Maestría en Ingeniería en Automatización de Procesos Industriales

Title

A fractional PID controller in a field programmable analog array tuned by neural networks

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September-December 2015

A Fractional PID controller in a field programable analog array tuned by neural networks

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1. Introduction

Currently the PID controller is the most widely used in industry due to its simple structure and relatively easy understanding.

This work proposes the introduction of a fractional order PID controller to obtain a more flexible and robust control than the conventional PID, with the inclusion of two additional degrees of freedom [1]. The $PI^{\lambda}D^{\mu}$ controller has an integrator of order λ and a differentiator of order μ, with $\lambda, \mu \in (0,2)$ allowing to ad restrictions and specifications for the tuning process [2], improving the performance of the system response.

In addition, it is proposed the use reconfigurable devices, such as FPGAs or FPAAs, to make changes *in situ*. It is also proposed the use of neural networks to estimate the values P, I, D, λ and μ in order to make the system insensible to variations in the plant parameters.

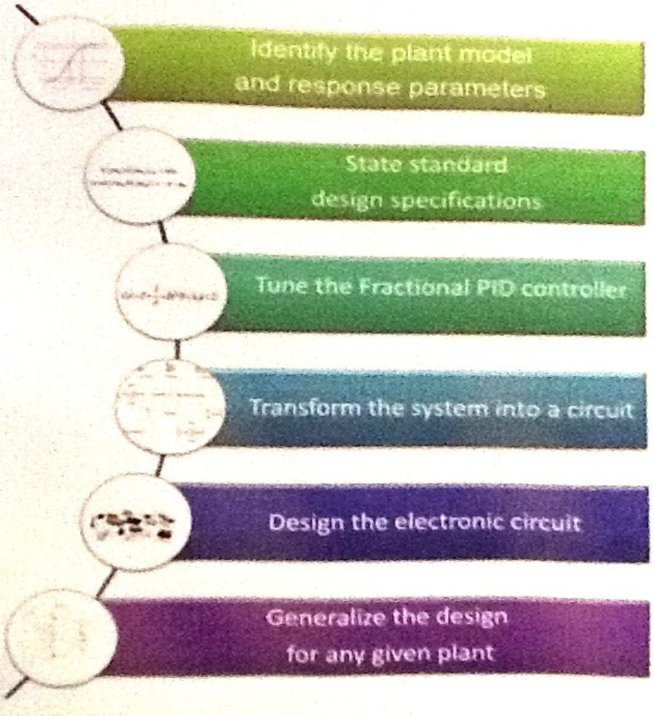
2. General objective

Tuning a PID controller of fractional order with radial basis neural networks, trained it offline with MATLAB and implement the system in a field programmable analog array.

3. Particular objectives

- To establish constraints and solve simultaneous equations to set the required system performance.
- To conduct radial basis neural network training in MATLAB and obtain the P, I, D, λ, μ data set.
- To assemble the system plant-controller within a programmable analog device.

4. Method



Identify the plant model and response parameters

State standard design specifications

Tune the Fractional PID controller

Transform the system into a circuit

Design the electronic circuit

Generalize the design for any given plant

Figure 1. Methodology to design the analog fractional PID controller

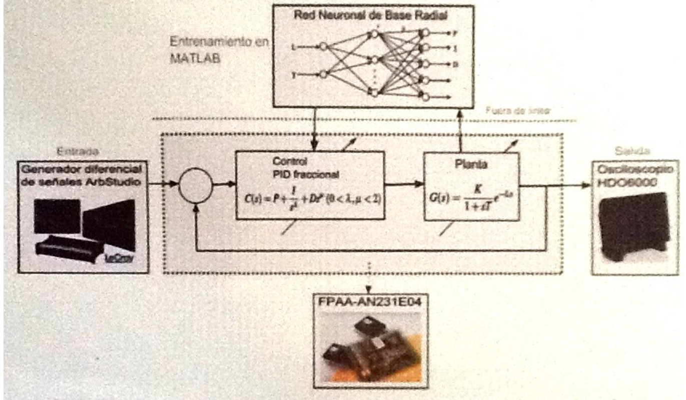


Figure 2. Components of the control system. From left to rigth: Reference, controller, plant, output. From top to button: neural network and discrete or on chip implementation.

5. Design

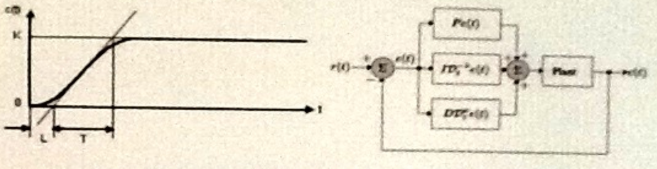
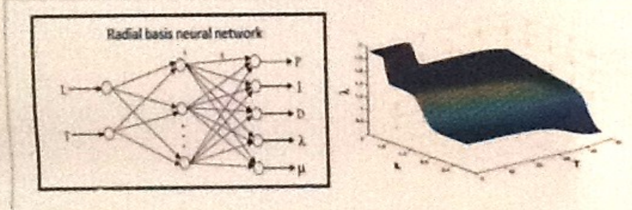


Figure 3. Response of the plant and its non-integer PID controller

Set of design equation and restrictions	
1. $\lvert C(j\omega_{cg})G(j\omega_{cg})\rvert_{\omega_{cg}=\frac{1}{2}\frac{rad}{s}} = 0dB$	Gain crossover frequency (ωcg)
2. $\arg(C(j\omega_{cg})G(j\omega_{cg})) = -\pi + \frac{2}{3}\frac{rad}{s}$	Phase margin (φm)
3. $\lvert T(j\omega)\rvert = \frac{\lvert C(j\omega)G(j\omega)\rvert}{\lvert C(j\omega)G(j\omega)+1\rvert} \leq -10dB, \omega \geq 10\frac{rad}{s}$	High frequency noise rejection
4. $\lvert S(j\omega)\rvert = \frac{1}{\lvert C(j\omega)G(j\omega)+1\rvert} \leq -20dB, \omega \leq \frac{1}{100}\frac{rad}{s}$	Output disturbance rejection
5. $\left.\frac{d\lvert\arg(C(j\omega)G(j\omega))\rvert}{d\omega}\right\rvert_{\omega=\omega_{cg}} = 0$	Robustness to variations in the gain of the plant

Figure 4. Tuning procedure to fulfill up to five specifications of a fractional controller



$$G(s) = \frac{K}{1+s}e^{-0.1s} \Rightarrow C_1(s) = 0.7469 + \frac{0.8740}{s^{1.2089}} + 0.0001s^{0.0603}$$

Figure 5. Neural network architecture for the approximation of the controller

Fractional Laplacian Operators and the corresponding approximation

$$\mathscr{L}\left[{}_{\mathrm{L}}\mathscr{D}^{\alpha} f(t)\right] = s^{\alpha}F(s) \qquad \mathscr{L}\left[\mathscr{I}^{\alpha} f(t)\right] = s^{-\alpha}F(s)$$

$$\frac{1}{s^{\alpha}} \approx \frac{(1-\alpha)s+(1+\alpha)}{(1+\alpha)s+(1-\alpha)} = \frac{As+1}{s+A}, \qquad A = \frac{1-\alpha}{1+\alpha}$$

$$s^{\alpha} \approx \frac{(1+\alpha)s+(1-\alpha)}{(1-\alpha)s+(1+\alpha)} = \frac{Bs+1}{s+B}, \qquad B = \frac{1+\alpha}{1-\alpha}$$

Figure 6. Approximation of fractional-order Laplacian operators

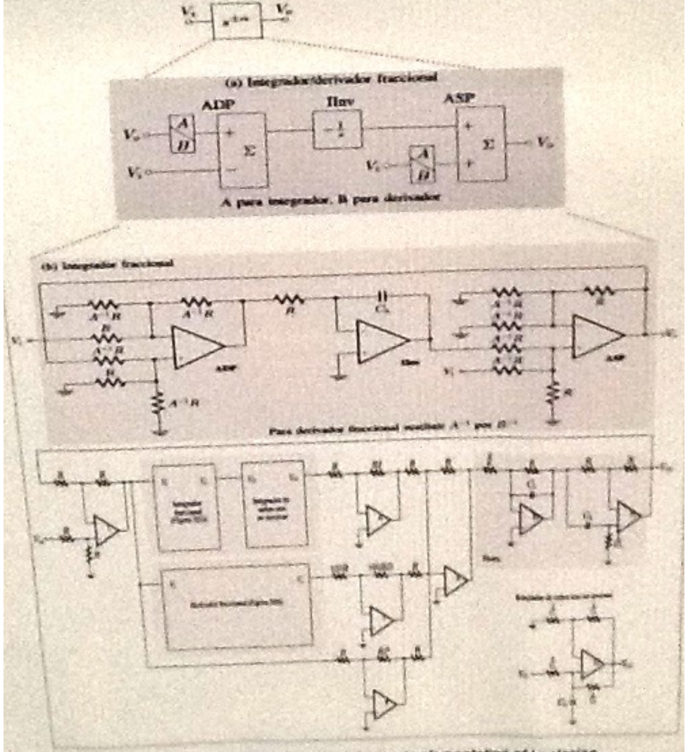


Figure 7. (a) Proposed methodology for the implementation of Laplacian operators. (b) Circuit realization. (c) Plant + fractional order PID controller.

6. Results

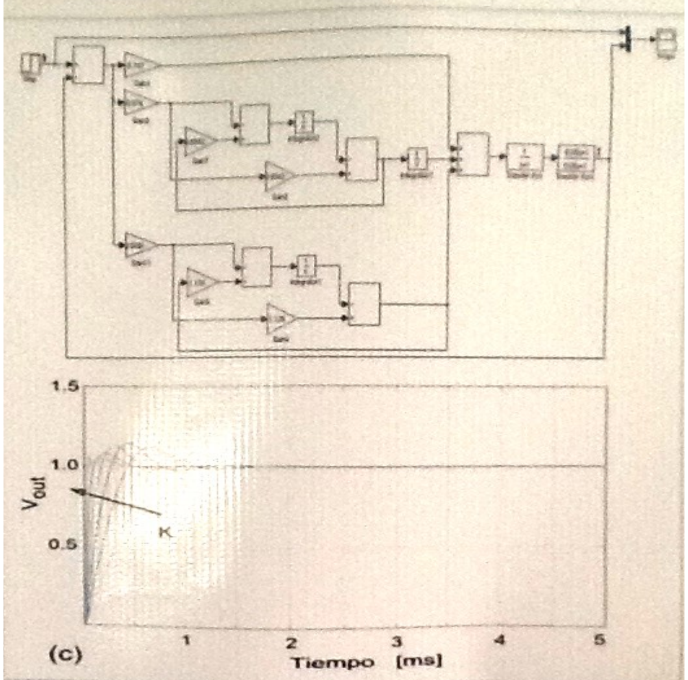


Figure 8. Simulink simulation of the fractional-order PID fractional controller. The plant has the following parameters: L=0.1, T=1, K=(0.125, 0.25, 0.5, 1, 2, 4, 8).

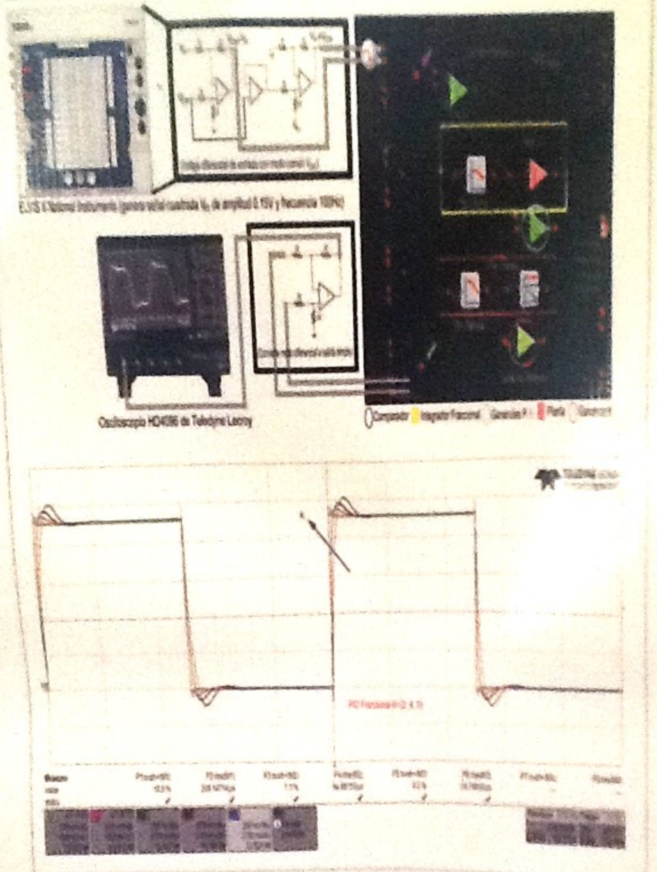


Figure 9. FPAA implementation, experimental setup and experimental results.

In Fig. 8 it is shown a block based simulation, the blocks have been taken from the proposed approximation method.

The PID fractional controller also was implemented in a FPAA (AN231E04); as is expected, the system has less sensitivity to plant gain variations as shown in Fig 8 and 9.

7. Conclusion

A fractional order PID controller has been designed taking temporal parameters and tuning it in the frequency domain. The results shown that the proposed method is valid, according to specifications. Once the neural network is finished the controller specifications would be known.

Acknowledgements

To CONACYT for being the holder of the scholarship 337393.

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