DEVELOPMENT OF A ROBOTIC MANIPULATOR WITH TWO DEGREES OF FREEDOM GOVERNED BY A FUZZY CONTROLLER

Jobson Francisco da Silva[1], jobsonfsilva@gmail.com
Fábio Meneghetti Ugulino de Araújo[2], meneghet@dca.ufrn.br
Alberdan Santiago de Aquino[1], alberdan@ifpb.edu.br
Emanuel Guerra de Barros Filho[1], emanuelguerra@uol.com.br
Thyago L. de Vasconcelos Lima[3], thyagolvasconcelos@gmail.com
Carlos Alberto Nóbrega Sobrinho[3], carlosautomacao@gmail.com
Milton Medeiros da Silva[1], miltoncientista@bol.com.br

[1]Instituto Federal de Educação, Ciência e Tecnologia da Paraíba, *Av. Primeiro de Maio, 720, Jaguaribe - João Pessoa (PB)*
[2] Universidade Federal do Rio Grande do Norte, *Campus Universitário Lagoa Nova, CEP 59072-970 – Natal-RN-Brasil*
[3]Universidade Federal da Paraíba - *Programa de Pós-Graduação em Engenharia Mecânica - Cidade Universitária - CEP 58.051-900 - João Pessoa – PB - Brasil*

Abstract. *The use of industrial robots has growned rapidly since the installation of the first industrial robot in 1961. Robots can be used in various industrial activities, from handling of materials, parts and tools, as well as in unhealthy activities for humans. This work shows the development and construction of two degrees of freedom robotic manipulator with rotary joints, driven by induction motors. The arm positioning is performed by a fuzzy controller. The developed robot moves in an area equal to a quarter of a sphere. Results showed the efficiency of the fuzzy controller when the arm motion is driven to reference values.*

Keywords: *robotic manipulator, fuzzy control, positioning control.*

1. INTRODUCTION

In the 50's and 60's industrial robots were introduced in order to replace the man in the execution of repetitive or hazardous tasks, aiming to improve quality, to increase productivity and to reduce production costs. Some of the most common tasks for which robots are designed to are: transportation and materials handling (Wawerla et al, 2010; Endo et al, 2008; Yong et al, 1999), assembly and manufacturing (Fei et al, 2010), point and arc welding (Yanping et al, 2009; Chen et al, 2008) and painting (Jarvis, 1973; Asakawa et al, 1997; Fuhlbrigge et al, 2008; Gazeau et al, 2011).

By the end of the 50's it was developed the first automated robot, a concept designed by J. K. Devol, called Unimate (Giralt, 1997). This project used principles of numerical control to control the manipulator and was hydraulically driven, similar to projects found nowadays. In 1961 this robot was installed at Ford Co. Since then, robotics has developed in such accelerated rate that recent research has been made about robots that imitate human movements (Komagome et al, 2007) and social robots present in shopping malls (Shiomi, 2009).

Figure (1) represents the archetype of a manipulator robot, inspired by the human arm. By programming the three arm angles (α, β, γ), and applying the appropriate commands to the motors of the three joints, the actuator is led to move to a specific point within the work spatial boundaries. Similarly, the three angles (ψ, θ, φ) are defined by programming, and the wrist actuators are controlled in order to make the element fixed in the end arm move, according to the desired orientation based on the task to be performed (Giralt, 1997).

From the second half of last century, with the increasing advancement of industrial automation, the automatic control of dynamic systems has gained increased attention. During this period, various control techniques have been developed such as robust control, optimal control, adaptive control, nonlinear control and intelligent control.

As an alternative to classical control techniques, intelligent control is applied, consisting of three basic approaches, according to Paraskevopoulos (1995): Knowledge-based expert systems, fuzzy logic control and control based on neural networks.

Regarding the fuzzy logic control, it incorporates the way human being thinks in a control system (Shaw and Simões, 2004). Through the fuzzy technology, the human operator experience is captured, which control processes and industrial plants, in order to include it in computerized controllers with the same or better performance than humans. The fuzzy control does not need mathematical modeling of the process, but the modeling of actions from the knowledge of a specialist, using linguistic terms, i.e., verbal descriptions. Moreover, fuzzy controllers also handle linear and nonlinear systems and are able to control complex multivariable systems, executing strategies for decision making in various types of plants. So this is a different approach from the classical control methods, which are developed through the mathematical modeling of plants, deriving the parameters to be controlled according to the state of the process (Shheibia, 2001).
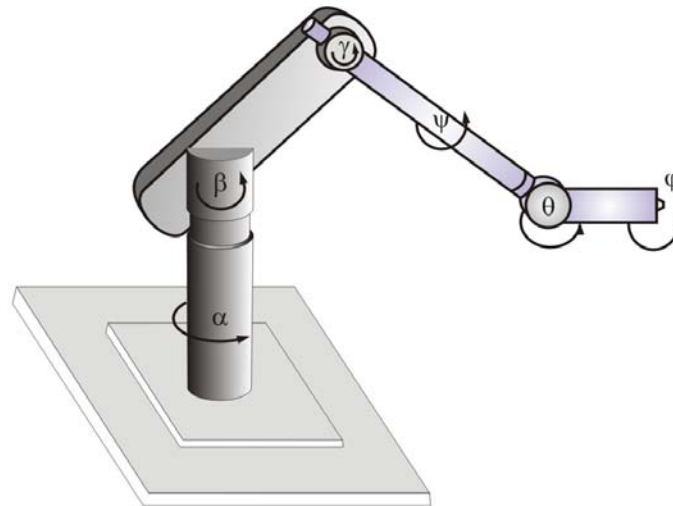
Figure 1. Six degrees of freedom robotic manipulator

Fuzzy control is applicable in the area of photovoltaic systems (Simões e Franceschetti, 1999; Weis e Xiao, 2003); in agriculture (Shen et al., 2007; Burgos-Artizzu et al., 2007); in physiotherapy (Kiryu et al., 2001); in the biomedical area (Held e Roy, 2000; Skelly e Chizeck, 2001); in robotics (Wai et al.; 2003; Yang et al., 2005; Bai e Wang, 2010; Biglarbegian et al., 2011; Huang et al, 2010).

2. THE EXPERIMENT

In order to conduct the research, a robotic manipulator with two degrees of freedom was built, represented in Fig (2). Its construction is justified because robots for teaching purposes are expensive and limited, since the control software employed in such platforms are proprietary, and do not allow access to the code inserted into previously compiled libraries, as well as its hardware does not provide documentation about the control circuit (Medeiros, 1998). Therefore, it was planned to build a low cost solution provided with technical documentation, thus enabling not only the realization of this work but also additional research conducted with other purposes.

Figure 2. Robotic manipulator

During the process of constructing the robotic manipulator, it was employed knowledge in mechanical engineering, which provides study methods for analysis of structures and mechanisms in static and dynamic situations, and in the field of electrical engineering and electronics, by providing the means to integrate sensors, interfaces, signal conditioning circuits, controllers and actuators. In addition to these fields of study, the theory of control has a great contribution, which enables the creation and validation of algorithms that control the movement of the robot as well as computer science, allowing the use of tools for programming robotic manipulators, enabling to the achievement of specific tasks (Romano, 2002). During the drafting of the manipulator, it was used low cost materials such as aluminum and 1020 steel. The data acquisition board, the components used in the signal conditioning circuits, potentiometers (position transducers), motors and frequency inverters were all acquired in the domestic market.

Both the base and the arm are driven by induction motors of 220V, 60 Hz and 0.33 Cv, driven by frequency inverters. Both engines are coupled to worm shafts, which in turn transmit motion to the base and arm through the gears. The rotation speed and direction of rotation of the motor shafts are controlled by fuzzy control signals sent to the frequency inverters. The total angular displacement of the arm is 100°, and the base is 120°, and for the protection of the system limit switches are used.

The positioning control of the system was implemented in closed loop. The fuzzy controller was developed in LabVIEW® programming environment, residing in a Core2Duo 2.5 GHz microcomputer equipped with a data acquisition interface type NI-DAQ6008. Multi-turn potentiometers (ten turns) coupled to the motor shafts by gears were used as position transducers, providing response signals proportional to the number of turns of their cursors. The potentiometer transducers have electrical resistance of 10 k $\Omega \pm 10\%$ and are equipped with three terminals (a, b, c). Terminals "a" and "b" are fed by a fixed voltage of 10 V, and the terminal "c" output, whose voltage varies with the rotation of its cursor, is connected to the analog input channel of the data acquisition board (AI1 to potentiometer of the base and AI4 for the potentiometer of the arm). Equations (1) and (2), obtained from data collected in the laboratory, represent the linear function that relate the voltage values with the values of the angular displacement of the motor shaft.

$$\theta_{base} = \frac{-120 \times V + 407,4}{5,43} \tag{1}$$

$$\theta_{braço} = \frac{-100 \times V + 507}{4,45} \tag{2}$$

3. IMPLEMENTATION OF THE FUZZY CONTROLLER

In order to control the system, a Mamdani algorithm, implemented in the computing environment LabView®, was used. The Mamdani model used is composed of conditional propositions whose antecedents are linguistic variables, as well as the consequent ones. The membership functions of input variables are distributed in universes of discourse ranging from -4 to 4, and were adjusted by changing their shapes and distributions in these universes of discourse.

3.1 Fuzzification Stage

Two input variables were used: the error (erro) between the reference position signal and the current position signal, and the derivative of this error (derro). The linguistic variable *erro* is composed of nine membership functions with triangular and trapezoidal shapes, called: NGG Negative (Very Large Negative), NG (Large Negative), NM (Medium Negative), NP (Small Negative), ZE (Zero) PP (Small Positive), PM (Medium Positive) PG (Large Positive) and PGG (Very Large Positive). Figure (3) shows the arrangement of linguistic terms of the error in its universe of discourse. Five membership functions with triangular and trapezoidal shapes are associated to the variable *derro*. They are defined by the words: NG, NP, ZE, PP and PG. The membership functions are seen in Fig (4).
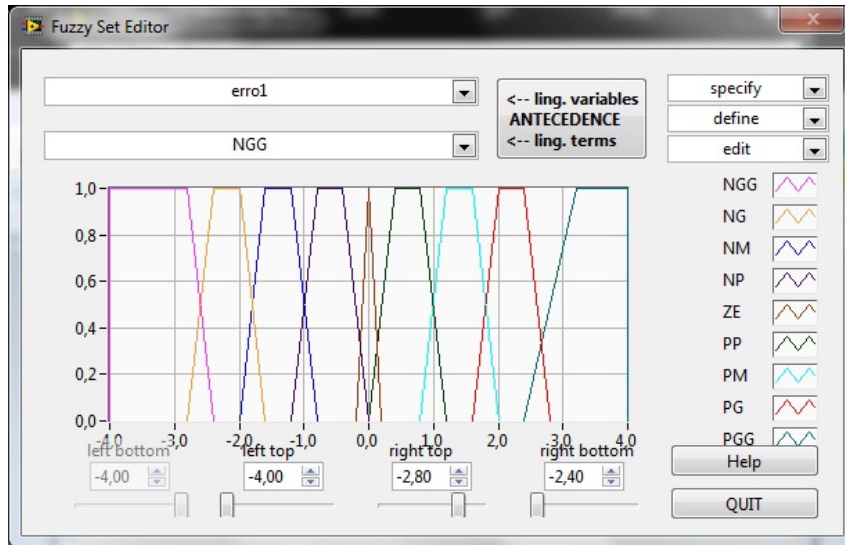
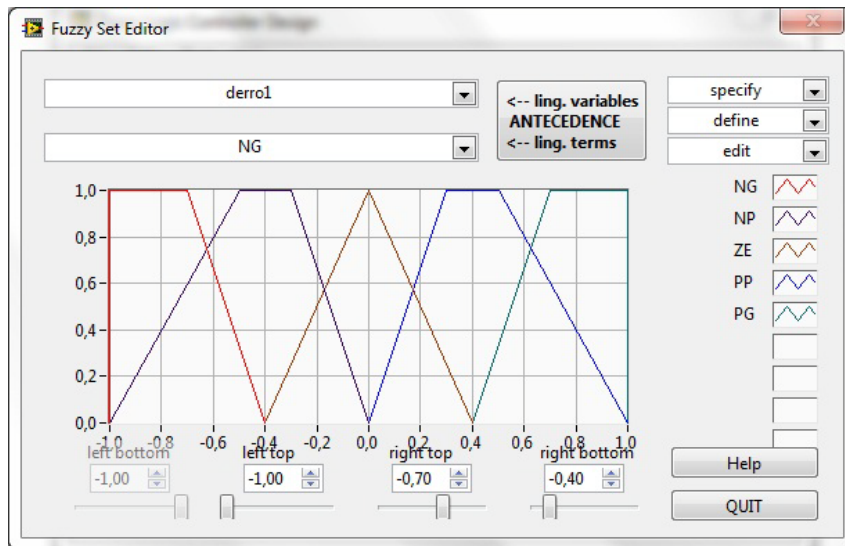Figure 3. Inference curves of linguistic variable Erro.

Figure 4. Inference curves of linguistic variable derro.

3.2 Fuzzy Inference Stage

The operations with fuzzy sets occur during the inference stage. The fuzzy set mapping within other fuzzy sets is done, and control rules, such as the conditionals IF-THEN, are activated and combined (Xavier, 2008). During the fuzzy inference process of this project, the composition of each control rule and the relationship between them were done according to Table (1), which shows the forty five control rules. At this stage of processing, the output values are obtained from the minimum value due to comparison between membership values of *erro* and *derro*.

Table 1. Fuzzy rules table

		Erro							
		NGG	NG	NM	NP	ZE	PP	PM	PG	PGG
dErro	NG	V0	V0	V0	V0	V0	V1	V2	V3	V4
	NP	V0	V0	V0	V0	V0	V1	V2	V3	V4
	ZE	V4	V3	V2	V1	V0	V1	V2	V3	V4
	PP	V4	V3	V2	V1	V0	V0	V0	V0	V0
	PG	V4	V3	V2	V1	V0	V0	V0	V0	V0

3.3. Defuzzification Stage

This fuzzy controller stage is responsible for converting the control action described by linguistic term to signals applied to control the plant. The control variable (output) is associated to a voltage variation in the analog output port NI-DAQ. This output variable is defined by five membership functions and a universe of discourse ranging from 0 to 0.7. The selected defuzzification method was the Center-of-Area (CoA), suggested by Bezerra (2009). Figure (5) shows membership functions of the control variable.
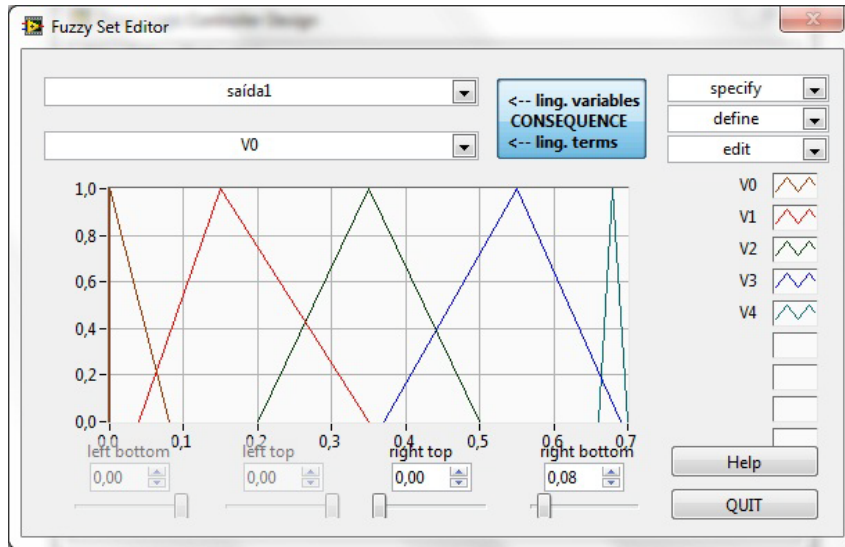

Figure 5 – Membership functions of control variable

After defining the input variables, the universe of discourse and the controller rules, the control surface is obtained. It represents all the situations that the fuzzy controller will respond within the limits imposed on the project. It is observed in Fig (6) that the controller has a control output that ranges from 0 (zero) to 0.7 volts for input values between -4 and 4 volts for the error, and -1 for the 1volts for the error variation.
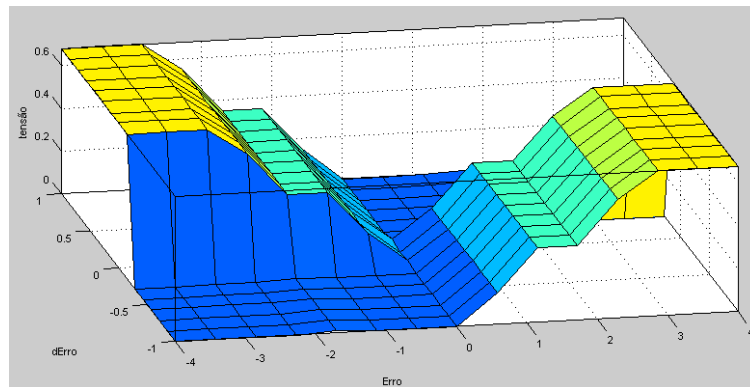

Figure 6 – Generated control surface for each fuzzy controller

4. RESULTS

The graphs represented in Fig (7) and (8) illustrate the arm and base behaviors, respectively, with a sequence of step functions as reference, in order to simulate the robot control in continuous work. Chart analysis gives settling time values, the overshoot and steady-state error. Collected data is shown in Table (2).
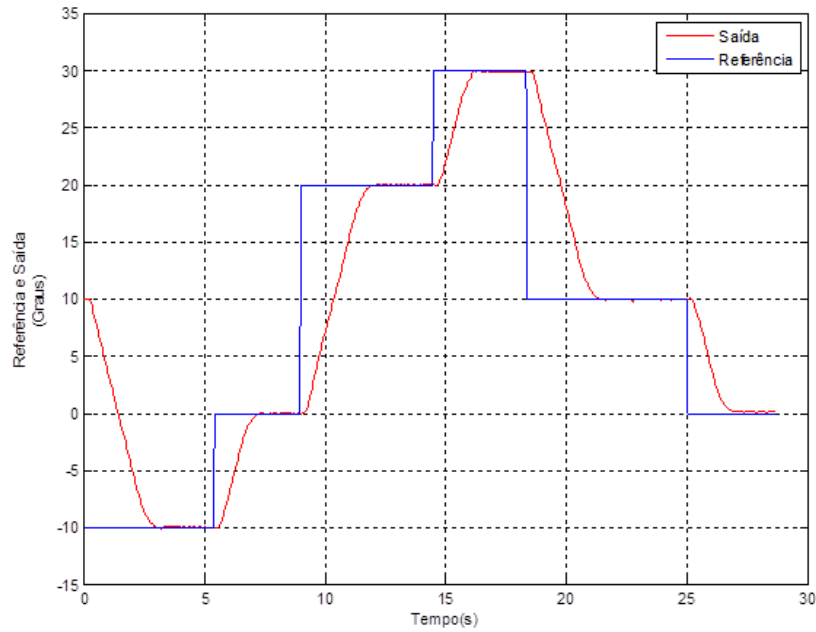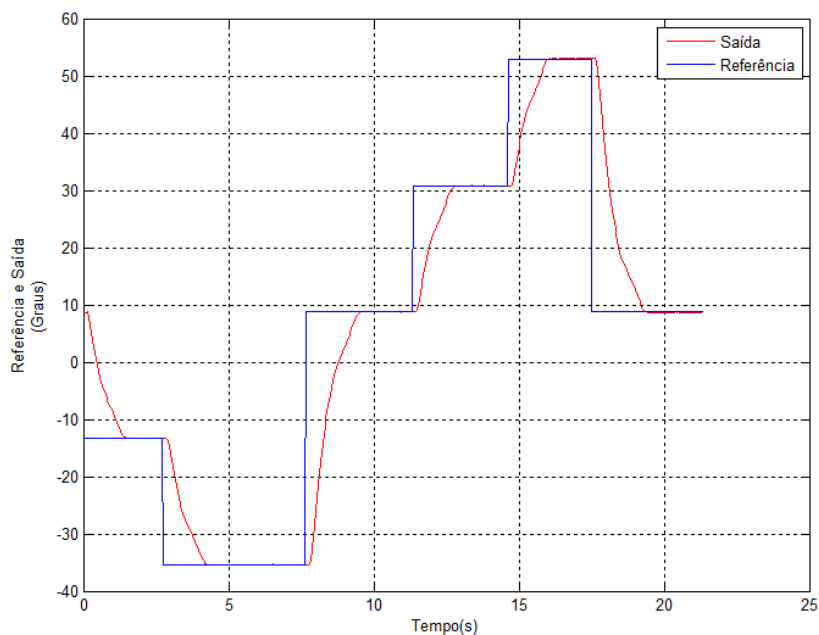
Figure 7 – Response to Variable Step – Arm

Figure 8 – Response to Variable Step – Base

Table 2. Maxima Experimental Performance Indicators of the Arm and Base

Measured	Figure 6 - Arm	Figure 7 - Base
Value	*Variable Step*	*Variable Step*
$Ts_{máx}$ (s)	2,993 (*between 30º and 10º*)	1,8561 (*between -35,47º and 8,729º*)
$UP_{máx}$ (%)	1,2 (*between 10º and-10º*)	NULL
$ess_{máx}$ (%)	0,71 (*between 30º and 10º*)	1,57 (*between -35,47º and 8,729º*)

Then, aiming to verify the controller behavior when faced to tracking a specific trajectory for the arm, it was imposed a sinusoidal reference signal which corresponds to an input signal of 30 degrees of amplitude, and period of 160 s. For the base, the applied input signal was a cosine function, with amplitude of 43 degrees, and period of 160s.

The obtained results for the described conditions are shown in Figures (9) and (10), which compares the reference signal and the output displayed by the plant to the arm and to the base, respectively.

The maximum obtained error was 0.09° for the arm and 0.28° for the base. Observing the graphs of sine and cosine functions, it is seen a good system performance in relation to the monitoring of the trajectories imposed as a reference
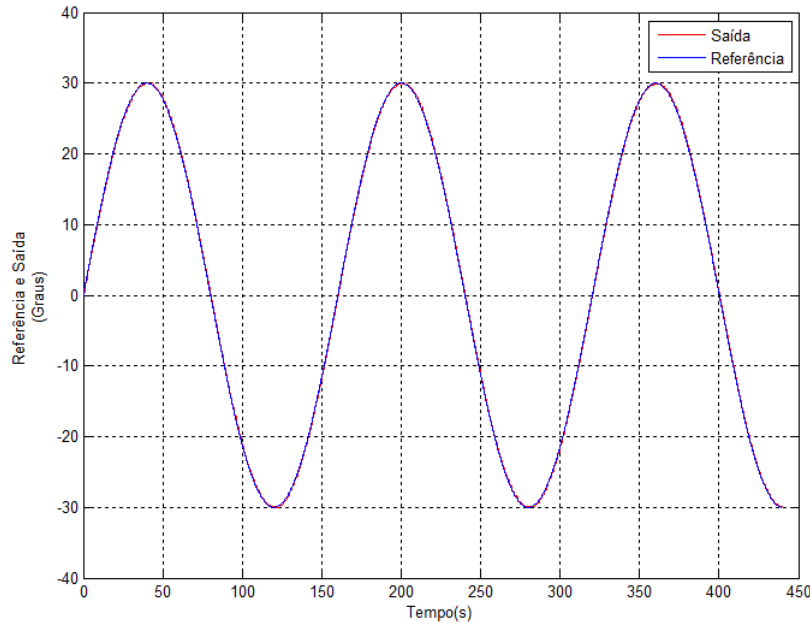

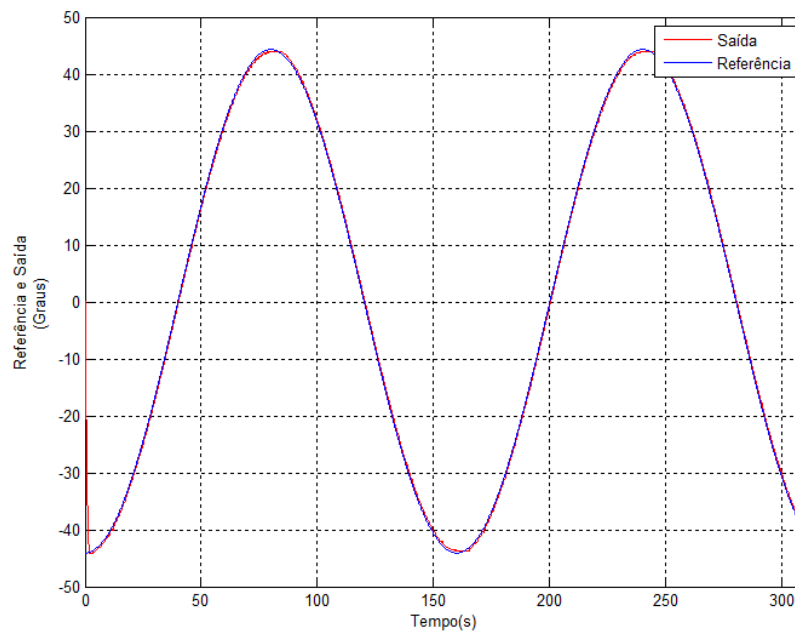Figure 9 – Servo-control for sinusoidal path – Arm

Figure 10 – Servo-control for co-sinusoidal path – Base

.

5. CONCLUSIONS

This paper presented the fuzzy logic control of a robotic manipulator of two degrees of freedom as well as a brief explanation about its constructive aspect. The control system applied to the robot was developed in both programming environments LabVIEW® and MATLAB®. Results demonstrate that when the robotic manipulator was subjected to step function input, the response had a maximum overshoot of 1.2% for the arm, whereas there was no overshoot for the base. This leads to conclude that the results are considered good, and that the percentage of observed overshoot in the arm can be reduced by allying gain and tuning of the controller.

Regarding the obtained results with the step function input, it was observed that the settling time is close to 3s for the arm. Again it is concluded that the actuator gains as well as the controller tuning can be improved, resulting in smaller settling times than those found so far. In situations in which sinusoidal or co-sinusoidal reference paths are imposed, it was verified a good performance, with maximum errors assuming very small values. Finally, it was concluded that the constructed robotic manipulator showed a good efficiency, especially when compared to other robotic structures with same size. The developed framework also enables implementation of various controls and monitoring methods. The fuzzy logic implementation has yielded a well-functioning robot and will motivate further research related to different types of control.

6. REFERENCES

Asakawa, N.; Takeuchi, Y. (1997). "Teachingless spray-painting of sculptured surface by an industrial robot". IEEE International Conference on Robotics and Automation, vol 3, pp.: 1875-1879.

Bai, Y.; Wang, D. (2010). "Applying fuzzy multi-criteria decision making for optimal robots and manipulators selection". IEEE International Symposium on Industrial Electronics, pp.: 1803-1808.

Biglarbegian, M.; Melek, W. W.; Mendel, J. M. (2011). "Design of Novel Interval Type-2 Fuzzy Controllers for Modular and Reconfigurable Robots: Theory and Experiments". IEEE Transactions on Industrial Electronics, vol. 58, issue 4, pp.: 1371-1384.

Burgos, -A. X. P.; Ribeiro, A.; Santons, M. (2007). "Controlador Borroso Multivariable para el Ajuste de Tratamientos em Agricultura de Precisión". Revista Iberoamericana de Automática e Informática Industrial, vol. 4, num. 2, pp.: 64-71.

Chen, H.B.; Lin, T.; Chen, S. B.; Wang, J. F.; Jia, J. Q.; Zhang, H. (2008). "Adaptive control on wire feeding in robot arc welding system". IEEE Conference on Robotics, Automation and Mechatronics, pp.: 119-122.

Endo, M.; Hirose, K.; Hirata, Y.; Kosuge, K.; Kanbayashi, T.; Oomoto, M.; Akune, K.; Arai, H.; Shinoduka, H.; Suzuki, K. (2008). "A car transportation system by multiple mobile robots – iCART". IEEE/RSJ International Conference on Intelligent Robots and Systems, pp.: 2795-2801.

Fei, M.; Haiou, Z.; Guilan, W. (2010). "Application of Industrial robot in rapid prototype manufacturing technology". 2nd International Conference on Industrial Mechatronics and Automation, vol. 1, pp.: 218-220.

Fuhlbrigge, T.; Chen, H.; Li, X. (2008). "Automated industrial robot path planning for spray painting process: A review". IEEE International Conference on Automation Science and Engineering, pp.:522-527.

Gazeau, J.-P.; Eon, A.; Zeghloul, S.; Arsicault, M. (2011). "New Printing Robot for High-Resolution Pictures on Three-Dimensional Wide Surfaces". IEEE Transactions on Industrial Electronics, vol. 58, issue 2, pp.: 384-391.

Giralt, G. (1997). "A robótica". Biblioteca Básica de Ciência e Cultura, Instituto Piaget, Lisboa-Portugal.

Held, C. M.; Roy, R. J. (2000). "Hemodynamic management of congestive heart failure by means of a multiple mode rule-based control system using fuzzy logic". IEEE Transactions on Biomedical Engineering, vol. 47, issue 1, pp.: 115-123.

Huang, H.-P.; Yan, J.-L.; Cheng, T.-H. (2010). "Development and Fuzzy Control of a Pipe Inspection Robot". IEEE Transactions on Industrial Electronics, vol. 57, issue 3, pp.: 1088-1095.

Jarvis, D. E. (1973). "The case for spray painting robot". Production Enginner, vol. 52, issue 5, pp.: 171-174.

Kiryu, T.; Sasaki, I.; Shibai, K.; et al (2001). "Providing Appropriate Exercise Levels for the Elderly". IEEE Engineering in Medicine and Biology, vol. 20, issue 6, pp.: 116-124.

Komagome, D.; Suzuki, M.; Ono, T.; Yamada, S. (2007). "RobotMeme – A proposal of Human-Robot Mimetic Mutual Adaptation". The 16th IEEE International Symposium on Robot and Human interactive Communication, pp.: 427-432.

Medeiros, A. A. D.; Santiago, G. S. (1998). "Desenvolvimento de um Braço Manipulador Didático de Baixo Custo Controlado por Computador". SPET 1998 – IV Simpósio em Pesquisa e Extensão em Tecnologia. Natal, RN, Brasil..

Paraskevopoulos, P.N. (1995). Digital Control Systems. 1ª ed., USA.: Editora Prentice Hall.

Romano, V. R. (2002). "Robótica Industrial". 1ª ed. São Paulo: Editora Edgard Blucher LTDA.

Shaw, I.S.; Simões, M. G. (2004). "Controle e Modelagem Fuzzy". São Paulo, SP, Brasil, Editora Edgard Blucher.

Shen, Y.; Zhongxiang, Z.; Enrong, M. (2007). "Double-Fuzzy Kalman Filter Based on GPS/IMU/MV Sensor Fusion for Tractor Autonomous Guidance". IEEE International Conference on Automation and Logistics, pp.: 61-65.

Shheibia, T. A. A. (2007). "Controle de um Braço Robótico Utilizando uma Abordagem Inteligente". Dissertação de Mestrado, UFPB, Brasil.

Shiomi, M.; Kanda, T.; Glas, D. F.; Satake, S.; Ishiguro, H.; Hagita, N. (2009). "Field trial of network social robots in a shopping mall". IEEE/RSJ International Conference on Intelligent Robot and Systems, pp.: 2846-2853.

Simões, M. G.; Franceschetti, N. N. (1999). "Fuzzy Optimization Based Control of a Solar Array System". IEEE Proceedings on Electric Power Applications, vol.146, issue 5, pp.: 552-558.

Skelly, M. M.; Chizeck, H. J. (2001). "Real-time Gait Event Detection for Paraplegic FES Walking". IEEE

Transactions on Neural Systems and Rehabilitation Engineering, vol. 9, issue 1, pp. 59-68.

Wai, R. J.; Duan, R. Y.; Wang, W. H.; et al (2003). "Implementation of Artificial Intelligent Control in Single-Link Flexible Robot Arm". In: Proceedings IEEE International Symposium on Computational Intelligence in Robotics and Automation, vol. 33, pp.: 1270-1275.

Wawerla, J.; Vaughan, R.T. (2010). "A fast and frugal method for team-task allocation in a multi-robot transportation system"..IEEE International Conference on Robotics and Automation, pp.: 1432-1437.

Weiss, H.; Xiao, J. (2003). "Fuzzy System Control for Combined Wind and Solar Power Distributed Generation Unit". IEEE International Conference on Industrial Technology, vol. 2, pp.: 1160-1165.

Xavier Filho, A. F. (2008). "Controlador Fuzzy Aplicado a um Sistema de Controle de Posição". Dissertação de Mestrado, UFPB, João Pessoa, PB, Brasil.

Yang, X.; Moallem, M.; Patel, R. V. (2005). "A fuzzy logic-based reactive navigation algorithm for mobile robots". In: Proceedings of 2005 IEEE Conference on Control Applications, vol. 197-202.

Yanping, L.; Haijiang, L. (2009). "Welding multi-robot task allocation for BIW based on hill climbing genetic algorithm". International Technology and Innovation Conference, pp.: 1-8.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.