Generalized Minimum Variance Controller Design for Pneumatic Systems

Khairuddin Osman[1], Nur Khairul Bariyah Mahyudin[1], Siti Fatimah Sulaiman[1, 2]
[1]*Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka, 76100 Durian Tunggal, Melaka, Malaysia.*
[2]*Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia.*
Khairuddin.osman@utem.edu.my

***Abstract*— Nowadays the pneumatic actuators are widely used. This is because of their low cost, ease of maintenance and high medium power to weight ratio. A position model has been proposed by using system identification techniques resulted in a transfer function model. One of the commonly control algorithms that used in the pneumatic actuators area is Generalized Minimum Variance (GMV) controller. The performance of an algorithm is obtained by combining a generalized minimum variance control with a recursive estimator for the controller parameter. In this, for ensuring the system output response can track any changes in the reference set point, an indirect self-tuning GMV control is used. The project aims to design a generalized minimum variance controller to control of the pneumatic system. The controller will be designed using MATLAB/SIMULINK based on the proposed model. The simulation results will be compared with the other types of controller (PID) to observe the performance of the GMV controller.**

***Index Terms*— Generalized Minimum Variance; Pneumatic Systems; System Identification.**

I. INTRODUCTION

Pneumatic system were selected for this study due to this driver is driving the next generation to be developed with new features, which an important mechanism of all-in-one compact the system. Nevertheless, the existing system implements just Proportional-Integrative-Derivative (PID) of the controller design is easy using the methods of trial and error [1-2]. There are other weaknesses for the presentation controls like slow reaction, time delay, overshoot extend back of issues and not appear to function with lower the strength parameters. In addition, the system only has result of the experiment and there is no validation for the performance of controller. These systems then has the potential to be is used as the tests for the validation for the development recently an algorithm and controller in using drive for several applications.

Development of the pneumatic system used in this research is presented as in [3-5]. The pneumatic system presents the next-generation actuator development with new features of better control, higher position and force accuracy, communication ability and all-in-one mechanism for compact system design. The pneumatic actuator is equipped with a microcontroller, which acts as the brain for the system, and performs the local control to suit the requirements of any related applications.

In a pneumatic system can be divided into two types of actuators specifically with the 0,169 mm accuracy of the location and positioning accuracy of 0.01 mm. The design of the actuator with the positioning accuracy of 0.01 mm positioning accuracy can be improved from 0169 mm to perform better if the experiment on the application but the operating system for both the driver is still the same. Design with the positioning accuracy of 0.01 mm will have a new position sensor with the high accuracy, a new kind of bar code tape for improved durability, enhanced design new circuit and it will not be implemented yet in any application. Figure 1 shows all parts of science to the positioning accuracy of 0.01 mm was used in this study. The actuator has a stroke of 200 mm and can deliver maximum power up to 120 N. KOGANEI- ZMAIR optical sensor was used by a smaller field than 0.01 mm can be detected [6-8].

For controller design, pneumatic system need be modeled representation. These models will be applied clearly or implicitly in design control. In general, there are two ways for determining the mathematical modeling of the system. First method is by using a theoretical analysis implementing law of nature. Second method is to use the system identification techniques conducted by the experiments on innovation model. Hence, controller approaches to control pneumatic actuators were investigated and proven for decades. In the early the design of controller, linear controller like PID controller, pole-placement controller, the intelligent controller (fuzzy and neural networks), predictive controller etc. were investigated [9-10]. About conspicuous trend is the combination and increase the two or more controllers in development of pneumatic system controller. Benefits each controller increase the other controller become controller made it popular among the investigators [11-15].

Main objective this research is to develop a model and designs the pneumatic system controller. These two models of the state and the power have been proposed to realize the compliance control of the stiffness features. Pneumatic system model in the transfer function obtained from the System Identification (SI) method. The development forecasts Generalized Minimum Variance (GMV) design was selected as the new control strategy for the pneumatic system. Controller performance evaluation has been done in MATLAB simulation.

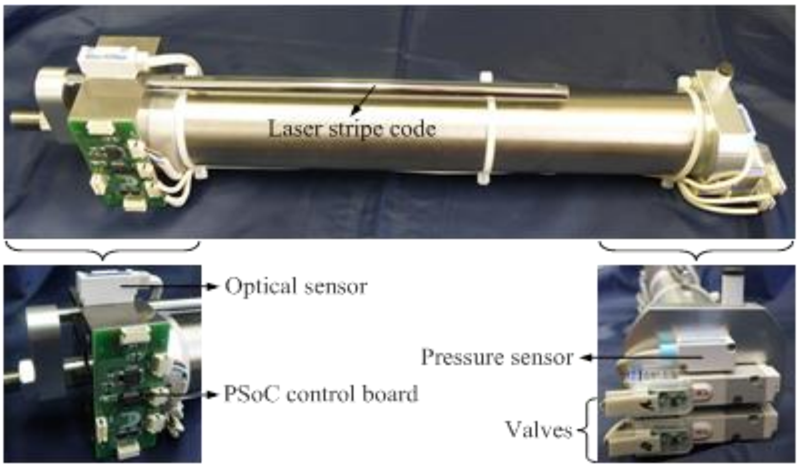

Figure 1: Pneumatic Actuator and its parts

II. METHODOLOGY

A. System Identification Technique

On System Identification, the measured input and output data obtained must be divided into two sets of data; the first data set for estimation, while the second data set for validation purpose. In this work, the first 1-750 samples of data were used for estimation and the remaining for validation purpose. To estimate a suitable model structure to approximate the model, System Identification Toolbox in MATLAB environment is employed. There are a few model structures which are commonly used in real world application and these structures also available in the MATLAB System Identification Toolbox.

Using System Identification Toolbox, the best fit of the output model is 91.39% as depicted in Figure 2. From the plot, a measured value is indicated by a black curve and the simulated model output is indicated by a green curve. The model plant is acceptable since the percentage of the best fit is greater than 90%. The Loss Function and Akaike's FPE of the ARX331 model is considered small with the value 0.01168 and 0.01185. The results are summarized in Table 1.

Table 1
Akaike's Model Validity Criterion Value Based on ARX331 Model Structure

Best Fit	91.39
Loss Function	0.01168
Akaike's FPE	0.01185

In this work, the ARX model structure is chosen since it is the simplest model incorporating the stimulus signal. ARX with the order of na= 3, nb=3 and nk=1 (ARX331) were selected in this work, and the discrete-time transfer function as obtained from the MATLAB System Identification Toolbox.

The model validation is considered as a final stage of the System Identification approach. As described earlier in a beginning, the second set of data (751-1500 samples) will be used for validation purpose. In this work, the model validation is to verify the identified model represents the process under consideration adequately. Akaike's Model Validity Criterion are used since it is a very popular method for validating a parametric model such as ARX model structure. The mathematical model obtained is validated based on its Best Fit, Loss Function, and Akaike's Final Prediction Error (FPE). A model is acceptable if the Best Fit is more than 90%.

Thus, the approximated model of ARX331 is acceptable since all those three criteria of Model Validation Criterion are satisfied.

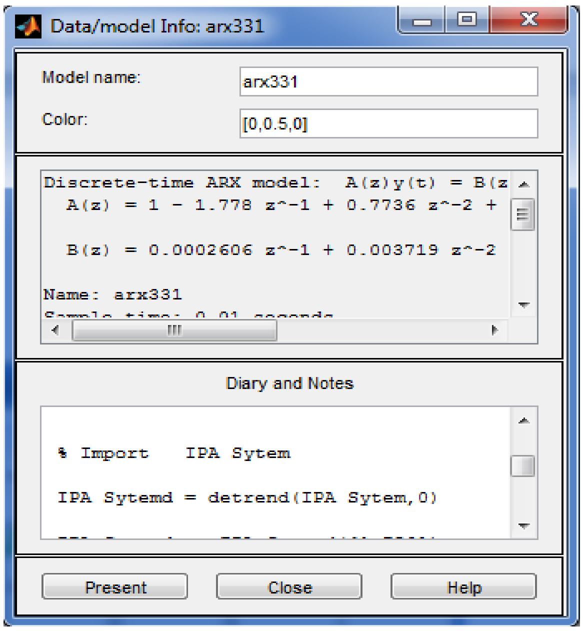

Figure 2: Model Info Window

The following third order Auto-Regressive with Exogenous Input (ARX) model in the form of discrete-time open-loop in position transfer function was obtained as presented in Equation (1).

$$\frac{B_{Position}\left(z^{-1}\right)}{A_{Position}\left(z^{-1}\right)}=\frac{0.002606z^{-1}+0.003719z^{-2}-0.002646z^{-3}}{1-1.778z^{-1}+0.7736z^{-2}+0.004083z^{-3}} \quad (1)$$

B. Generalized Minimum Variance (GMV) Controller

This research suggests that the Generalized Minimum Variance (GMV) controller design for pneumatic systems. GMV formulation can handle linear process. GMV controller is the design should be carried out to estimate the condition of the pneumatic system model. A GMV controller will provide the estimation for the internal state of the system that has been set, the measurement input and the output system [16].

Plant Model

$$y(t) = \frac{Z^{-k}B}{A}u(t) + \frac{C}{A}\,\xi(t) \tag{2}$$

Assume C = 1, control model is:

$$u(t) = \frac{-\hat{G}}{\hat{F}}y(t) + \frac{\hat{H}}{\hat{F}}\,w(t) \tag{3}$$

From Equation (1), fill A(z) and B(z) in Equation (2) and factored

$$y\,(t) = \frac{B\,(z)}{A\,(z)}$$

$$= \frac{z^{-1}(0.0002602 \quad + 0.003719^{z-1} + 0.002646^{z-2}}{1 - 1.788^{z-1} + 0.7736^{z-2} + 0.004083^{z-3}}\,u(t)$$

$$+ \frac{1}{A}\xi(t)$$

Where,

$$A = 1 - \ 1.778^{z-1} \ + 0.7736^{z-2} \ + 0.004083^{z-3}$$

,

$n_a = 3$

$$B \ = 0.0002606 + \ 0.003719^{z-1} \ - \ 0.002646^{z-2}B$$

,

$n_b = 2$

$C = 1$, $n_c = 0$

and $k = 1$

In this work, Weight tuning for value of P and R is assumed to be 1, while Q value to be 1.27. Finding Parameters to be used:

(i) $n_g = \max(n_a - 1, n_p + n_c - k)$
$n_g = \max(2 - 1, 0 + 0 - 1)$
$n_g = \max(1, -1)$
$n_a = 1$ (choose maximum value)
So, G = $g_{o+}\, g_{1\,z^{-1}}$

(ii) H = RC, C = 1
H = h_o

(iii) $n_e = k - 1$
$n_e = 1 - 1$
$n_e = 0$

E = 1

(iv) F = BE + QC, C = 1

F = (0.0002606 + 0.003719z^{-1} – 0.002646z^{-2} (1) + (1) (1)
F = 0.0002606 + 0.003719z^{-1} – 0.002646z^{-2} + 1
F = 1.0002606 + 0.003719z^{-1} – $z^{-20.002646}$
F = $f_0 + f_{1z-1} + f_{2z-2}$

The steps in designing self-tuning GMV controller in this work can be summarized as below:

Step 1:

$$\varnothing\,(t) = [y\,(t) - w\,(t-1) + u\,(t-1)] \begin{bmatrix} P \\ R \\ Q \end{bmatrix}$$

Step 2:

$$\hat{\varnothing}\,(t) = [\,y\,(t-1) \quad y\,(t-2)\;u(t-1)\;u(t-2)\;u\,(t-3) \quad - w(t-1)\,] \begin{bmatrix} \widehat{g0} \\ \widehat{g1} \\ \widehat{fo} \\ \widehat{f1} \\ \widehat{f2} \\ \widehat{h0} \end{bmatrix} - + \xi(t)$$

Step 3:

$$u(t) = \frac{(go + g_{1_{z-1}})}{f_0 + f_{1_{z-1}} + f_{2_{z-1}}}\,y(t) + \frac{h_0}{f_0 + f_{1_{z-1}} + f_{2_{z-1}}}\,w(t)$$

III. Results And Discussion

Based on Figure 3 and Table 2, clearly described that each controller has their own advantage and disadvantage. The control objective is able to maintain the process pressure of the system at a given value. Three types of controllers are designed and presented in this work. From the simulation result obtained, it can be concluded that the ARX331 have zero percent overshoot compare with ARX223 have 180 percent overshoot and PID have 2.5 percent overshoot. For peak time ARX331 is zero peak time but ARX223 at 6.6s and PID at 16s. For settling time ARX331 at 120s and compare with ARX223 at 4.8s and PID at 19.2s. Rise time for ARX331 at 2s, ARX223 at 0.4s and PID. For steady state error ARX223 and PID have zero steady state and ARX331 have 0.1 steady state errors.

The ARX model 331, ARX223 and PID controller were used to represent which kind of real pneumatic systems. Method of using experimental data to approximate the real model is easier than the issue of mathematical modelling by using control law. Although deceptively simple, to the correct frequency, trial error method is use and the sampling rate would be an issue and the also take the time to have a good mode and the acceptable.

In order to prove that the model gained is controlled, the controller design by using algorithms GMV has also been used and presented. The models approximated to that used in the study of system simulation and real-time feedback describes acceptable performance. In a pneumatic system developed by the GMV algorithm approach allows for the collection of data on the position. To compare the performance of GMV, certain parameters were certainly well known. The results earned from simulations and experiments prove that a real-time model developed will be used for a variety of basic research, such as improved performance of the controller. Furthermore, the pneumatic system can work well as sound system and this makes the controller in accordance with the achievement of good control.

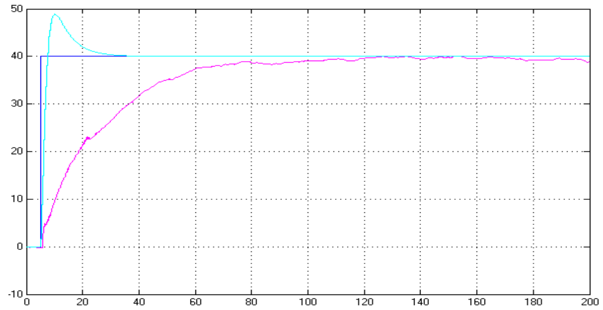

Figure 3: Output GMV and PID

Table 2 Performances of the Controllers Designed

Product yield / mmol	Controller	
	GMV	PID
Peak Time, T_p (s)	0	15
Settling Time, T_s (s)	120	19.2
Rise Time, T_r (s)	2	8s
Steady State Error, e_{ss} (%)	0.1	0
Percent Overshoot, *OS* (%)	0	2.5

IV. CONCLUSION

This research has presented the system identification model and development of Generalized Minimum Variance (GMV) algorithm in a pneumatic system. The MATLAB model using system identification toolbox approximately plant model (position) the input-output experimental data were presented.

For future research will be done in two ways that can study other types of modelling and other types of controller algorithm design. Modelling own position is an opportunity to examine the issues in detail using SI. Control of compliance is provided by the compressibility the air that is supplied with a driver which depends on the strength parameters. The Stiffness is the resistance of an elastic body to deflection or deformation by the force applied, which is an important feature common to the pneumatic system. To study the effect of damping, viscosity control has been realized by a combination of the two methods of control, status and control of force and speed and viscous response variable coefficients.

ACKNOWLEDGMENT

The authors would like to thank Universiti Teknikal Malaysia Melaka (UTeM), Ministry of Education (MOE) Malaysia under the Research Acculturation Grant Scheme (RAGS) No. RAGS/1/2014/TK03/FKEKK/B00063, Universiti Teknologi Malaysia (UTM) and Okayama University, Japan for their support

REFERENCES

[1] Faudzi, A.A.M., Osman, K., Rahmat, M.F., Azman, M.A. and Suzumori, K., 2012. Controller design for simulation control of intelligent pneumatic actuators (IPA) system. Procedia Engineering, 41, pp.593-599.
[2] Faudzi, A.A.M., Osman, K., Rahmat, M.F., Mustafa, N.M.D., Azman, M.A. and Suzumori, K., 2012, July. Nonlinear mathematical model of an Intelligent Pneumatic Actuator (IPA) systems: Position and force controls. In Advanced Intelligent Mechatronics (AIM), 2012 IEEE/ASME International Conference on (pp. 1105-1110). IEEE.
[3] Faudzi, A.A., Suzumori, K. and Wakimoto, S., 2008, November. Distributed Physical Human Machine Interaction Using Intelligent Pneumatic Cylinders. In Micro-NanoMechatronics and Human Science, 2008. MHS 2008. International Symposium on (pp. 249-254). IEEE.
[4] Faudzi, A.A.M., Suzumori, K. and Wakimoto, S., 2009, July. Design and control of new intelligent pneumatic cylinder for intelligent chair tool application. In Advanced Intelligent Mechatronics, 2009. AIM 2009. IEEE/ASME International Conference on (pp. 1909-1914). IEEE.
[5] Faudzi, A.A.M., Suzumori, K. and Wakimoto, S., 2010, July. Development of pneumatic actuated seating system to aid chair design. In Advanced Intelligent Mechatronics (AIM), 2010 IEEE/ASME International Conference on (pp. 1035-1040). IEEE.
[6] Khairuddin Osman, Ahmad 'Athif Mohd Faudzi, M. F. Rahmat and Koichi Suzumori, "System Identification and Embedded Controller Design for Pneumatic Actuator with Stiffness Characteristic," Mathematical Problems in Engineering, vol. 2014, 13 pages, 2014
[7] Khairuddin Osman, A. A. M. Faudzi, M. F. Rahmat, N. D. Mustafa, M. A. Azman and K. Suzumori, System Identification Model for an Intelligent Pneumatic Actuator (IPA) System, IEEE/RSJ International conference on Intelligent Robots and Systems, Algarve, Portugal, (October 2012).
[8] Khairuddin Osman, A. A. M. Faudzi, M. F. Rahmat, N. D. Mustafa and K. Suzumori, Predictive Functional Controller Design for Pneumatic Actuator with Stiffness Characteristic, 2013 IEEE/SICE International Symposium on System Integration (SI International 2013, SII2013), Kobe, Japan, (15-17 December 2013).
[9] Khairuddin Osman, A. A. M. Faudzi, M. F. Rahmat, N. D. Mustafa, Amar Faiz Zainal Abidin and K. Suzumori, Proportional-Integrative Controller Design of Pneumatic System Using Particle Swarm Optimization, 2013 IEEE Student Conference on Research & Development(SCOReD), Putrajaya, Malaysia, (16-17 December 2013).
[10] M.F. Rahmat, Sy Najib Sy Salim, Ahmad 'Athif Mohd Faudzi, Zool Hilmi Ismail, S.I.Samsudin, N.H.Sunar and K.Jusoff (2011). Non-linear Modeling and Cascade Control of an Industrial Pneumatic Actuator System. Australian Journal of Basic and Applied Sciences, 5 (8), 465-477.
[11] Ling, T. G., Rahmat, M. F., Husain, A. R. and Ghazali, R. (2011). System identification of electro-hydraulic actuator servo system. 4th International Conference On Mechatronics (ICOM), 1-7.
[12] Rahmat, M., Sunar, N., Salim, S., Najib, S., Abidin, Z., Shafinaz, M., Fauzi, A. and Ismail, Z. (2011). Review on Modeling and Controller Design in Pneumatic Actuator Control System. International Journal on Smart Sensing and Intelligent Systems, 4 (4).
[13] Ali, H.I., Noor, S.B.B.M., Bashi, S.M. and Marhaban, M.H., 2009. A review of pneumatic actuators (modeling and control). Australian Journal of Basic and Applied Sciences, 3(2), pp.440-454.
[14] Ali, H.I., Noor, S.B.B.M., Bashi, S.M. and Marhaban, M.H., 2009. Mathematical and intelligent modeling of electropneumatic servo actuator systems. Australian Journal of Basic and Applied Sciences, 3(4), pp.3662-3670.
[15] Rahmat, M.F., Salim, S., Najib, S., Mohd Faudzi, A., Ismail, Z.H., Samsudin, S.I., Sunar, N.H. and Jusoff, K., 2011. Non-linear modeling and Cascade control of an industrial pneumatic actuator

system. Australian Journal of Basic and Applied Sciences, 5(8), pp.465-477.
[16] Sulaiman, S. F., Osman, K., Rahmat, M. F. A., Zainal Abidin, A. F. And Khairuddin, I. M., 2014. Tracking Performances Of A Hot Air Blower System Using Different Types Of Controllers. Journal of Theoretical & Applied Information Technology, 69(2).