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Fuzzy Control of an Antagonistic System Driven by Pneumatic Muscle Actuators

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***Abstract*—Due to high nonlinearity of pneumatic systems pneumatic artificial muscles (PAMs) also known as pneumatic muscle actuators (PMAs) are difficult to control, therefore a robust control is necessary to achieve the desired motion or position. Several control methods have been applied to control different systems driven by PMAs. The early control methods were based on classical linear controllers and then some modern control strategies have been developed (e. g. adaptive, fuzzy, neural network, sliding mode and others). In this paper the possibility of using a fuzzy control system on a variation of the classical ball and beam setup is presented. On the basis of experimental results, especially the achieved overshot the following is concluded: the fuzzy control is a promising method for controlling pneumatic servo-systems actuated by PMAs.**

Keywords—Pneumatic Muscle Actuators, PMAs, Fluidic Muscles, Fuzzy Logic, LabVIEW

I. INTRODUCTION

This paper examines the possibility of using fuzzy logic to control the position of pneumatic artificial muscles. The accurate positioning of actuators is an important cause in any application especially concerning the field of robotics. Since air can be compressed it is the inherent nature of pneumatic actuators to be nonlinear. Pneumatic muscle actuators share this nonlinearity. These are actuators that turn pneumatic pressure into linear motion. Contrary to pneumatic cylinders where the applied pressure expands in the chamber and drives the piston along the shaft with a force proportional to the square of the diameter and the pressure, in PMAs the applied pressure expands the muscle radially. Since the muscle membrane consists of a flexible material such as rubber and a wire mesh with high tensile strength laying on one another or galvanized together, the applied pressure causes the flexible material to expand forcing the mesh to take up its shape. Since the strands of the mesh are more resistant to stretching than the flexible material the radial expansion is accompanied by axial contraction. In PMAs the force is proportional to the diameter of the muscle and pressure.

This simple construction of a flexible material and wire mesh reduces weight and allows for easy assembly far simpler than traditional pneumatic cylinders. These actuators also require no maintenance or oil since there are no moving parts, this makes them an ideal candidate for industrial and mobile robotics where the high power to weight ratio makes PMAs more advantageous than pneumatic cylinders in certain applications, however PMAs have 3 distinct drawbacks. They have a short range of motion compared to traditional cylinders, their nonlinearity is coupled with hysteresis, and they can only exert force in one direction [1-2]. Because of this they require eider an antagonistic setup or a spring over muscle setup [3].

In the last decade there has been a cornucopia of research regarding the positioning of PMAs with results showing that a precision of 0.01 mm can be achieved over an extensive operating temperature using both antagonistic and spring over muscle setups [4].

Several robotics applications have been developed [5-6], and some of them use PMAs where the aforementioned setups were used to achieve motion [7-9]. Various control systems have been used for the positioning of these systems. Most prominent were sliding mode control and adaptive fuzzy control just to name a few with no clear indicator of which one is superior [4], [10-11].

In this paper we attempt to prove that a classical fuzzy logic controller can be used to achieve precision comparable to the aforementioned works.

II. MATERIALS AND METHODS

Fig. 1 shows the ball and beam system which consists of 2 FESTO DSMP 10-250N PMAs which have a 10 mm diameter and 250 mm of contracting length connecting to the beam. Force-contraction (relative displacement) functions of these muscles are demonstrated in Fig. 2 [12].

The ball that we position runs in a groove along the beam the beam has a length of 1 m. On both ends of the beam there are 2 SHARP GP2Y0A21YK infrared proximity sensors to measure the distance of the ball from each edge, Fig. 3 shows the nonlinear characteristic of these sensors [13]. To regulate the pressure the PMAs are connected to their own VPPM-6L-L-1-G18-0L6H-V1N- S1C1 pressure regulators, these regulators have an analog input range of 0-10 V and a pressure regulation range of

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0-600 kPa. Processing of the sensor data is done on an NI-cRIO-9074 to collect the analog values from the proximity sensors an analog input card is required similarly to control the pressure regulators an analog output card is required. For this purpose we have selected an NI 9201 which is a 12 bit analog input module with 500 kS/s on all 8 channels and a NI 9263 which is a 16 bit analog output module with 100 kS/s on al 4 channels. Both of these have a voltage range of 0-10 V.

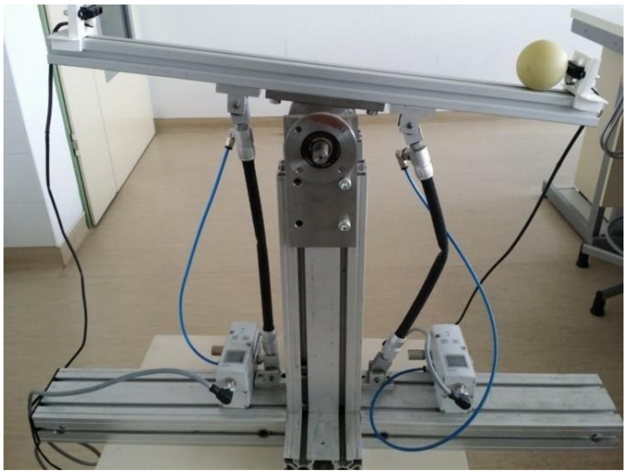

Fig. 1. The ball and beam system

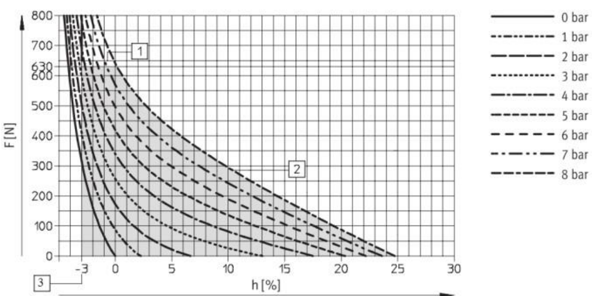

Fig. 2. Permissible force F [N] as a function of the contraction h [%]

After the system components have been selected, the next step was to find an equation for the response of the infrared sensors, since their nonlinear response was too difficult to handle. First we chose a distance range on which we would use the sensor, based on the response the sensor gives shown in Fig. 3 we selected a large range of

100-800 mm. We conducted sample measurements along this region Fig. 4 and have concluded that while the SHARP GP2Y0A21YK infrared proximity sensor is capable of detecting position at a distance of 800 mm the output voltage differential is minute, finding a suitable equation along this range yields equation (1)

$$y = 259.672701 * x^{-1.040961} \tag{1}$$

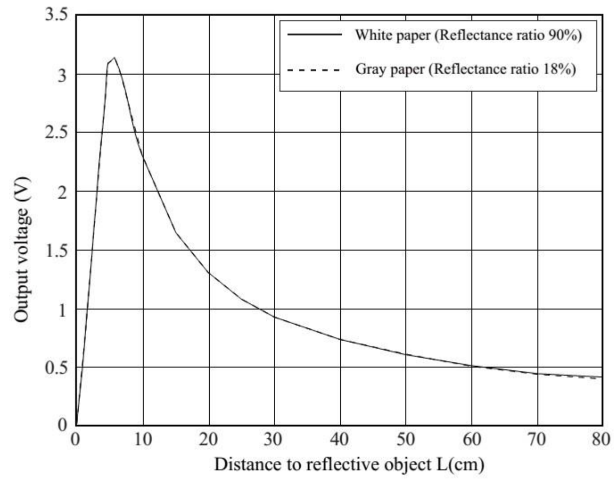

Fig. 3. Nonlinear characteristic of the SHARP GP2Y0A21YK sensor

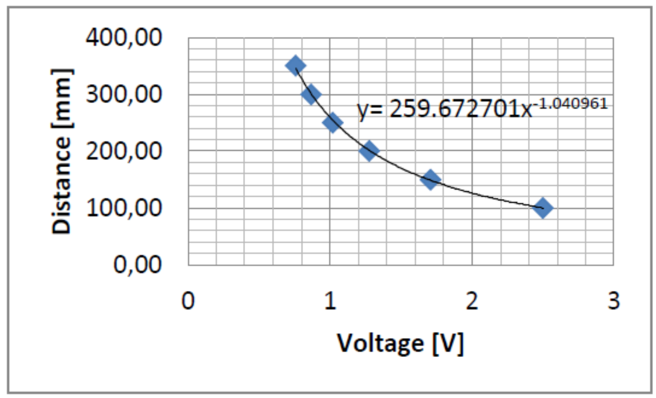

Fig. 4. Equation based on measured points

Analysing equation (1) we can see that for distances longer than 350 mm the change in voltage is minute and is discarded for the purpose of higher accuracy. To compensate for the loss in range we used 2 infrared proximity sensors and read the result of the one that gives the higher output voltage.

Now that we have a way to relate distance to voltage, we have an input for our system which is position from centre, by deriving this input we have a measurement of speed as well. Using these two as the input of our fuzzy system and voltage differential as our output we have created the following fuzzy membership functions Fig. 5, Fig. 6 and Fig. 7

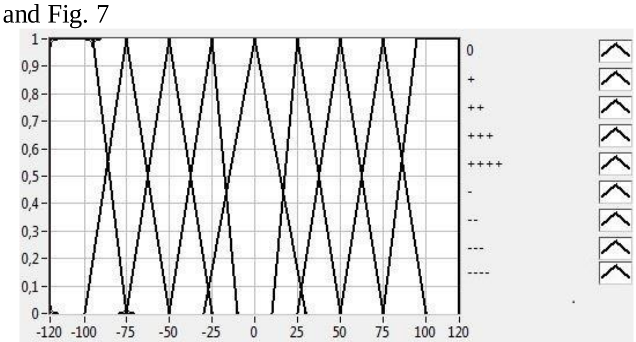

Fig. 5. Fuzzy membership function for position from centre

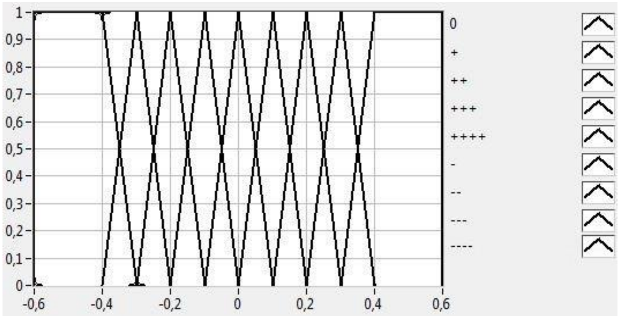

Fig. 6. Fuzzy membership function for velocity

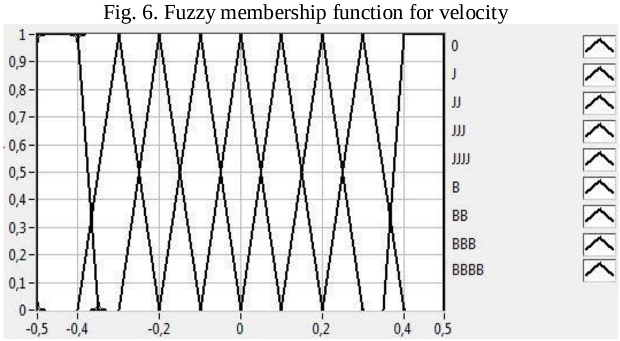

Fig. 7. Fuzzy membership function for output voltage differential

We used triangular membership functions for the system with trapezoidal membership functions at the ends of the ranges. We used 9 membership functions to classify distance and 9 membership functions to classify velocity these range from ---- to ++++ each symbol noting a greater degree of position and velocity. Using the established membership functions we created the following rules for the system shown in Table 1. Using the rules in Table 1 we have calculated the control surface shown in Fig 8. We can see that the control surface has a smooth transition and has saturation in the ends

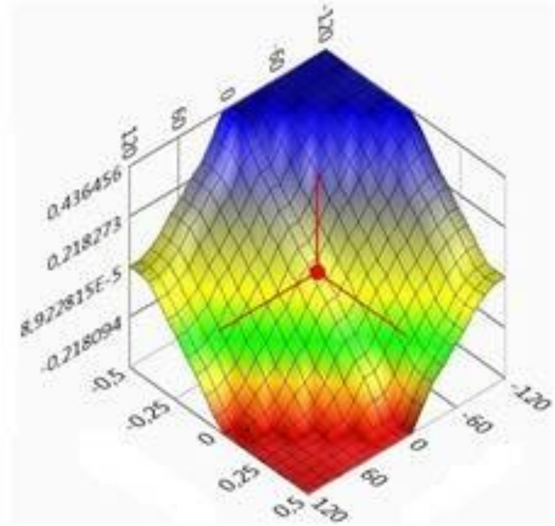

Fig. 8. Fuzzy system control surface

III. Results

Fig. 9 shows the response of the system to minor disturbances. We placed the ball away from the centre 3 times and waited for the system to respond and settle.

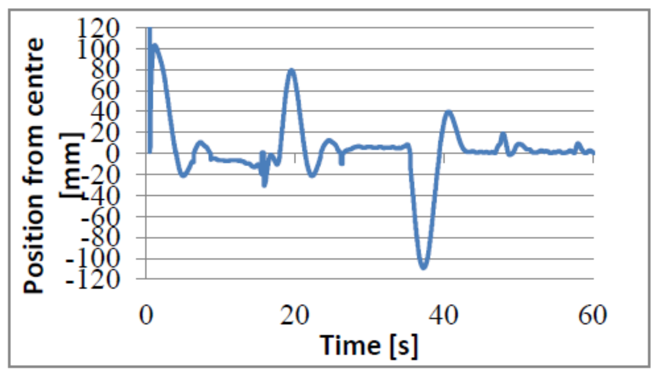

Fig. 9. Position as a function of time

TABLE I.
Fuzzy System Rules

Distance [mm] Velocity [m/s]	----	---	--	-	0	+	++	+++	++++
----	JJJJ	JJJJ	JJJJ	JJJJ	JJJJ	JJJ	JJ	J	0
---	JJJJ	JJJJ	JJJJ	JJJJ	JJJ	JJ	J	0	B
--	JJJJ	JJJJ	JJJJ	JJJ	JJ	J	0	B	BB
-	JJJJ	JJJJ	JJJ	JJ	J	0	B	BB	BBB
0	JJJJ	JJJ	JJ	J	0	B	BB	BBB	BBBB
+	JJJ	JJ	J	0	B	BB	BBB	BBBB	BBBB
++	JJ	J	0	B	BB	BBB	BBBB	BBBB	BBBB
+++	J	0	B	BB	BBB	BBBB	BBBB	BBBB	BBBB
++++	0	B	BB	BBB	BBBB	BBBB	BBBB	BBBB	BBBB

The system has minimal overshoot and settles within an acceptable time of about 10 s, since the settling speed is dependent on the incline of the beam and we worked with the maximum incline we could not develop a faster response in this system.

IV. CONCLUSION AND FUTURE WORK

We have concluded that next to sliding mode control fuzzy control is a viable alternative for positioning of PMAs with certain drawbacks. There is no known systematic approach to design fuzzy controllers it is a very time consuming activity based on trial and error, however this setup is excellent as a demonstration device for fuzzy systems in education. Students can easy test their own fuzzy controller and intuitively interpret the results.

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