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Simulation of an x-y pneumatic position control system using a smart control algorithm

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A B S T R A C T

This paper deals with the use of a new switching control scheme used to assure good tracking performance of a pneumatic X-Y table and to reduce the control effort and get a faster response of the system. Simulation studies of an x-y pneumatic positioning control system are introduced using the Approaching Index Switching Algorithm (AISA). The value of the approaching index is used to switch between two different control sets. The first set is a lightly damped one used to ensure a faster response of the system, and the second control set is a tightly damped one used to approach the final destination. The system is simulated using MATLAB/Simulink and the results obtained using (AISA) are compared with those of the (PD) control. The results showed that 50% faster response is obtained. Meanwhile, this great enhancement in the speed of response is shown to be attainable although a 50% reduction of allowable limits of the control signal is enforced compared to those allowed to the PD controller. much better performance using the AISA compared to those of the PD control. All the desired specifications of the system such as error, stability, and power consumption are robustly satisfied under AISA.

1. Introduction

Pneumatic systems have been used in all branches of industry such as material handling equipment, medical equipment, and machine tools operations. Unlike typical electric and hydraulic actuators, pneumatic actuators can provide extremely nonlinear performance due to the compressibility of the air. Their primary advantages are their high payload-to-weight and payload-to-volume ratios, as well as their high speed and force capabilities. Another factor that makes them desirable for usage in the industry is their low cost [1]. Due to the compressibility of air, poor friction characteristics, and low damping, pneumatic drives require complex controllers, as opposed to the readily controlled conventional electric DC motors used with ball screwdrivers that have been frequently utilized in the past. As a result, traditional PID feedback controllers [2], [3] are ineffective even for position control. X-Y dual-axial intelligent servo pneumatic-piezoelectric hybrid actuators for position control with high response and large stroke are developed Chiang [4]. X-Y decoupling controllers were also created and have been found to reduce interactions between the movements of the X- and Y-axes. [5] the discrete-valued model-predictive control algorithm (DVMPC2 includes a more flexible cost function, and an improved prediction strategy describes the position control of pneumatic actuators using inexpensive on/off valves [6]. The most widely used controllers in the pneumatic actuator system are proportional-integral-derivative (PID), sliding mode controller (SMC), and adaptive controller. Most of the recommended control strategies studies involve a lot of complicated parameters and require complex math equations.

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Most researchers still believe in control loops based on proportional integral derivatives (PID) controllers because they are simple and easy to understand. The most significant advantage of this type of control application is its simplicity; it

only requires three parameters to be considered to achieve effective control. However, it may have difficulty dealing with systems with a high degree of nonlinearity [7]. To improve the positioning of pneumatics, a large amount of research is devoted to the development of improved control methods, which are known to be highly nonlinear. Even though controllers that are based on show ideas are exceedingly popular, the fact that they need to be able to prove their system reliability makes them difficult to put into practice. Some people believe that clever calculations, such as neural systems and run-of-the-mill controllers, are the best way to go since they do not require a model. The ability to upgrade controllers so they can be modified on-the-fly without stopping the manufacturing process is a versatile feature. They were tried freely based on their ability to track step and sine wave trajectories [8]. An adaptive robust coordinated motion control strategy of the cylinder drives the dual-axis gantry. Using an online recursive least squares estimation algorithm to obtain the correct estimation model, the degree of parameter reduction is determined using parametric uncertainty [9].

In this research, a proportional-valve controlled pneumatic X-Y table system is built for the position tracking controltheta is experiments. The pneumatic cylinders controlled by proportional valves are essential nonlinear system. Thus, the constant-gain linear controller, like PD, cannot track the position reference input accurately. Here, the Approaching index switching Algorithm AISA introduced in [10], and [11] is used to control the X-Y table to follow the desired trajectory.

The AISA is implemented to verify the tracking ability of the system to different reference inputs. The simulation results using the traditional PD and the AISA controllers are given for comparison for the same control Controller parameters. The effect of inertial disturbance is also added to test the controller's performance.

2. Modeling

The pneumatic X-Y positioning system studied in this article consists of two identical cylinders with bore size of 20 mm and 200 mm stroke in x- and y-directions. Two solenoid on-off valves, 2 flow control valves, and a sliding table. The payload is installed on a sliding table. If the air is an ideal gas; air in the cylinders and hoses has uniform density, adiabatic flow, negligible air leak, supply pressure is constant, and the stiction force of the rod is negligible.

2.1 Servo motor

Servomotors are an electromechanical device widely used as an actuator for precise linear or angular motion. MG995 is a typical cheap hobby servomotor. The DC motor converts the electrical voltage applied to its terminals in rotational motion. The gearbox decreases the speed provided by the DC motor and increases the torque applied to the output shaft. The electronic control board reads the PWM (Pulse Width Modulation) signal sent to the servo, converts it to an angle, compares it with the current angle, and calculates the required control action.

The servo motor can be approximated to a 1st order system as follows:

$$\theta + \tau D\theta = GV \tag{1}$$

or

$$\theta = \frac{G}{1+\tau D} V \tag{2}$$

Where, τ is the time constant of the servo motor, θ is the angle in radians, and V is the voltage applied to the servomotor.

2.2 Gear Ratio (GR) and Flow Control valve (FCV)

The flow control valve is to regulate the flow rate in the pneumatic cylinder. GR is referred to the gear box ratio between the servo motor and the flow control valve as the Mg995 servo designed as following

$$GR = \frac{T_1}{T_2} = 6 \tag{3}$$

The gear box is used to amplify the valve opening due to servo motion and accordingly the flow rate out of the valve q. The equation relating the flow out of the valve and the angle of the servo motor is given by $q = q(\theta)$

Where, q is the inlet flow rate, and the supply pressure is constant. Linearizing this equation gives:

$$q = c_1\theta \tag{4}$$

Where q is the flow rate and is equal to the rate of change of the volume of the chamber, and θ is the servomotor angle that opens the flowrate control valve.

It is easy to sow that the flow rate to the cylinder is given as follows:

$$q = A * velocity\ of\ the\ piston \tag{5}$$

Where, A is the pneumatic cylinder area, and v is the velocity of the cylinder rod.

$$q = A * v = A\frac{\Delta Y}{\Delta t} = ADy \tag{6}$$

The air flow rate to the cylinder is a function of the valve opening and the pressure resisting the motion of the rod and it can be given as follows:

$$q = q(\theta, p) \tag{7}$$

Where, p is the pressure drop across the piston due to load added, ⍰ is the opening angle of the flow control valve.

Linearizing the above equation, we get

$$q = \left.\frac{\partial q}{\partial \theta}\right|_p \theta + \left.\frac{\partial q}{\partial p}\right|_\theta p = c_1\theta - c_2 p \tag{8}$$

Where $c_1 = \left.\frac{\partial q}{\partial \theta}\right|_p$ and $c_2 = \left.\frac{\partial q}{\partial p}\right|_\theta$ are constants.

The force transmitted to the piston is given by:

$$pA = F = M\,a = MD^2y \tag{9}$$

Where, M is the load added to the piston and a is the acceleration of the piston assuming negligible friction forces.

From equation (7), and (8) we get

$$q = c_1\theta - \frac{c_2 M}{A} D^2 y \tag{10}$$

This equation relates the volume flow rate q with the output angle ⍰ of the servo motor and the load M added to the pneumatic cylinder with the cylinder acceleration.

From equation (5), and (9)

$$ADy = c_1\theta - \frac{c_2 M}{A} D^2 y \tag{11}$$

The X-Y pneumatic positioning system is a combination of two single axes. It is important to consider the influence between the motions of the two axes which should be considered in the controller design by a decoupling compensator.

A Block diagram representing the X_Y positioning control system is shown in Figure 1.

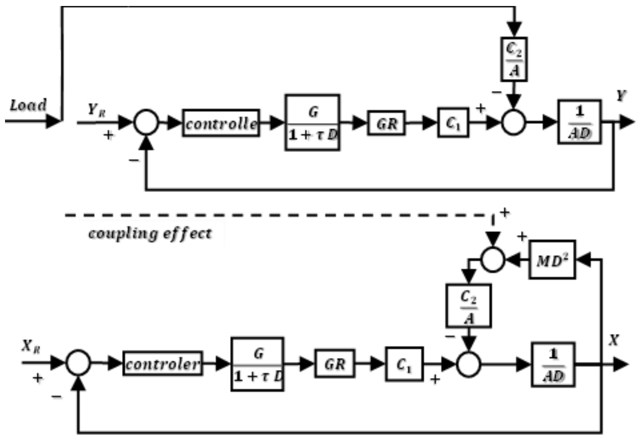

Figure :1 Simplified Block diagram representation of the system.

2.3 Controller

In this work, the Approaching Index Switching Algorithm controller introduced in [11] is applied to the pneumatic X-Y positioning system to enhance its performance. A comparison of the results obtained using the AISA and the traditional PD controller is carried out.

2.3.1 PD controller

PD-control is combination of feedforward and feedback control as shown in Figure 2, because it operates on both the current process conditions and predicted process conditions. In PD-control, the control output is a linear combination of the error signal and its derivative. PD-control as shown in contains the proportional control's damping of the fluctuation and the derivative control's prediction of a process error. In this control, the purpose of the D-only control is to predict the error to increase the stability of the closed-loop system. A PD controller is described by:

$$u(t) = k_p\, e(t) + k_d \frac{d}{dt} e(t) \tag{12}$$

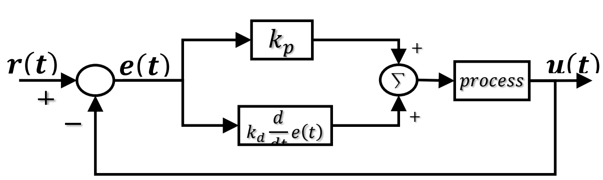

Figure :2 PD controller

2.3.2 Approaching Index Switching Algorism controller

The Approaching Index Switching Algorithm (AISA) is a control system designed to differentiate between the system needs during travelling to the desired destination and its need to stop at the destination value. An index is designed to provide a measure of the percentage of the remaining distance and the original value of the distance. A switch is designed to decide if the system is approaching its destination or not according to a comparison of its value and the preset switching value ε_s.

The value of the index is expressed as $\varepsilon(t) = |e(t)/\Delta r|$ where $e(t)$ is the value of the error at time t and Δr, is the required change of the reference set value. Starting at a value of one, the system moves to the final position where the value of the index is zero.

The switching decision can be expressed as follows:

$$\begin{Bmatrix} if: \varepsilon(t) \le \varepsilon_s & switch\ to\ closed - loop \\ else\ if: \varepsilon(t) > \varepsilon_s\ and\ e(t) < 0 & K = -k\ switch\ to\ open - loop \\ else:\ K = k & switch\ to\ open - loop \end{Bmatrix}$$

The first control set is a lightly damped set that ensures faster response of the system. The second control set is a well damped set and is used to slow down the system when it is reaching its final destination. A schematic representation of the switching mechanism [11], is shown in Figure 3.

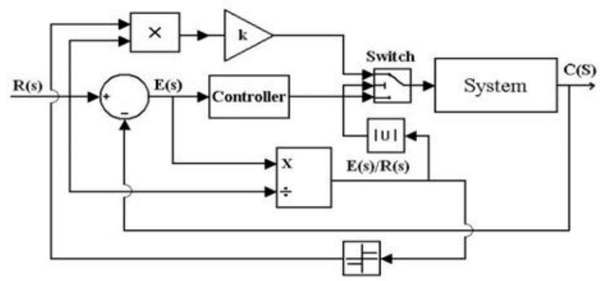

Figure :3 Schematic representation of the AISA

3. Simulation

In this section, the simulation results of X-Y pneumatic positioning system using an AISA [11] are presented. Two controllers, a lightly damped one and a well damped one are switched according to the switching policy discussed earlier. The simulation results obtained are compared with those of a conventional PD controller.

The resulting system is required to meet the following specifications:

- The control input should not exceed ± 5 v due to physical constraints.
- The overshoot and undershoot of the resulting step response should be kept at less than 10%.
- The simulation results obtained were processed using Simulink package.

Table :1 System parameters

parameter	Description	Value (unit)
G	Servo motor steady state gain	1
τ	Servo motor time constant	0.2 (sec)
c_1	Flow rate constant	4.79 *10-4 (m3/sec)

c_2	Pressure drop constant	2.93205*10-4 (m3/s.pa)
GR	Gear ratio	6
M	Mass loaded	2.05 (Kg)
A	Internal Area of the pneumatic cylinder	0.000314 (m2)

Figure 4 shows the simulation results of the position control of the X-axial pneumatic actuator using the AISA compared to two a moderately damped PD control, and a critically damped PD control.

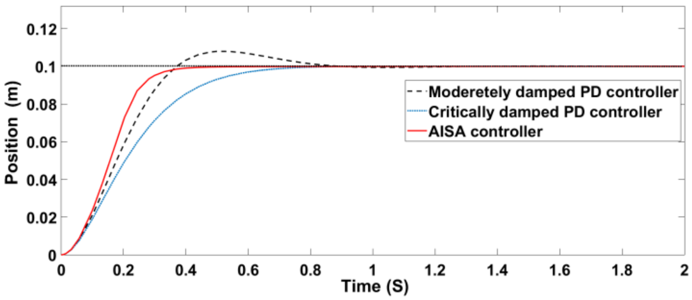

Figure :4 Response of the x-axes using PD controllers compared to that of the AISA

It is clear from the figure that the AISA has amazingly fast response compared to both PD controllers. The saving in time using the AISA is approximately 50% without overshoot compared to that of both the PD controllers.

It is important to realize that the accompanying control effort used shown in figure 5 for each case is confined within the allowable levels in each of the three cases.

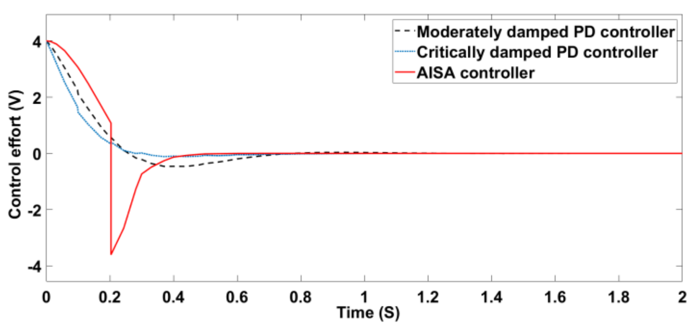

Figure :5 Control effort of the x-axes using PD controllers compared to that of the AISA

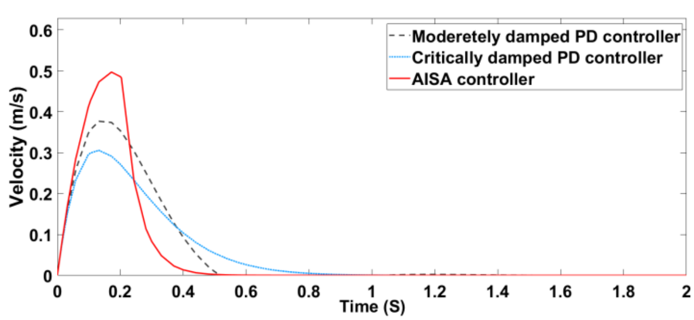

Figure :6 Speed Response of the x-axes using PD controllers compared to that of the AISA

As shown in Figure 6, it is clear that by using AISA higher velocity of the rod is obtained.

Figure 7 shows a comparison between the PD controller and the AISA controller for X axis response where there is a mass of 0.5 kg connected to the end of the cylinder rod. A much better response is also obtained using the AISA compared to that of the PD control.

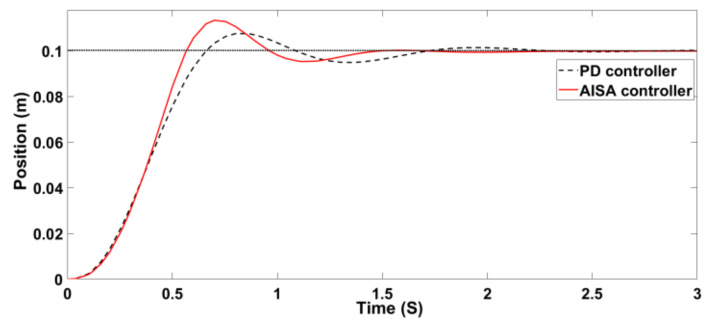

Figure :7 The response of X-axes carrying a mass of 0.5 kg using the PD controller compared to that of the AISA.

The corresponding control effort and velocity of the cylinder rod are given in figure 8 and figure 9, respectively.

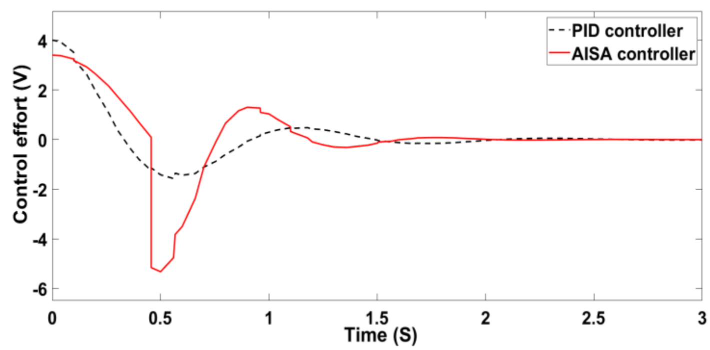

Figure :8 Control effort of the X-axes carrying a mass of 0.5 kg using the PD controller and the AISA.

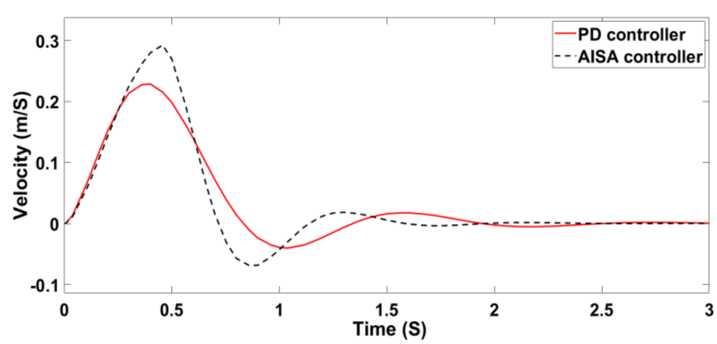

Figure :9 velocity of the X-axes carrying a mass of 0.5 kg using the PD controller and the AISA.

Further enhancement to the response of the cylinder is shown in figure 10, where the switching is done between three different control sets to ensure using a suitable set for each stage of the motion, instead of the two sets as the AISA is originally defined. In this case. It is clear from figure 10 that the multi-stage AISA controller greatly suppresses the oscillating behavior of the response given by the traditional PD control.

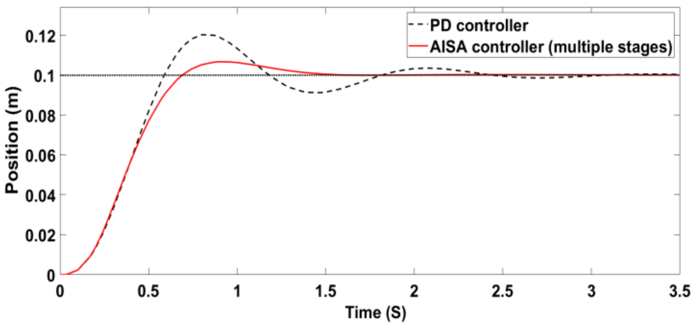

Figure:10 The response of X-axes carrying a mass of 0.5 kg using the PD controller compared to that of a multistage switching of the AISA.

The control effort and piston speed related to the response given in figure 10 are shown in figure 11 and figure 12.

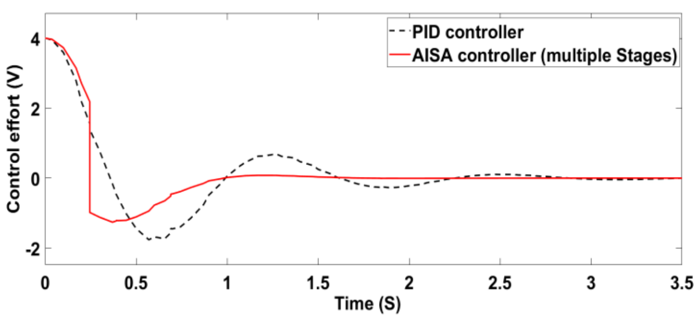

Figure 11: control effort on X-axes carrying a mass of 0.5 kg using the PD controller compared to that of a multistage switching of the AISA.

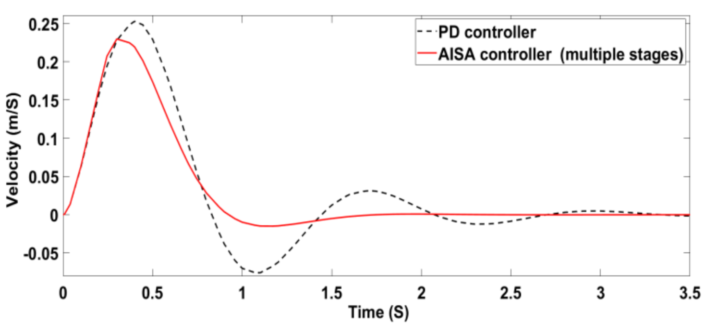

Figure :12 velocity *of X-axes carrying a mass of 0.5 kg using the PD controller compared to that of a multistage switching of the AISA.*

It is very important to keep the amplitude of the control effort corresponding to any enhancement of the speed of response within the allowable limits to avoid saturating the controller, and to lower the demand for more powerful hardware.

Figures 13-15 show the response of the cylinder using multistage AISA with a limitation of 50% to the amplitude of the control signal used compared to that of the amplitude allowed to the PD controller.

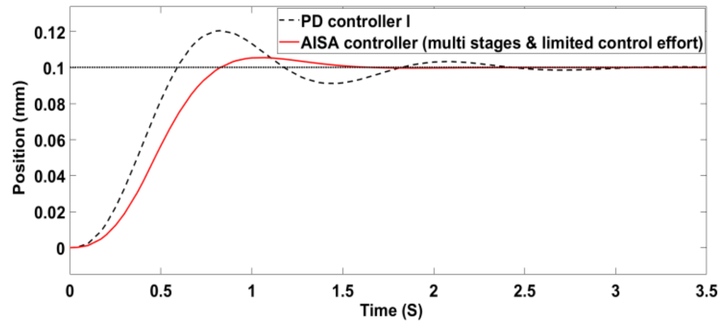

Figure 13 The response of X-axes carrying a mass of 0.5 kg using the PD controller compared to that of a multistage switching of the AISA and using 50% reduction of the maximum amplitude used by the PD control signal.

It is surprisingly clear the that, at least 30% enhancement in the speed of response is obtained using the limited control signal.

Furthermore, the cylinder speed is shown to be averaged with lower values of the maximum speeds attained and no fluctuations in the cylinder speed are shown compared to large speed fluctuations and limits obtained using the traditional PD controller.

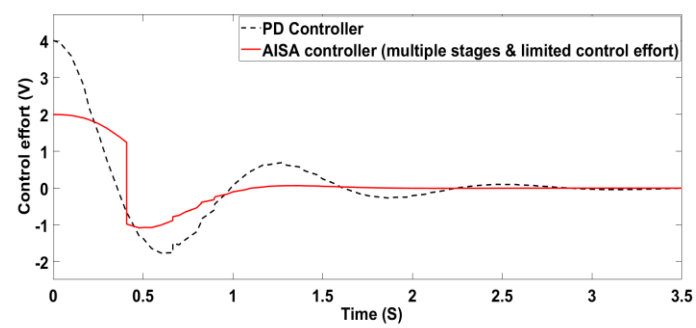

Figure 14 The control effort on X-axes carrying a mass of 0.5 kg using the PD controller compared to that of a multistage switching of the AISA and using a 50% reduction of the maximum amplitude used by the PD control signal.

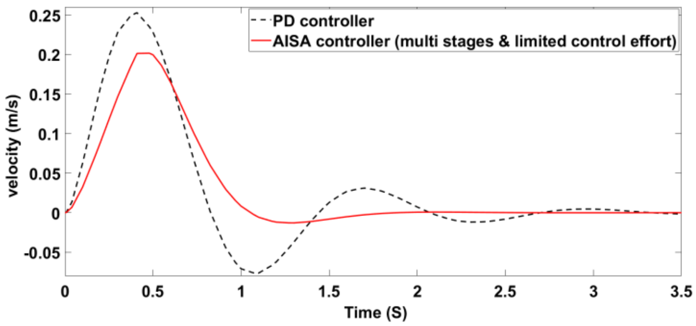

Figure 15 The velocity of X-axes carrying a mass of 0.5 kg using the PD controller compared to that of a multistage switching of the AISA and using 50% reduction of the maximum amplitude used by the PD control signal.

The simulation results of positioning control of XY dual-axial pneumatic system are shown in figures 16-18. The strokes of the X and Y-axis are (50 mm, 50 mm). The X-axes are supposed to move the Y axes arrangement of 0.5 kg and the load carried by the Y axes is also 0.5 kg and it is supposed to be loaded on the arrangement of the Y axes. Accordingly, the load carried by the X axes is 1 kg.

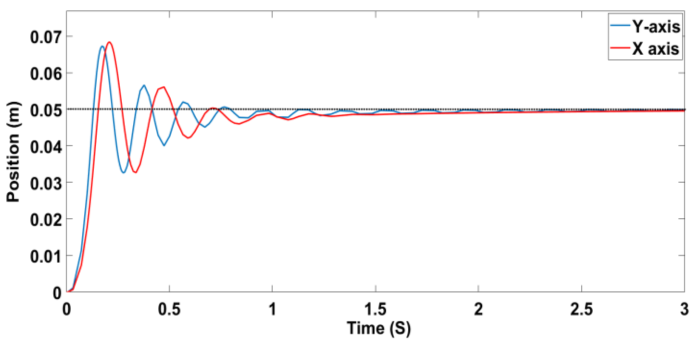

Figure 16 Position control of the X-Y pneumatic system under loading conditions using the PD controller compared to that of a multistage switching of the AISA.

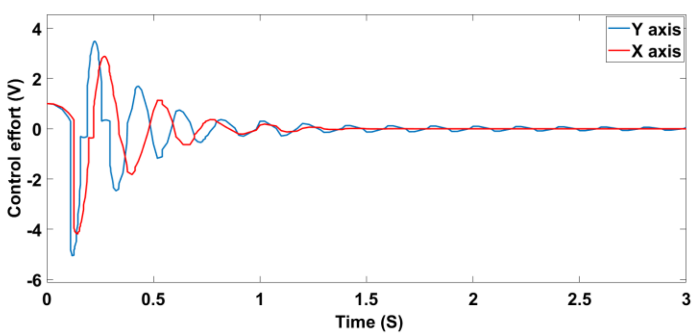

Figure :17 control effort of the X-Y pneumatic system under loading conditions using the PD controller compared to that of a multistage switching of the AISA.

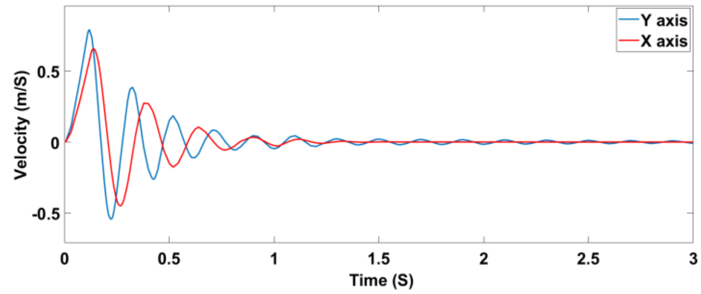

Figure:18 velocity of the X-Y pneumatic cylinder under loading conditions using the PD controller compared to that of a multistage switching of the AISA.

4. Conclusions

The simulation results of the approaching index switching algorithm (AISA) compared to the traditional PD controller for an x-y pneumatic position control system. It is clear that the AISA controller is much more efficient in maneuvering and is more efficient than PD Controller, approximately, 50% faster response is obtained. Meanwhile, this great enhancement in the speed of response is shown to be attainable although a 50% reduction of allowable limits of the control signal is enforced compared to those allowed to the PD controller. Finally, it is clear from the results that the speed of the cylinder road is kept lower with damped fluctuations compared to that of the PD controller.

5. Future works

In the future, extensive experimental work will be carried out to investigate the performance capabilities of the AISA.

6. Acknowledgment

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Y. Zhang, A. Nishi "Low-pressure air motor for wall-climbing robot actuation" Mechatronics, 13 (4) (2003), pp. 377-392.

[2] Shen YD, Hwang YR. "Dynamic modeling, and controller design for air motor" In: SICE–ICASE, 2006. International joint conference. 2006. p. 461–6.

[3] Hogan, N., "Impedance Control: An Approach to Manipulation: Part I - Theory" Transactions of the ASME in the Journal of Dynamic Systems, Measurement, and Control, vol. 107, pp. 1-7, 1985.

[4] Mao-Hsiang Chiang" Development of X-Y Servo Pneumatic-Piezoelectric Hybrid Actuators for Position Control with High Response, Large Stroke, and Nanometer Accurac" Sensors 2010, 10, 2675-2693.

[5] Haitao Qi, Gary M. Bone, and Yile Zhang "Position Control of Pneumatic Actuators Using Three-Mode Discrete-Valued Model Predictive Control".Actuators; Basel pp.56-86, 2019.

[6] Deyuan Meng, Aimin Li, Fei Chen, and Kai Zhang. Coordinated motion control of a pneumatic-cylinder-driven biaxial gantry for contour tracking tasks. Transactions of the Institute of Measurement and Control 2018, Vol. 40(7) 2249–2258.

[7] Jamian, Syamiza; Salim, S N S; Kamarudin, M N; Zainon, M; Mohamad, M S SYED " Review on controller design in pneumatic actuator drive system," Telkomnika; Yogyakarta, (Feb 2020): 332-342.

[8] Behrad Dehghan "Position Control of a Pneumatic System using Adaptive Intelligent Methods" M.A.Sc. Thesis, Queen's University, June 2012.

[9] Deyuan Meng, Aimin Li, Fei Chen, and Kai Zhang. "Coordinated motion control of a pneumatic-cylinder-driven biaxial gantry for contour tracking tasks" Transactions of the Institute of Measurement and Control 2018, Vol. 40(7) 2249–2258.

[10] Shehab R. Tawfeic "The Approaching Index Switching Algorithm" IEEE 7th International Conference on Intelligent Engineering Systems March 4-6, 2003.

[11] Shehab R. Tawfeic "Track Seeking Control for Hard Disk Drives Using the Approaching Index Switching Algorithm" Proceedings of the International Conference on Computer and Communication Engineering May 13-15, 2008, Kuala Lumpur, Malaysia.