Jurnal Kejuruteraan dan Sains Kesihatan
Journal of Engineering and Health Sciences
Jilid 2 2018: 79-92

TRACKING PERFORMANCE OF PNEUMATIC POSITION USING GENERALIZED MINIMUM VARIANCE CONTROLLER (GMVC).

Nur Khairul Bariyah Mahyudin[1], Zuraida Hanim Zaini[1],
Khairudin Osman[2], Siti Fatimah Sulaiman[2]

[1]Kolej Universiti Islam Melaka
[2]Universiti Teknikal Malaysia Melaka

ABSTRACT

System modeling is an important task to develop a mathematical model that describes the dynamics of a system. The scope for this work consists of modeling and controller design for a particular system. Parametric approach using Auto Regressive with Exogenous input (ARX) model structure will be used to estimate the mathematical model or approximated model plant. In this research, the approximated plant model is estimated using System Identification approach. Once the mathematical model is obtained, Generalized Minimum Variance (GMV) controller are designed and simulated in MATLAB. Finally, a comparative study based on simulation is analyzed and discussed in order to identify which controller deliver better performance in terms of the system's tracking performances.

Keywords: Pneumatic Position Systems, System Modelling, System Identification, Generalized Minimum Variance Controller.

Jurnal Kejuruteraan dan Sains Kesihatan
Journal of Engineering and Health Sciences
Jilid 2 2018: 79-92

PRESTASI MENGESAN POSISI PNEUMATIK MENGGUNAKAN KAWALAN VARIANS MINIMUM UMUM (GMVC)

Nur Khairul Bariyah Mahyudin[1], Zuraida Hanim Zaini[1],
Khairudin Osman[2], Siti Fatimah Sulaiman[2]

[1]Kolej Universiti Islam Melaka
[2]Universiti Teknikal Malaysia Melaka

ABSTRAK

Sistem pemodelan adalah tugas penting untuk membangunkan model matematik yang menggambarkan dinamik sistem. Skop kerja ini terdiri daripada reka bentuk dan reka bentuk pengawal untuk sistem tertentu. Pendekatan parametrik yang menggunakan struktur regresif Auto dengan struktur input (ARX) Eksogen akan digunakan untuk menganggarkan model matematik atau kilang model anggaran. Dalam penyelidikan ini, model yang dianggarkan menggunakan pendekatan Sistem Pengenalan. Sebaik sahaja model matematik diperolehi, Pengawal Minimum Pengubahsuaian (GMV) direka dan disimulasikan dalam MATLAB. Akhirnya, kajian komparatif berdasarkan simulasi dianalisis dan dibincangkan untuk mengenal pasti pengawal mana yang menyampaikan prestasi yang lebih baik dari segi prestasi pengesanan sistem.

Kata kunci: Sistem Posisi Pneumatik, Pemodelan Sistem, Sistem Pengenalan, Pengawal Minimum Pengubahsuaian.

1.0 INTRODUCTION

Pneumatic system are widely used in many industries due to several advantages over the other actuators that include cleanliness, low cost, ease to implement, and high power-to weight ratio [1, 2]. However, due to compressibility of air and nonlinearity of the valve as well as the presence of friction force between the sliding surfaces of piston, an accurate position control of a pneumatic actuator is difficult to achieve.

Modeling pneumatic system using theoretical analysis required highly knowledge on the system. In this work, there are several steps to be considered while doing this work; identify a process, obtain the mathematical model of the system, analyze and estimate the parameters using System Identification approach, design appropriate controllers for controlling the system and implement it to the system by simulation, and lastly make analysis and justification based on the results obtained.

A mathematical modeling process was provided a very useful method in this work since it was used in identifying a process, representing the dynamic, and describing the behavior of a physical system. A mathematical model of a physical system can be obtained using two approaches; analytical approach (physics law) and experimental approach (System Identification) [2]. Study on [3] found that the main problem of applying a physical law is, if a physical law that governing the behavior of the system is not completely defined, then formulating a mathematical model may be impossible. Thus, an experimental approach using System Identification was considered in this work. The term *Identification* was first introduced by Zadeh (1956) that refers to the problem of determining the input-output relationships of a black box or modeling based on observed experimental data. Lennart Ljung (2008) defined *System Identification* as the art and science of building mathematical models of dynamic systems from observed input-output data. In this work, a mathematical model of the temperature response for the system is developed based on the measured input and output data set obtained from Real Laboratory Process which can be obtained from MATLAB demos. System Identification Toolbox which is available in MATLAB is then used to estimate the parameters and approximate the system models according to the mathematical models obtained. Basically, System Identification approach offers two techniques in describing a mathematical model, which are parametric and non-parametric method.

In this work, parametric approach using AutoRegressive with Exogenous input (ARX) model structure is chosen to estimate and validate the approximated system model. In order to ensure the validity of the ARX model, Model Validation Criterion was used to decide whether the ARX model obtained should be accepted or rejected. Once the model have been identified and validated, appropriate controllers were designed to improve the output performance of the system. The tracking performances of the system by simulation using different type of controllers designed in order to maintain the process temperature at a given value will then be carried out, analyzed, and justified.

2.0 EXPERIMENTAL SETUP

Pneumatic system is driven by an air compressor which offers a low vibration level, minimum noise, longer life time and higher pressure. Experiment for position control or compliance control was carried out in normal movement of the actuator as in Figure 1 where both real-time systems are used. Typically, there are two analog output channels used to send the control signal to the two ON/OFF valves, and one analog input channel to receive the pressure sensor signal as shown in Figure 2. One pressure regulator was used in order to maintain the pressure value with 0.6 MPa setting value. The piston rod in this experiment was set to be fixed during the data collection process to get the right values for the measured force as mentioned in (Boulet *et al.*, 1993).

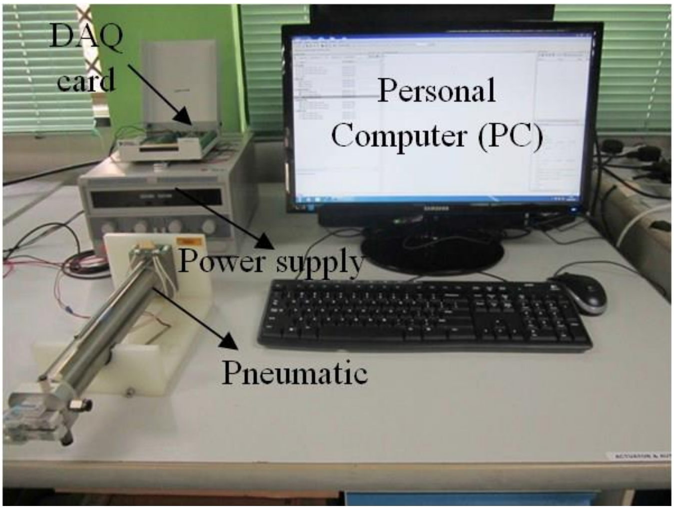

Figure 1: Position control.

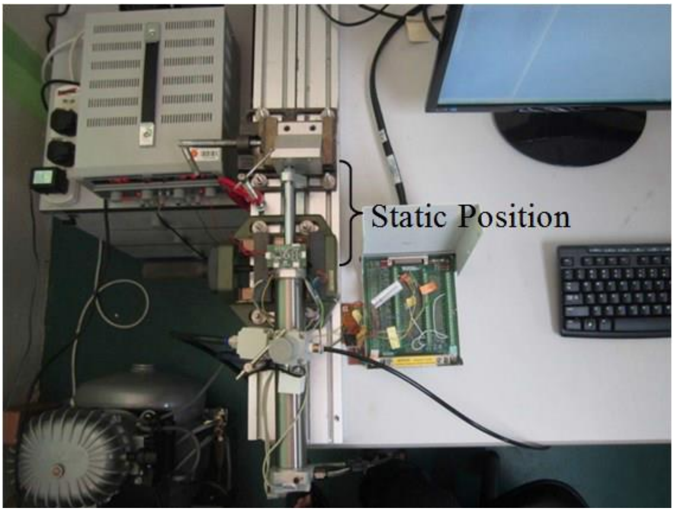

Figure 2: Pneumatic System

3.0 MODELLING

A mathematical model of the system is developed based on the measured input and output data set obtained from Real Laboratory Process which can be obtained from MATLAB demos. In this work, 1500 measurements of collected input and output data from Real Laboratory Process was sampled at the sampling interval is 0.01 seconds. Input and output data of pneumatic system are shown in Fig. 3.

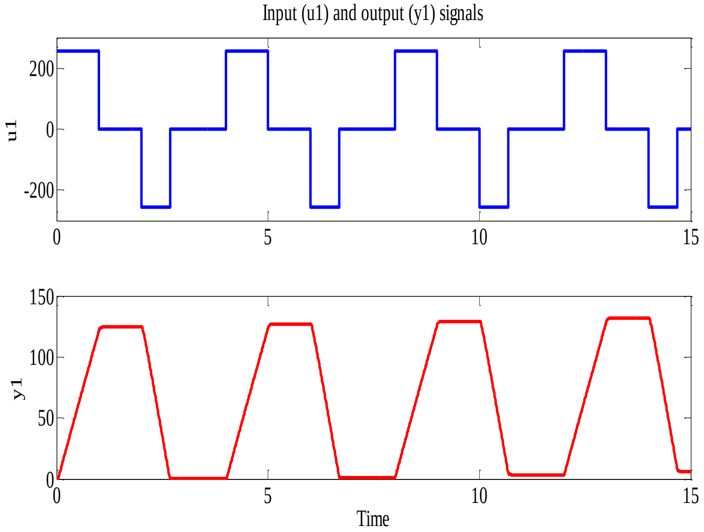

Figure 3: Input and output data of pneumatic system

In 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 MATLAB System Identification Toolbox: AutoRegressive with Exogenous input (ARX), AutoRegressive Moving Average with Exogenous input (ARMAX), Output Error (OE), and Box Jenkins (BJ).

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 MATLAB System Identification Toolbox can be represented as:

$$\frac{B\left(z^{-1}\right)}{A\left(z^{-1}\right)}=\frac{0.002606z^{-1}+0.003719z^{-2}-0.002646z^{-3}}{1-1.778z^{-1}+0.7736z^{-2}+0.004083z^{-3}}$$

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; to check the validity between the measured and desired data under a validation requirement. Akaike's Model Validity Criterion is used since it is 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%. The term *fit* means the closeness between the measured and simulated model output, and it can be calculated using Eq. (2):

$$\text{Fit} = 100\left[1-\frac{norm(\hat{y}-y)}{norm\ (y-y)}\right]\%$$

y: true value
ŷ: approximate value

A model is acceptable if the Loss Function and Akaike's FPE is as smallest as possible. The values of Loss Function and Akaike's FPE can be calculated using Eq. (4) and (5):

$$V = \frac{e^2(k)}{N} = \frac{e^T(k).e(k)}{N}$$

e (k) : error vector

$$FPE = V\frac{1+\frac{d}{N}}{1-\frac{d}{N}}$$

V: loss function
d : no. of approximated parameter
N: no. of sample

Using System Identification Toolbox, the best fit of the output model is 89.18% 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 blue 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 ARX223 model is considered small with the value 0.001168 and 0.01185. The results are summarized in Table 1.

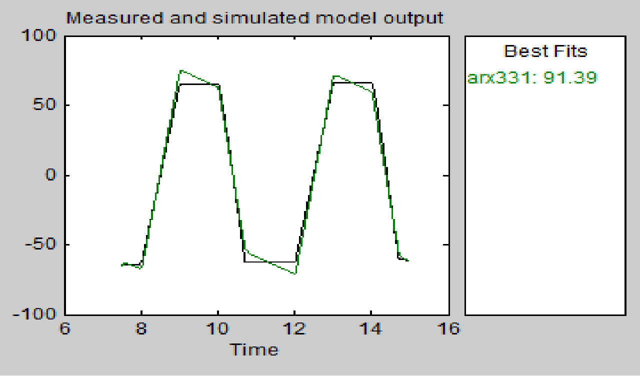

Figure 4: Measured and Simulated Model Output (Best Fit)

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

ARX 331	
Best Fit	91.39
Loss Function	0.01168
Akaike's FPE	0.01185

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

4.0 CONTROLLER DESIGN

Several studies are currently kept on tackling this issue on designing a suitable controller for improving the output performance of the system considered. Eko Harsono (2009) designed a Proportional (P) and Proportional-Integral (PI) Controller, and has implemented both controllers to the simulation and real-time process. Mohd Fahmy (2010) designed a Proportional-Integral-Derivative (PID) controller to control the system and he proposed Ziegler Nichols tuning method for tuning those PID parameters. An intelligent tuning method for PID controller using Radial Basis Function Neural Network (RBFNN) tuning method was presented by Ibrahim (2010). In this work, two different types of controllers, namely Proportional-Integral-Derivative (PID) controller and Generalized Minimum Variance (GMV) controller have been proposed.

A. Proportional-Integral-Derivative (PID) Controller.

A PID controller is one of the feedback type controller normally used in process industries. C.C. Yu (1999) in [8] found that more than 90% of the control loops in industries are of this type. PID controller, on the other hand, has proved to be rather popular in many control system applications due to its flexibility, simple structure, performance is quite robust for a wide range of operating conditions, and also provides adequate performance in the vast majority of applications [9]. As the name suggested, a PID controller consists of three basic parameters, which are proportional, integral, and derivative. Each parameter has their own functionality [10] and the performance of a PID controller is mainly determined by these three parameters. Figure 4 illustrates the PID controller in a closed-loop system and a general PID equation is given by Eq. (7).

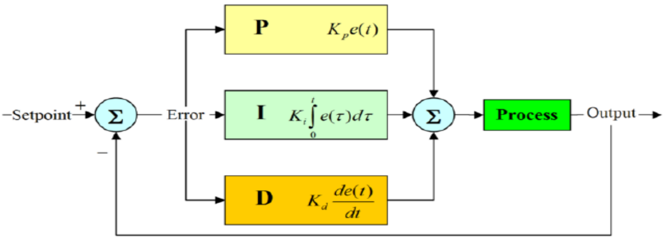

Figure 5: The PID Controller in a Closed-Loop System

$$PID = K_p\, e(t)^2 + K_i \int e(\tau)d\tau + K_d \frac{d}{dt}e(t)$$

In PID controller, it is necessary to decide which parameter to be used and specify its correct value. This is because; incorrect value of parameters may affect performances of the controller. Because of this, tuning these three PID parameters are crucial and many studies are kept tackling on this issue. As years passed by, “try and error” method (normally used to tune the PID parameters) is considered as a wasting time method. This is due to the performances of PID controller nowadays can be improved with automatic tuning, automatic generation of gain schedules, and continuous adaptation [10].

B. Generalized Minimum Variance (GMV) Controller.

GMVC is an extension of Minimum Variance Control (MVC). This method is introduced in order to accommodate servo control and to overcome disadvantages introduced by MVC, where in MVC there are some drawbacks that the designer must consider when applying it: the performance of MVC is affected by time delay, *k*, MVC ignores the amount of control effort required, and many more. The general block diagram of GMV controller is shown in Figure 5 below.

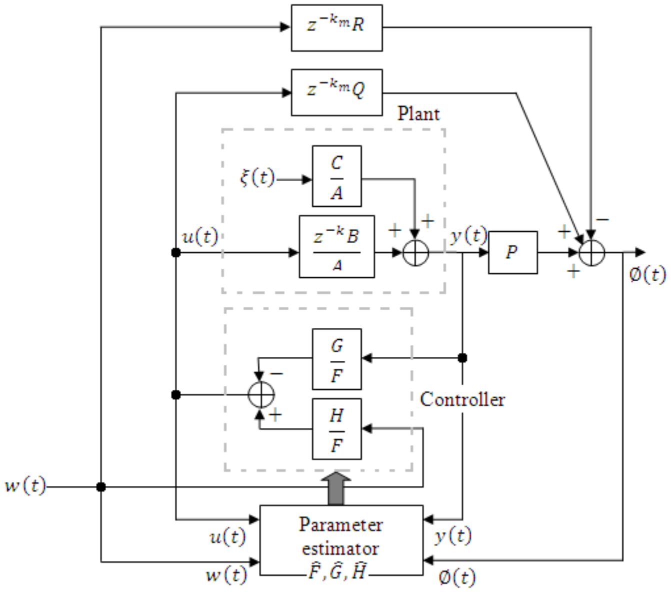

Figure 5: The General Structure of GMV Controller Block Diagram

5.0 RESULT AND ANALYSIS

Table 2: Performances of the Controllers Designed

	Controller		
Response Characteristics	Generalized Minimum Variance (GMV) Controller ARX 331	Generalized Minimum Variance (GMV) Controller ARX 223	Proportional Integral Derivative (PID) Controller PID
Percent Overshoot, OS (%)	0	180	2.5
Peak Time, Tp (s)	0	6.6	15
Settling Time, Ts (s)	120	4.8	19.2
Rise Time, Tr (s)	2	0.4	8s
Steady State Error, Ess (%)	0.1	0	0

Based on 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.

6.0 CONCLUSION

This research has presented the system identification model and development of Generalized Minimum Variance (GMV) algorithm in pneumatic system. The MATLAB model using system identification toolbox approximately plant model (position) the input-output experimental data was presented. The ARX model 331, ARX223 and PID controller was 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 modeling by using control law. Although deceptively simple, to 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 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 using for a variety of basic research, such as improved performance of the controller. Furthermore, the pneumatic system can worked well as sound system and this makes the controller in accordance with the achievement of good control.

ACKNOWLEDGEMENTS

The authors would like to thank Universiti Teknikal Malaysia Melaka (UTeM) for their financial support.

REFERENCES

Akira Inoue, Akira Yanou, Takao Sato, Yoichi Hirashima., 2001. *A State-Space Based Design of Generalized Minimum Variance Controller Equivalent to Transfer-Function Based Design.* Proceedings of the American Control Conference.

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.

Faudzi, A.A.Suzumori, K., and Wakimoto, S., 2008, November. *Distributed Physical Human Machine Interaction Using Intelligent Pneumatic Cylinders*. In Micro-Nano Mechatronics and Human Science, 2008. International Symposium on (pp.249-254).IEEE.

Faudzi, A.A.M., 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.

Khairuddin Osman, Ahmad ‘Athif Mohd Faudzi, M. F. Rahmat and Koichi Suzumori, *System Identification and Embedded Controller Design for Pneumatic Actuator with Stiffness Characteristics*, Mathematical Problems in Engineering, vol.2014, 13 pages, 2014.

Khairuddin Osman, Ahmad ‘Athif Mohd Faudzi, M. F. Rahmat, Omer Faris Hikmat and Koichi Suzumori, *Predictive Functional Control with Observer (PFC-O) Design and Loading Effects Performance for a Pneumatic System*, The Arabian Journal for Science and Engineering, 2014. (Abstracting/Indexing: ISIWoS IF 0.385, Q3) – 16 October 2014.

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).

Syed Najib Syed Salim, Mohd Fua’ad Rahmat, Ahmad’Athif Mohd Faudzi, Zool H.Ismail, and Noorhazirah Sunar., 2014. *Position Control of Pneumatic Actuator Using Self-Regulation Nonlinear PID.* Hindawi Publishing Corporation,2014.

S. Chillari, S. Guccione, G. Muscato.,2001 *An Experimental Compariosn Between Several Pneumatic Position Control Methods*. Proceedings of the 40th IEEE Conference on Decision and Control.

W.T.Chung, A.K.David., 1999. *Digital and Laboratory Implementation of a Generalised Minimum Variance Controller for an HVDC link*. IEEE Proceedings, 146(2).

Toru Yamamoto, Akira Inoue, Sirish l.Shah., 1999. *Generalized Minimum Variance Self-Tuning Pole-Assignment Controller with a PID Structure.* Proceedings of the 1999 IEEE International Conference on Control Applications

.