



UNIVERSITI PUTRA MALAYSIA

**DESIGN AND DEVELOPMENT OF A TWO-DEGREE OF FREEDOM
SERIAL BALL AND SOCKET ACTUATOR WITH ADAPTIVE LEARNING
CONTROL ALGORITHM**

HAYDER M. A. ALI AL-ASSADI

FK 2008 49



**DESIGN AND DEVELOPMENT OF A TWO-DEGREE OF FREEDOM
SERIAL BALL AND SOCKET ACTUATOR WITH ADAPTIVE LEARNING
CONTROL ALGORITHM**

By

HAYDER M. A. ALI AL-ASSADI

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia
in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

April 2008



Dedication

**TO MY DAUGHTER LAYLA, MY WIFE, MY FATHER, MY FAMILY, AND
MY COUNTRY IRAQ**



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy

**DESIGN AND DEVELOPMENT OF A TWO-DEGREE OF FREEDOM
SERIAL BALL AND SOCKET ACTUATOR WITH ADAPTIVE LEARNING
CONTROL ALGORITHM**

By

HAYDER M. A. ALI AL-ASSADI

April 2008

Chairman: Associate Professor Datin Napsiah Ismail, PhD

Faculty: Engineering

The implementation of robot for various applications has increased dramatically and this attributed to the rise in demands and development in fundamental components. Two types of joints are commonly found in serial robot manipulator, revolute joints (provide rotation motion) and prismatic joints (provide translation motion). These joints are restricted to one degree of freedom, to simplify the mechanics, kinematic, dynamic, and control of the manipulator.

For more complex articulation such as human arm shoulder or leg hip joints, two revolute joints are required. The shoulder or hip joint; in biomedical literature, are usually considered as a ball and socket joint. In engineering the ball and socket joint is the mechanical connection used between parts to provide some relative angular motion in virtually all directions.

This study presents the development and implementation of a two degree of freedom serial ball and socket actuator controlled by an adaptive learning algorithm. The ball and socket actuator has been proposed as an alternative actuator to the conventional

one degree of freedom revolute actuator. The actuator is fabricated from ball and socket joint powered by two electro-hydraulic cylinders. An electronic board, transistor relay driver circuit, is designed for the purpose of establishing communication interface between the computer, adaptive learning algorithm and the actuator mechanism.

Artificial Neural Network (ANN) is the adaptive learning algorithm for controlling the ball and socket actuator. ANN is well-known algorithm that simulates the human brain ability of learning and predicting sets of information. In this approach, ANN will learn the controlling parameters to obtain the operation condition, for the mechanical and power elements, of each individual movement of the end effector rod without any prior knowledge of the actuator.

In addition, kinematic and dynamic simulation models of the ball and socket actuator were derived and modeled. These models represent the kinematic and dynamic relationships, implemented by using MATLAB/SIMULINK software package. In these models, full kinematic and dynamic simulations are achieved. All realistic factors such as position, velocity, acceleration, reactions, and forces, required to represent the real system accurately are incorporated.

The results from manually operating the ball and socket actuator are collected and analysed to demonstrate the performance of the newly actuator. The analysis includes the end effector dynamic behaviour for both the Cartesian and Spherical coordinates. The manually collected experimental controlling datasets had been provided for ANN to learn in off-line mode. Training process is carried out to build

controlling knowledge. The result of implementing the build controlling knowledge for on-line operating the ball and socket actuator shows a fully obeyed actuator end effector to the desired kinematic behaviour within the workspace. Finally, the results extracted from operating the kinematic and dynamic simulation are compared to the manual operation results for the both models validation technique.

The fabricated actuator has successfully achieved the two degree of freedom actuator to be implemented in a serial robot manipulator. Overall performance of the new ball and socket actuator shows an effective obey to the instruction from the adaptive learning algorithm. Thus, the adaptive learning algorithm as a controlling algorithm can adopt any modification in the actuator mechanism and hydraulic power system, without any changes in the controlling algorithm, through updating the controlling knowledge. Therefore, the two degree of freedom serial actuator powered by hydraulic system could add improvement to the serial robot manipulator for more degrees of freedom, flexibility and high load for any new applications.

Abstrak thesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**REKABENTUK PEMBANGUNAN DUA-DARJAH KEBEBASAN BEBOLA
BERSIRI DAN SOKET DENGAN ALGORITHMMA KAWALAN**

By

HAYDER M.A. ALI AL-ASSADI

April 2008

Chairman: Professor Madya Datin Napsiah bt Ismail, PhD

Fakulti: Kejuruteraan

Implementasi robot untuk pelbagai aplikasi telah meningkat dan menyebabkan peningkatan permintaan dan perkembangan komponen-komponen asas. Terdapat dua jenis penghubung yang biasa dijumpai pada pemanipulasi robot iaitu penghubung berputar (pergerakan berputar) dan penghubung prismatik (pergerakan translasi). Penghubung-penghubung ini terhad kepada satu darjah kebebasan untuk menerangkan mekanik, kinematik, dinamik dan kawalan pemanipulasi.

Bagi pergerakan yang kompleks contohnya seperti lengan (bahu) manusia atau penghubung peha, dua penghubung berputar diperlukan. Penghubung tangan (bahu) atau kaki; dalam literasi biodemik biasanya dianggap sebagai bebola dan penghubung soket. Dalam kejuruteraan, bebola dan penghubung soket adalah penghubung yang digunakan antara bahagian-bahagian untuk menghasilkan pergerakan dalam pelbagai arah maya.

Penyelidikan ini adalah tentang perkembangan dan implementasi bebola dan soket dua darjah kebebasan yang dikawal oleh pemadan pembelajaran algorithmma. Bebola dan soket telah dicadangkan sebagai alatan penggerak alternatif bagi alatan

penggerak berputar satu derajat pergerakan bebas. Alatan penggerak dihasilkan daripada bebola dan penghubung derajat kebebasan soket dan dikuasai oleh dua silinder elektro-hidraulik. Papan elektronik, litar transistar pemacu berganti dihasilkan untuk tujuan mengembangkan komunikasi antara komputer, menggerakkan kawalan pemadan pembelajaran algorithma dan mekanisma alatan penggerak.

Rangkaian sarat tiruan merupakan pemadan pembelajaran algorithma untuk mengawal bebola dan soket. Rangkaian sarat tiruan merupakan algoritma yang terkenal untuk mensimulasikan keupayaan pembelajaran bagi otak dan menganggarkan informasi. Dalam kajian ini, rangkaian sarat tiruan akan belajar mengawal parameter bagi memperoleh operasi untuk unsur mekanikal dan kuasa, setiap pergerakan batang pegasan tanpa pengetahuan asas mengenai alatan penggerak.

Tambahan lagi, model-model simulasi kinematik dan dinamik bagi alatan penggerak bebola dan soket telah dihasilkan. Model-model ini akan melambangkan hubungan kinematik dan dinamik, diimplementasi menggunakan perisian MATLAB/SIMULINK. Dalam model-model ini, simulasi kinematik dan dinamik yang lengkap dapat dicapai. Semua faktor realistik diperlukan untuk melambangkan sistem sebenar yang tepat. Faktor-faktor ini adalah seperti posisi, halaju, pecutan, tindakbalas dan daya yang dikira dalam simulasi.

Keputusan daripada operasi manual alatan penggerak bebola dan soket diperolehi dan dianalisa untuk demonstrasi keupayaan alatan penggerak baru. Analisa ini

merangkumi ciri-ciri dinamik hujung lengan bagi kedudukan kartesian dan polar. Data kawalan manual yang dikumpul untuk rangkaian sarat tiruan bagi mempelajari mod bukan dalam talian. Proses latihan dijalankan untuk menghasilkan pengetahuan tentang kawalan. Keputusan daripada implementasi operasi dalam talian untuk alatan penggerak bebola dan soket menunjukkan batang pegasan penggerak menurut arahan sepenuhnya bagi ciri-ciri kinematik yang diingini dalam kawasan kerja. Akhirnya, keputusan pengoperasian simulasi kinematik dan dinamik dibandingkan dengan keputusan operasi manual untuk bagi kedua-dua model. .

Alatan penggerak yang direka telah berjaya mencapai dua darjah kebebasan alatan penggerak untuk diimplementasi dalam robot manipulator bersiri. Keseluruhan pencapaian untuk alatan penggerak bebola dan soket baru menunjukkan keberkesanan mematuhi arahan daripada pemadan pembelajaran algorithma. Oleh yang demikian, pemadan pembelajaran algorithma sebagai algoritma kawalan dapat menerima apa-apa pengubahsuaian dalam mekanisma alatan penggerak dan sistem kuasa hidraulik tanpa apa-apa perubahan dalam algoritma kawalan, melalui kemaskini pengetahuan kawalan. Oleh itu dua darjah pergerakan bebas yang dikuasakan oleh sistem hidraulik dapat menambah perkembangan kepada pemutar robot bersiri bagi lebih banyak darjah pergerakan bebas, fleksibel dan beban tinggi bagi aplikasi-aplikasi yang baru.

ACKNOWLEDGEMENTS

All praise to supreme almighty Allah swt. the only creator, cherisher, sustainer and efficient assembler of the world and galaxies whose blessings and kindness have enabled the author to accomplish this project successfully.

The author gratefully acknowledges the guidance, advice, support and encouragement he received from his supervisor, Associate Professor Datin Dr. Napsiah Ismail who keeps advising and commenting throughout this project until it turns to real success.

Great appreciation is expressed to Associate Professor Dr. Ishak Bin Aris and Professor Dr. Abdel Magid Hamouda for their valuable remarks, help advice and encouragement.

Appreciation also to the Faculty of Engineering for providing the facilities and the components required for undertaking this study.

I certify that an Examination Committee met on (April, 30 2008) to conduct the final examination of Hayder M. A. Ali Al-Assadi on his Doctor of Philosophy thesis entitled “Design and Development of A Two-Degree of Freedom Serial Ball and Socket Actuator with Adaptive Learning Control Algorithm” in accordance with University Pertanian Malaysia (Higher Degree) Act 1980 and University Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Megat Mohamad Hamdan Megat Ahmad, PhD

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Shamsuddin Sulaiman, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Abd Rahman Ramli, PhD

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohd Marzuki Mustafa, PhD

Professor
Faculty of Engineering
Universiti Kebangsaan Malaysia
(Independent Examiner)

HASANAH MOHD GAZALI, Ph.D.

Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 22 July 2008

This thesis was submitted to the Senate of University Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Napsiah Ismail, PhD

Associate Professor
Faculty of Engineering
University Putra Malaysia
(Chairman)

Ishak Aris, PhD

Associate Professor
Faculty of Engineering
University Putra Malaysia
(Member)

Abdel Magid Hamouda, PhD

Professor
Faculty of Engineering
University of Qatar
(Member)

AINI IDERIS, PhD

Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 14 August 2008

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

HAYDER M. A. ALI AL-ASSADI

Date: 30 June 2008

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	vi
ACKNOWLEDGEMENTS	ix
APPROVAL	x
DECLARATION	xii
LIST OF TABLES	xvi
LIST OF FIGURES	xvii
LIST OF ABBREVIATIONS	xxii
CHAPTER	
I	
INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	4
1.3 Aim and Objective	6
1.4 Scope of Study	6
1.5 Thesis Contribution	7
1.6 Thesis Layout	7
II	
LITERATURE REVIEW	9
2.1 Introduction	9
2.2 Ball and Socket Joint	10
2.2.1 Mechanical Foundation	10
2.2.2 Applications in Biomechanical	12
2.2.3 Application in Parallel Robots	14
2.3 Robot Powering Systems	16
2.4 Computer Communication Interfaces	24
2.4.1 Parallel Port	27
2.5 Adaptive Learning Algorithm	32
2.5.1 Synaptic weights	34
2.5.2 Summation Neurons	35
2.5.3 Activation Function (Transfer Function)	35
2.5.4 Forward Propagation Algorithm	37
2.5.5 Backward Propagation Algorithm	39
2.5.6 Application of ANN as Controlling Algorithm	40
2.6 Numerical Simulation	42
2.6.1 Numerical Integration Method (Runge-Kutta)	43
2.6.2 Kinematics Simulation in Robotics	45
2.6.3 Dynamics Simulation in Robotics	47
2.7 Summary	49

III	MATERIALS AND METHODS	51
	3.1 Introduction	51
	3.2 Structure of Study	51
	3.2.1 Literature Review	53
	3.2.2 Experimental Study (Hardware development)	53
	3.2.3 Controlling Software (Software development)	58
	3.2.4 Numerical Simulation	61
	3.2.5 Validation of Ball and Socket Actuator	63
	3.2.6 Analysis the Results	63
	3.3 System Design	64
	3.3.1 Actuator Mechanism Design	64
	3.3.2 Hydraulic Power Circuit	67
	3.3.3 Communication Interface Board Design	70
	3.3.4 Controlling Approach Strategy	74
	3.3.5 Scaling Targets Controlling Data	80
	3.3.6 Adaptive Learning Algorithm	81
	3.3.7 Controlling Algorithm software	83
	3.3.8 Training the Controlling Algorithm	87
	3.4 Summary	90
IV	DEVELOPMENT OF KINEMATIC AND DYNAMIC SIMULATION	92
	4.1 Introduction	92
	4.2 Kinematic Simulation	92
	4.2.1 Vector Loop Equations	93
	4.2.2 Analysis of Position Equations	95
	4.2.3 Velocity Analysis Equations	96
	4.2.4 Analysis of Acceleration Equations	97
	4.2.5 MATLAB/SIMULINK Kinematic Simulation Model	100
	4.2.6 Error Equation for Kinematic Simulation	102
	4.3 Dynamic Simulation	103
	4.3.1 Analysis of Forces and Moments Equations	104
	4.3.2 Vector Loop Analysis Equations	108
	4.3.3 Vectors Equations for the Center of Gravity Accelerations	109
	4.3.4 MATLAB/SIMULINK Dynamic Simulation Model	111
	4.3.5 Error Equation for Dynamic Simulation	113
	4.4 Summary	115
V	RESULTS AND DISCUSSION	117
	5.1 Introduction	117
	5.2 Results of Fabricating the Ball and Socket Actuator	117
	5.3 Results of Training the Controlling Algorithm	140
	5.4 Kinematic Simulation Results	147
	5.5 Dynamic Simulation Results	163
	5.6 Summary	187

VI	CONCLUSION AND SUGGESTION	190
	6.1 Conclusion	190
	6.2 Suggestions and Future Work Recommendation	193
	REFERENCES	194
	APPENDICE A	200
	APPENDICE B	201
	APPENDICE C	212
	BIODATA OF THE STUDENT	224
	LIST OF PUBLICATIONS	225

LIST OF TABLES

Table		Page
2.1	The output state of the parallel port (DB25 cable)	29
4.1	The kinematics initial condition of the ball and socket actuator	102
4.2	Initial condition for dynamic simulation of the actuator mechanism	113
5.1	The assigned initial condition for the kinematic simulation	148
5.2	Operating condition for zero motion of the actuator mechanism	149
5.3	Operating condition for partial motion of the actuator mechanism	150
5.4	Operating condition for full motion of the actuator mechanism	151
5.5	Operating condition for motion from point (9) to point (6)	152
5.6	The assigned initial condition for the dynamic simulation	164
5.7	The inputs for zero motion and zero forces of the actuator mechanism	165
5.8	The inputs for partial motion scenario of the dynamic simulation	165
5.9	The inputs for full operation scenario of the dynamic simulation	166
5.10	The inputs for operating end effector rod from point (9) to point (6)	168
B1	The inputs for operating end effector rod from point (9) to point (4)	201
C1	The Measured Error vector for the dynamic simulation	212
C2	The linear parameters of link 3 and link 2	213
C3	The angular parameters for link 2	214
C4	The angular parameters for link 3	215
C5	The angular parameters for link 1	216
C6	Center of Gravity Acceleration for link 2 and link 1 in the x, y, and z coordinates	217
C7	Center of Gravity Acceleration for link 3 in x, y, and z coordinates	219
C8	Force generated at joint 0 and joint 13	220



C9	Force generated at joint 24 and joint 3	221
C10	Force generated at joint 4	222



LIST OF FIGURES

Figure		Page
2.1	The basic shape of a ball and socket joint	11
2.2	Ball and socket joint used in automotive applications	11
2.3	Moog hydraulic Valve	20
2.4	Indication of lines of printer parallel port	28
2.5	DB25 parallel port connection cable.	32
2.6	Nonlinear model shows the process of Artificial Neuron	34
2.7	Sigmoid activation functions for three different values of the slope parameters	36
3.1	Flowchart for the structure of study	52
3.2	A schematic drawing of the actuator mechanism	54
3.3	Flowchart of the developed actuator mechanism with adaptive learning algorithm.	64
3.4	The real fabricated actuator mechanism	65
3.5	The schematic diagram of the hydraulic circuit powered the actuator.	68
3.6	Actual implemented hydraulic system.	69
3.7	PC parallel port adaptor	70
3.8	The schematic circuit diagram of an individual transistor relay circuit	72
3.9	The real fabricated communication interface board	73
3.10	The digital vernier caliper utilized to measure the hydraulic cylinder length.	75
3.11	The achieved dimensions of the ball and socket actuator	76
3.12	The motion analyses of actuator mechanism with the achieved workspace area	78
3.13	Designed ANN adaptive learning algorithm model	82
3.14	The schematic diagram of controlling algorithm software	83
3.15	Flowchart for training function using forward and backward learning	85

3.16	Flowchart for Show_Result function using forward learning.	86
3.17	Percentage error acquired with iteration	88
4.1	The assigned three dimensions coordinate space	94
4.2	Assigned Spherical polar coordinate system	95
4.3	Kinematic simulation window for the ball and socket actuator	101
4.4	The developed kinematic simulation with error equation	103
4.5	The actuator mechanism elements with forces and reaction applied	105
4.6	SIMULINK diagram of dynamic simulation for the ball and socket actuator	112
4.7	The developed dynamic simulation with error equation	114
5.1	The allocated Cartesian coordinates for the actuator mechanism	119
5.2	The measured Cartesian coordinate for the actuator mechanism	119
5.3	A single point dataset of x, y, and z measured position for point one	120
5.4a	The measured positions of x- coordinate for the end effector rod	121
5.4b	The measured positions of y- coordinate for the end effector rod	121
5.4c	The measured positions of z- coordinate for the end effector rod	121
5.5	A single dataset of velocity in x, y, and z coordinates	123
5.6a	The calculated velocity in x- coordinates	124
5.6b	The calculated velocity in y- coordinates	124
5.6c	The calculated velocity in z- coordinates	124
5.7	A single dataset of accelerations in x, y, and z coordinates	125
5.8a	Calculated acceleration in x- coordinate	127
5.8b	Calculated acceleration in y- coordinate	127
5.8c	Calculated accelerations in z- coordinate	127
5.9	A single point dataset of angular displacements (ϕ) and (θ)	129
5.10	Angular displacement (ϕ) of end effector rod	130



5.11	Angular displacement (θ) of end effector rod	130
5.12	A single point dataset of angular velocity (ω_ϕ) and (ω_θ)	131
5.13	The calculated angular velocities (ω_ϕ) for the end effector	132
5.14	The calculated angular velocity (ω_θ) for the end effector rod	132
5.15	A single point dataset of angular accelerations (α_ϕ) and (α_θ)	133
5.16	The calculated angular acceleration (α_ϕ)	133
5.17	The calculated angular acceleration (α_θ)	134
5.18	Deviation between the theoretical and real angular displacement (ϕ)	136
5.19	Deviation between the theoretical and real angular displacement (θ)	137
5.20	Ball and socket actuator operated by the adaptive learning algorithm	141
5.21	The proposed points for the controlling approach	142
5.22	The predicted valve order by the adaptive learning algorithm	143
5.23	The predicted time by the adaptive learning algorithm	144
5.24	The error vector for zero motion of end effector rod.	150
5.25	The error vector with a partial motion of the actuator mechanism	151
5.26	The measured error vector after activating all the inputs	152
5.27	Linear displacement (r_3) of link 3	153
5.28	Linear velocity (\dot{r}_3) of link 3	154
5.29	Linear acceleration (\ddot{r}_3) for link 3	155
5.30	Linear displacement (r_2) of link 2	155
5.31	Linear velocity (\dot{r}_2) of link 2	156
5.32	Linear acceleration (\ddot{r}_2) for link 2	157
5.33	Values of θ_2 , $\omega_{\theta 2}$, and $\alpha_{\theta 2}$ for link 2 varying with time	157
3.34	Values of ϕ_2 , $\omega_{\phi 2}$, and $\alpha_{\phi 2}$, for link 2 varying with time	158

5.35	Values of θ_3 , ω_{θ_3} , and α_{θ_3} for link 3 varying with time	159
5.36	Values of ϕ_3 , ω_{ϕ_3} , and α_{ϕ_3} , for link 3 varying with time	160
5.37	Values of θ_1 , ω_{θ_1} , and α_{θ_1} for link 1 varying with time	160
5.38	The values of ϕ_1 , ω_{ϕ_1} , and α_{ϕ_1} for link 1 varying with time	161
5.39	The overall error vector for zero motion scenario	165
5.40	The error vector from the partial running of two cylinders, r_2 and r_3	166
5.41	The error vector from the full operation of the dynamic simulation	167
5.42	The linear displacement (r_3) of link 3	168
5.43	The linear velocity (\dot{r}_3) of link 3	169
5.44	The linear acceleration (\ddot{r}_3) of link 3	170
5.45	The linear displacement (r_2) of link 2	171
5.46	The linear velocity (\dot{r}_2) of link 2	171
5.47	The linear acceleration (\ddot{r}_2) of link 2	172
5.48	The centre of gravity acceleration ($A_{c1,x}$, $A_{c1,y}$, and $A_{c1,z}$) for link 1	173
5.49	The centre of gravity acceleration ($A_{c2,x}$, $A_{c2,y}$, and $A_{c2,z}$) for link 2	174
5.50	The centre of gravity acceleration ($A_{c3,x}$, $A_{c3,y}$, and $A_{c3,z}$) for link 3	175
5.51	The values of θ_2 , ω_{θ_2} , and α_{θ_2} varying with time	176
5.52	The values of ϕ_2 , ω_{ϕ_2} , and α_{ϕ_2} varying with time	177
5.53	The values of θ_3 , ω_{θ_3} , and α_{θ_3} varying with time	177
5.54	The values of ϕ_3 , ω_{ϕ_3} , and α_{ϕ_3} , varying with time	178
5.55	The values of θ_1 , ω_{θ_1} , and α_{θ_1} , varying with time	179
5.56	The values of ϕ_1 , ω_{ϕ_1} , and α_{ϕ_1} , varying with time	180
5.57	The computed forces $F_{0,x}$, $F_{0,y}$, and $F_{0,z}$ in joint J_0	181

5.58	The computed forces $F_{13,x}$, $F_{13,y}$, and $F_{13,z}$ in joint J_{13}	182
5.59	The computed forces $F_{24,x}$, $F_{24,y}$, and $F_{24,z}$ in joint J_{24}	183
5.60	The computed forces $F_{3,x}$, $F_{3,y}$, and $F_{3,z}$ in joint J_3	184
5.61	The computed forces $F_{4,x}$, $F_{4,y}$, and $F_{4,z}$ in joint J_4	185
B1	The linear displacement (r_2) of link 2	201
B2	The linear velocity (\dot{r}_2) of link 2	202
B3	The linear acceleration (\ddot{r}_2) of link 2	202
B4	The linear displacement (r_3) of link 3	203
B5	The linear velocity (\dot{r}_3) of link 3	203
B6	The linear acceleration (\ddot{r}_3) of link 3	204
B7	The centre of gravity acceleration ($A_{c1,x}$, $A_{c1,y}$, and $A_{c1,z}$) for link 1	204
B8	The centre of gravity acceleration ($A_{c2,x}$, $A_{c2,y}$, and $A_{c2,z}$) for link 2	205
B9	The centre of gravity acceleration ($A_{c3,x}$, $A_{c3,y}$, and $A_{c3,z}$) for link 3	205
B10	The values of θ_2 , ω_{θ_2} , and α_{θ_2} varying with time	206
B 11	The values of ϕ_2 , ω_{ϕ_2} , and α_{ϕ_2} varying with time	206
B12	The values of θ_3 , ω_{θ_3} , and α_{θ_3} varying with time	207
B13	The values of ϕ_3 , ω_{ϕ_3} , and α_{ϕ_3} , varying with time	207
B14	The values of θ_1 , ω_{θ_1} , and α_{θ_1} , varying with time	208
B15	The values of ϕ_1 , ω_{ϕ_1} , and α_{ϕ_1} , varying with time	208
B16	The computed forces $F_{0,x}$, $F_{0,y}$, and $F_{0,z}$ in joint J_0	209
B17	The computed forces $F_{13,x}$, $F_{13,y}$, and $F_{13,z}$ in joint J_{13}	209
B18	The computed forces $F_{24,x}$, $F_{24,y}$, and $F_{24,z}$ in joint J_{24}	210
B19	The computed forces $F_{3,x}$, $F_{3,y}$, and $F_{3,z}$ in joint J_3	210
B20	The computed forces $F_{4,x}$, $F_{4,y}$, and $F_{4,z}$ in joint J_4	211

LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
3D	Three Dimensional
DC	Direct Current
I/O	Input/Output
CPU	Central Processing Unit
TTL	Transistor Transistor Logic
ROM	Read-only Memory
RAM	Random-Access Memory
MOS	Read-Write Memory
PC	Personal Computer
LPT	Line Print Terminal
BIOS	Basic Input Output System
SPP	Standard parallel port
EPP	Enhanced Parallel Port
ECP	Extend Capability Port
MLPN	Multilayer Propagation Network
ANNNA	Artificial Neural Network Nonlinear Adaptive
USB	Universal Serial Bus

CHAPTER ONE

INTRODUCTION

1.1 Background

Robot manipulators play a leading role in almost all manufacturing processes. The effect of any enhancement will improve both the manufacturing process and the production rate. However, robots have the advantages of being deployed in dangerous environment, working for a longer period of time, and maintaining a high level of quality when completing task of a repetitive nature (Pryor, 2002).

Robotic systems are a class of dynamic systems which are closely parallel to a human's range of tasks. A robotic manipulator is composed of joints and links. Joints denote the prime mover and its respective axis of motion. The actuated motion may be revolution around the axis or a translation along the axis. These joints are known as revolute and prismatic joints, respectively. Links are connected by these joints.

The revolute joint has one Degrees Of Freedom (DOF) and because of its simplicity, it is by far the most used joint in robotics. Consequently, serial robot manipulator requires an individual revolute joint for each rotational degree of freedom. To imitate the shoulder or hip joint in human, two revolute actuators are required to provide the necessary 2 DOF motions. The present revolute actuator powered by electrical motor has some limitations, will be detailed in the problem statement.