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Robust µController Implementations for a Linear Pneumatic Actuator Interaction

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A B S T R A C T

Over the years, pneumatic systems have recorded a remarkable performance in automated applications, based on their cost to efficiency ratio and ease of energy transmission. Therefore, their drawback of not being totally controllable devices in terms of position accuracy, still represents a challenge task for engineers. In this paper, a traditional three term controller (PID) is designed for the task which is implemented in the system with an intelligent and not straightforward manner. The Integral term of the controller is not operating all the time during and parallel to the pneumatic piston stroke. The I-term will be switched 'on' and 'off', considering the system performance and needs. This ensures a robust control algorithm design, a faster system response and the avoidance of chattering around the demand position of the piston set point. In addition to this, an electrical board will be designed and produced in order to host all electronics like, a microprocessor, various amplifiers and converters, and a serial port for communication between the user and the system. An interface window is also implemented for the user to be able to export information of the system and record all data acquisition results as well as provide to an engineer a useful tool for re-programming the controller and download multiple versions of control code to the system. All results of the system performance are monitored and a representative pack of them are illustrated in the main body of this paper.

1. Introduction

Servo pneumatic systems play an indispensable role in industrial applications thanks to their variety of advantages, like: simple operation, clean, low cost, high speed and easy maintenance. Generally, The dynamics of these systems are highly nonlinear and their models inevitable contain parametric uncertainties and unmodeled dynamics. The pneumatic servo system is a very nonlinear time-variant control system because of the compressibility of air, the friction force between the piston and the cylinder, energy and thermal effects inside the cylinder, the flow rate through the servo valve, etc. In recent research work like [1-3], all the above problems are highlighted as well as that the application of nonlinear robust control techniques is a necessity for successful operation of pneumatic systems. Although PID (Proportional, Integral, Derivative) controller is still the most widely used approach due to its ease of implementation, the need for overcoming highly nonlinear phenomena turns away the use of classical PID controllers nowadays.

Therefore modern control techniques were designed and tested in pneumatic actuators in order to improve the performance of such systems considering position accuracy and repeatability as the two main performance characteristics. Fuzzy logic control, neural networks method, adaptive control, self-tuning or gain scheduling, the so-called "Soft Computing" control techniques, are approaches that have been already used for the task with remarkable outcomes. Among these techniques, much previous work from the above authors proved to be very confident in solving position control problem of a pneumatic servo system and all non-classical control methods have attracted considerable attention because they provide a systematic approach to the problem of maintaining stability and consistent performance in the face of modelling imprecision and disturbances. To implement a technique like them, though, requires high expertise from an engineer, high level of

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computing programming knowledge and control design skills. In an industrial environment this cannot always be succeeded due to multiple production line circumstances like low cost demand and the ability of a non-expert engineer to operate and control pneumatic systems for actuation. In this paper, our scope is to investigate and afterwards demonstrate how the all-time classic PID controller and its transformations can be robust and effective enough to control the position of a pneumatic cylinder based on a simple mathematical model of the system. At the top of all these, the most important part of the system is an interface board which will host the controller and all electronics peripherals. The interface card will be designed and assembled in order to be used for long term operations of the system. The criteria for choosing these specific microprocessor and electronics, details are provided in the following paragraphs, are low cost, reliability and multitasking capabilities. The ease of use in terms of programming was taken under consideration since the multiple input positioning system requires long control algorithms to be compiled by the microcontroller. One of the interface board main purposes is also data acquisition and real time data monitoring on a computer screen. In this paper, the pneumatic positioning system description and the control method implementation are given in the first paragraphs. The electronic interface board parts and assembly details will follow and finally the results and some further future applications will be discussed.

2. System Description

The pneumatic positioning system under investigation consists of a double acting pneumatic cylinder (type DSW-32-80PPV-A), stroke of 80mm, combined with a pneumatic proportional control servo-valve (type MPYE-5-1/8). The controller of the plant will have to read the current position of the pneumatic piston and correct the input of the system in order to minimize the error. The position sensor is a Linear Variable Differential Transducer (LVDT) and pressure sensors are also included in the system to increase the performance of the controller, by providing more data to it. This type of position sensor was selected among others as in [4-6], due to its simple assembly and unbeatable repeatability. The main layout of the system with all its parts connected is provided in Figure. 1.

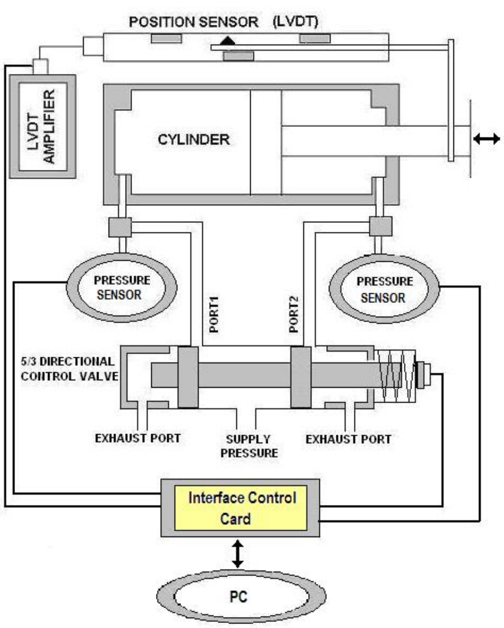

Figure. 1. The system main layout

It is obvious that the inputs of the system are the actual piston position provided by the LVDT and the two different air pressure values given by the pressure sensors. The output of it is the control signal in Volts produced by the microprocessor as a result of the control algorithm implementation that drives the servo-valve. The last one is the control device of the plant, which operates the whole system under the controller's commands. The valve opens and closes its ports in order to compress or decompress air in the two cylinder chambers and therefore move the piston. At this point the difficult part of the system dynamics and controlling occur, since the air compression is a highly nonlinear phenomenon. The mathematical model of the pneumatic cylinder and the valve consists of third order system equations and in fact they are also switching depending on the air pressure. All mathematics and system modeling can be found in [7-8]. It must be stated that 100% position accuracy of any pneumatic piston has not be achieved yet and therefore there is still area for more research like the one in this project.

3. The Interface Board

In order to be able to control and record the behaviour of the pneumatic plant, an interface card was designed and assembled. This should be able to convert the analog and continuous signal into digital words and also the digital input into an analog control signal to drive the pneumatic servo valve. Criteria like low cost electronics and multiple power supplies for the microcontroller and its peripheral equipment should be kept. The pneumatic valve response time is 50msec so the interface card should be faster than that to drive the valve properly. The controller reads the current position of the pneumatic piston and corrects the input of the system according to the control algorithm in order to minimize the error.

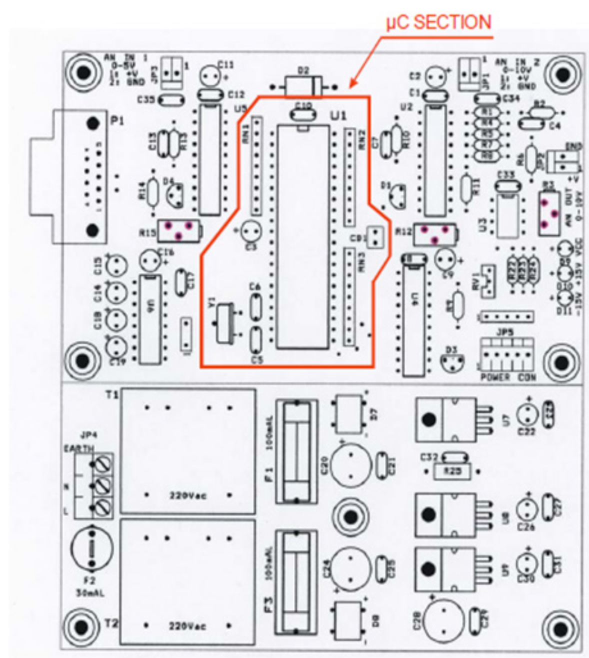

Figure. 2. The interface board drawing with the microcontroller section highlighted

Pressure sensors are also available to increase the performance of the controller. The first sensor, the LVDT, produces an analog signal of 0-5 Volt. An Analog to Digital Converter is used, specified to the highest accuracy for such a signal. The pressure sensor, varies between 0-10 Volts, so the Analog to Digital converter needs to be circuited a different way, to produce the maximum accuracy like [9-11]. If its input is 5-10Volts then it moves down. At the exact input of 5Volts there is no action. A Digital to Analog Converter transmits the digital control input into a continuous signal. The interface board consists of four main stages. The first is the microcontroller (μC) stage, which is the AT89C51. The second stage is the 5V input Analog to Digital Converted (ADC). The third one is the 10V input Analog to Digital Converter. The fourth stage is the 10V output Digital to Analog Converter (DAC). The microprocessor, a flash AT89C51, is responsible to synchronize the communication between the sensors and the computer and an overall view of the interface board that highlights the microcontroller section is provided in Figure. 2.

At this point it was considered as necessary to include another copy of the board schematics in order to illustrate the power supply management section of it. Therefore Figure 3 is added below to present the part that the 220VAC main input is transformed to lower DC voltages in order to supply the microcontroller and its peripheral electronics.

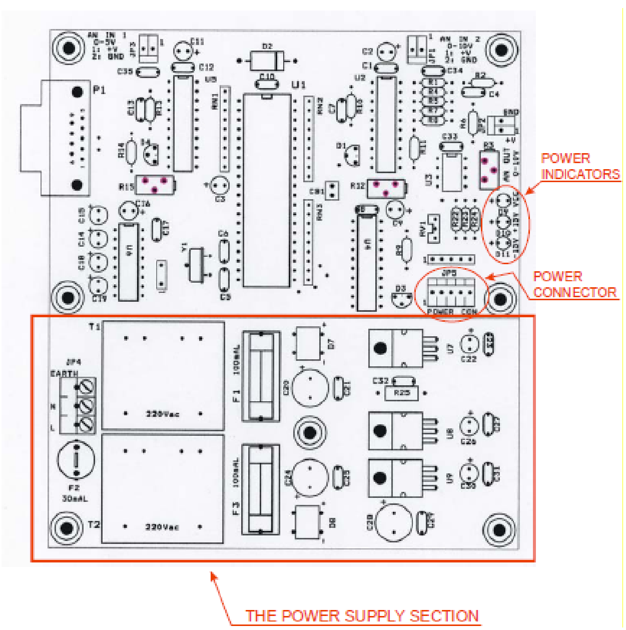

Figure. 3. The interface board drawing with power supply section highlighted

The serial interface and the control of the converters are being controlled in this stage. The clock frequency is selected to be 11.0592 MHz so it can be divided exactly for the RS-232 serial communication. A circuit breaker, which is shorted on power up, is used for downloading every new program code to the microcontroller. For the second and third design stages, the Analog to Digital Converters, a ADC0803 8 bit μC compatible is used. This is a common ADC, with excellent characteristics. It's a successive approximation A/D converter that uses a potentiometric ladder. This converter appears as a memory location to the Input-Output ports of the μC and so no interfacing logic is needed. In addition to this, the voltage reference input can be adjusted to allow encoding any smaller analog voltage span to the full 8 bit resolution. Another significant feature is that this converter has an on-chip clock generator and the conversion time is 100 μsec. For the 10 V input ADC stage the same converter is used with just a voltage divider added to the input of the converter. The fourth stage of the interface control board is the DAC0830, which is used as a Digital to Analog converter in a voltage switching configuration. In this configuration the ladder is operated as a voltage switching network and not as the standard current switching. The reference voltage is connected to one of the current output terminals and the output voltage (V_{ref}) is provided by the normal reference pin of the microcontroller. The converter output is a voltage in the range from 0V to $255*V_{ref}/256$ as a function of the applied digital code. In this configuration the applied reference voltage must be always positive to prevent unacceptable behavior. There is also a dependence of conversion linearity and gain error on the voltage difference between the supply voltage and the voltage applied to the normal current output terminals. This is a result of the voltage drive requirements of the ladder switches. The power supplies voltages needed for the Interface board are +5V, +15V and -15V. A power supply providing all these voltages is included on the card. If an external power supply is to be used then the card can be further minimized and the part with the power supply equipment can be removed. Then the voltages needed for the interface board can be supplied to it through a power supply connector. Assembling this kind of boards with ADCs and DACs, it is critical to design in a certain way the power lines, especially ground connections, to ensure proper operation. In this board, special care has been given to this. In addition, it would be useful at this point to highlight the interface controls between the user-engineer and the system. The micro-processor provides a user friendly environment for programming, which is illustrated in Figure 4.

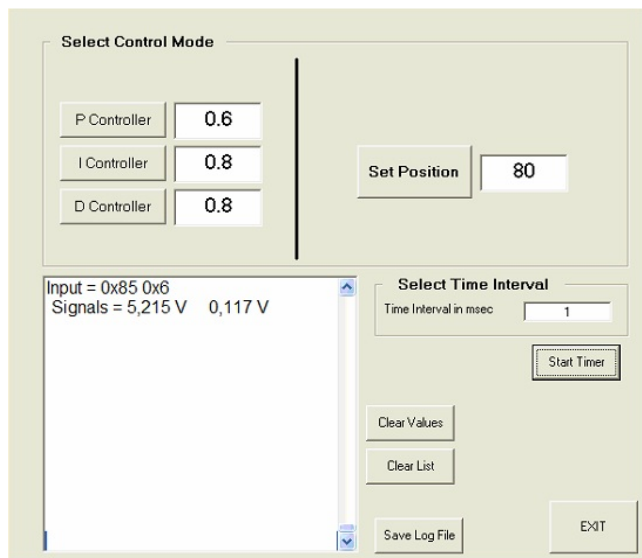

Figure. 4. The programming interface panel

In the above figure, there are three different buttons corresponding to the three terms of the controller gains. There are also buttons to set the piston target position, to start the experimentation timer and the log window that monitors the system's signals. In Visual Basic 6.0 (vb6) is quite simple to build an interface software. The functions needed are few which makes it even easier. This program is built in order to test the interface card's functionality. The interval of the control signal and the PID's parameters can be selected. There is an ability to save out logs in an Excel File where an analysis of them can take place afterwards. The gains of each parameter and the Desired Position of the system (mm) can be shown then. On the left part a list shows the input and output signal, values presented as hex and volts. The user sets the parameters and the desired position in mm while by pressing the Start Timer button, the control begins. The Timer stops when the system reaches the desired position or if the user stops the control by pressing the same button. In order to save the information of the response, the button "Save Log File" needs activation and all information is saved in an excel sheet. In the first two lines of this sheet, the Starting Position and the Desired Position are saved. The parameters of PID Controller are logged in lines 5, 6, 7. Then, from line 10 and after the system response and the control signal are saved. The control signal in mm is saved in the same column with the previous information. In the next two columns is the response of the plant, in mm and volts. Experiments have an empty column between them. The maximum length of the data logged is 1000. If the plant has not settled in desired position in 1000msec then the control automatically stops, and so do the data being logged. Else, the column length depends in the time the user stops the timer (the samples are taken when the timer overflows). The user can save up to ten experiments this way and all following data will be overwritten. The layout of the interface was a custom design that meets the requirements of this specific task. The versatility of the interface design in this project is a helpful tool for an engineer in order to communicate and control multiple dynamic systems.

4. System Performance

Although the design of the classical three-term control for nonlinear multivariable systems has been extensively studied in many books and papers, the design procedures for such high order nonlinear systems, like the pneumatic systems, may be complicated and vary from case to case. A simple approach to robust control, and the main topic of this chapter, is the implementation in the system of a classical controller which would automatically choose whether or not all terms of control P, I, D are appropriate for the application. During experimentation we managed to witness that the system operates satisfactory with the use of PD control and that the existing steady state position error was the main unwanted characteristic of the system behavior. The solution to that was to address the I-term control in the controller so that the steady state error would be eliminated. The need for retuning three rather than two control gains on one hand and the fact that the overall system behavior became oscillatory under the influence of the I-term, turned us to implement a clever idea of using the I-term only for beneficiary results. The new technique, which was addressed in the system, is based on "switching" the Integration term 'on' and 'off' according the value of the steady state error. Although the integration term is limiting the steady state error to tiny values close to zero over short periods, it is also producing the unacceptable system response over long time periods of operation. This technique introduces another secondary 'zone' of the steady state error which is placed in the middle of the primary 'zone' of 4mm (+/- 2 mm) when the I-term switches on, discussed earlier in this section. The secondary zone of values is, like the primary zone, split into two parts, 0.5 mm above and 0.5 mm below the demand piston position respectively. The idea of the new control algorithm is that the I-term is switched on when the error is within the primary zone (2mm above the demand position and 2mm below it) but when the error values are very small, i.e., within the secondary zone of values, it switches off. When the system performs without the influence of the I-term, the behavior is not oscillatory, and therefore if the steady state error remains always in the secondary zone, the response is considered to be acceptable. The new algorithm is based on the generic PID algorithm with this slight modification allowing the existence of the secondary zone and in fact this method provides the privilege to the system of 'deciding', according to the value of steady state, error whether to perform with or without the integration influence. The operation of the system required the implementation of manual retuning, but the undesired oscillations of the system were eliminated. In Figure 5 the system response when this method is applied to it, is shown.

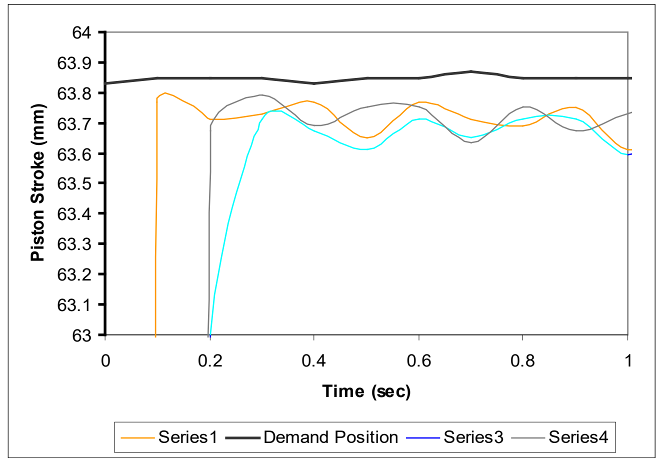

Figure. 5. The system performance focused around target position

In order to estimate the steady state error, the position axis of the plot is extremely focused around the desired position value (64mm). The system responses, as well as the demand position signal, therefore appear noisy. There are three different system responses, test1 (orange line), test2 (gray line) and test3 (light blue line), which are the average curves of ten different experiments each, with the same control gain values and the desired target position is set to the ¾ of the piston stroke. The system with the new method of the secondary zone of error values performs rather well, there are no oscillations during long time operations (50 sec) as there were before, with the simple PID control and the critical factor of this research project, the position accuracy, is minimized in values between 0.16mm and 0.2mm of the demand position.

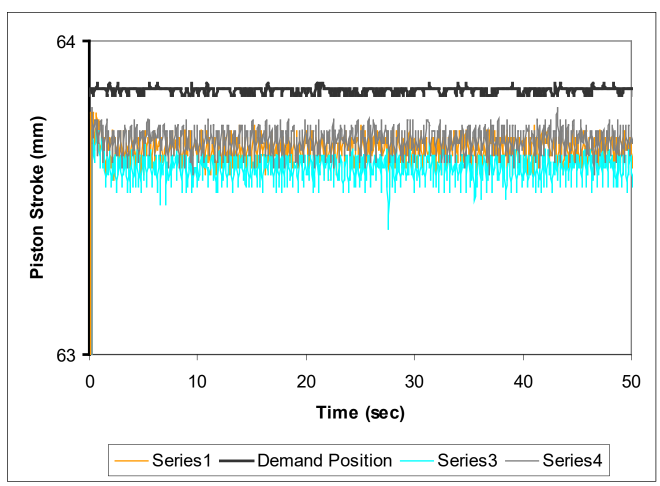

Fig. 6. The system performance

The piston position percentage accuracy is calculated as the 0.28% of the overall stroke of the piston, a value that is excellent considering the nature of the system. After all, this new method of control improved the overall system response and the time spent on retuning the re-designed algorithm was worth it for the aim of this project. The experimentation to back-up our results was designed as follows. During 8 hours continuous operations of the system all responses of the PD, PID, Auto-selective I-Term, were recorded. Then, an average response of each one of the techniques was plotted and an illustration of that is provided in Figure 6.

5. Conclusions and Further Applications

Throughout experimentation and during all tests the system proved its robustness in position accuracy of the piston and repeatability of it. The control algorithm supported that fact and never failed to be compiled and downloaded to the micro controller. Therefore this smart and innovative control technique is a more than acceptable solution to control a highly nonlinear system such a pneumatic positioning actuator. Given the fact that the 100% percentage accuracy has not been yet achieved in a worldwide level, there is still a small gap for further improvements referring to the controller's performance. Perhaps an Intelligent Control Method could assist in that and be adopted in the system for further experimentation.

On the other hand, a significant advantage of the work presented in this paper is the interface board. Its versatility allow for more complex controller design experimentations without any upgrade in the hardware of this specific interface card. The microcontroller source code, as the software part, is the only bit that needs to be re-designed in order to adopt the new control method algorithm. Furthermore, the ability of these electrical components is proven to be stable and capable enough to host multiple control tasks and monitor their performance successfully and experimentations with methods as found in [12] will follow.

As a summary, it can be stated that this research work introduced a versatile and reliable interface board to host any kind of controller design in order to control the position of a linear pneumatic actuator with highly standards of robustness.

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