UNIVERSITI MALAYSIA PAHANG

PENGISYTIHARAN TESIS

Nama Penuh Penulis : Wan Sulaiman Bin Wan Mohamad

Tarikh Lahir : 11 Januari 1980

Tajuk : A Study of Energy Utilisation in A Variable Link Length 3 DOF Revolute Articulated Manipulator

Sesi Akademik : Semester 2 2010/2011

Saya mengaku bahawa tesis ini diklasifikasikan sebagai:

☐	**SULIT**	(Mengandungi maklumat sulit di bawah Akta Rahsia Rasmi 1972)
√	**TERHAD**	(Mengandungi maklumat terhad seperti yang dinyatakan oleh organisasi di mana penyelidikan telah dijalakan)
☐	**CAPAIAN TERBUKA**	Saya bersetuju tesis saya diterbitkan sebagai capaian terbuka atas talian (seluruh teks)

Saya mengaku Universiti Malaysia Pahang mempunyai hak berikut:

1. Tesis ini adalah hakmilik Universiti Malaysia Pahang
2. Perpustakaan Universiti Malaysia Pahang mempunyai hak untuk membuat salinan bagi tujuan penyelidikan sahaja
3. Perpustakaan mempunyai hak untuk membuat salinan tesis bagi tujuan pertukaran akademik

_________________________	_________________________
Tandatangan	**Tandatangan Penyelia**
800111-06-5241	PROF MADYA DR WAN AZHAR BIN WAN YUSOFF
NO. KAD PENGENALAN	**NAMA PENYELIA**
Tarikh: 4 Julai 2011	Tarikh: 4 Julai 2011

A STUDY OF ENERGY UTILISATION IN A VARIABLE LINK LENGTH 3 DOF REVOLUTE ARTICULATED MANIPULATOR

WAN SULAIMAN BIN WAN MOHAMAD

Thesis submitted in fulfilment of the requirements
for the award of the degree of
Master of Engineering in Mechanical

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JULAI 2011

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Engineering in Mechanical.

Signature

Name of Supervisor: DR. WAN AZHAR BIN WAN YUSOFF

Position: ASSOCIATE PROFESSOR

Date: 4th JULAI 2011

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. This thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature

Name: WAN SULAIMAN BIN WAN MOHAMAD

ID Number: MMM 07001

Date: 4th JULAI 2011

TABLE OF CONTENTS

CHAPTER 2 LITERATURE REVIEW

CHAPTER 4 SIMULATION AND RESULTS

CHAPTER 5 EXPERIMENT AND RESULTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

$\omega\, or\, \dot{\theta}$	Angular velocity
d	Distance
θ	Angular position/displacement
α or $\ddot{\theta}$	Angular acceleration
Θ, Φ	Angles
t	Time
t_b	Blending time
E	Energy
E_{actual}	Actual energy
e_e, e_t, e_m	Electrical, thermal and mechanical efficiency respectively
τ	Torque
V	Velocity vector
R	Displacement vector
K	Kinetic energy
P	Potential energy
M,m	Mass
h	Height
I	Mass Moment of Inertia/ Product inertia
L	Lagrangian Function
g	Gravitational acceleration
L	Link length
X,Y,Z	Axes

LIST OF ABBREVIATIONS

LSPB	Linear segment parabolic blending
PC	Personal computer
AC	Alternating current
DOF	Degree of freedom
2D	Two-dimensional
3D	Three-dimensional
PE	Potential Energy
KE	Kinetic Energy
TE	Total Energy

ABSTRACT

Determination of manipulator link lengths is one of the important criteria in robotic design. Previous researches on link lengths optimization did not take much into account on the energy consumed by a manipulator's actuators. The purpose of this study is to find the minimum energy utilization for a 3 DOF revolute articulated manipulator to perform certain point-to-point task by varying the link lengths. The lengths of the second and third link of the developed manipulator can be varied accordingly. The investigation of energy for different link length combinations was carried out theoretically and experimentally. In the simulation, the work-energy method was constituted in order to determine the average mechanical energy of the manipulator. In the experiments, the actual energy of the system was calculated by multiplying the reading torque with the angular displacement of each link. Both energy for different link length combinations from the simulation and experiment were compared with the energy consumed by the fixed manipulator link length. These comparison yielded percentage savings. Then, the percentage savings from the simulation were compared with the percentage savings obtained from the experiments. The simulation shows that, different trajectory of motions results in different link length combinations that could give optimum average energy utilization. Results of the simulations and experiments show that, improved of mechanical energy utilization could be achieved by having variable link length of manipulator rather than having fixed length of manipulator's arms. The result of optimized link length from the experiment shows that the saving of energy utilization could be achieved up to **16.73 %** corresponding to the **19.66 %** saving obtained from the simulation. All in all, the use of the variable link length manipulator is utterly important as far as energy saving is concerned.

REFERENCES

Ashitava, Ghosal. 2006. *Robotics Fundamental Concepts and Analysis*. New Delhi: Oxford University Press.

Bagchi, Sandipak. 2005. *Design optimization and synthesis of manipulators based on various manipulation indices*. Ms Thesis. University of Texas.

Banga, V. K., Singh, Y., and Kumar, R. 2007. Simulation of robotic arm using Genetic Algorithm and AHP. *Proceedings of World Academy of Science, Engineering and Technology,* pp. 95-101.

Baruh, Haim 1999. *Analytical dynamics*. WCB: McGraw-Hill.

Berner, D. F. and Snyman, J. A.. (1998). The Influence of Joint Angle Constraints on the Optimum Design of a Planar Robot Manipulator Following a Complicated Prescribed Path. *An International Journal Computers and Mathematics with Applications* **37**: 111-124.

Bobrow, JE, Dubowsky S, Gibson JS. 1985. Time-optimal control of robotic manipulators. *International Journal Robotics*. **4**(3):3–17.

Brady, M. Hollerbach, J.M., Johnson,T.L., T. Lozano-Perez, and Mason,M. T.1982. Robot Motion: Planning and Control. MIT Press, Cambridge, Mass.

Brian, Bramer, Susan Bramer 1997. *C For Engineer*: 2nd ed. USA: John Wiley & Sons, Inc.

Chettibi, Taha. 2006. Synthesis of dynamic motions for robotic manipulators with geometric path constraints. *Journal of Mechatronics*. **16**: 547–563.

Craig J.J. 2005. *Introduction to Robotics: Mechanics and control.* 3rd ed. New Jersey. Prentice Hall.

Copty, N. 2008. *OpenMP specifications 3.0*. SD West, Santa Clara, CA: Sun Microsystems.

Corke, PI. 1996. A Robotics toolbox for MATLAB. *Journal of Robotics and Automation*. **3**(N1): 24–32.

Denavit, J, and R.S. Hartenberg. 1955. A kinematic notation for lower- pair mechanisms based on matrices. *Journal of Applied Mechanics*. **108**: 215-221.

Dombre, Etienne, Wisama Khalil. 2007. *Robot manipulators: modeling, performance, analysis, and control*. UK: ISTE ltd.

Friedman, R. 2009. OpenMP compilers (online). http://openmp.org/wp/openmp-compilers/ (November 2009).

Garg, Devendra P. and Kumar, Manish. 2002. Optimization techniques applied to multiple manipulators for path planning and torque minimization. *Journal of Engineering Application of Artificial Intelligent*. **15**: 241–252.

Gasparetto,A. and Zanotto, V. 2006. A new method for smooth trajectory planning of robot manipulators. *Journal of mechanism and machine theory*. **42**: 455–471.

Guillaume, Morel., Iagnemma, Karl. and Dubowsky, Steven. 1999. The precise control of manipulators with high joint-friction using base force/torque sensing. *Journal of Automatica*. **36**: 931-941.

Hibbeler, R.C. 2004. *Engineering mechanics dynamics*: 3rd ed. Singapore: Prentice-Hall, Inc.

Hannah, J. and Stephens, R.C. 1970. *Mechanics of machines*. 3rd ed. UK: Edward Arnold Ltd.

Herman, Przemysław. 2008. Dynamical couplings reduction for rigid manipulators using 3 generalized velocity components. *Mechanics Research Communications*. **35**: 553-561.

Huang, B., Milenkovic, V. 1983. Kinematics of major robot linkages. *Robotics International of SME*, pp. 16–31.

Hossain Md.Zubaer, Souvenir Muhammad and TAGM Zaki Nuruddin Jubery. 2004. Dynamics analysis of 2-link revolute joint robot manipulator. *3rd International Conference on Electrical & Computer Engineering ICECE*, pp. 222-225.

Jazar, Reza N. 2007. *Theory of Applied Robotics: kinematics, dynamics, and control*. New York: Springer.

Kang, GS. and McKay DN. 1985. Minimum-time control of robotic manipulators with geometric path constraints. *IEEE Trans Automation Control*; AC-30(6).

Karlik, Bekir, Aydin. Serkan. 1999. An improved approach to the solution of inverse kinematics problems for robot manipulators. *Engineering Applications of Artificial Intelligence*. **13** (2000): 159-164.

Klafter, Richard D., Chmielewski Thomas A., Negin Michael. 2006. *Robotics Engineering, An integrated approach*. India: Prentice- Hall of India Private Limited.

Koren, Yoram. 1976. *Robotics for Engineers*. USA: McGraw-Hill Book Company.

Koren, Yoram. 1983. *Computer Control of Manufacturing Systems*. USA: McGraw-Hill, inc.

Kucuk, Serdar. and Bingul, Zafer. 2006. Comparative study of performance indices for fundamental robot manipulators. Journal of Robotics and Autonomous Systems. **54**: 567–573.

Leary, Warren. 1992. Robot named Dante to explore inferno of Antarctic volcano. *The New York Times*. 8 December: B7.

Loduha, T.A., Ravani, B. 1995. On first-order decoupling of equations of motion for constrained dynamical systems. *Transactions of the ASME Journal of Applied Mechanics*. **62**: 216–222.

Lou, Yunjiang. 2006. *Optimal design of parallel manipulator*. Ms Thesis. The Hong Kong University of Science and Technology.

Marcelo R.M. Crespo Da Silva. 2004. *Intermediate Dynamics: complemented with simulations and animations*. USA: McGraw-Hill.

Mark, Austin, Chancogne David. 1999. *Engineering Programming C, Matlab, Java.* USA: John Wiley & Sons, Inc.

Mattson, T. dan Eigenmann, R. 1999. OpenMP: an API for writing portable SMP application software. (Online). http://www.openmp.org/presentations/sc99/sc99_tutorial.pdf (Februari 2010)

Meriam, J.L., L.G.Kraige. 2003. *Engineering Mechanics Dynamics: 5th ed*. USA: John Wiley and Son, Inc.

Merkel, H., Thomas, C. 1998. Optimization of Robotic Manipulator Base Position Using Total Joint Motion. Phd. Thesis. North Dakota State University.

Mooring, B.W., Roth, Z.S., Driels, M.R., 1991. *Fundamentals of Manipulator Calibration*. USA : Wiley.

Morel, G. and Dubowsky, S. 1996. The Precise Control of Manipulators with Joint Friction: A base force/torque sensor method. *Proceedings of the IEEE international conference on robotics and automation*. **1**:360-365.

Niku, Saeed. 2001. *Introduction to Robotics; analysis, systems, application*. USA: Prentice Hall.

Nise. Norman S, 2003.*Control System Engineering*: 4th ed. USA: John Wiley and Son, Inc.

Palm III, William J. 2005. *Introduction to Matlab 7 for Engineers*. Singapore: McGraw-Hill Companies.

Rehg, James A. 2003. *Introduction to Robotics in CIM Systems*: 5th ed. USA: Prentice – Hall.

Salisbury, Kenneth, Jr. 1998. The Heart of Microsurgery, *Mechanical Engineering*, pp. 46-41.

Saramago, S.F.P and Steffen Jr., V.1997.Optimization of the trajectory planning of robot manipulators taking into account of the dynamics of the system. *Journal of mechanical and machine*. **33**(7): 883-894.

Schildt, Herbert 1997. *Teach Yourself C*: 3rd ed. USA: McGraw-Hill Companies.

Schilling R.J. 1990. *Fundamental of Robotics*: *Analysis and control*. USA: Prentice Hall Inc.

Shigley Joseph E., Charles R.Mischke. 2001. *Mechanical Engineering Design*.6th ed. Singapore : McGraw-Hill Companies, Inc.

Spong, Mark., Hutchinson, Seth., and Vidyasagar. 2006. *Robot Modeling and Control*. USA: John Wiley & Sons, inc.

Sun, S.D., A.S. Morris, A.M.S. Zalzala. 1996. Trajectory planning of multiple coordinating robots using genetic algorithms. *Journal of Robotica*. **14**: 227–234.

Tabarah, E. B. Benhabib, R.G. Fenton. 1994. Optimal motion coordination of two robots–a polynomial parameterization approach to trajectory resolution. *Journal of Robotic*. **11** (7): 615–629.

The international Federation of Robotics, and the United Nations, "World robotics 2001," Statistics, Market Analysis, Forecasts, Case studies and Profitability of Robot Investment, United Nations Publication, New York and Geneva, 2001.

Tsai, Ying Chien. 1982. *Synthesis of robots/manipulators for a prescribed working space*. Phd. Thesis. Oklahama State University.

Wan Yusoff, W.A. 2003. *Efficient reference-pulse CNC interpolator utilizing general parametric curve*. Ph.D. Thesis. Universiti Sains Malaysia, Malaysia.

Wells, Dare A. 1967. *Theory and Problems of Lagrangian Dynamics, with a Treatment of Euler's Equations of Motion, Hamilton's Equations, and Hamilton's Principles*. USA: McGraw-Hill McGraw-Hill. , Inc.

Zha, Xuan F. 2002. Optimal pose trajectory planning for robot manipulators. *Journal of Mechanism and Machine Theory*. **37**: 1063–1086.

Zhihong, Man. 2005. *Robotics*: 2nd ed. Singapore: Prentice –Hall.