MODELING, POSITION AND VISCOSITY CONTROL OF INTELLIGENT PNEUMATIC ACTUATOR

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Specially dedicated to

my beloved parent, siblings, and friends who always give spiritual support to me

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ABSTRACT

Intelligent pneumatic actuator (IPA) is a new developed actuator which integrates actuator, and others new features such as microcontroller and various micro sensors. This type of actuator has the capability to communicate with computer to give better control, higher position and force accuracy. In prior to that, several experimental setup for the stiffness and viscosity control had been done using conventional PI controller. The previous experimental results showed that these control algorithms were feasible for the real IPA system. In this project, the work focuses more on the reverse engineering method, which is from existing real IPA system which had been developed by Dr. Ahmad 'Athif Mohd Faudzi, to simulation analysis for the validation of other controllers. The objectives of this project are to develop a simulation model to represent the real IPA system, and design other controllers to be applied in this developed simulation model. For the simulation model, nonlinear mathematical modeling based on fundamental physical derivation is presented. Open-loop and closed-loop simulation works are done to confirm this model based on this derivation. Closed-loop IPA system is divided into two main control algorithms, which are position control for position tracking control and viscosity control for force tracking control. Several controllers which are related to the fuzzy logic are designed and applied to these control algorithms. The simulation results from these controllers are then validated and compared with result of using conventional PI controller. The comparison is made by analyzing their performances based on control theory. Lastly, due to the nonlinearities problem exist in nonlinear mathematical model, linearization method is proposed to obtain a new linear model to ease the controller design and analysis. For the future research, it is recommended to implement all the proposed controllers to the real-time IPA system.

ABSTRAK

Aktuator pneumatik pintar (IPA) adalah aktuator baru yang menggabungkan aktuator, dan ciri-ciri baru lain seperti pengendali mikro dan pelbagai sensor mikro. Aktuator jenis ini mempunyai keupayaan untuk berkomunikasi dengan komputer untuk memberi kawalan yang lebih baik, serta kedudukan dan daya yang tepat. Sebelum itu, beberapa setup eksperimen berdasarkan kekukuhan dan kelikatan dengan menggunakan pengawal PI konvensional, telah dijalankan. Keputusan daripada setup eksperimen itu menunjukan bahawa algoritma kawalan itu boleh dilaksanakan untuk sistem IPA yand sebenar. Dalam projek ini, kerja-kerja adalah ditumpu kepada kaedah kejuruteraan undur, bermaksud daripada sistem IPA yang sebenar kepada simulasi analisis untuk pegesahan pengawal lain. Tujuan-tujuan bagi projek ini adalah untuk membuat satu model simulasi bagi mewakili sistem IPA sebenar, serta mereka pengawal lain untuk diaplikasikan dalam model simulasi ini. Model matematik tidak linear berdasarkan terbitan fizikal asas dibentangkan bagi model simulasi ini. Kerja-kerja untuk simulasi gelung terbuka dan gelung tertutup dilakukan untuk mengesahkan model ini adalah betul. Kemudian sistem IPA gelung tertutup boleh dibahagikan kepada dua algoritma kawalan utama, iaitu kawalan kedudukan untuk mengawal kedudukan dan kawalan kelikatan untuk mengawal daya. Beberapa pengawal yang berdasarkan fuzzy logik direka and digunakan untuk kedua-dua algoritma kawalan itu. Selepas itu, semua keputusan daripada simulasi dibandingkan dengan hasil daripada menggunakan pengawal PI konventional. Perbandingan itu dibuat dengan menganalisis prestasi mereka berdasarkan teori kawalan. Akhir sekali, disebabkan masalah tidak lelurus wujud dalam model matematik tidak linear, maka kaedah ‘pelinearan’ dicadangkan untuk mendapatkan model linear yang baru. Bagi penyelidikan masa depan, pengawal-pengawal baru yang direka boleh diimplikasikan kepada sistem IPA yang sebenar.

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LIST OF SYMBOLS AND ABBREVIATIONS

3D	-	Three dimension
ANFIS	-	Adaptive neuro-fuzzy inference system
CAD	-	Computer-aided design
CAM	-	Computer-aided manufacturing
DC	-	Direct current
FIS	-	Fuzzy inference system
FLC	-	Fuzzy logic controller
GUI	-	Graphical user interface
IC	-	Integrated circuit
IPA	-	Intelligent pneumatic actuator
LED	-	Light emitting diode
MIMO	-	Multi input multi output
MISO	-	Multi input single output
PASS	-	Pneumatic Actuator Seating System
PI	-	Proportional-integral
PSoC	-	Programmable system on chip
PSPM	-	Permanent magnet synchronous motor
PWM	-	Pulse-width modulation
RMSE	-	Root mean square error
SI	-	System identification
VRML	-	Virtual reality modeling language

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CHAPTER 1

INTRODUCTION

1.1 Overview of the project

In the new era of technology world, actuators were invented and applied in various fields. There are many types of actuators: electromagnetic, electrostatic, piezoelectric, pneumatic and hydraulic actuators. These actuators not only used for automation applications in many industries, they are also being used in others applications such as home applications, micro machines, medical applications, in special environments and in physical human-machine applications.

One of the popular types of actuators is pneumatic actuators. Terminology of pneumatics came from a Greek word *pnein,* meaning to blow or breath. Pneumatics is a kind of technology involves the study and application of pressurized gas to generate mechanical motion. Recently, pneumatic system has been widely implemented in various kinds of applications such as industrial manipulators and robotics fields. Pneumatic cylinder or actuator plays vital roles in the pneumatic system. Since many years ago, pneumatic system was extensively used in lots of machines in factories to help or assist operations. A pneumatic actuator mainly consists of a piston, a cylinder, and valves as shown in Figure 1.1.

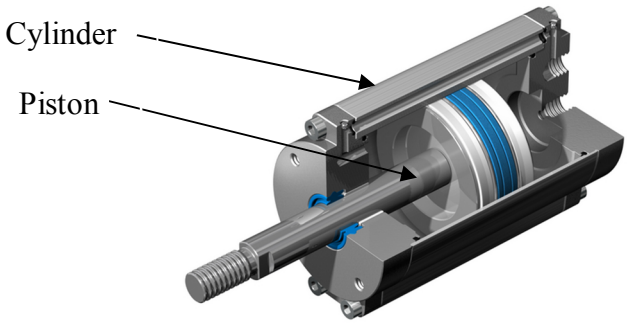

Figure 1.1: Basic structure of a pneumatic actuator. [31]

Intelligent actuator was initially developed by P. Strickland *et al.* [1] where this research focused on the development of the actuators and highlighted new approach of designing servo systems. The development consists of control and fault tolerant software, communication links, microcontroller, sensor system and actuator. By having the assistant from a CAD/CAM facility, 'SERVOCAM', they managed to construct intelligent servo systems for robotic systems and the results shows that the approach is feasible. Development of an intelligent pneumatic cylinder and its application to pneumatic servo mechanism was then presented by K. Suzumori *et al.* [2] where this research contributed to develop intelligent cylinder that can control position and speed. Micro functional elements such as optical encoder, micro pneumatic control valves and a micro-processor were started to be utilized to achieve high control performance.

Intelligent Pneumatic Actuator (IPA) is a new type of developed actuator which represents the upgraded version of earlier actuator model. Many researchers and industrial technicians are interesting in applying these new pneumatic actuators due to their advantages over others actuator model. The positive advantages of pneumatic actuators are low in cost, high-power-to-weight ratio, light, easier to maintenance, and have a simpler structure design if compared to other types of actuators. Moreover, pneumatics actuators are less sensitive to temperature changes and substance contamination. Figure 1.2 shows one example of intelligent pneumatic actuator.

Figure 1.2: New LA36 intelligent pneumatic actuator from LINAK. [32]

Intelligent pneumatic actuator have been developed by A.A.Mohd Faudzi *et al.* [3] where in this research, IPA was developed and applied to Pneumatic Actuator Seating System (PASS) as an application. The appearance of the IPA is shown in Figure 1.3. Intelligent pneumatic actuator integrates microprocessors and some micro sensors to give better control and thus can achieve higher position and force accuracy. The movement of the stroke inside the chamber of actuator is controlled by on/off valve. The benefit of intelligent pneumatic actuator is it can provide accurate position tracking, deal with different value of stiffness and damping function, and movement of piston can be controlled by regulating the air pressure of only one chamber inside the cylinder.

Figure 1.3: Intelligent pneumatic actuator. [3]

1.2 Problem Statements

The new intelligent pneumatic actuator (IPA) which had been developed by A.A.Mohd Faudzi [3], was used on chair type human-machine interaction tool, Pneumatic Actuated Seating System (PASS). Sufficient information was required on this human-machine interaction chair in order to obtain how position, stiffness and viscous coefficient can affect the contour shape, spring and damping characteristics. Thus, several previous experimental setups have been conducted for these control algorithms. Based on his research, real IPA closed loop system was controlled by using conventional PI controller for position and viscosity control. However, this IPA system is not yet controlled with other controllers to achieve higher control performances. Therefore, better controllers need to be designed, for the purpose of giving high control performances and minimizing the errors. In this study, to ease the controllers design, the works are done in MATLAB simulation. On the other hand, previous mathematical modeling of pneumatic actuator which had been derived from other researchers was a nonlinear system; therefore a new linear model is needed for controller design.

1.3 Objectives

The objectives for this project are:

1. To develop the nonlinear modeling of the Intelligent Pneumatic Actuator.
2. To design controllers (using fuzzy logic) for the position and viscosity control of IPA.
3. To do the simulation analysis through MATLAB Simulink and compare results with other controllers.
4. Obtain the linear model of IPA by using linearization technique.

1.4 Scope of Works

Basically, the scope of works for this project is shown as following:

1. Study and understand the nonlinear mathematical modeling of the IPA.
2. Do the modeling from the nonlinear mathematical equations to represent IPA plant by using MATLAB Simulink.
2. Design various kinds of controllers for position and viscosity control for the nonlinear model.
3. Obtain result using Simulink MATLAB, and compare result from conventional PI controller.
4. Linearize the current nonlinear model into linear system using theory of Taylor Series Expansion.

REFERENCES

[1] P. Strickland, J. E. L. Hollis, J. Billingsley and B. Haynes, "Intelligent Actuators", *Intelligent Control and Instrumentation, 1992. SICICI '92. Proceedings., Singapore International Conference on*, 1992, pp. 630-635.

[2] Koichi Suzumori, Junichi Tanaka and Takefumi Kanda, "Development of an Intelligent Pneumatic Cylinder and Its Application to Pneumatic Servo Mechanism", *International Conference on Advanced Intelligent Mechatronics*, 2005.

[3] Ahmad 'Athif Mohd Faudzi, "Development of Intelligent Pneumatic Actuators and Their Applications to Physical Human-Mechine Interaction System", *Ph.D. thesis, The Graduate School of Natural Science and Technology, Okayama University, Japan*, vol. September, 2010.

[4] Jaime Fonseca, João L. Afonso and Julio S. Martins, "Fuzzy Logic Speed Control of an Inductor Motor", *Minho University*, 1998.

[5] C. Aprea, R. Mastrullo and C. Renno, "Fuzzy Control of the Compressor Speed in a Refrigeration Plant", *International Journal of Refrigeration 27 (2004)*, pp. 639-648.

[6] Tiberiu Vesselenyi, Simona Dziţac, Ioan Dziţac, Mişu-Jan Manolescu, "Fuzzy and Neural Controllers for a Pneumatic Actuator", *International Journal on*, 2009, Vol. II (2007), No. 4, pp. 375-387.

[7] Prahlad Kumar Sahoo and Nirmal Kumar Barik, "Speed Control of Separately Excited DC Motor using Self Tuned Fuzzy PID Controller", *Bachelor thesis*, *National Institute of Technology Rourkela*, 2010-2011.

[8] K.H. Chua, W.P. Hew and C.P. Ooi, "A Comparative Analysis of PI, Fuzzy Logic And ANFIS Speed Control of Permanent Magnet Synchronous Motor", *ELEKTROPIKA*, Vol. 1, 10-22, 2011.

[9] M.F. Rahmat and Sy Najib Sy Salim, "Non-linear Modeling and Cascade Control of an Industrial Pneumatic Actuator System", *Australian Journal of Basic and Applied Sciences*, 5(8): 465-477, 2011.

[10] Edmond Richer and Yildirim Hurmuzlu, "A High Performance Pneumatic Force Actuator System Part 1 - Nonlinear Mathematical Model", *Mechanical Engineering Department Dallas*, 2001.

[11] John F. Blackbum, Gerald Reethof, and J. Lowen Shearer, "Fluid Power Control. New York and London: Technology Press of M.I.T. and Wiley", 1960.

[12] D. Ben-Dov and S. E. Salcudean, "A Force-Controlled Pneumatic Actuator", *IEEE Transactions on Robotics and Automation*, vol. 11, no. 6, pp. 906-911, 1995.

[13] Xue-kui Wang and Xu-hong Yang, "Adaptive Neuro-fuzzy Inference System PID Controller For Sg Water Level Of Nuclear Power Plant", *8th International Conference on Machine Learning and Cybernetics*, Baoding, July 2009.

[14] Brahim GASBAOUI and Chaker ABDELKADER, "Adaptive Fuzzy PI of Double Wheeled Electric Vehicle Drive Controlled by Direct Torque Control", *Leonardo Electronic Journal of Practices and Technologies*, p. 27-46, 2010.

[15] Ahmad' Athif Mohd Faudzi, Koichi Suzumori and Shuici Wakimoto, "Development of an Intelligent Pneumatic Cylinder for Distributed Physical Human-Machine Interaction", *Advanced Robotics*, 23:1-2, pp.203-225.

[16] Ahmad' Athif Mohd Faudzi, Koichi Suzumori and Shuici Wakimoto, "Design and Control of New Intelligent Pneumatic Cylinder for Intelligent Chair Tool Application", *IEEE/ASME International Conference*, 2009.

[17] Ahmad' Athif Mohd Faudzi, Khairuddin Osman and M.F. Rahmat, "Nonlinear Mathematical Model of an Intelligent Pneumatic Actuator (IPA) Systems: Position and Force Controls", 2011.

[18] Kishore Balasubramanian and Kuldip S. Rattan, "Fuzzy Logic Control of a Pneumatic Muscle System Using a Linearizing Control Scheme", *Wright State University Dayton*, OH- 45435.

[19] Vladislav Blagojević and Miodrag Stojiljković, "Mathematical and Simulink Model of the Pneumatic System With Bridging of the Dual Action Cylinder Chambers", *Series: Mechanical Engineering* Vol. 5, No 1, 2007, pp. 23-31.

[20] Ahmad 'Athif Mohd Faudzi and Koichi Suzumori, "Stiffness and Viscous Coefficient Characteristics for Ergonomics Chair Design", *IEEE/ASME International Conference*, 2011.

[21] R. Nejat Tuncay, Zeynep Erenay and Murat Yilmaz, "Rapid Control Prototyping Approach to Fuzzy Speed Control of Brushless DC Motor", *Istanbul Technical University, Turkey*.

[22] Mohd Shahrieel Mohd Aras and Syed Najib Bin Syed Salim, "Comparison of Fuzzy Control Rules using MATLAB Toolbox and Simulink for DC Induction Motor-Speed Control", *International Conference*, 2009.

[23] Chen Ying and Zhang Jia-fan, "Design and Hybrid Control of the Pneumatic Force-feedback Systems for Arm-Exoskeleton by using On/off Valve", *Mechatronics* 17 (2007) 325–335.

[24] Medhat K. Bahr Khalil, "Estimated versus Calculated Viscous Friction Coefficient in Spool Valve Modeling", *IFPE Technical Conference*, 14.2, 2008.

[25] J. M. Tressler, T. Clement and H. Kazerooni, "Dynamic Behavior of Pneumatic Systems for Lower Extremity Extenders", *International Conference on Robotics and Automation*, May 2002.

[26] Xiangrong Shen and Michael Goldfarb, "Simultaneous Force and Stiffness Control of a Pneumatic Actuator", *Journal of Dynamic Systems, Measurement, and Control*, Vol. 129 / 425-434, 2007.

[27] Hua O. Wang and Kazuo Tanaka, "An Approach to Fuzzy Control of Nonlinear Systems: Stabilities and Design Issues", *IEEE Transactions on Fuzzy Systems*, vol. 4, no. 1, February 1996.

[28] Mohanadas K P and Shaik Karimulla, "Fuzzy and Neuro-fuzzy Modelling and Control of Nonlinear Systems".

[29] Dave Carr. Jeff Shearer, "Nonlinear Control and Decision Making using Fuzzy Logic in Logix", *Rockwell Automation*, Inc., Publication 9324-WP006A-EN-P – August 2007.

[30] Zhao Dezong, Li Chunwen and Ren Jun, "Fuzzy Speed Control and Stability Analysis of A Networked Induction Motor System with Time Delays and Packet Dropouts", *Nonlinear Analysis: Real World Applications*, volume 12, issue 1, pages 273–287, February 2011.

[31] Pneumatic Actuator (http://www.stoneleigh-eng.com/pneumatic_actuators.html)

[32] Actuator to Linear Actuator - LA36 (http://www.projectlink.com.au/actuator-to-linear-actuator-la36-)