding, cutting and molding are not attainable to have a perfect safety strategy in all contingencies. Physical safety barrier or safety gate to keep the robot is one of the commonly used safety strategy that installed out of the robot workplace. The purpose of having this safety barrier is to define a restricted area for robot against access by humans when the robot operation.

© Universiti Teknikal Malaysia Melaka

Other than teleoperation robot, some robot also required for collaboration between workers to complete the task given. Therefore, it's not a practical way to shut down the robot for collision avoidance. This problem can be solved by implement the force-torque sensor combine with the appropriate control method on the robot. The robot will react based on that real time moment when sensor reached the specify information required, such as force and direction, and then robot will be controlled by limiting the maximum allowable velocity of the robot's movement.

With the limit speed mode of the robot, still no adequate to ensure the safety of approaching worker because this will create an unexpected high axis speeds when motion of robot manipulator pass near the worker. In this situation, if the singularities are not possible to avoided, the robot needs to stop operation and warning or display precaution signal should be provided at that situation to increase the alertness among workers.

In this research, the main idea is to design or develop a sensor based manipulator's collision avoidance strategy that will detect approaching motion of human and produce a new reference trajectory for the manipulator to avoid collision with human.

1.3 Objectives

1. To design and develop a sensor based manipulator's collision avoidance system using robotics simulator.
2. To detect approaching motion of human motion using proximity sensor.
3. To analyze the system performance in term of position of sensors for both simulation and hardware prototype.

© Universiti Teknikal Malaysia Melaka

1.4 Scopes

1. The experiment is tested on a simple two link planar manipulator.
2. Arduino Mega is used as microcontroller to interface with sensor and manipulator.
3. The safety method is more focus on pre-contact strategy.
4. The rotation angle of revolute joint is limited to between 0 - 180 degree.
5. The experiment is done for two different position of sensor.
6. Only one obstacle is being considered in the system.

1.5 Thesis Organization

There are total 5 chapter in this report where each chapter is divided into subsections which will discuss on specific topic in detailed. In chapter 1, the motivation for designing a sensor based collision avoidance manipulator is explain first, followed by objective, scope and the problem statement of this project. While in chapter 2, there are consist of the method and sensor used from previous related work. Synthesis and analysis parts based on previous related work also will covered in chapter 2. Several theoretical analysis of the body of method and principles associated with the project needed to accomplish and this will be described in detailed in chapter 3. For the last two chapter, it will covered the preliminary result and conclusion parts of this report.

© Universiti Teknikal Malaysia Melaka