Positioning of a 3-degrees-of -freedom robot with pneumatic actuators

Posicionamiento de un robot de 3 grados de libertad con actuadores neumáticos

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KEYWORDS:

Pneumatic robot arm, fuzzy control, pneumatic actuators, intelligent control, neuro-fuzzy algorithm.

ABSTRACT

Interest in the use of pneumatic actuators has become increasingly significant, especially because of the potential benefits of employing clean energies. There are previous works related to this project; some made abroad that innovates in control methods but only in specific applications, and others in Mexico that progressively increase the complexity of the system. In this paper the difficulty of a generic three-degrees-of-freedom (DoF) robot arm control is tested, searching for the most efficient method to reproduce the positioning of the final effector (a griper) accurately. Furthermore, the ambitious goal of the project is to adequately develop an algorithm capable of being properly adjusted to any multipurpose robot system with pneumatic actuators. It is carefully considered the various non-linearities of the system. This work relied mostly on intelligent control techniques and modern programmable devices, the intention is to achieve similar or better results than previous projects. The possible combination of intelligent and even classical control can reasonably achieve the estimated conclusion, the first being flexible for developing robust design for non-linear systems.

PALABRAS CLAVE:

Brazo manipulador neumático, control difuso, actuadores neumáticos, control inteligente, algoritmo neuro-difuso.

RESUMEN

El interés por el uso de actuadores neumáticos se ha vuelto cada vez más importante, especialmente debido a los beneficios de emplear energías limpias. Existen relacionados con este artículo, algunos hechos fuera del país donde se innova en métodos de control, pero solo en aplicaciones específicas, y otros elaborados dentro del país donde se incrementa la complejidad del sistema y control. En este trabajo se prueba la dificultad de un brazo robótico genérico de tres grados de libertad (DoF), se busca el método más eficiente de reproducir el posicionamiento del efector final (una pinza) de una forma precisa. Además, la meta de este proyecto es de crear un algoritmo capaz de ser ajustado a cualquier sistema robótico multipropósito con actuadores neumáticos de tres grados de libertad. Se pretende obtener resultados similares o mejores que proyectos anteriores, los resultados preliminares muestran que la combinación de control neuronal, difuso, o incluso clásico puede obtener los resultados estimados, siendo los dos primeros muy flexibles para desarrollar un diseño original y efectivo de control.

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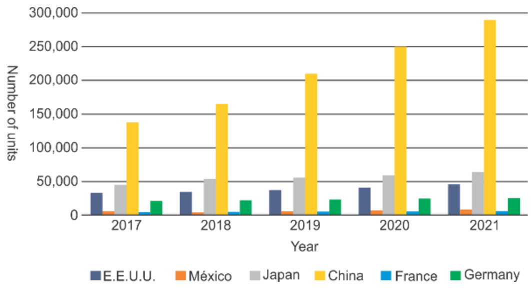
1. Introduction

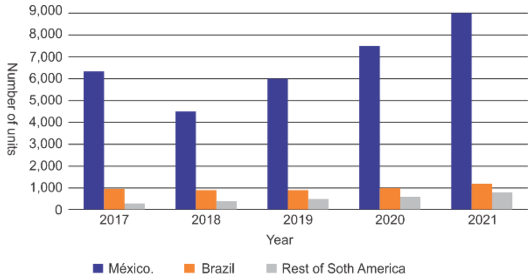
Despite the several robotic trademarks (ABB, Mitsubishi, Kuka, Fanuc, etc.), the study of modern design, control and technologies are universally valid [1]. The use of pneumatic actuators does not pretend to compete with actual electrical robots but produce an alternative technology and take its advantages in certain applications.

Electrical actuators are easy to control, but they may require expensive maintenance. Pneumatic ones are clean, not expensive to maintain and can be used in high voltage free areas. Many issues with compressed air result in a non-linear mathematical model; because of the flow into the valves is non-uniform and has delay propagation, as well as others like friction in the joints.

According to UNESCO foreign countries that manufacture industrial robots like the United States, Denmark and Japan see Mexico as a potential consumer for their products, because of all robotic systems are imported [3]. In contrast, China is the biggest importer in the world with 30% of the global market, and Mexico dominates the Latin American; this is displayed in figure 1 where is raising the use of multipurpose robots every year, it is foreseen that in 2021 Mexico increase its market 26% (figure 1a) and China 21% (figure 1b) [2], [4].On the other hand, China implements an ambitious agenda in which intends to have 75% of the robots made in the country by 2025. China should be taken as an example to follow to promote the creation of national technology and not depend on foreign trademarks.



(a)



(b)

Figure 1: Estimated annual shipments (number of units) of multipurpose industrial robots in selected countries. (a) China compared with other international countries. (b) Mexico compared with other Latin American countries [2].

In January 1994, Hasselroth designed an algorithm to control a five DoF pneumatic robot, implementing 200 neurons with two cameras as feedback [5]. In 2016 R. Arreguín, made in his work the performance of a pneumatic PD control embedded into an FPGA [6]. Also, in 2016 Sanchez developed a tool that allow to accurately simulate the behavior of a two DoF robot manipulator [7]. In 2019 these published works were presented: Mu published a novel method of predictive fuzzy control typically combined with a neural network for a pneumatic servo system [8]; Katzschmann developed a computationally efficient way to design and simulate soft robots [9]; and Perez properly presented the development of a pneumatic robot simulation with 4 DoF [10].

In this paper, an algorithm of positioning is proposed, it can be fuzzy, neural, or a combination of both of them; the hypothesis is to sufficiently demonstrate that best performance is achieving by implementing an intelligent control the behavior of pneumatic actuators; causing movement in a robot and put the final effector in the desired position.

There are many programmable devices or development boards, the most reliable option for this project is an FPGA, because of the considerable amount of hardware required for the robot. An advanced DSP was additionally used for DC control motor tests. The favorites trademarks are Altera, Microchip and Texas Instruments.

Modern programming languages represent excellent tools to automate the control design process, for simulation Octave/MATLAB or also Python provide the most competent performance. They accurately simulate the entire system; in addition, these languages are the best option to generate hardware description scripts to later synthesize them.

The robot prototype is available in the mechatronic laboratory located in the engineering faculty of the university (UAQ). An image of this prototype is shown in figure 2.

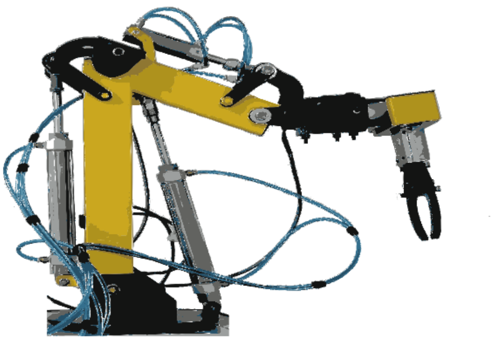


Figure 2: Image of the robot used in this project.

1.1. Scope for the first part of the project

The specific objectives are conventionally delimited for the following list. The intention is to reasonably achieve preliminary results for the best development of the completed project.

- Analysis of DC Motor for air flow control. The lack of information about speed valve control tended to investigate an innovative way to achieve this task.
- Study of best hardware, software, and sensors tools for the project development.
- Script development for rapid creation of VHDL fuzzy control core in Octave/MATLAB.
- Preliminary simulations of the fuzzy controller in an FPGA.

2. Methodology

The methodology used to develop this project is shown in figure 3, which is divided in 8 steps. In the followed the steps description are presented.

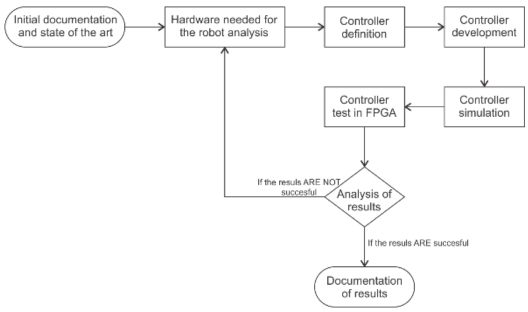


Figure 3: Block diagram of the project.

(1) Initial documentation and state of art: Initial step for carefully exploring a state of art included in the references of this paper; also includes justification for the project, figure 1 contains essential information because of representing a national problem of producing our own technology.

(2) Hardware needed for this project: Every DoF consists of a 5/2-way pneumatic valve, 2 throttle valves; one linear encoder and two DC motors with quadrature encoder. The schematic diagram of one DOF pneumatic system is illustrated in figure 4, this is valid for the three DOF. This is essential for the selection of hardware: an FPGA.

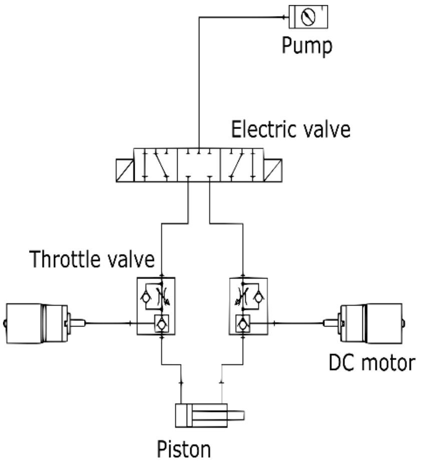


Figure 4: Schematic of one DoF pneumatic system.

(3) Controller definition: The implementation of a PI fuzzy controller is the first to test, this controller is typically used for DC motors and it is useful to begin the VHDL code, some plots are shown in results section; the subsequent is to implement a neural algorithm to adjust membership functions.

(4) Controller development: This is one of the most challenging steps of the project, not only because of intelligent control to perform but the VHDL code to write. Therefore, it relies on high-level languages like Octave or python, also useful for plotting, LabVIEW for saving data from the FPGA, this may do more rapidly and easier the controller development. In figure 5 is shown all the implemented programming languages.

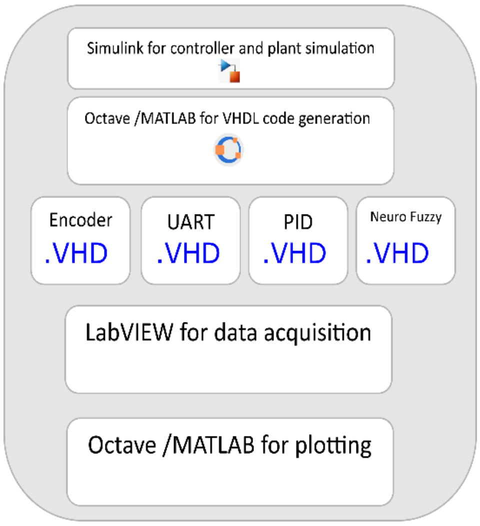


Figure 5: Programming languages used for this project.

(5) Controller simulation: Simulation has relation with direct kinematic of the manipulator, Simulink is the best option for this task. For DC motor PID TUNER can obtain the approximate equations to simulate the plant and the controller. For testing the functionality of VHDL code a co-simulation between Simulink and Model Sim can be a powerful tool.

(6) Controller tests in an FPGA: Experimental tests with intelligent control represent the core of this ambitious project, plotting results with Octave.

(7) Analysis of results: If the results are satisfactory, proceed to the following step, otherwise, it is reconsidered to return to any of the previous steps.

(8) Documentation of results: the final step is to write results and conclusions.

2.1. Direct and inverse kinematics

Direct and inverse kinematics offer the mathematical analysis for robot manipulators, first one is useful for simulation (the easiest problem); in the case of three DoF represents the calculation of the position of the final effector from the known joint angles. Inverse kinematics is for controller design, calculates the joint variables from the position of the final effector; the solution depends largely on the structure (in this case, a pneumatic one). It is frequently deal with several solutions for the joint variables resulting in the same position of the robot final effector, figure 6 shows the direct and inverse kinematics relation [1], [7], [10].

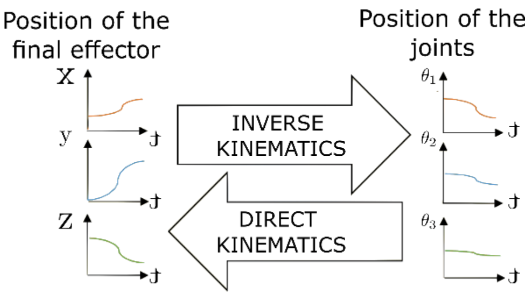


Figure 6: Direct and inverse kinematics relation [10].

3. Direct kinematics of a 3-DOF manipulator

A three DoF robot is shown in figure 7 and its direct kinematics is given in equations (1) to (6) [7].

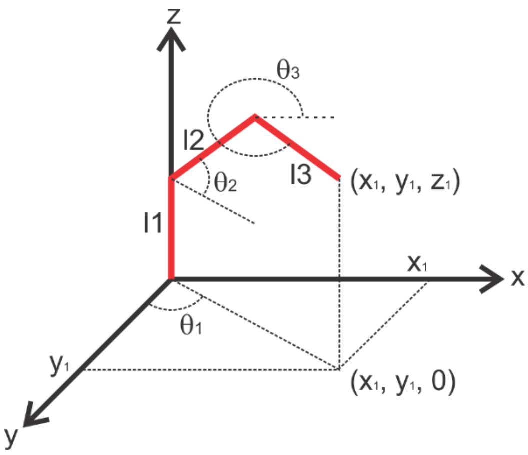


Figure 7: Schematic of a three DoF pneumatic robot [6].

Where:

- l_1, l_2, l_3 → Pneumatic robot links length.
- θ_1 → Angle of the link l_1 with respect to the *Y* axis.
- θ_2 → Angle of the link l_2 with respect to the *XY* plane.
- θ_3 → Angle of the link l_3 with respect to the *XY* plane.

The angle between θ'2 and θ2 will always be π/2, also θ'3 and θ3 angles preserve this relation each other.

According to figure 7 one the analysis starts in the plane XY, obtaining θ_1 value, as it is shown in equation 1.

$$\theta_1 = tg^{-1}\left(\frac{y_1}{x_1}\right) \tag{1}$$

Now, the analysis is limitedly exclusive to the plane XY, using figure 8.

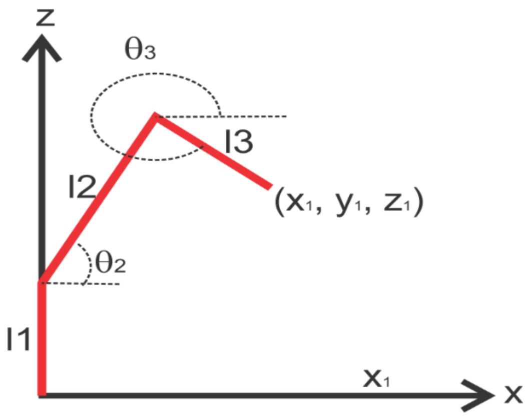


Figure 8: Plane XY perspective [6].

To simplify the analysis, the origin is moved l_1 units up, removing first link, it is indicated in figure 9.

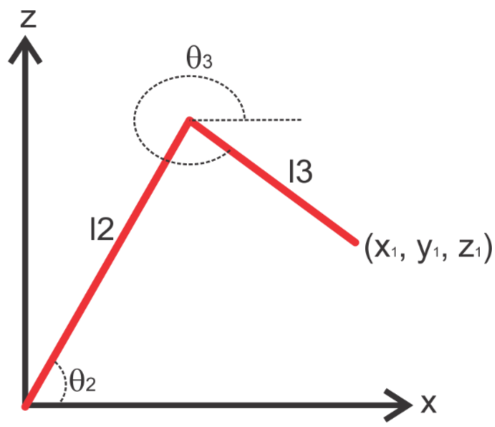


Figure 9: Simplified form for the analysis [6].

To continue the analysis, it considers figure 10, and equations (2) to (7) are obtained [6].

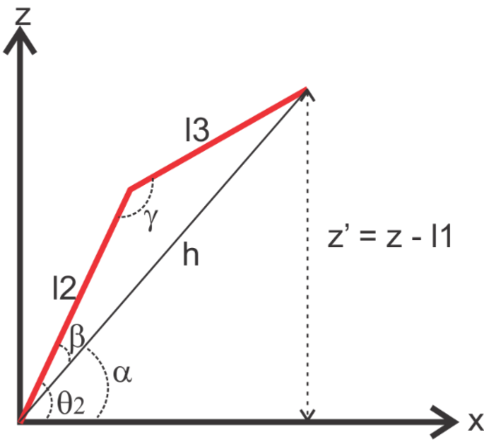


Figure 10: Modified form for the analysis [6].

$$h = \sqrt{x^2 + y^2 + z'^2} \qquad (2)$$

$$\alpha = sen^{-1} \frac{z'}{\sqrt{x^2 + y^2 + z'^2}} \qquad (3)$$

$$l_3^2 = l_2^2 + h^2 - 2l_2 h cos\beta \qquad (4)$$

$$\beta = \theta_2 - \alpha \qquad (5)$$

$$\cos(\theta_2 - \alpha) = \frac{l_2^2 + h^2 - l_3^2}{2l_2 h} \qquad (6)$$

$$\theta_2 = cos^{-1}\left(\frac{l_2^2 + h^2 - l_3^2}{2l_2 h}\right) + \alpha \qquad (7)$$

Using the Law of Cosines, it is obtained:

$$h^2 = l_3^2 + l_2^2 + -2l_2 h cos\beta \qquad (8)$$

reflecting γ variable, it is obtained as $\gamma = cos^{-1}\left(\frac{l_2^3+l_2^2-h^2}{2l_3 l_2}\right)$ From figure 11, it is obtained $\gamma + \alpha' = 180°$ and clearing γ', it is obtained, finally, θ_3 is obtained giving $\theta_3 = \theta_2 - \alpha'$, replacing α', $\theta_3 = \theta_2 - 180° + \gamma$ is obtained.

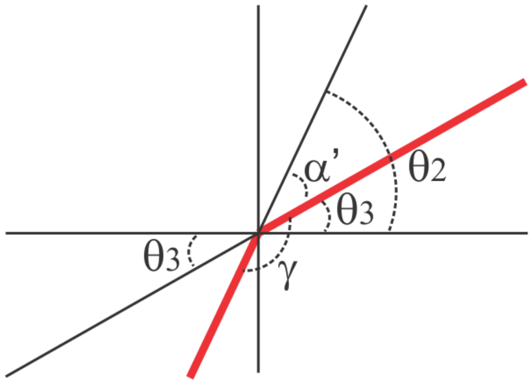


Figure 11: Complementary angles to solve the inverse kinematic [6].

We know the γ value, so, finally we obtained equation (9)

$$\theta_3 = \theta_2 - 180° + cos^{-1}\left(\frac{l_3^2 + l_2^2 - h^2}{2l_3 l_2}\right) \qquad (9)$$

In conclusion, the three main equations for the cinematic movement are:

$$\theta_1 = tan^{-1}\left(\frac{y_1}{x_1}\right) \qquad (10)$$

$$\theta_2 = cos^{-1}\left(\frac{x^2 + y^2 + (z - l_1)^2 + l_2^2 - l_3^2}{2l_2\sqrt{x^2 + y^2 + (z - l_1)^2}}\right) + sen^{-1}\left(\frac{z - l_1}{\sqrt{x^2 + y^2 + (z - l_1)^2}}\right) \qquad (11)$$

$$\theta_3 = \theta_2 + cos^{-1}\left(\frac{l_2^2 + l_3^2 - x^2 - y^2 - (z - l_1)^2}{2l_2 l_3}\right) - 180 \qquad (12)$$

3.1. DC motors Control

Although an intelligent controller is selected for the position control of the final effector, a classic method is suitable for DC motors speed. Adjusting the speed is also essential, in this case since a rapid movement of the motor may cause an abrupt vibration in the actuators.

The equation (13) has the form for a discrete PID controller, where Kp is a proportional constant, TI and TD are integral and derivative time constants, T0 is the sample period, e(k) is the error input, and u(k) is the controller output [11], [12].

$$u(k) = K_p\left\{e(k) + \frac{T_0}{T_I}\sum_{i=1}^{k} e(i-1) + \frac{T_D}{T_0}[e(k) - e(k-1)]\right\} \quad (13)$$

According to [11], equation (13) is a non-concurrent algorithm, no ideal for industrial applications; it is required to have the most adequate development in this part to be untroubled with the intelligent control. Recurrent algorithms are, therefore, more suitable for practical use. The equation (14) represents the algorithm implemented[12].

$$u(k) = q_0e(k) + q_1e(k-1) + q_2e(k-2) + q_3e(k-3) + q_4e(k-4) + u(k-1) \quad (14)$$

Where:

$$q_0 = K_p\left(1 + \frac{T_0}{T_I} + \frac{T_D}{6T_0}\right) \qquad q_1 = -K_p\left(1 - \frac{T_D}{3T_0}\right) \qquad q_2 = -K_p\frac{T_D}{T_0}$$

$$q_3 = K_p\frac{T_D}{3T_0} \qquad q_4 = K_p\frac{T_D}{6T_0}$$

Involving equation (14) a speed and position control in figure 12 is designed, implemented in simulation and experimentally; for this PID TUNER from MATLAB can get the plant system with a DC motor step response.

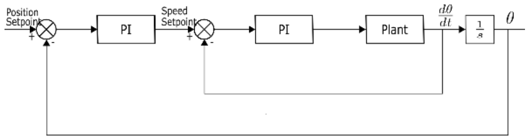


Figure 12: Control system proposed for the DC motors.

3.2. Fuzzy Control.

The fuzzy controller design has four principal components [13] [14] [15]:

- **The rule-base:** it holds the knowledge, a set of rules, of how the best for the plant controlling, the general way to represent is the form *IF **A** AND **B** THEN **C.***
- **The inference mechanism:** it evaluates which rules are relevant at the current time and then decides what the input to the plant should be.
- **The fuzzification interface:** it modifies the inputs so that can be represented and compared to the rules in the rule-base.
- **The defuzzification interface:** it converts the conclusions reached by the inference mechanism into the inputs to the plant, there are several forms of defuzzification methods, in this work it is simplified using Sugeno inference.

In figure 13 a fuzzy controller architecture is shown, this is very useful for the hardware implementation in a FPGA, for this task MATLAB script is written that generates the most important VHDL code of the fuzzy controller, the scripts were based on [14] work, the highlights of using MATLAB for VHDL code are:

- The rapid generation of a look of table (LUT) for the membership functions and division values. An accurately binarization of variables in a desired fixed-point format.
- Fast modifications can be made for several VHDL files, avoiding mistakes and files corruption.

- The rapid creation of files with correct names according to the file purpose.

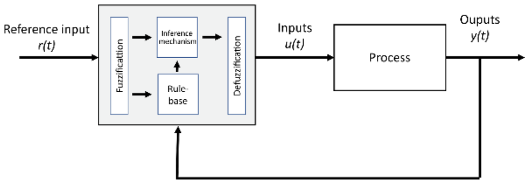


Figure 13: Generic fuzzy controller architecture.

In figure 14 the completed design of a PI fuzzy controller is shown. The figure 14(a) and figure 14(b) represents the error and derivative error membership functions inputs, the y plot represents the degree of membership of each function ($\mu(x)$). The figure 14(c) is the singleton membership function output of the system. We are using the Sugeno inference method because it does not require many computational resources. The table 1 is the rule-base table for the controller where E is the error and dE is the derivative error.

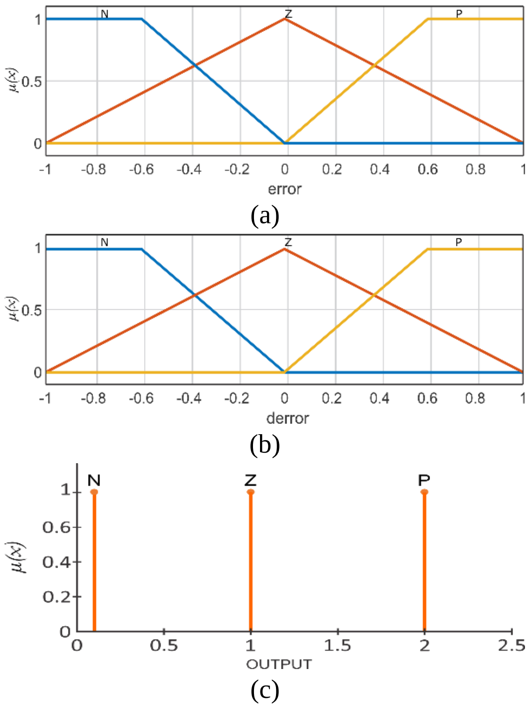


Figure 14: PI fuzzy controller design.

Table 1: Rule-base for the fuzzy control.

		E		
		N	Z	P
dE	N	N	Z	P
	Z	N	Z	P
	P	N	Z	P

3.3. Fuzzy Control.

In figure 15 a sketch hardware is observed, the principal component of the hardware is the FPGA, it contains, serial communication, PI controls for DC motor, and the intelligent for the robot. Every D0F uses 2 DC motors, each DC motor has its control signal optocoupled to avoid electrical noise and voltage peaks, the encoder signal is read for the FPGA, another encoder set in the robot joint gives the feedback signal, this can be replaced by an accelerometer sensing the angle links (θ_1, θ_2, θ_3).

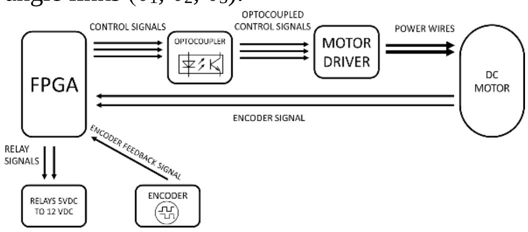


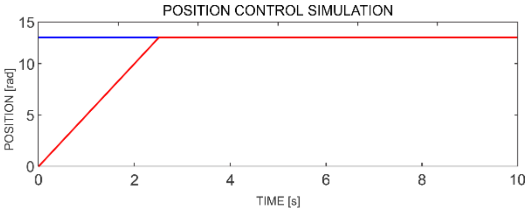
Figure 15: implementation for a one degree of freedom.

4. Results

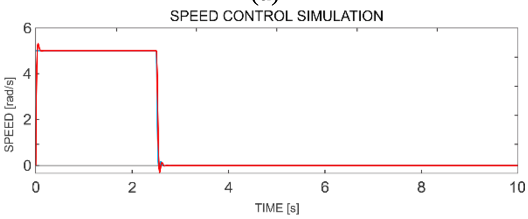
PID Tuner is used only for plant identification, the PI parameters are adjusted in the experimental analysis, equation (15) is the plant transfer function.

$$G(s) = \frac{0.99667}{1 + 0.024022S} \qquad (15)$$

In figure 16 the simulation is shown. A position setpoint was fixed to *2rad* and speed to *5rad/s*, also a sample period of *10ms* is chosen, all signals were normalized as shown on figure 6a, were position was reached accurately, in figure 6b the speed is shown which reached maximum speed to *5rad/s* showing that the desired position is close to being achieved, the speed reached a value that tend to zero.



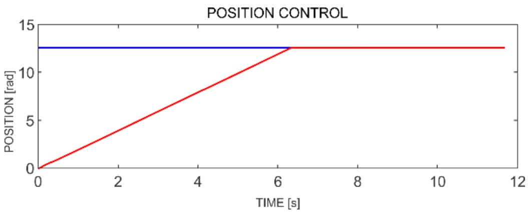
(a)



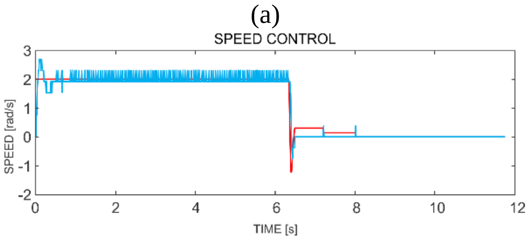
(b)

Figure 16: Simulation of a DC motor control. (a) DC motor position simulation. (b) DC motor speed simulation.

In figure 17 the experimental results are plotted, where figure 17(a) shows the position control signal, figure 7(b) shows speed control signal to achieve better results a low-pass filter was implemented, the results were similar to the simulation.



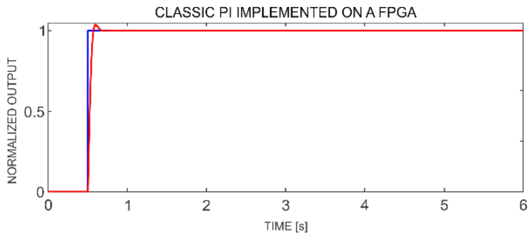
(a)



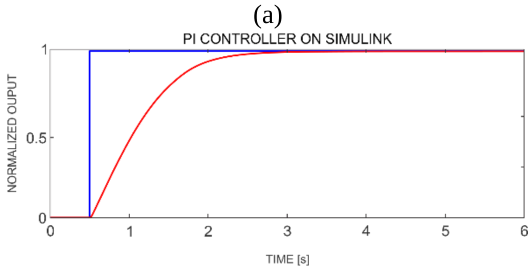
(b)

Figure 17: Experimentation of a DC motor control. (a) Experimental DC motor position control. (b) Experimentation of a DC motor control.

The results of a PI-Fuzzy controller are shown in figure 18, where figure 18(a) shows a simulation developed in Simulink and figure 18(b) shows a co-simulation between Model Sim and Simulink to analyze possible experimental results.



(a)



(b)

Figure 18: Experimentation of a speed DC motor control implemented on a FPGA and Simulink. (a) PI implemented on FPGA. (b) PI implemented on Simulink

5. Conclusions and future work

Figures 16, 17, and 18 show the accurate functionality of the flow control prototype. The FPGA is a powerful tool, but VHDL has a high learning curve, for that reason, the support of languages such as Matlab, Octave, or Python is essential for automate the VHDL code generation.

The future work is to involve of neural network for fuzzy controller membership functions, for a constant adjustment of the robot. Prototype Interface for VHDL blocks, to more flexible configuration.

References

[1] R. Kelly and V. Santibáñez, Control de movimiento de robots manipuladores. Pearson educación, 2003.
[2] M. Haegele, "Executive Summary World Robotics 2018 Service Robots." 2018.
[3] E. Gonzales Islas, "La era de los robots," MILENIO, 2019. https://www.milenio.com/negocios/la-era-de-los-robots.
[4] H. Huifeng and C. Chen, "'Made In China 2025': a peek at the robot revolution under way in the hub of the 'world's factory,'" South China Morning Post. 2018.
[5] T. Hesselroth, K. Sarkar, P. P. Van Der Smagt, and K. Schulten, "Neural network control of a pneumatic robot arm," IEEE Trans. Syst. Man. Cybern., vol. 24, no. 1, pp. 28–38, 1994.
[6] J.-M. Ramos-Arreguin, S. Tovar-Arriaga, J. Vargas-Soto, and M. Aceves-Fernandez, "FPGA embedded pd control of A 1 dof manipulator with a pneumatic actuator," Int. J. Robot. Autom., vol. 31, 2016, doi: 10.2316/Journal.206.2016.3.206-4362.
[7] S. Sánchez Solar, J. C. Pedraza Ortega, E. Gorrostieta-Hurtado, and J.-M. Ramos-Arreguín, "Path Tracking Simulation for a Two-Degree-of-Freedom Pneumatic Manipulator Robot," 2016.
[8] S. Mu, S. Goto, S. Shibata, and T. Yamamoto, "Intelligent position control for pneumatic servo system based on predictive fuzzy control," Comput. Electr. Eng., vol. 75, pp. 112–122, 2019.
[9] R. K. Katzschmann et al., "Dynamically closed-loop controlled soft robotic arm using a reduced order finite element model with state observer," in 2019 2nd IEEE International Conference on Soft Robotics (RoboSoft), 2019, pp. 717–724.
[10] J. A. P. Delgado, J. M. R. Arreguín, G. I. P. Soto, and E. G. Hurtado, "Design, kinematic model and simulation of a 4-DOF pneumatic robot," Pist. Educ., vol. 40, no. 130, 2018.
[11] K. Ogata and J. W. Brewer, "Modern Control Engineering," J. Dyn. Syst. Meas. Control, 1971, doi: 10.1115/1.3426465.
[12] V. Bobál, J. Böhm, J. Fessl, and J. Machácek, Digital self-tuning controllers: algorithms, implementation and applications. Springer Science & Business Media, 2006.
[13] H. T. Nguyen, A First Course in FUZZY and NEURAL CONTROL. 1987.
[14] K. M. Passino, S. Yurkovich, and M. Reinfrank, Fuzzy control, vol. 42. Citeseer, 1998.
[15] P. P. Cruz, Inteligencia artificial con aplicaciones a la ingeniería. Alfaomega, 2011.

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