Fuzzy control of an electropneumatic actuator

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Abstract

Present work describes the design and implementation of a Fuzzy system for the automation of an electropneumatic actuator, to control the steering of a lawnmower. This controller acts as one of the lowest level agents in an AMARA type architecture outdoor robots navigation. Some results are displayed to show the system performance under regular working conditions in real time.

Key words: Electropneumatic actuators, Fuzzy PD control, outdoor vehicles, autonomy, AMARA architecture.

1 INTRODUCTION

The development of an autonomous outdoor vehicle is a great challenge that involves the integration of many research fields, from the mechanical design and control of the actuation system, through the sensors and perception mechanisms to the design of an architecture to deal with intelligent behaviour, adaptation and interactions.

The three main actuation systems in Robotics are electromagnetic, hydraulic and pneumatic. Pneumatic actuators hold an intermediate position between hydraulic and electromagnetic, with respect to force to mass. Compared to hydraulic they are lower cost, cleaner and safer. On the other hand they are more compact and have better response than a comparable electric motor [Henri98]. Each actuation type represents a non-linear dynamical system, difficult to be controlled all over the required working conditions.

Fuzzy controllers have been widely applied for industrial processes due to their simplicity and effectiveness, as non-analytic model based control system [Altrock94], [Meier94], [Li00], [Costa Branco00]. They have been successfully used for a wide number of applications dealing with complex and non linear processes, wherein they are proved to be robust and less sensitive to parametric variations and noise than conventional controllers [Sugeno85], [García-Alegre91], [Gasós92], [García-Alegre95]. In addition, Proportional-Derivative (PD) controllers provide high sensitivity and tend to increase the stability of the overall feedback control system [Malki94], corresponding to the requirements of current application. Present work deals with the design of a flexible and robust control system for an electropneumatic actuator to accomplish vehicle elementary motion, as are *turn* and *forward*. To this aim a Fuzzy controller has been fully designed and tested on a lawnmower for autonomous outdoor navigation.

2 FUZZY CONTROL OF AN ELECTRO_PNEUMATIC ACTUATOR

The initial actuation system has been changed by two specially designed electropneumatic actuators to reach autonomous navigation in outdoor environments [García-Alegre93], [García-Alegre98], [Cañas99], [Reyes99].

The actuators have been integrated on the commercial vehicle, named ROJO, Figure 1. Each system is composed of: an electrovalve, a pneumatic cylinder, actuator adapters and a potentiometric sensor to detect the piston position. The piston is either pushed or pulled by the air pressure entering through the left or the right orifices of the cylinder. Air volume is controlled with two electrovalve by Pulse Width Modulation (PWM).

Figure 1. Two electropneumatic cylinders integrated in ROJO lawnmower

The air compressed reservoir is a tank located at the rear of the vehicle platform, fulfilled by an mechanical air compressor powered by the vehicle motor. The main characteristic parameters of the actuation system are displayed in Table1.

Table 1. Pneumatic cylinder data

Piston diameter	32 mm
Orifice Diameter	0.9 mm
Supply pressure	7-9 bar
Actuator range	200 mm
Cylinder diameter	40 mm
Cylinder length	270 mm

At each one-step control loop, the on-board processing system compares the current piston position with the goal position to derive the next reference, Figure 2.
The time response of the piston is about two hundred milliseconds, fast enough to run from one end to the other of the cylinder in a one-step control cycle. However this high sensitivity is a source of instability that has to be considered at the controller design stage.
For this reason a derivative component at the control system has been introduced to reduce the oscillations, smoothing the output as far as the error decreases.
The admitted tolerances in steering and driving (5 to 10 %) and the difficulty of deriving an analytic model of the whole system due to uncertainty in the tank pressure, PWD control of the electrovalve, leakage at the valves and cylinder orifices, actuator link displacements, point all together to the design of a Fuzzy controller, based on conventional control heuristics.
Thus a Proportional-Derivative Fuzzy controller is proposed which has as inputs the difference between current and reference piston position, the current error, and the error in the former one-step control cycle.

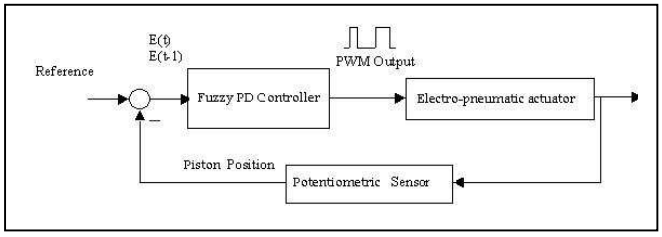

Figure 2. Electropneumatic actuator control-loop

3 FUZZY CONTROL ENVIRONMENT

An updated version of the FuzzyShell [Gasos90], has been. This tool is an aid in the design of any Fuzzy controller, and speeds up its tuning process, been extremely helpful in real time applications dealing with a multiplicity of Fuzzy controllers: *forward, turn, avoid.*
It is released as an ANSI-C library. The dynamic memory allocation allows for unbounded number of variables, linguistic labels and rules. All variables and rules are defined in a text file, with a fixed syntax, that it read and interpreted from the control program. This text file, namely knowledge base, gathers all the knowledge on the system to be controlled and consequently is domain dependent.
The environment allows to built specific knowledge bases, avoiding the time consuming task of low level programming to develop new applications. Modifications of the knowledge base and tests are easy to perform as no changes have to be introduces either in the control program or in the inference engine. This tool keeps the user at a higher level of abstraction, giving relevance to the expert knowledge.

4 FUZZY ELECTROPNEUMATIC CONTROLLER

Present approach uses a Fuzzy rule-based system [Lee90] to estimate input-output relations without the need of an analytical model. The knowledge base encapsulates the non-linear dynamic of the actuation system to act on the steer axe. The actuation system is controlled by an on-board processing system; in present stage and for the preliminary experimentation a PC-K6-2/400Mhz. Main characteristics of this processing system are: low power consumption and high speed floating point operations when using the 3Dnow instructions set.

4.1 FUZZY VARIABLES AND FUZZY RULES

There are two types of variables, input and output. The first ones show the state of the system. The output variables correspond to the control actions to be performed. In the definition of the variables at the text file, input and output variables are indistinguishable and they may be entered in any order. The differentiation occurs implicitly when the rules are defined, as inputs appears in the rule antecedent and outputs in the consequent. The same variable may be used both as an input and an as output [Gasos 89].
The linguistic values of each variable, are represented by a membership function defined by means of four parameters (a,b,c,d). With these parameters multiple

shapes can be obtained, as are: (a,b,c,d) trapezium, (a,a,b,b) rectangle, (a,b,b,c), (a,a,a,b), (a,b,b,b) triangle, (a,a,a,a) singleton.
Fuzzy inputs are the current error value *e(t)* and the previous one *e(t-1),* their difference corresponding to the derivative error. Error is measured subtracting the piston reference signal from the measured signal, as read from the potentiometer sensor. Output is the width of the voltage pulse to be sent to the electrovalve, *pwm*. This width is related to the opening period of the electrovalve orifice, which in turn is related to the volume of air pressured that enters on the left/right side of the cylinder. Variables have five linguistic values non uniformly distributed along their universe of discourse. *Error* and *previous_error* are displayed in Figure 4, and *pwm* in Figure 5.

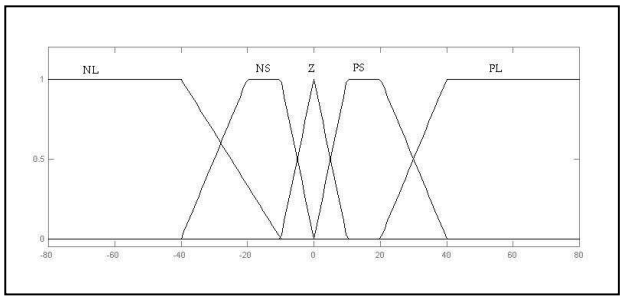

Figure 4. Linguistic labels for the input error variable

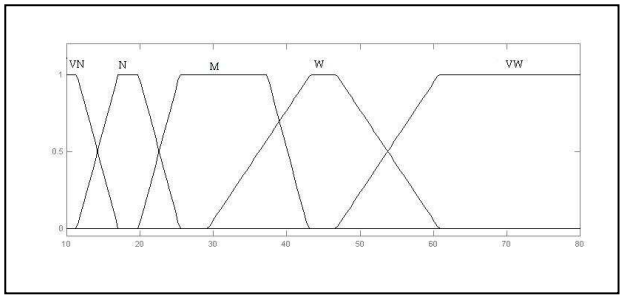

Figure 5. Linguistic labels for the pwm output variable

The knowledge base for the Fuzzy control of the steering is described in Table 2. It is composed of thirteen rules, having two input and one output variables. The syntax of the input file is direct and Fuzzy rules and variables can be easily modified.

4.2 THE INFERENCE ALGORITHM

The inference engine is based on a centre of mass (COM) algorithm that fuses the outputs of each rule in the knowledge base, to derive a crisp value. Its input variables, which define the current state of the system, are matched against the antecedent of each rule. The fusion of the antecedent conditions is performed by means of one of the typical T-norms, that is the product.

4.3 THE FUZZY CONTROL PROGRAM

The Fuzzy PD controller is basically composed of: a Fuzzy library that includes an interpreter of the knowledge base, previously defined in a text file, and a set of control loops. The Fuzzy PD controller, accepts rules with the pattern:
IF (A =a) AND (B=b) THEN (C=c), with an unbounded number of conjunctive conditions in the antecedent but with only one condition in the consequent.
A call to the library is performed whenever an action is needed. At that moment the current input variables related to the potentiometric sensor are requested, being the one-step control cycle about 250 ms.
Several controllers, each one defined through its knowledge base, can use the Fuzzy library at the same time. This is extremely useful to both test slightly different controllers during the tuning process and to built up a multiagent architecture, wherein an agent is defined as a control process in charge of reaching or maintaining a goal.
In the PD Fuzzy controller the *error* is measured in degrees, through a calibration process that involves piston position and steer angle. The range for the piston position is -20 cm to +20 cm., for the wheels angle is -40º to +40º and for the error -80º to +80º. The output variable is *pwd*, that is the width of the pulse to be applied to the electrovalve. Its value is given in percentage, ranging from 10% to 80% of the 250ms. control cycle.

5 RESULTS

The performance of the actuator was examined under a wide range of conditions, to completely cover the range of the steer angle universe of discourse (-40º to +40º).
The objective of the Fuzzy control system is to achieve a reference value, in the whole variables range, in a short time and without high oscillations. The performance of a given controller can be evaluated through three standard parameters: 1) the rising time Tr, 2) the stationary error Es and, 3) the oscillation amplitude O. These parameters can be extracted from the experimental curves that describe the piston position evolution with time on a great variety of initial and final conditions, covering the working space.

Table 2. Knowledge base of the fuzzy PD controller

```
#Fuzzy controller data file
steer controller

label error(t) negative_large = -80 -80 -40 -10
label error(t) negative_small = -40 -20 -10 0
label error(t) zero =  -10 0 0 10
label error(t) positive_small   = 0 10 20 40
label error(t) positive_large  = 20 40 80 80

label error(t-1) negative_large = -80 -80 -40 -10
label error(t-1) negative_small = -40 -20 -10 0
label error(t-1) zero =  -10 0 0 10
label error(t-1) positive_small   = 0 10 20 40
label error(t-1) positive_large  = 20 40 80 80

label pwm very_narrow = 10 10 11 17
label pwm narrow = 11 17 19 25
label pwm medium =  19 25 37 42
label pwm wide   = 29 43 46 60
label pwm very_wide  = 46 60 80 80

IF ( error(t) = zero ) THEN ( pwm = very_narrow )
IF ( error(t) = negative_large ) AND ( error(t-1) = negative_large ) THEN
( pwm = very_wide )
IF ( error(t) = negative_large ) AND ( error(t-1) = negative_small ) THEN
( pwm = wide )
IF ( error(t) = negative_large ) AND ( error(t-1) = zero )           THEN
( pwm = wide )
IF ( error(t) = negative_large ) AND ( error(t-1) = positive_small ) THEN
( pwm = wide )
IF ( error(t) = negative_large ) AND ( error(t-1) = positive_large ) THEN
( pwm = wide )
IF ( error(t) = negative_small ) AND ( error(t-1) = negative_large ) THEN
( pwm = medium )
IF ( error(t) = negative_small ) AND ( error(t-1) = negative_small ) THEN
( pwm = narrow )
IF ( error(t) = negative_small ) AND ( error(t-1) = zero )           THEN
( pwm = very_narrow )
IF ( error(t) = negative_small ) AND ( error(t-1) = positive_small ) THEN
( pwm = narrow )
IF ( error(t) = negative_small ) AND ( error(t-1) = positive_large ) THEN
( pwm = medium )
IF ( error(t) = positive_small ) AND ( error(t-1) = negative_large ) THEN
( pwm = medium )
IF ( error(t) = positive_small ) AND ( error(t-1) = negative_small ) THEN
( pwm = narrow )
IF ( error(t) = positive_small ) AND ( error(t-1) = zero )           THEN
( pwm = very_narrow )
IF ( error(t) = positive_small ) AND ( error(t-1) = positive_small ) THEN
( pwm = narrow )
IF ( error(t) = positive_small ) AND ( error(t-1) = positive_large ) THEN
( pwm = medium )
IF ( error(t) = positive_large ) AND ( error(t-1) = negative_large ) THEN
( pwm = wide )
IF ( error(t) = positive_large ) AND ( error(t-1) = negative_small ) THEN
( pwm = wide )
IF ( error(t) = positive_large ) AND ( error(t-1) = zero )           THEN
( pwm = wide )
IF ( error(t) = positive_large ) AND ( error(t-1) = positive_small ) THEN
( pwm = wide )
IF ( error(t) = positive_large ) AND ( error(t-1) = positive_large ) THEN
( pwm = very_wide )
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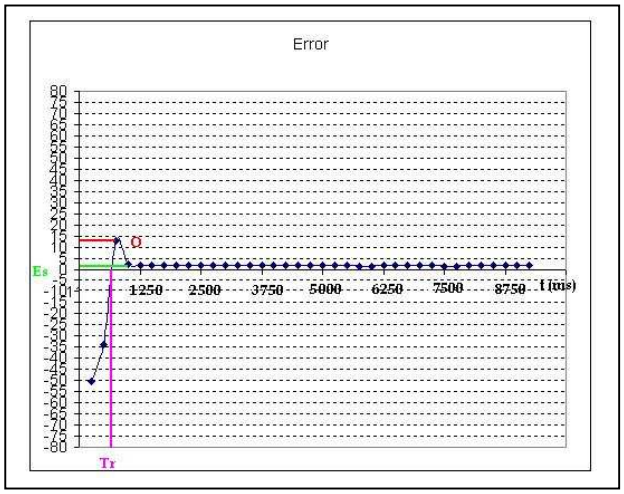
One of these time response curves is displayed in Figure 6. In average the rise time is about 500ms., the stationary error falls below 5º and the oscillation is less than 5º. The rise time is well within the time response required for real time performance and the oscillation and stationary error agree with the tolerances initially requested.
The surface control of the Fuzzy PD controller is also displayed in Figure 7. The Fuzzy PD controller developed has been tested in a concrete terrain. This framework would allow for a quick implementation of different Fuzzy PD controllers focused on a navigation on different terrain as are: flat soil, rough or rocky terrain, with some additional effort.



Figue 6. Fuzzy PD response curve

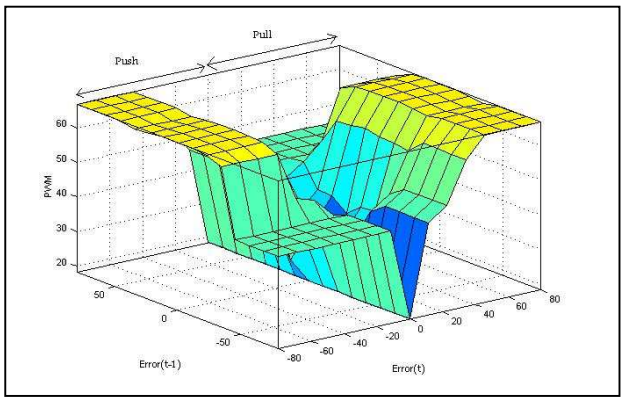


Figure 7. Steering Fuzzy PD control surface

6 COMMENTS AND CONCLUSIONS

The Fuzzy PD controller here developed is a non-analytic-model based control system, that has been quite easily designed, implemented and validated for a complex non linear system.
This Fuzzy PD control system for an electropneumatic actuator, has proved to work within the admitted tolerances along the whole piston run.
Such Fuzzy controllers are able to account, in a single model, for a wide range of operating conditions reaching the desired reference in a short number of one-step feedback control loops and displaying a smooth behaviour.
The Fuzzy environment used would be of a great help on the subsequent design of a multiagent control architecture, AMARA type. Each agent will use in a flexible way its perception and action as defined through its knowledge base, in a flexible manner, allowing the control of several variables each one having a different control cycle.

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