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NON-PARAMETRIC IDENTIFICATION TECHNIQUES FOR INTELLIGENT PNEUMATIC ACTUATOR

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Graphical abstract

Abstract

The aim of this paper is to present experimental, empirical and analytic identification techniques, known as non-parametric techniques. Poor dynamics and high nonlinearities are parts of the difficulties in the control of pneumatic actuator functions, which make the identification technique very challenging. Firstly, the step response experimental data is collected to obtain real-time force model of the intelligent pneumatic actuator (IPA). The IPA plant and Personal Computer (PC) communicate through Data Acquisition (DAQ) card over MATLAB software. The second method is approximating the process by curve reaction of a first-order plus delay process, and the third method uses the equivalent n order process with PTn model parameters. The obtained results have been compared with the previous study, achieved based on force system identification of IPA obtained by the (Auto-Regressive model with eXogenous) ARX model. The models developed using non-parameters identification techniques have good responses and their responses are close to the model identified using the ARX system identification model. The controller approved the success of the identification technique with good performance. This means the Non-Parametric techniques are strongly recommended, suitable, and feasible to use to analyze and design the force controller of IPA system. The techniques are thus very suitable to identify the real IPA plant and achieve widespread industrial acceptance.

Keywords: Non-Parametric Identification, PTn Model, Intelligent Pneumatic Actuator (IPA)

1.0 INTRODUCTION

System identification is the art and science of building mathematical models of dynamic systems from observed input-output data. The main aim of the system identification is to determine a mathematical model of a physical/dynamic system from observed input/output data. Development of identification began in mid-1960s by (Ho, and Kalman) [4] and (Astrom and Bohlin) [3] who proposed two common identification techniques that are still used in field of engineering. Ho, and Kalman determine the minimal state-space representation from impulse response data. Astrom and Bohlin developed Auto-Regressive Moving Average (ARMA) model and Auto-Regressive Moving Average with eXogeneous (ARMAX) model. The Auto-Regressive model with eXogenous (ARX) model structure provides a much simpler estimation solution than the ARMAX model. Zhu (1998) [1] and Hjalmarsson (2003) [2] identified high order ARX models that are reduced before being used in control design. Non-Parametric method had been used to approximate the first order model by Skogestad [6]. Researchers team from University of Zagreb, Croatia and INA-Oil Industry cooperated to develop non-parametric identification technique achieved with better performance with n parameter model called PTn model [7]. For model derivation of the IPA, System Identification (SI) was proposed to obtain the transfer function Equation. SI techniques are based on the relationship between the input and output of the system. The modeling was simulated using MATLAB software. However, mathematical modeling has a limitation to derive because the pneumatic actuator system is complex and has several unknown estimation parameters [8], [11]. Chang and Tseng suggested system identification by complex mathematically derivation obtained by linear time invariant (LTI) model of the servo pneumatic system [12]. A comparison study by Jouppila (2010) compared the analytical and non-analytical model of a pneumatic system and good precision was achieved, which means the non-analytical model is suitable for system analysis and for testing of controllers [13]. Identification of frequency characteristic was demonstrated for pneumatic system and controlled using Programmable Logical Controller [14]. A research group from University of Washington and Institute for Neural Computation San Diego had also identified system parametric model for pneumatic actuator based on real parameters [15].

2.0 THE STRUCTURE OF THE IPA CYLINDER

Nowadays, the pneumatic actuators are becoming popular in the scope and the expansion strategies for their sophistication and performance. The intelligent pneumatic actuator is a new generation of actuators developed for Research and Development (R&D) purposes in the academic and industrial fields. It can be integrated with microprocessor, and various micro sensors. This type of actuators has communication ability, local control functions and reduces the number of cables connected, as well as high performance actuator motions [16]. They are extensively used in the automation of production machinery, robotics, and in the field of automatic control. For instance, pneumatic circuits that convert the energy of compressed air into mechanical energy are widely used, and various types of pneumatic controllers are found in the industry. The actuator is equipped with five main components, as shown in Figure 1. There are three elements of the optical encoder; an LED light source, a photo detector IC and optical lenses. The role of the lenses is to focus the LED light onto the code strips. This light will be reflected and received by the photo detector IC. The encoder, which is used as position sensor, is mounted at the bottom of the PSoC board. There are two chambers available in IPA. By manipulating the pressure in Chamber 1, the right and left movements of the actuator can be controlled. The method of controlling the actuator movements is by supplying constant air pressure to Chamber 2 at 0.6 MPa (P_1) while regulating air inside Chamber 1 from (0-0.6) MPa (P_2). Right and left movements depend on the algorithm to drive the valve using PsoC PWM duty cycle in chamber 1. Pressure sensor is connected to PsoC for pressure data reading. The chamber pressure is the input for the control action of the cylinder. The pressure sensor then reads the pressure in Chamber 1, and the force F_d is calculated as follows:

$$\mathrm{F}_d = P_2 A_2 - P_1 A_1 \quad (1)$$

where P_1 and P_2 are pressure data, and A_1 and A_2 are cross-sectional areas in Chamber 1 and 2. Assume that P_1 (constant 0.6MPa), and A_1 and A_2 are known values. By reading the pressure in P_2 Chamber 2, force data, F_d can be known. The actuator applies 2 valves, two ports and two positions to drive the actuator. The valves are attached at the end of the actuator. By controlling only the air inlet in chamber 1, the control mechanism will be easier compared to controlling both chambers. Valve 1 will control the air inlet while valve 2 will control the air exhaust. The method of controlling the valves is by using PWM duty cycle driven by PSoC. The movements of the actuator depend on the valves operation [8], [9]. The possible movements of the actuator cylinder depend on the valves operation, as follows:

(i) Valve 1 OFF. Valve 2 OFF - cylinder stops
(ii) Valve 1 OFF. Valve 2 ON - cylinder moves to the right side
(iii) Valve 1 ON. Valve 2 OFF - cylinder moves to the left side
(iv) Valve 1 ON. Valve 2 ON - no operation

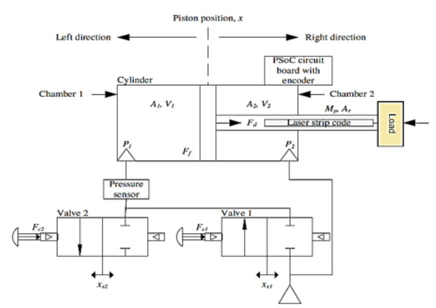

Figure 1(a) Schematic diagram of the IPA

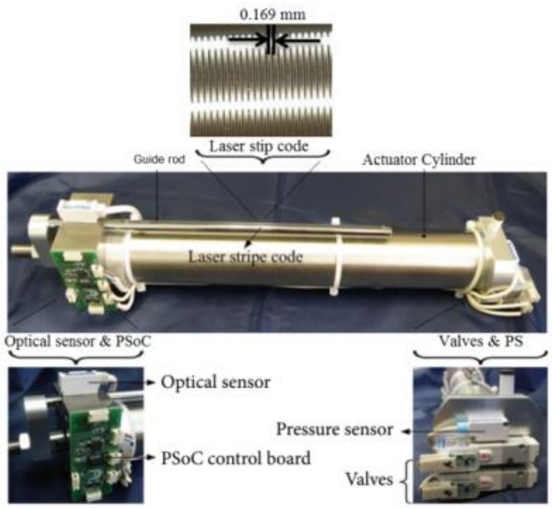

Figure 1(b) Components of the IPA cylinder

3.0 EXPERIMENTAL SYSTEM SETUP

Pneumatic actuator is driven by an Air compressor, which offers a low vibration level, minimum noise, longer life time and higher pressure. Data Acquisition Card DAQ-6221 is used to connect the sensors and actuator to the computer in order to complete the data collection and control the process through the computer. Typically, two analog output channels are used to send the control signal to the two valves, and one analog input channel to receive the pressure sensor signal. One pressure regulator is used in order to maintain the pressure value with 0.6 MPa setting value. The piston rod, fixed during the real time experimental data collection for the force identification, then controls the force using predictive control. Experimental data identification technique is used to obtain real-time model of the IPA system. The IPA and Personal Computer (PC) communicate through Data Acquisition (DAQ) card over the MATLAB software, as shown in Figure 2.

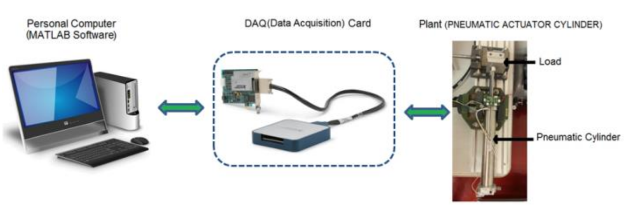

Figure 2 Real experimental setup of the IPA

4.0 NON-PARAMETRIC IDENTIFICATION TECHNIQUES OF THE IPA

The most popular conventional methods used in open loop process identification are the tangent method and curve reaction method. These methods provide two most vital information used to calculate process parameters and to simplify the control design such as calculate the optimum PID control values [19]. The first order of step response real experiment is approximated based on the input/output the model and determined by applying non-parametric system identification based on experimental data response of the IPA, as shown in Figure 5. The process gain is described based on the steady state effect of the input change to the change of the output. The time constant exact value is calculated at 63.28% of the output response [6], [10], [20]. The dead time can be directly read from the output response.

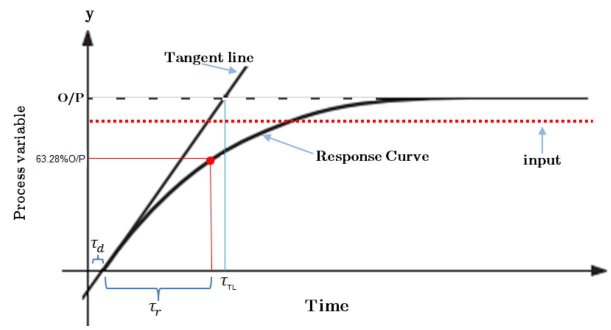

Figure 3 Curve reaction and tangent line approximation methods

Referring to curve fitting and tangent line method approximation graphs as shown in Figure 3, and from the real experiment as Figure 5 the force step response the plant is approximated by a first-order plus dead time (FOPTD) reaction curve with set point 80 gives the process gain, $k_p = \frac{\Delta y}{\Delta u} = \frac{129-0}{82-0.61} = 1.585 \cong 1.6$, where Δy is the change in the output signal, Δu is the change in the input signal. The time constant calculated at 63.28% of the output response τ_r=0.245, and the time delay estimated to be more than zero τ_d=0.001 to simplify the controller parameters calculations. The delay can be set up as parameter estimation to obtain controller setting [6].

$$G_{IPA-1st} = \frac{1.6}{0.245\,s+1} e^{-0.001s} \tag{2}$$

The FOPDT approximation would be derived from an experimental test of the dynamic system and compared with the identified third order system identification in unit step response. Time delay needs to be adjusted to be more than zero to achieve a satisfactory match and simplify the control parameters analysis.

The tangent line method as shown in Figure 3 and Figure 5 is used to identify the model to equivalent n order process model with PTn model parameters [7]. The following transfer function is obtained by identification of the PTn model parameters based on tangent line method as

$$G_{\mathrm{PTn}} = \frac{k_p}{1+(\tau_d+\tau_{TL})s+((\tau_d/2)+\tau_{TL})\tau_d s^2+((\tau_d/6)+(\tau_{TL}/2))\tau_d{}^2 s^3+\cdots} \tag{3}$$

The equivalent PTn expression parameters are calculated as the second order system n=2 as following: $k_p = 1.6,\ (\tau_d + \tau_{TL}) = 0.2387, ((\tau_d/2) + \tau_{TL})\tau_d = 2.39E-4.$

In this section, the experimental setup is described for pneumatic actuator cylinder. The force of pneumatic actuator has been modeled based on experimental data. The curve reaction model has a good response and its response is close to the model identified using system identification. Meanwhile, the PTn technique shows improvement in the response compared to the curve reaction method, which means, approximately techniques are effective and feasible to analyze and design the force controller of the IPA based on achieved reasonable dynamical matching with the real system with the non-parametric identification. The comparison between first order $G_{IPA-1st}$ and second order G_{PTn} shown in Figure 4.

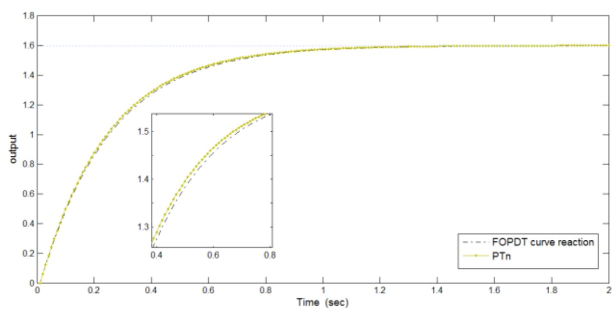

Figure 4 Identification response of 1st order Curve reaction and 2rd order PTn non-parametric techniques of IPA

In this research, the force model identification was obtained by [11] using ARX model (Auto-Regressive model with eXogenous). The plant mathematical models were developed using MATLAB System Identification Toolbox from open-loop input-output experimental data . The plant model was derived from the measured input and output signals of a real plant that needed to be identified. The ARX model structure was chosen for its best result which fulfilled the criteria for system identification.

$$y(t) = \frac{B(z^{-1})}{A(z^{-1})} z^{-d} u(t-1) + \frac{1}{A(z^{-1})} e(t) \tag{4}$$

By assuming that noise is zero, the following equation has beenderived as:

$$\frac{Y(z^{-1})}{U(z^{-1})} = z^{-d} \frac{b_0 + b_1 z^{-1} + b_2 z^{-2} + \cdots + b_{nb} z^{-nb}}{1 + a_1 z^{-1} + a_2 z^{-2} + \cdots + a_{na} z^{-na}} \tag{5}$$

where $na \geq nb$, d is time delay, na is number of poles, $nb$is number of zeros, $U(z^{-1})$ is the input and $Y(z^{-1})$ is the output. The parameters of the force model identification [8], [11] with sampling time=0.01 were: $b_1 = 0.03938, b_2 = 0.04506,$ $b_3 = 0.01286, a_1 = -0.60870,\ a_2 = -0.27020, a_3 = -0.06021$

The system identification third order system could be transferred to S-domain state as follow:

$$G_{SI-3rd} = \frac{6.102\, s^2 - 91.95\, s + 520000}{s^3 + 281\, s^2 + 74990\, s + 325400} \tag{6}$$

The behavior of FOPDT curve reaction identification in Equation (2) and the third order system identification in Equation (6) are shown in Figure 5.

The Identification techniques of Non-Parametric 1st order in Equation (2), PTn expression technique as Equation (3), 3rd system identification technique in Equation (6) and the experimental data response and of the IPA are shown in Figure 5 and the approximations followed the tracking and were quite efficient to identify the force model of IPA. Increasing the order of the model effective to enhance the model response to be near from the system identification model as shown in figure 5.

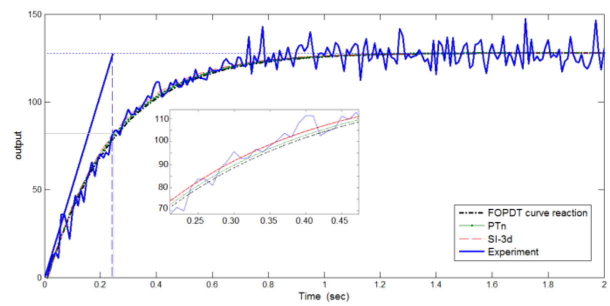

Figure 5 Identification response of Non-Parametirc (1st ,and 2nd) order models VS Parametric 3rd order and Experimental data of the IPA

5.0 EVALUATION OF THE NON-PARAMETRIC TECHNIQUE BASED ON PREDICTIVE CONTROL

Model predictive control family is mostly used for industrial processes. The GPC performance objective is very similar to the DMC but is minimized via recursion on the Diophantine identity by Clarke [18]. The closed form solution of model predictive control law is given as:

$$\Delta \mathrm{u} = (\mathrm{G}^{\mathrm{T}}\mathrm{G} + \mathcal{X}_{\lambda})^{-1}\mathrm{G}^{\mathrm{T}}(\mathrm{w} - \mathrm{f}) \tag{7}$$

where G is the dynamic matrix, $\mathcal{X}_{\lambda} = \lambda\mathrm{I}$, where I is diagonal matrix, w is a vector of the reference trajectory, and f is a matrix calculated using the Diophantine equation. Another modified matrix proposed in [17] achieved better performance and gave more quality responses compared to the conventional matrix especially in term of overshoot. The modified matrix depends on the move suppression coefficient λ , the diagonal matrix, and other values created from the open-loop response of the original system.

The parameters of the predictive control strategy are the move suppression coefficient λ, prediction horizon P, and control horizon M. Each parameter has its own formula. These parameters are calculated based on the $\mathrm{G}_{\mathrm{IPA-1st}}$ approximation [17].

Based on the force model step response, the plant was approximated by using a first-order plus dead time (FOPTD) as $G_{IPA-1st}$ to get the value for move suppression. The predictive horizon was P=126, the control horizon was M=5 for conventional method, while the predictive horizon was P=126, the control horizon was M=10 for the modified method. The move suppression for the conventional method was λ_c=2.25, and for the modified method was $\lambda_{p\gamma}$ =1.92. The simulation results are shown in Figure 6. In terms of rise time, overshoot, behavior tracking and disturbance rejection, the modified method has been proven more efficient compared to the conventional method.

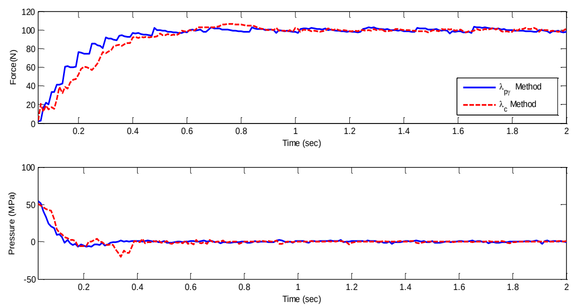

Figure 6 Real time results Predictive control of IPA

6.0 CONCLUSION

Non-parametric identification techniques have been presented in this paper. An alternative methods of analyzing open-loop response of a process simulated based on experimental data has been investigated. The force model identification techniques of IPA have been modeled based on experimental data. This model that has been identified using non-parametric identification techniques has shown close results with the system identification model. Meanwhile, the Non-Parametric PTn technique shows improvement in the response compared to the curve fitting method technique. The controller has proven the success of the identification technique with good performance. In conclusion, Non-Parametric techniques are recommended, suitable, and feasible to analyze and design the force controller of the IPA system.

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