**UNIVERSITI PUTRA MALAYSIA**

# ROBOT MANIPULATION TRAJECTORY PLANNING IN COMPLEX POSITION

**RAZALI SAMIN**

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# 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

**ROBOT MANIPULATION TRAJECTORY PLANNING IN COMPLEX POSITION**

**By**

**RAZALI SAMIN**

**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**


**Pengerusi:** **Dr. Napsiah Ismail**

**Fakulti :** **Institut Teknologi Maju**



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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| | |
|---|---|
| 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