OBSERVER-BASED RECEDING HORIZON CONTROLLER FOR POSITION AND FORCE CONTROL OF A PNEUMATIC ACTUATOR

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ABSTRACT

Pneumatic systems are widely used in automation industries and in the field of automatic control. Unfortunately, some nonlinearities are existed in these actuators. These nonlinearities have made controlling these actuators more difficult to get good dynamic performance. In this project, Receding horizon controller (RHC) is proposed to control the position and the force of a pneumatic actuator. RHC is a predictive controller that predicts the future output and decides the acting signal to reduce the future errors. The type of RHC used in this project is a state feedback controller. Three types of pole assignment observers are used in this project in order to estimate the states of the position and the force models. The observers are designed, incorporated with RHC and then compared in terms of their estimation errors. The implementations of RHC and the observers are carried out using MATLAB/Simulink. Using a data acquisition system (DAQ) real time control between the computer and the pneumatic actuator is established. The RHC shows good control performance both in controlling the position and the force. The experimental and the simulation results of RHC are compared to validate the controller. To further evaluate the RHC controller, its results are compared with other controllers done in previous works, and it is found that RHC has some advantages over these controllers in terms of the control performance criteria.

ABSTRAK

Sistem pneumatik digunakan secara meluas dalam industri automasi dan dalam bidang kawalan automatik. Malangnya, wujud keadaan tidak linear dalam aktuator terbabit. Keadaan tidak linear ini telah menyebabkan kawalan terhadap aktuator lebih sukar untuk mendapatkan kawalan dinamik yang lebih baik. Dalam projek ini, *Receding Horizon Controller* (RHC) dicadangkan untuk mengawal posisi (*position*) dan daya (*force*) penggerak pneumatik. RHC adalah pengawal ramalan yang meramalkan output akan datang dan memutuskan isyarat yang bertindak untuk mengurangkan kesilapan-kesilapan akan datang. Jenis-jenis RHC digunakan dalam projek ini adalah keadaan pengawal suap balik (*feedback controller*). Tiga jenis pemerhati tugasan kutub (*pole-assignment observers*) telah digunakan dalam projek ini untuk menganggarkan keadaan-keadaan mengenai posisi dan model daya. Pemerhati direka, digabungkan dengan RHC dan kemudian dibandingkan dari segi kesilapan anggaran mereka. Perlaksanaan RHC dan pemerhati dijalankan menggunakan MATLAB / Simulink. Dengan menggunakan Sistem Perolehan Data (DAQ) kawalan masa sebenar (*real time*) di antara komputer dan penggerak pneumatik telah dihasilkan. RHC telah menunjukkan prestasi kawalan yang baik dalam mengawal bagi kedua-dua posisi dan daya. Eksperimen dan keputusan simulasi RHC kemudiannya dibandingkan untuk mengesahkan kemampuan pengawal. Untuk menilai selanjutnya pengawal RHC, keputusan yang dibandingkan dengan pengawal lain yang dilakukan dalam kerja-kerja sebelum ini, dan didapati bahawa RHC mempunyai beberapa kelebihan berbanding pengawal lain dari segi beberapa kriteria prestasi kawalan.

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LIST OF ABBREVIATIONS

ARMAX	-	Auto-Regressive Moving Average with Exogenous
ARX	-	Auto-Regressive with Exogenous
CCF	-	Controllable Canonical Form
DRNN	-	Diagonal Recurrent Neural Network
IPA	-	Intelligent Pneumatic Actuator
MPC	-	Model Predictive Control\Controller
OCF	-	Observable Canonical Form
PI	-	Proportional-Integral
PID	-	Proportional-Integral-Derivative
PWM	-	Pulse Width Modulation
RHC	-	Receding Horizon Control
SI	-	System Identification

CHAPTER 1

INTRODUCTION

1.1 An Overview on Pneumatic Actuators

Pneumatic actuators are widely used in a variety of automation industries. If they are given precision tracking ability in addition to their relatively small size, light weight and high speed, they can be used for many robotic and medical applications.

Moreover, pneumatic actuators are safe and reliable. They have relatively small size compared to hydraulic actuators. Moreover, they have fast response, and at high temperatures and in nuclear environments, they have the advantages over hydraulic actuators because gases are not subjected to the temperature limitations (Ali *et al*., 2009).

These merits, and more others, of pneumatic systems have motivated many researchers among the years to propose different approaches of controllers to get better accuracy and better dynamic performance. Their main interest is to control the position, but due to different industry and automation requirements, their interests had extended to control the force, stiffness and viscosity of the pneumatic actuators.

The difficulties of controlling pneumatic actuators are mostly because of the nonlinearities existed. The high frictional forces that the pneumatic actuator is subjected to, the compressibility of air, the valve dead zone, etc are all sources of the nonlinearities. As a result, these nonlinearities made it difficult to achieve accurate position control of the pneumatic actuators.

There are mainly two types of pneumatic actuators, the piston-cylinder type, which is the most popular and existed one, and the rotary type. Based on the historical development, pneumatic systems were created since the 16th century (Ahmad *et al*., 2012). Since then, many development has been done to the pneumatic actuators to suit different automation and industry purposes according to the desired accuracy and performance and to the amount of force that is needed to each particular application. In the 20 century, more complex and intelligent pneumatic systems were developed. The Intelligent pneumatic actuator (IPA) system, which is dealt with in this study, is referred from Faudzi *et al*., where A. A. M. Faudzi developed intelligent actuators and applied them to Pneumatic Actuator Seating System (PASS) as an application.

1.2 Problem Statement

There are difficulties in controlling the position and force of pneumatic actuators due to the nonlinearities existed.

More work regarding the position and force control is needed to achieve higher accuracy and better dynamic performance.

1.3 Project Objectives

The objectives of this project are:

1) To design and implement a receding horizon controller based on the discrete-time model of a pneumatic actuator to simulate position and force control.
2) To design a discrete-time observer to estimate the states.
3) To conduct real time control with the pneumatic actuator.
4) To validate the results with the experimental data and with a different controllers.

1.4 Scope of Work

The mathematical models of position and force are previously developed by Ahmad *et al*., (2012) and Elnimair, (2013) respectively. Using these models, Receding Horizon Controller (RHC) is studied, designed, tuned and implemented using MATLAB/Simulink. Three types of observers are designed (to estimate the states) and implemented using MATLAB/Simulink also. The position and force control are simulated. Thereafter, using data acquisition (DAQ) system real time control is conducted with the pneumatic plant for performance testing

REFERENCES

Ahmad ‘Athif Mohd Faudzi, Koichi Suzumori and Shuichi Wakimoto, 2009. *Development of an Intelligent Pneumatic Cylinder for Distributed Physical Human–Machine Interaction*, Advanced Robotics, 23, 203–225.

Ahmad 'Athif Mohd Faudzi, Khairuddin Osman, Rahmat, M.F., Nu'man Din Mustafa, Asyraf, A. M., Koichi Suzumori., 2012. *Nonlinear Mathematical Model of an Intelligent Pneumatic Actuator (IPA) Systems: Position and Force Controls*, AIM 2012.

Alexandru, S., P. G. and Bogdan C., 2006. *Aspects Regarding The Neuroadaptive Control Structure properties Application to The Nonlinear Pneumatic Servo System Benchmark, Electrotechnics, Electronics*, Automatic Control, Informatics, pp. 82-86.

Ali, H. I., Noor, S. B. B. M., Bashi, S. M. & Marhaban, M. H., 2009. *A Review of Pneumatic Actuators (Modeling and Control)*, Australian Journal of Basic and Applied Sciences, 2, pp. 440-454.

Asyraf Azman, M., Ahmad 'Athif Mohd Faudzi, Mohamed Omer Elnimair, Omer F. Hikmat, Khairuddin Osman, Chai Chang Kai, 2013. *P-Adaptive Neuro-Fuzzy and PD-Fuzzy Controller Design for Position Control of a Modified Single Acting Pneumatic Cylinder*, IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2013).

Charles, L. P. and Troy N. H., 1990. *Digital Control System Analysis And Design, Second Edition*, Printice-Hall International.

Chikh, L., Poignet, P., Pierrot, F. & Michelin, M., 2010. *A Generalized Predictive Force Controller for Electropneumatic Cylinders*, In 8th IFAC Symposium on Nonlinear Control Systems (NOLCOS'2010), pp. 1058-1063.

Elnimair, M. N., *System Identification And Pi Neuro-fuzzy Control Of A Pneumatic Actuator*, Master Thesis, Universiti Teknologi Malaysia, 2013.

Faudzi, A.A.M., Suzumori, K., Wakimoto, S., 2008. *Distributed Physical Human Machine Interaction Using Intelligent Pneumatic Cylinders*, International Symposium on Micro-NanoMechatronics and Human Science (MHS 2008), pp. 249-254.

Faudzi, A. A. M., Osman, K. B., Rahmat, M. F., Mustafa, N. M. D., Azman, M. A. & Suzumori, K., 2012. *Controller Design for Simulation Control of Intelligent Pneumatic Actuators (IPA) System*, Procedia Engineering, 41, pp. 593-599.

Faudzi, A.A.M., Suzumori, K., Wakimoto, S., 2009. *Design and Control of New Intelligent Pneumatic Cylinder for Intelligent Chair Tool Application*, IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2009), pp. 1909-1914.

French, L.G. and Cox, C.S., 1988. *The Robust Control of a Modern Electropneumatic Actuator*, IFAC, Automatic Control in Space.

Garcia, M. R., Vilas, C., Santos, L. O. & Alonso, A. A., 2012. *A Robust Multi-Model Predictive Controller for Distributed Parameter Systems*, Journal of Process Control, 22 (1), pp. 60-71

Garcia, C.E, Prett, D.M. & Morari, M., *Model Predictive Control: Theory and Practice -a Survey*, Automatica, 25(3), pp.335-348, 1989.

Gary, M.B. and Shu, N., 2007. *Experimental Comparison of Position Tracking Control Algorithms for Pneumatic Cylinder Actuators*, IEEE/ASME Transactions on Mechatronics, 12(5), PP. 557-561.

Han K.L., Gi, S.C. & Gi, H.C., 2002. *A study on Tracking Position Control of Pneumatic Actuators*, Mechatronics, 12, pp. 813-83.

Jihong, W., Junsheng, P. & Philip, M., 1999. *Accurate Position Control of Servo Pneumatic Actuator Systems: An Application to Food Packaging*, Control Engineering Practice, 7, pp. 699-706.

Junbo, S. and Yoshihisa, I., 1997. *Robust Tracking Controller Design for Pneumatic Servo System*, International Journal of Engineering Science, 35(10/11), pp. 905-920.

Karim, K., Pascal, B. & Louis, A.D., 2008. *Force Control Loop Affected By Bounded Uncertainties and Unbounded Inputs for Pneumatic Actuator Systems*, ASME, Journal of Dynamic Systems, Measurement and Control, 130, pp. 1-9.

Karl, J. A. and Wittenmark B., 1997. *Computer-Controller Systems Theory and Design,Third Edition*, Printice hall.

Khayati, K., 2004. *A Robust Feedback Linearization Force Control of a Pneumatic Actuator*, IEEE International Conference on Systems, Man and cybernetics.

Liuping, W., 2009. *Model Predictive Control System Design and Implementation Using MATLAB*, Springer books, pp. 1-40

Nagarajan, R. and Weston, R.H. 1985. *Front end control schemes for pneumatic servo-driven modules*, Proc. Inst. Mech. Engrs, 199(27), pp. 1-280.

Samaoui, M., X. B. and Thomasset, D., 2004. *Robust Position Control of an Electropneumatic System Using Second Order Sliding Mode*, IEEE.

Somyot, K. and Manukid, P., 2005. *Force Control in a Pneumatic System Using Hybrid Adaptive Neuro-Fuzzy Model Reference Control*, Mechatronics, 15, pp. 23-41.

Van Varseveld, R. B. & Bone, G. M. 1997. *Accurate Position Control of a Pneumatic Actuator Using On/Off Solenoid Valves*. Mechatronics, IEEE/ASME Transactions on, 2, pp. 195-204.

Worthmann, K, 2012. *Estimates on the Prediction Horizon Length in Model Predictive Control*, 20th International Symposium on Mathimatical Theory of Networks and Systems (MTNS2012).

Xuesong, W. and Guangzheng, P., 2003. *Modeling and Control for Pneumatic Manipulator Based on Dynamic Neural Network*, IEEE, 223, pp. 1-2236.

Yi, C.T. and An, C.H., 2008. *Multiple-Surface Sliding Controller Design for Pneumatic Servo Systems*, Mechatronics.