



**UNIVERSITI PUTRA MALAYSIA**

**ROBOT MANIPULATION TRAJECTORY PLANNING  
IN COMPLEX POSITION**

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**ITMA 2002 2**

**ROBOT MANIPULATION TRAJECTORY PLANNING  
IN COMPLEX POSITION**

**By**

**RAZALI SAMIN**

**Thesis Submitted to the Graduate School, Universiti Putra Malaysia,  
in Fulfilment of the Requirements for the Degree of Master of Science**

**January 2002**



## DEDICATIONS

To :

My Parents,

My Brothers

My Sisters



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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**January 2002**

**Chairman: Dr. Napsiah Ismail**

**Faculty : Institute of Advanced Technology**

The study proposed and demonstrated a strategy smooth trajectory planning to follow the path constrained with time optimal trajectories for the manipulator. The problem in trajectory planning was to find a smooth trajectory function and optimal joint optimisation processes. Such trajectories were obtained by considering the kinematics properties for velocities, accelerations and jerks profiles in joint coordinates for the end-effector to move the path constraints. The method was based on the position profile composed of three polynomial segments such as 4-3-4, 3-5-3 and 3-cubic trajectory and five polynomial segments for 5-cubic trajectory. These polynomial segments combination allowed the analytical solution to the minimum time trajectory problem under consideration of velocity, acceleration and jerk by using Mathematica software.

A number of simulations were performed to demonstrate the trajectory methods using robot simulation PUMA 560 model. The robot simulation model was developed using Mechanical Desktop software and the analytical analysis was done



using visualNastran software. The simulations showed that the trajectory ability methods for the investigation under varying time ratio conditions and the operations such as Pick and Place Operation (PPO) and Continuous Path (CP).

For comparison on varying time ratio 4-3-4 gave a reasonably smooth for normal trajectory condition and a ramp at middle segment to generate a minimum free-space time compared to 3-5-3 and cubic trajectories. For PPO and CP, 4-3-4 trajectory generated a lower values for accelerations and jerks compared to 3-5-3 and cubic trajectories. This showed the 4-3-4 trajectory was the best type of joint interpolated trajectory planning for any path planning operations.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia  
Sebagai memenuhi keperluan untuk ijazah Master Sains

## **PERANCANGAN TRAJEKTORI BAGI MANIPULASI ROBOT DI DALAM KEDUDUKKAN KOMPLEK**

**Oleh**

**RAZALI SAMIN**

**January 2002**

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Satu strategi telah dicadang dan ditunjuk ajar untuk perancangan trajektori yang lancar mengikut kekangan laluan dengan masa optimum untuk manipulasi. Masalah dalam perancangan trajektori adalah kesukaran mencari fungsi trajektori yang sesuai untuk proses-proses kelancaran dan masa yang optimum.

Trajektori boleh didapati dengan merujuk sifat-sifat kinematik untuk profil-profil kelajuan, pecutan dan getaran dalam koordinasi sambungan untuk “end-effector” bergerak mengikut kekangan laluan. Kaedah trajektori yang digunakan berdasarkan tiga segmen polinomial bagi 4-3-4, 3-5-3 and 3-cubic trajektori dan lima segmen polinomial bagi 5-cubic. Gabungan segmen polinomial ini membolehkan penyelesaian dan analisa terhadap masalah trajektori dengan masa yang minimum dibawah kelajuan, pecutan dan getaran dirujuk menggunakan perisian “Mathematica”.



Untuk simulasi pula, telah dijalankan terhadap kaedah trajektori menggunakan simulasi robot model PUMA 560. Model robot simulasi ini dibangunkan dengan perisian “Mechanical Desktop” dan kemudian analisa simulasi dijalankan menggunakan perisian “visualNastran 4D”. Keputusan simulasi menunjukkan kaedah trajektori boleh digunakan untuk menggerakkan robot dengan kajian dibawah keadaan berbeza mengikut nisbah masa dan operasi-operasi seperti PPO dan CP.

Keputusan simulasi menunjukkan perbandingan terhadap perbezaan nisbah masa telah memberikan trajektori 4-3-4 satu gerakan yang lebih lancar berbanding 3-5-3 dan cubic. Bagi operasi-operasi PPO dan CP, trajektori 4-3-4 juga menghasilkan nilai yang paling rendah untuk pecutan dan getaran berbanding 3-5-3 dan cubic. Ini menunjukkan trajektori 4-3-4 adalah jenis yang terbaik untuk perancangan trajektori bagi operasi-operasi rancangan laluan yang diambilkira.

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master of Science.

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## TABLE OF CONTENTS

		<b>Page</b>
DEDICATION		ii
ABSTRACT		iii
ABSTRAK		v
ACKNOWLEDGEMENTS		vii
APPROVAL		viii
DECLARATION		x
LIST OF TABLES		xiv
LIST OF FIGURES		xv
LIST OF ABBREVIATIONS		xxi
<b>CHAPTER</b>		
1	<b>INTRODUCTION</b>	1
	1.1 Introduction	1
	1.2 PUMA 560 Robot Manipulator	3
	1.3 Trajectory Planning	5
	1.4 Problem Statement	9
	1.5 Objectives	13
	1.6 Thesis Overview	13
2	<b>LITERATURE REVIEW</b>	14
	2.0 Introduction	14
	2.1 Type of Robot Motion	14
	2.1.1 Slew Motion	14
	2.1.2 Joint-Interpolated Motion	15
	2.1.3 Straight-line Motion	15
	2.1.4 Circular Interpolation Motion	16
	2.2 Robot Path Control	16
	2.2.1 Limited Sequence	16
	2.2.2 Point-to-point	17
	2.2.3 Controlled Path	19
	2.2.4 Continuous Path	20
	2.3 Trajectory Generation	21
	2.3.1 End-effector Path Specification	23
	2.3.2 Path Constraints	23
	2.3.3 Kinematics and Dynamics Constraints	23
	2.3.3.1 Kinematics Constraint	23
	2.3.3.2 Dynamics Constraint	25
	2.3.4 Optimisation Criteria	26
	2.3.5 Joint Trajectory	26
	2.4 Methods of Recording Trajectories	29
	2.5 Manipulator Trajectory Techniques	30
	2.5.1 Pick and Place Operation (PPO) Technique	30
	2.5.2 Continuous Path (CP) Operation	35
	2.6 The Kinematics of Six-Revolute Manipulators	39
	2.6.1 The Denavit-Hartenberg Notation	40



	2.6.2	Algorithm for D-H Representation	42
	2.6.3	Direct Kinematics	44
	2.6.4	Inverse Kinematics	46
2.7		Time-Optimal Motion	49
2.8		Description for Trajectory Planning Techniques	51
	2.8.1	The 4-3-4 Joint Trajectory	52
	2.8.2	The 3-5-3 Joint Trajectory	52
	2.8.3	Cubics Joint Trajectory	52
2.9		Mathematica Software	53
2.10		Mechanical Desktop	54
2.11		MSC.visualNastran Desktop 4D	55
3		METHODOLOGY	57
	3.1	Method Overview	57
	3.2	Object Location	59
	3.3	Knot Points Geometry Model	60
	3.4	Kinematics Modelling	60
	3.4.1	D-H for PUMA 560 Robot	61
	3.4.2	Kinematics Equations for RX90 Robot	62
	3.5	Trajectory Planning Method	63
	3.5.1	Joint-Interpolated Trajectories	64
	3.5.2	Derivation of the Joint-Interpolated Trajectory Polynomials	67
	3.5.2.1	The 4-3-4 Trajectory	67
	3.5.2.2	The 3-5-3 Trajectory	71
	3.5.2.3	The 3-Cubic Trajectory	75
	3.5.2.4	The 5-Cubic Trajectory	78
	3.5.3	Jerk Constraint	82
	3.6	Building a PUMA 560 Robot Model using Mechanical Desktop (MD)	83
	3.7	Viewing a PUMA 560 Robot model in VisualNastran	85
	3.8	Implementation and Simulation	86
	3.8.1	Generating The Interpolated Joint Trajectory Profiles	87
	3.8.2	Investigation on Varying Time Ratio Condition	88
	3.8.3	Trajectory Planning Implementation on Robot Simulation	89
4		RESULTS AND DISCUSSION	92
	4.1	The Joint Trajectories Under Varying Condition	92
	4.1.1	Positions, Velocities, Accelerations and Jerks in Varying Condition for Time Ratio ( $t_1 : t_2 : t_3 = 5.0 : 4.0 : 5.0$ )	95
	4.1.2	Positions, Velocities, Accelerations and Jerks in Varying Condition for Time Ratio ( $t_1 : t_2 : t_3 = 3.0 : 0.5 : 3.0$ )	107
	4.1.3	Positions, Velocities, Accelerations and Jerks in Varying Condition for Time Ratio ( $t_1 : t_2 : t_3 = 0.5 : 3.0 : 0.5$ )	111
	4.2	Simulation Results Based on PPO	115
	4.2.1	Simulation Results on 4-3-4 Joint Trajectory	116
	4.2.2	Simulation Results on 3-5-3 Joint Trajectory	118
	4.2.3	Simulation Results on Cubic Joint Trajectory	121

4.3	Simulation Results for CP Motion Planning	123
4.3.1	CP Motion for 4-3-4 Joint Interpolation Trajectory	124
4.3.2	CP Motion for 3-5-3 Joint Interpolation Trajectory	126
4.3.3	CP Motion for Cubic Joint Interpolation Trajectory	128
4.4	Result Analysis	130
5	CONCLUSIONS AND RECOMMENDATIONS	133
5.1	Conclusions	133
5.2	Recommendations for Future Research	134
	REFERENCES	136
	APPENDICES	141
	BIODATA OF THE AUTHOR	222



## LIST OF TABLES

Table		Page
3.1	D-H parameters for PUMA 560 robot	62
3.2	Constraints for planning joint-interpolated trajectory	66
3.3	Basic algorithms for generating joint trajectory.	87
4.1	The 4-3-4 trajectory results for condition time ratio 5.0 : 4.0 : 5.0	104
4.2	The 3-5-3 trajectory results for condition time ratio 5.0 : 4.0 : 5.0	105
4.3	The 3-cubic trajectory results for condition time ratio 5.0 : 4.0 : 5.0	105
4.4	The 5-cubic trajectory results for condition time ratio 5.0 : 4.0 : 5.0	106
4.5	The 4-3-4 trajectory results for condition time ratio 3.0 : 0.5 : 3.0	108
4.6	The 3-5-3 trajectory results for condition time ratio 3.0 : 0.5 : 3.0	109
4.7	The 3-cubic trajectory results for condition time ratio 3.0 : 0.5 : 3.0	109
4.8	The 5-cubic trajectory results for condition time ratio 3.0 : 0.5 : 3.0	110
4.9	The 4-3-4 trajectory results for condition time ratio 0.5 : 3.0 : 0.5	113
4.10	The 3-5-3 trajectory results for condition time ratio 0.5 : 3.0 : 0.5	114
4.11	The 3-cubic trajectory results for condition time ratio 0.5 : 3.0 : 0.5	114
4.12	The 5-cubic trajectory results for condition time ratio 0.5 : 3.0 : 0.5	115
4.13	The 4-3-4 joint trajectory results for PPO motion	118
4.14	The 3-5-3 joint trajectory results for PPO motion	120
4.15	The cubic joint trajectory results for PPO motion	122
4.16	The 4-3-4 trajectory results for CP planning motion	126
4.17	The 3-5-3 trajectory results for CP planning motion	128
4.18	The cubic trajectory results for CP planning motion	130



## LIST OF FIGURES

Figure	Page
1.1 PUMA 560 robot configuration	4
1.2 Path planning versus trajectory planning	5
1.3 The trajectory testing for ABB robot (ABB manual)	7
1.4 The cutting line for 100% ( $3.3 \text{ m/s}^2$ ) acceleration	8
1.5 The cutting line for 300% ( $10 \text{ m/s}^2$ ) acceleration	8
2.1 Point to point motion	17
2.2 Illustration of the path of the manipulator of a point to point robot as it moves from one point to another (combined horizontal and vertical movement)	18
2.3 Comparison of controlled-path and noncontrolled-path operation	19
2.4 Continuous path motion	20
2.5 (a) In continuous path, real time programming points are automatically programmed. (b) In point to point, the path generated is not easily predicted.	21
2.6 Trajectory generation planner.	22
2.7 A manipulator following a trajectory connecting point A and B.	27
2.8 A manipulator at a singular configuration interrupting the motion.	28
2.9 A manipulator that allows continuation of the motion.	28
2.10 Passive drive of a robot by an operator.	29
2.11 Manual control from a master station.	30
2.12 Time history of position with a cubic polynomial time law.	34
2.13 Time history of velocity with a cubic polynomial time law.	34
2.14 Time history of acceleration with a cubic polynomial time law.	34
2.15 Trajectories of pick and place task for Cartesian trajectories.	37

2.16	Trajectories of a pick and place task in joint trajectory of one joint.	38
2.17	The direct and inverse kinematics problem.	40
2.18	D-H represent the transformation matrix between links.	43
3.1	Proposed Method	58
3.2	Object to reference coordinate	59
3.3	The skeletal of PUMA 560 robot	61
3.4	A PUMA 560 robot modelling in Mechanical Desktop 5.	84
3.5	VisualNastran Menu in Mechanical Desktop.	84
3.6	A PUMA 560 Robot Model in visualNastran	86
3.7	Implementation of trajectory planning simulation profiles.	88
3.8	The checkbox for prescribed motion.	90
3.9	Prescribed motion dialog box shows the component	91
4.1	PUMA 560 robot simulation with EE tracking line motion	93
4.2	Cartesian trajectory for robot simulation movement.	94
4.3	Properties of constraint with rotation value.	94
4.4	The 4-3-4 Joint Trajectory for Position ( $t_1 : t_2 : t_3 = 5.0 \text{ s} : 4.0 \text{ s} : 5.0 \text{ s}$ )	96
4.5	The 3-5-3 Joint Trajectory for Position ( $t_1 : t_2 : t_3 = 5.0 \text{ s} : 4.0 \text{ s} : 5.0 \text{ s}$ )	96
4.6	The 3-cubic Joint Trajectory for Position ( $t_1 : t_2 : t_3 = 5.0 \text{ s} : 4.0 \text{ s} : 5.0 \text{ s}$ )	97
4.7	The 5-Cubic Joint Trajectory for Position (3.5s : 2.5s : 2.0s : 2.5s : 3.5s)	97
4.8	The 4-3-4 Joint Trajectory for Velocity (5.0s, 4.0s, 5.0s)	98
4.9	The 3-5-3 Joint Trajectory for Velocity (5.0s, 4.0s, 5.0s)	98
4.10	The 3-Cubic Joint Trajectory for Velocities (5.0s, 4.0s, 5.0s)	99
4.11	The 5-Cubic Joint Trajectory for Velocity (5.0s, 4.0s, 5.0s)	99
4.12	The 4.3.4 Joint Trajectory for Acceleration (5.0s, 4.0s, 5.0s)	100
4.13	The 3-5-3 Joint Trajectory for Acceleration (5.0s, 4.0s, 5.0s)	100

4.14	The 3-Cubic Joint Trajectory for Acceleration (5.0s, 4.0s, 5.0s)	101
4.15	The 5-Cubic Joint Trajectory for Acceleration (5.0s, 4.0s, 5.0s)	101
4.16	The 4-3-4 Joint Trajectory for Jerk (5.0s, 4.0s, 5.0s)	102
4.17	The 3-5-3 Joint Trajectory for Jerk (5.0s, 4.0s, 5.0s)	102
4.18	The 3-Cubic Joint Trajectory for Jerk (5.0s, 4.0s, 5.0s)	103
4.19	The 5-Cubic Joint Trajectory for Jerk (5.0s, 4.0s, 5.0s)	103
4.20	Robot simulation for trajectories of PPO for cartesian trajectories	116
4.21	Robot simulation for 4-3-4 joint trajectory PPO motion	117
4.22	4-3-4 cartesian trajectory planning for PPO	117
4.23	Robot simulation for 3-5-3 joint trajectory PPO motions	119
4.24	3-5-3 cartesian trajectory planning for PPO	120
4.25	Robot Simulation for cubic-spline joint trajectory PPO motion	121
4.26	Cubic cartesian trajectory planning for PPO	122
4.27	CP motion for 10 points operation	123
4.28	CP motion for 4-3-4 trajectory	125
4.29	CP motion for 3-5-3 trajectory	127
4.30	CP motion for cubic-spline trajectory	129
C1	4-3-4 Joint Trajectory for Position (3.0s : 0.5s : 3.0s)	176
C2	3-5-3 Joint Trajectory for Position (3.0s : 0.5s : 3.0s)	176
C3	3-Cubic Joint Trajectory for Position (3.0s : 0.5s : 3.0s)	177
C4	5-Cubic Joint Trajectory for Position (3.0s : 0.5s : 3.0s)	177
C5	4-3-4 Joint Trajectory for Velocity (3.0s : 0.5s : 3.0s)	178
C6	3-5-3 Joint Trajectory for Velocity (3.0s : 0.5s : 3.0s)	178
C7	3-Cubic Joint Trajectory for Velocity (3.0s : 0.5s : 3.0s)	179
C8	5-Cubic Joint Trajectory for Velocity (3.0s : 0.5s : 3.0s)	179





C9	4-3-4 Joint Trajectory for Acceleration (3.0s : 0.5s : 3.0s)	180
C10	3-5-3 Joint Trajectory for Acceleration (3.0s : 0.5s : 3.0s)	180
C11	3-Cubic Joint Trajectory for Acceleration (3.0s : 0.5s : 3.0s)	181
C12	5-Cubic Joint Trajectory for Acceleration (3.0s : 0.5s : 3.0s)	181
C13	4-3-4 Joint Trajectory for Acceleration (3.0s : 0.5s : 3.0s)	182
C14	3-5-3 Joint Trajectory for Acceleration (3.0s : 0.5s : 3.0s)	182
C15	3-cubic Joint Trajectory for Acceleration (3.0s : 0.5s : 3.0s)	183
C16	5-cubic Joint Trajectory for Acceleration (3.0s : 0.5s : 3.0s)	183
D1	4-3-4 Joint Trajectory for Position (0.5s : 3.0s : 0.5s)	184
D2	3-5-3 Joint Trajectory for Position (0.5s : 3.0s : 0.5s)	184
D3	3-Cubic Joint Trajectory for Position (0.5s : 3.0s : 0.5s)	185
D4	5-Cubic Joint Trajectory for Position (0.5s : 3.0s : 0.5s)	185
D5	4-3-4 Joint Trajectory for Velocity (0.5s : 3.0s : 0.5s)	186
D6	3-5-3 Joint Trajectory for Velocity (0.5s : 3.0s : 0.5s)	186
D7	3-Cubic Joint Trajectory for Velocity (0.5s : 3.0s : 0.5s)	187
D8	5-Cubic Joint Trajectory for Velocity (0.5s : 3.0s : 0.5s)	187
D9	4-3-4 Joint Trajectory for Acceleration (0.5s : 3.0s : 0.5s)	188
D10	3-5-3 Joint Trajectory for Acceleration (0.5s : 3.0s : 0.5s)	188
D11	3-Cubic Joint Trajectory for Acceleration (0.5s : 3.0s : 0.5s)	189
D12	5-Cubic Joint Trajectory for Acceleration (0.5s : 3.0s : 0.5s)	189
D13	4-3-4 Joint Trajectory for Jerk (0.5s : 3.0s : 0.5s)	190
D14	3-5-3 Joint Trajectory for Jerk (0.5s : 3.0s : 0.5s)	190
D15	3-cubic Joint Trajectory for Jerk (0.5s : 3.0s : 0.5s)	191
D16	5-cubic Joint Trajectory for Jerk (0.5s : 3.0s : 0.5s)	191
E1	Position profiles for 4-3-4 trajectory for pick-and-place operation	192



E2	Position profiles for 3-5-3 trajectory for pick-and-place operation	193
E3	Position profiles for cubic spline trajectory for pick-and-place operation	194
E4	Velocity profiles for 4-3-4 trajectory for pick-and-place operation	195
E5	Velocity profiles for 3-5-3 trajectory for pick-and-place operation	196
E6	Velocity profiles for cubic spline trajectory for pick-and-place operation	197
E7	Acceleration profiles for 4-3-4 trajectory for pick-and-place operation	198
E8	Acceleration profiles for 3-5-3 trajectory for pick-and-place operation	199
E9	Acceleration profiles for cubic-spline trajectory for pick-and-place operation	200
E10	Jerk profiles for 4-3-4 trajectory for pick-and-place operation	201
E11	Jerk profiles for 3-5-3 trajectory for pick-and-place operation	202
E12	Jerk profiles for cubic-spline trajectory for pick-and-place operation	203
F1	Joint 1 position, velocity and acceleration profiles for 4-3-4 trajectory for 10 points	204
F2	Joint 2 position, velocity and acceleration profiles for 4-3-4 trajectory for 10 points	205
F3	Joint 3 position, velocity and acceleration profiles for 4-3-4 trajectory for 10 points	206
F4	Joint 4 position, velocity and acceleration profiles for 4-3-4 trajectory for 10 points	207
F5	Joint 5 position, velocity and acceleration profiles for 4-3-4 trajectory for 10 points	208
F6	Joint 6 position, velocity and acceleration profiles for 4-3-4 trajectory for 10 points	209
F7	Joint 1 position, velocity and acceleration profiles for 3-5-3 trajectory for 10 points	210
F8	Joint 2 position, velocity and acceleration profiles for 3-5-3 trajectory for 10 points	211
F9	Joint 3 position, velocity and acceleration profiles for 3-5-3 trajectory for 10 points	212



F10	Joint 4 position, velocity and acceleration profiles for 3-5-3 trajectory for 10 points	213
F11	Joint 5 position, velocity and acceleration profiles for 3-5-3 trajectory for 10 points	214
F12	Joint 6 position, velocity and acceleration profiles for 3-5-3 trajectory for 10 points	215
F13	Joint 1 position, velocity and acceleration profiles for 3-5-3 trajectory for 10 points	216
F14	Joint 2 position, velocity and acceleration profiles for 3-5-3 trajectory for 10 points	217
F15	Joint 3 position, velocity and acceleration profiles for 3-5-3 trajectory for 10 points	218
F16	Joint 4 position, velocity and acceleration profiles for 3-5-3 trajectory for 10 points	219
F17	Joint 5 position, velocity and acceleration profiles for 3-5-3 trajectory for 10 points	220
F18	Joint 6 position, velocity and acceleration profiles for 3-5-3 trajectory for 10 points	221



## LIST OF ABBREVIATIONS

ABB	: Asea Brown Boveri Ltd
RIA	: Robotic Industries Association of America
CAD	: Computer Aided Drawing
CIM	: Computer Integrated Manufacturing
CP	: Continuous Path
D-H	: Denavit and Hertenberg
DOF	: Degree of Freedom
EE	: End-effector
ID	: Identity for specific item number
MD	: Mechanical Desktop
OCT	: Optimal Control Theory
PMP	: Pontryagin's Maximum Principle
PPO	: Pick and Place Operation
VisualNastran	: MSC.visualNastran Desktop 4D
$\tau$	: Torque for actuator
$\theta_i$	: is the included angle of axes $x_{i-1}$ and $x_i$
$\alpha_i$	: is the included angle of axes $z_{i-1}$ and $z_i$
3D	: Three Dimensions
4D	: Four Dimensions
$a$	: approach vector of the hand
$q_f$	: Final value for position
$q_i$	: Initial value for position
$s$	: sliding vector of the hand.
$t$	: Time in general



- $t_f$  : Final time  
 $t_i$  : Initial time  
  
 $w$  : Angular velocity  
  
 $z_{i-1}$  and  $z_i$  : are the axes of two revolute pairs  
 $a_i$  : is the distance between two feet of the common perpendicular  
 $d_i$  : is the distance between the origin of the coordinate system  $x_{i-1}, y_{i-1}, z_{i-1}$  and the foot of the common perpendicular  
 $I$  : Moment  
 $p$  : position vector of the hand  
 $n$  : normal vector of the hand

# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

Robotic is now firmly established as a critical manufacturing technology, believed for its reliability, accepted by today's workforce, and gaining in use at the multi-industries. Robot is also called robotic arm and known as fixed base manipulators that commonly found in industries.

Both fixed base manipulators and mobile robot conform to the *Robotic Industries Association of America (RIA)* defines a robot as “a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specified device through variable programmed motions for the performance of variety of tasks” (Daniela, C. 1998, Sciavicco, L. and Siciliano, B. 1996, and Fu, K.S. 1987). However, the focus for this work is on fixed base manipulator.

Industrial robot has seen a big shift in the applications where robots are applied and present three fundamental capacities that make them useful in manufacturing processes; material handling (e.g. palletising, part sorting and packaging), manipulation (e.g. arc and spot welding, spray painting, and laser and water jet cutting), and measurement (e.g. object inspection, contour finding and imperfect detection) (Sciavicco, L. and Siciliano, B. 1996). The high capability demands capable to perform complex tasks in minimum time.



A manipulator in general, is a mechanical system aimed at manipulating objects. Manipulating means to move something with one's hands, as it derives from the Latin *manus*, meaning *hand*. The basic idea behind the foregoing concept is that hands are among the organs that the human brain can control mechanically with the highest accuracy, as the work of an artist like Picasso, of an accomplished guitar player, or of a surgeon can attest (Angeles, J. 1997).

The manipulators have existed ever since the need for manipulating probe tubes containing radioactive substances during World War II (Fu, K.S. 1987 and Angeles, J. 1997). They have developed to the extent that they are now capable of actually mimicking motions of the human arm. Now, these mechanical devices emulation of the human arm or hand can be programmed to automatically manipulate objects in physical space and the real world.

The control of interaction between a robot manipulator and the environment is crucial for successful execution of a number of practical tasks where the robot end-effector (EE) has to manipulate an object or perform some operation on a surface. Typically examples include polishing, deburring, machining or assembly. A general strategy to control interaction with environment can be based on the number of degree of freedom (DOF) involved. During interaction, the environment set constraints on the geometric paths followed by EE. This situation is generally referred to as constrained motion.

When only the translation DOF of the motion are constrained, the interaction task can be classified as a 3-DOF task because only linear forces may arise during