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Experimental Development of Fuzzy Controllers for Thermal and Pneumatic Processes

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Abstract

In this project, a Fuzzy control system is proposed in an industrial process training module with two independent systems between them, one thermal and the other pneumatic. The control algorithm is developed in Python language v3.6 executed by a Raspberry Pi B+, both controllers depend on the error and change in error that are updated in times of 2 s and 1 s, for temperature and pressure respectively, communication with the plants uses A/D and D/A converters, the thermal Fuzzy was analyzed with three temperature references [50,100 and 150]°C, with a rise time of 191 s, 360 s and 505 s; steady state error of 5.5%, 0.7% y 0.7%, in the pneumatic system the speed of change between references is evaluated from 10 psi to 15 psi varying the activation of the compressor at the beginning of the

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experiments, the settling times obtained are 111 s and 106 s, with the compressor off the result is 116 s and 88 s, besides a maximum excess of 13% with inherent oscillations to the type system that are in an acceptable range.

Keywords: Raspberry Pi; control system; instrumentation, fuzzy; Python.

Desarrollo experimental de controladores Fuzzy para procesos térmicos y neumáticos

Resumen

En este proyecto, se propone un sistema de control Fuzzy en un módulo de entrenamiento de procesos industriales con dos sistemas independientes entre sí, uno térmico y otro neumático, el algoritmo de control se desarrolla en lenguaje Python v3.6 ejecutado por una Raspberry Pi B+, ambos controladores dependen del error y cambio en el error que se actualizan en tiempos de 2 s y 1 s, para temperatura y presión respectivamente, la comunicación con las plantas emplea conversores A/D y D/A, el Fuzzy térmico se analizo con tres referencias de temperatura [50,100 y 150]°C, con un tiempo de subida de 191 s, 360 s y 505 s; error de estado estacionario de 5.5 %, 0.7 % y 0.7 %, en el sistema neumático se evalúo la velocidad de cambio entre referencias de 10 psi a 15 psi variando la activación del compresor al inicio de los experimentos, los tiempos de asentamiento que se obtienen son 111 s y 106 s, con el compresor apagado el resultado es de 116 s y 88 s, además de un sobrepaso máximo de 13 % con oscilaciones inherentes al tipo sistema que se encuentran en un rango aceptable.

Palabras clave: Raspberry Pi; sistema de control; instrumentación; Fuzzy; Python.

1 Introduction

Maintaining an industrial process under safe conditions is the main purpose of a control system [1]. For implementing a certain control process, the production plants and their embedded systems must be modernized and optimized [2], this allows to monitor the variables that are being controlled and grants that the plant is working under safety conditions for the operator and even for the control system. It is also made to establish the method or the way in which the system will be regulated, this adaptation is known as instrumentation [3]. Overall, when a control and instrumentation systems are executed under minimal or null human intervention, the system is called automated [4], in order to take a modern approach to control, this work proposes the use of Fuzzy as an algorithm for two simulated industrial applications [5].

There is a lot of embedded hardware to develop Fuzzy control systems [6], however most of the applications are made by licensed hardware and software, as an alternative to this is the Raspberry Pi (RPi) single board computer, which has got much popularity these years, due to its great hardware capacity, which improves each year, the free-licensed policy for its programming as well as the fact that it counts with 40 general purpose ports for communication (GPIO) [7]. By virtue of it, the usage of RPi has been expanding to many areas such as control systems, as Li Jianshuo, *et al* illustrated [8]. They developed a predictive control with constant evolution based in a neuro-fuzzy method, for a drying process with a microwave, where the temperature and the humidity are the control objective, obtaining successful results into a highly complex environment with a great efficiency and security, furthermore getting adequate discrepancies between predicted and measured data. In the same way, Celis-Peñaranda, José M., *et al* [9], who implemented an adaptive control system to optimize a traffic light junction, decided to use a RPi model B, with a database to enhance the system performance. The RPi has been applied as a monitoring device as well, for instance, Navdeti, Pooja *et al* [10], showed an RPi B+ application, where it was implemented to observe health sings in medical patients. The goal was to check parameters like the hearth rate, Electrocardiogram (ECG), and temperature, saving and displaying these data with an LCD screen. Finally, it can be seen that RPi is also useful for mechanic proposes [11]. An instance was the application of a Rpi 3B into the hydrogen injection system for combustion engines by using the OBD-II communication protocol, Fuzzy has also been used for industrial applications related to motion control [12] who obtained results to optimize steady state errors and reduce energy consumption. The fuzzy has been utilized in a variety of projects, where it may be mentioned [13],[14],[15].

In this work it is proposed the usage of a RPi 2B+ as the main embedded system to develop a fuzzy control process for two independent variables (temperature and air pressure) inside an industrial process training module, available in the energy and control researching laboratory in the Francisco de Paula Santander University. The data acquisition is done by adapting the communication between the actuators and the RPi, with Analog-Digital converters (A/D) and a graphic interface. In addition, Digital-Analog circuits are designed to complete the same task. The operation of the system is evaluated applying velocity test for different input data in the controller.

2 Materials and methods

The implementation of the controllers follows these steps: Firstly, the plants components are identified by means of a description to organize hierarchically the hardware and its general interaction. Secondly, It is laid out the Fuzzy methodology that was utilized with its references as well as its terminology.

2.1 Plant description

The control process was carried out in the industrial process training module seen in the Figure 1. It regulates two physic systems: The temperature in a cylindric oven and the pneumatic pressure in a tank, both systems are totally independents, therefore two SISO (Single input single output) controllers were implemented for this task.

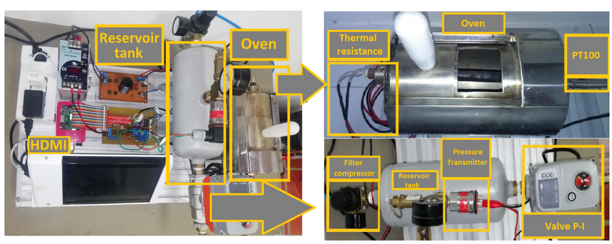

Figure 1: Industrial process simulation module.

By identifying the components that has each controlled system, it is stablished a general schematic of the embedded system hardware with its general elements and its interaction. It is found in Figure 2.

The measurements exposition and the interaction with the processes are displayed in a HDMI screen using and graphic interface, under a hierarchical schematic, the communication employs converters to take samples

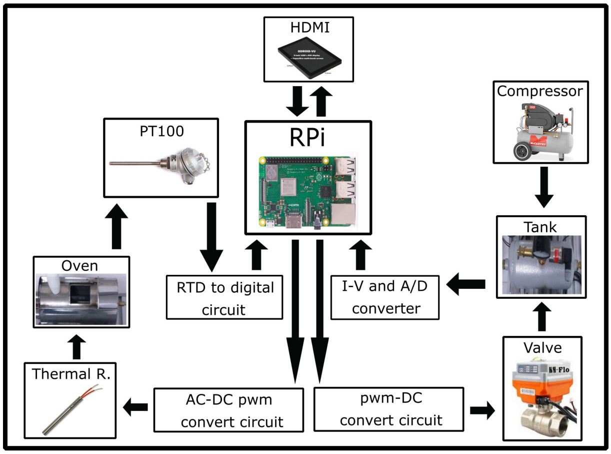

Figure 2: General hardware diagram

from the sensors to the RPi, and actuator circuits which are controlled by PWM.

The RPi does not feature analog ports in its GPIO pins, to complete a successful communication for the inputs as well as the outputs of data, it is required to adapt these signals implementing circuits for each plant, at the thermal plant was used an A/D converter connected to a RTD (Resistance Temperature Detector) [16],[17], and a PWM-DC converter to operate the actuator. On the other hand, the pneumatic system includes a dedicated A/D converter which is implemented to take samples from the pressure transmitter and a PWM-DC converter is built for the actuator.

For the thermal system measurement, it was opted for an RTD-Digital converter model max31865 [18], this integrated circuit is able to take data samples with 15 bits of resolution by using SPI communication protocol. The pneumatic system uses the MBS3000 transmitter [19], whose output signal is an electric current between 4-20mA proportional to the pressure, to obtain this measure the output is connected to a A/D converter model mcp3008 trough a current to voltage circuit converter and Finally the data is delivered to the micro-computer utilizing SPI protocol.

The thermal actuator is a cartridge type heating resistor [20], for its operation an AC/DC converter controlled by PWM was designed, in the power transfer is used an IRF630 mosfet transistor, that is able to operate under 200VDC and 7A, this is activated through an optocoupler to protect the RPi from the power circuit.

The control process for the pneumatic actuator, requires from 0 to 10VDC, where 10VDC means that the valve is totally opened. Its circuit consists of PWM-DC converter with adjustable gain [21]. this operates with a low pass filter that converts the PWM signal in a DC signal, which is connected to a pair of amplifiers: a non-inverter amplifier circuit and to a buffer that grants suitable current for the valve.

2.2 Fuzzy control system design

The methodology to implement a Fuzzy control consists therefore of a series of steps that are detailed below and are supported by [22],[23],[24], the methodology contains three stages or blocks: the first stage consists of modeling Fuzzy universes in linguistic sentences, that is, assigning the membership functions of the universes or sets in order to calculate the belonging of the variables, these functions can be triangular, trapezoidal, Gaussian, polynomial or linear fractions by parts, among others [25]. For the design of the controllers the triangular and trapezoidal functions were taken into account due to the low computational cost and for having good response speed [26], the mathematical description to calculate the membership of variables is found in Equations (1),(2).

$$Triangular\ \ \mu(A) \begin{cases} \frac{x-a_l}{a_m-a_r}, & a_l \le x \le a_m \\ \frac{a_r-x}{a_r-a_m}, & a_m \le x \le a_r \\ 0, & otherwise \end{cases} \tag{1}$$

$$Trapezoidal\ \ \mu(A) \begin{cases} \frac{x-a_l}{a_h-a_l}, & a_l \le x \le a_h \\ 1, & a_h \le x \le a_m \\ \frac{a_r-x}{a_r-a_m}, & a_m \le x \le a_r \\ 0, & otherwise \end{cases} \tag{2}$$

From the above equations the constants $[a_l, a_r]$ can be interpreted as the upper and lower limits of the membership functions, μ_A is the degree of belonging of the variable to the universe, its value is between 0 and 1, given the case that two universes interpolate between them , the belonging of the variable is determined in the second stage of the design, for the triangular function the variable a_m represents the upper vertex of the triangle , for the trapezoid there are two upper vertices a_h y a_m, finally x represents the number to which the degree of belonging is calculated [27].

In the second stage of design, the logical connectivity with which the membership functions interact is determined, in case there are interpolation of two universes with a variable, there are several functions proposed to determine the degree of membership depending on whether the interpolation is the result of union, interception or complement [28], the functions are found in Equation (3).

$$\begin{aligned} \mu_{B\bigcap C}(x) &= min(\mu_B(x), \mu_C(x)) \\ \mu_{B\bigcup C}(x) &= max(\mu_B(x), \mu_C(x)) \\ \mu_{\bar{B}}(x) &= 1 - \mu_B(x) \end{aligned} \tag{3}$$

The behavior that the system will have is established based on the correct and adequate interpretation of the experience and knowledge of the designer to create the basis of rules[29], these rules are the central part of the controller since they represent the intelligence of the system and its capacity to make decisions like a human being, each Fuzzy rule consists of two parts: an antecedent and a consequence as detailed in the Equation (4).

$$IF\ \ A\ \ THEN\ \ B \tag{4}$$

Where IF represents the antecedent and the consequence comes from THEN, the Equation (4) has a single input and output, for control systems it is common to use a system with two inputs and one output, the rules must have some characteristics to maintain their consistency: it is not possible to have two or more rules whose antecedents are the same and also have different outputs, the antecedents and consequences must be adjacent to each other, the adjacent rules must also provide a continuous output to guarantee the output flow in the controller and finally all the Fuzzy sets must be use to create the rule bases.

In the third stage once decided the output for the controller based on the rules, it is necessary to transform this set into a real numerical value that can be accepted by the system that is controlled, this process is called defuzzification, there are several methods for this calculation, however in this work the centroid method was applied because of its low response time [30].

The control systems developed are divided into two block diagrams shows in Figures 3 and 7 and although they are independent of each other, the signal notation for both is shared, so it is described in Table 1.

Table 1: Common signals in controllers

Nombre señal	Descripción
r(k)	Set point
e(k)	Error
Δe(k)	Change in error
u(k)	Output (PWM)
y(k)	Variable to be regulated
Ke	Sensitivity constant

For both control systems the error and change in error is expressed by the following Equations (5), (6).

$$e(k) = error - setpoint \tag{5}$$

$$\Delta e(k) = \frac{e(k) - e(k-1)}{\Delta t} * Ke \tag{6}$$

The error represents the deviation from the ideal value or set point, while the change in the error shows the change in the error over time, this allows evaluated the control action and its effect in the plant.

The open source library scikit-fuzzy [31] was used, this provides all the necessary tools for the creation of the Fuzzy Universes, set graphics, rules and inference, communication with the systems and controllers test.

2.2.1 Fuzzy thermal controller. The thermal controller is show in the block diagram in Figure 3, from this the inputs and outputs that the controller receives are inherent and must be transformed into fuzzy sentences to regulate the system, the execution frequency is 2 seconds, this time was used because the temperature is a variable that changes slowly, then two seconds provide a sufficient margin to observe the changes in the system and also decreases the use of the processor by execute less computer cycles in the RPi [32].

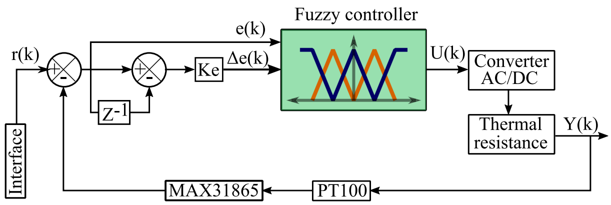

Figure 3: Block diagram thermal control system.

The inputs and outputs are converted into Fuzzy universes that represent the size of the variables, there are two inputs: error and change in error, there is a single output u(k), for the creation of the universes and sets were taken experimental data in conjunction with mathematical models to understand the behavior of the system [33].

The error is represented in the range of [-20 to 160]°C with steps of 1°C, these steps are 1°C to maintain accurate tracking of the variable without impact in performance since smaller steps increase the number of elements in the temperature matrix, the range was created taking into account that the user selectable set point is between [50 to 150]°C and the minimum system temperature is the ambient temperature and maximum 170°C.

This universe is divided into sets named with a label and also a membership function is assigned to each division, the error change originally had a magnitude of [-0.5 to 0.25]°C, however, in order to improve its range and allow observing the changes of the error properly it was decided to multiply this universe by a constant (Ke) whose value is 20, this value is sufficient to allow easily observing the behavior and improve the sensitivity of the changes; a higher value would unnecessarily increase the size of the matrix, therefore after this the change of the error was left with a range [-10 to 5]°C with decimal steps of 0.1°C, the output is a universe with a size of [0 to 100]PWM in steps of 0.1 PWM, this size is equivalent to the PWM of RPi, the distribution of the universes is show in Figure 4.

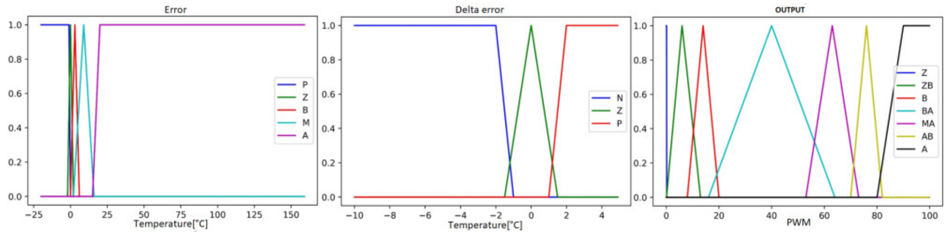

Figure 4: Fuzzy Universes of temperature.

The relationships between inputs and outputs are defined, that is, the inference, creating a total of 15 rules, which are specified in Table 2 following a precedent (IF) and consequence (THEN) structure.

Table 2: Rule base thermal controller

Output		Δerror		
		N	**Z**	**P**
Error	**A**	A	A	A
	M	Z	MA	AB
	B	Z	B	BA
	Z	Z	Z	ZB
	P	Z	Z	Z

To interpret this rule base, first the membership functions of each set are described, for the error there are 5 statements: A(high), M(medium), B(low), Z(zero) and P(Positive) being error [A] the highest degree of error and error [P] the case in which at temperature has exceeded the set point, the Δerror has 3 statements: N(negative) when the control action is effective, Z(zero) when the error is unaffected and P(positive) when the control action increases the error, for output 7 statements: Z(zero), ZB(zero low), B(low), BA(low high), MA(medium high), AB(high low), A(high); where output [Z] means no load in the actuator and output [A] is the maximum load in the actuator.

The out of the controller is interpreted with the value of the error and the change that it had in time, for example, when error [A] for the controller its output should be high regardless of the change in the error to achieve a reduction as fast as possible, to interpret the Table 2 the rule structure is presented: IF error [x] AND Δerror [x] THEN output [x].

2.2.2 Fuzzy pneumatic controller. The pneumatic controller is described in the block diagram show in Figure 5, from this are inferred the inputs and outputs that must be transformed into rules sentences to regulate the system, its frequency of execution is 1 second, since the pressure is a variable that changes quickly.

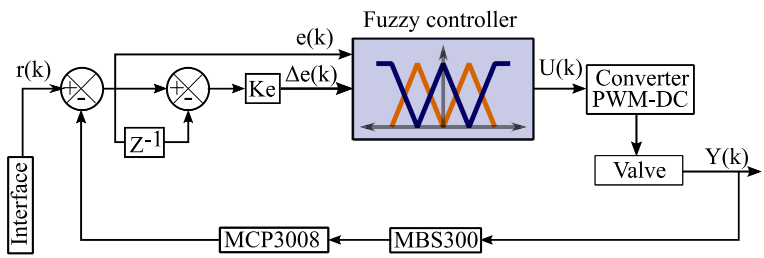

Figure 5: Block diagram pneumatic control system.

For the creation of the universes and sets were taken experimental data in conjunction with mathematical models to understand the behavior of the system, the error is represented with the range of [-25 to 25]Psi with steps of 0.1 Psi, the range was created taking into account that the set point chosen by the user varies between [10 to 20]Psi and the steps are 0.1 Psi to increase the precision in the reduced size of the universe, the air pressure changes with greater speed and the same happens with the error, the change in the error has a magnitude of [-10 to 5]Psi in steps of 0.1 Psi after having improved its sensitivity by multiplying it by a constant (Ke) with a value of 10 similar to the temperature controller's Ke, the output is a universe with a size of [-0.2 to 0.2]PWM in steps of 0.01 PWM, has this size because the output does not change quickly, so is the result of a addition or subtraction of PWM that is opening or closing the valve gradually and does so in steps of 0.1 PWM either positive or negative, the representation of the universes is show in Figure 6.

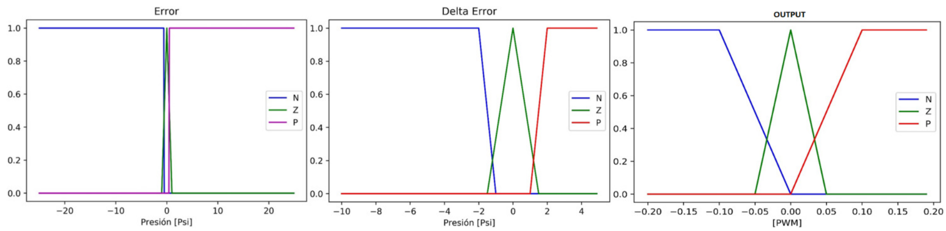

Figure 6: Fuzzy Universes of pressure.

The relationships between the inputs and outputs for the error and change in the error are defined, creating a total of 9 rules, which are specified in Table 3, following a precedent (IF) and consequence (THEN) structure.

Table 3: Rule base pneumatic controller

Output		Δerror		
		N	**Z**	**P**
Error	**N**	P	P	P
	Z	P	Z	N
	P	N	N	N

To interpret this rule base, first the membership functions of each set are described, for the error there are 3 sentences: P(positive) the set point is exceeded, Z(zero) without error and N(negative) the set point has not yet been reached, Δerror has 3 sentences: N(negative) when the control action is effective, Z(zero) when the error is unaffected and P(positive) when the control action increases the error, for the output 3 statements: P(positive) opens the valve, Z(zero) no change and N(negative) closes the valve.

The behavior of the controller is interpreted with the value of the error. If error [N] slowly opens the valve until error [Z] is reached and likewise if error [P] slowly closes the valve until error [Z] is reached, in case of error [Z] Δerror is taken into account to keep the controller stable, to interpret table 3 the rule structure is presented: IF error [x] AND Δerror [x] THEN output [x].

3 Results and discussion

The results obtained are based on the tests of the controllers, first for the Fuzzy of temperature three points of reference were selected for low, average and high temperature, the points are [50, 100 and 150] °C respectively, these values cover the inferior and superior limits that are admitted like set point by the system, in the Figure 7 is show the response of the controller with the set point in 50°C, the control actions that were executed and the graph of the error through time can be observed [34]. Likewise, the time response graphs of the developed controllers are implemented through the Python language, extracting the data obtained from the experiments and analyzing them independently. This represents an alternative for the analysis in the development of this type of controllers using open source.

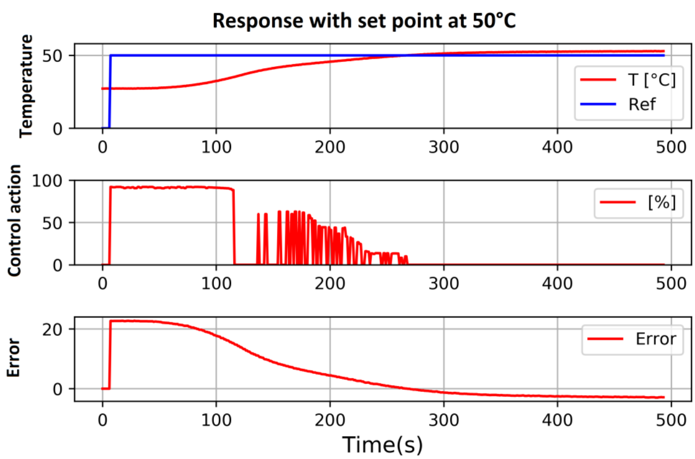

Figure 7: Controller response with 50°C reference.

In addition of the temperature and error graphs, the graph of the control action is shown, from this action an ON-OFF behavior is observed which decreases the self-heating effect of the RTD PT100 and is consistent with the rule base, modeled the parameters that are extracted from this 50 degree test are shown in the Figure 8.

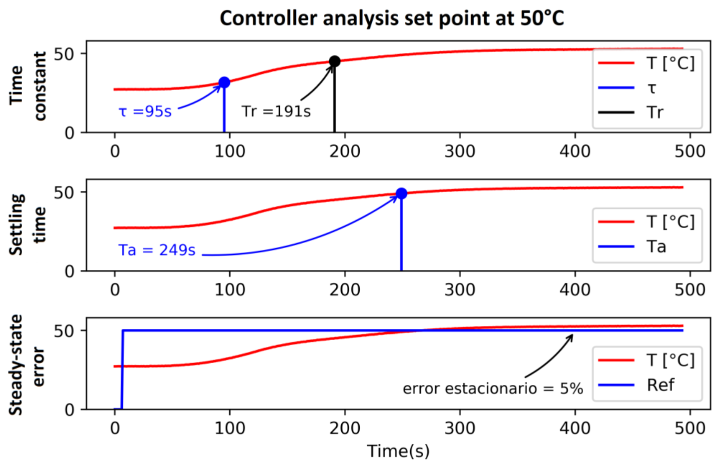

Figure 8: Analysis of controller parameters with 50°C reference.

For a reference of 50°C the following results are obtained: a time constant (τ) of 95 sec this is the value at which 63.2% of the set point is reached, a lifting time (Tr) of 191 sec this is the time it takes the system to reach 90% of its final value, a settling time (Ta) of 249 sec this is the time in which the temperature stabilizes in a range of [2 to 5]% of the set point and a permanent state error of 5.5% maximum recorded value in the settling time.

Figure 9 shows the output obtained when applying a reference of 100°C, this data collection has 30 seconds of sampling before activating the controller, therefore this time will be subtracted when calculating the parameters of the controller.

In addition of the temperature and error graphs, the control action graph is shown, where it can be seen that after a certain time the temperature in the oven decreases from the set point and the controller sends a low output on the actuator to hold the temperature, the parameters that are extracted from this test of 100°C are shown in the Figure 10.

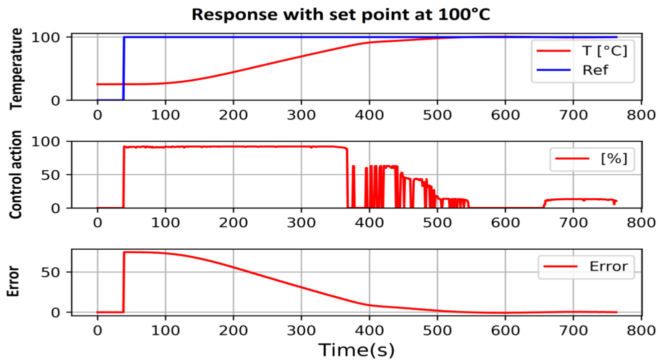

Figure 9: Controller response with 100°C reference.

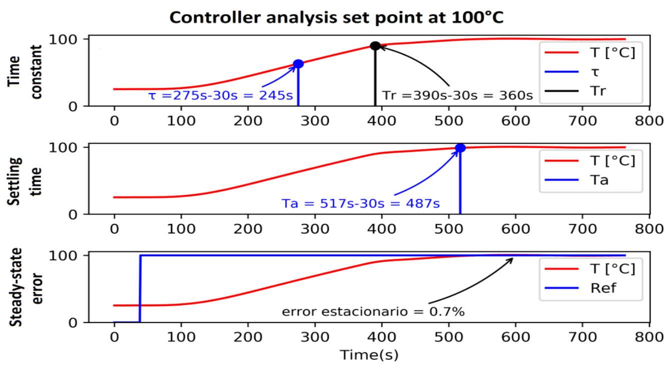

Figure 10: Analysis of controller parameters with 100°C reference.

For a reference of 100°C the following results are obtained: a time constant (τ) of 245 sec this is the value at which 63.2% of the set point is reached, a rise time (Tr) of 360 sec this is the time it takes the system to reach 90% of its value, a settling time (Ta) of 517 sec this is the time in which the temperature stabilizes in a range of [2 to 5]% of the set point and a permanent state error of 0.7% maximum recorded value at the settling time.

The Figure 11 shows the output obtained by applying a reference of 150°C, like the previous data collection, this has 30 seconds of sampling time before activating the controller, therefore this time will be subtracted when calculating the controller parameters.

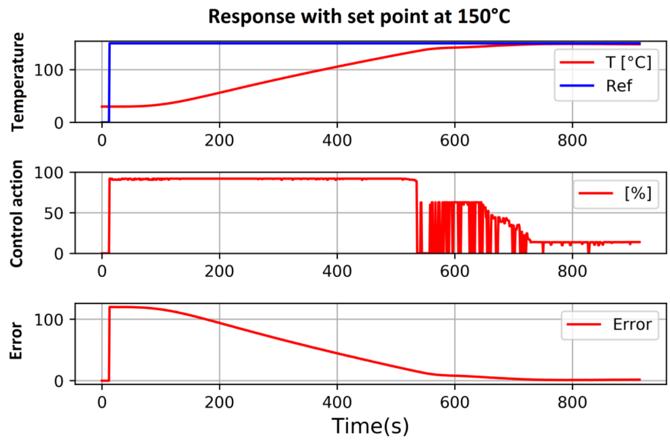

Figure 11: Controller response with 150°C reference.

The graph of the control action is also shown, from this graph it can be seen that, in addition to its ON-OFF operation, when it reaches its reference point, the control action never decreases to zero and a constant low output is maintained, which prevents the system from cooling down, the parameters that are extracted from this 150 degree test are show in the Figure 12.

For a reference of 150°C the following results are obtained: a time constant (τ) of 324 sec this is the value at which 63.2% of the set point is reached, a lifting time (Tr) of 505 sec this is the time it takes the system to reach 90% of its value, a settling time (Ta) of 697 sec this is the time in which the temperature stabilizes in a range of [2 to 5]% of the set point and a permanent state error of 0.7% maximum recorded value in the settling time.

Table 4 is constructed from the above experiments, comparing the behavior of the controller with the different system inputs.

The controller for low temperatures presents a higher degree of stationary error, while for higher temperatures this effect is notably reduced, when comparing the time constant (τ) with respect to the percentage of the settling time it can be seen that at 50°C the best time was obtained with 38.15% of Ta, when comparing the rise time (Tr) the difference between

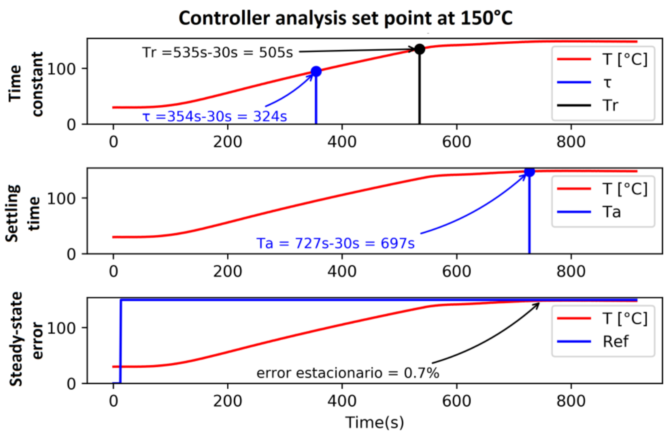

Figure 12: Analysis of controller parameters with 150°C reference.

Table 4: Temperature controller performance comparison

Set point	T(seg)	% Ta	Tr(seg)	%Ta	Ta(seg)	Error
50°C	95	38.15	191	76.71	249	5.5%
100°C	245	50.31	360	73.92	487	0.7%
150°C	324	46.48	505	72.45	697	0.7%

controllers is minimal for the references of 100°C and 150°C and for the reference of 50°C is obtained a little bit more time, finally for the control action its behaviour is ON-OFF in all cases, for the reference of 150°C the actuator keeps its activation with low constant power to hold the set point, for the reference of 100°C the actuator works alternatively between off and on at low power once the set point is reached and in the case of 50°C there is no control action after reached the set point.

For the pneumatic controller, the time it takes to change the variable following the setpoint is evaluated, so two tests were made in this way, the first is made with the pressure already at its maximum and the second by turning on the compressor at the same time as the controller. the control actions that were executed with the compressor on, in addition to the graph of the error through time are show in Figure 13.

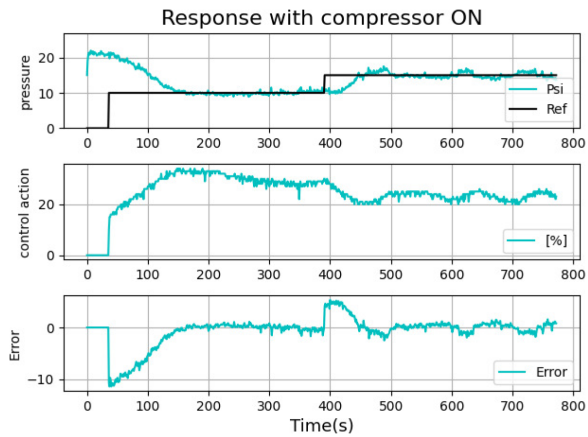

Figure 13: Controller response with compressor on.

The settling times for the controller with compressor on are show in Figure 14, for the first reference of 10 Psi the controller takes 111 seconds to stabilize the pressure (t1), after this a change of reference to 15 Psi is applied, the time of this is calculated from the change of set point therefore its value will be of t3-t2 that is 106 seconds.

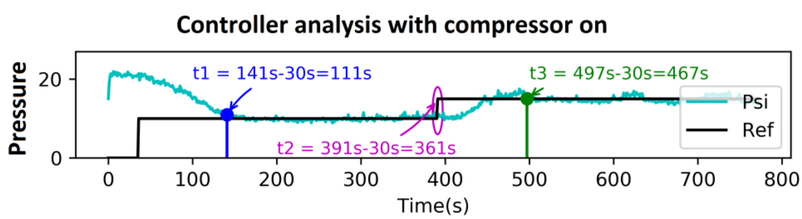

Figure 14: Settling times with compressor on.

In the second test the compressor is turned on at the same time as the controller is activated, the result is show in the Figure 15.

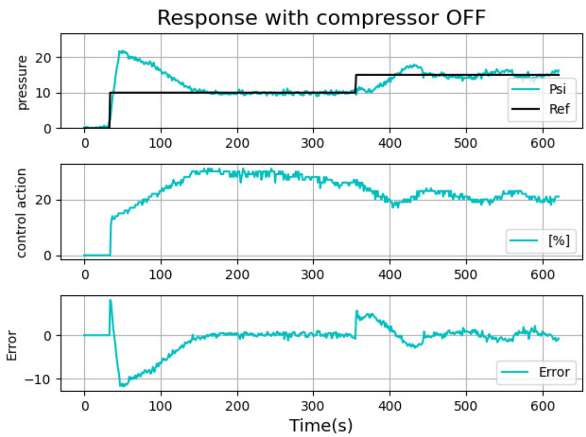

Figure 15: Controller response with compressor off.

The settling times for the controller are show in the Figure 16, for the first reference of 10 Psi the controller takes 116 seconds to stabilize the pressure (t1), after this a change of reference to 15 Psi is applied, the time of this is calculated from the change of set point therefore its value will be of t3-t2 that is 88 seconds.

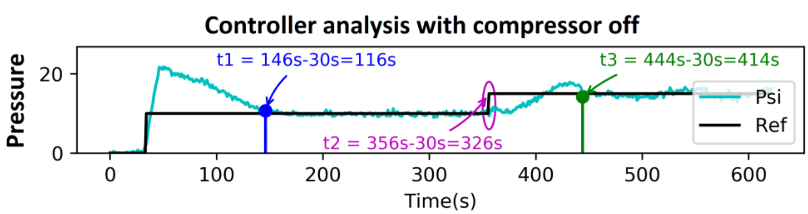

Figure 16: Settling times with compressor off.

Table 5 is constructed from the above experiments, comparing the behaviour of the controllers when compressor start on or off at the same time of controller is activated. When comparing the first reference at 10 Psi, the results obtained have a difference of 116sec-111sec = 5sec, and therefore cannot be attributed to the compressor being turned OFF, this is due to the fact that the compressor is oversized in the reservoir tank and full its pressure at a higher speed than the changes made by the controller.

Table 5: Pneumatic controller performance comparison

Compresor	Set point	Tiempo estabilización
Encendido	10 Psi	111 seg
	15 Psi	106 seg
Apagado	10 Psi	116 seg
	15 Psi	88 seg

The control action in both experiments shows a triangular outlet behavior where the control action on the valve is to open and close it in a cyclic manner to keep the internal pressure level adjusted by releasing or increasing it as required, this being consistent with the rule base that regulates the system.

4 Conclusions

For the temperature controller, it can be concluded that the controller at 50 °C obtains a better time constant(τ) with a value of 38.15% settling time compared to the references of [100 and 150]°C with [50.31 and 46. 48]% settling time respectively, this is mainly due to the fact that the temperature at which the system starts is that of the environment, for the rise times the best results are obtained at [100 and 150]°C, with [73.92 and 72.45]%Ta respectively while at 50°C 76.71% settling time was obtained, the permanent state error obtained is 0.7% for the references of [100 and 150]°C while at 50°C it is 5.5%, this high margin of error is due to the fact that the rules that manipulate the temperature when the error is close to zero are the same in all cases and a control action that affects little a high temperature if it has a greater effect at low temperatures, in addition to this the control signal always works in ON-OFF mode with a frequency of 2 s which allows changes to be generated in the system without overheats that make exceed the target temperature.

The experiments with the pneumatic system show that the compressor is over-dimensioned for the reservoir tank since its speed to full the pressure is higher than the speed of the control system since its changes are of 0.1% in the opening of the valve, in a first reference of 10 Psi a difference of 5 s was obtained, for the second reference an instability of the controller was generated with an overshoot of 13% that caused a time difference of 18 s for the controller, the control signal presents a triangular behavior that opens and closes the valve as the pressure is stabilized.

The fuzzy control algorithms have the advantage that they are easily alterable, can be modified to gain precision by including more groups in a universe which increases the sensitivity of the controller, likewise, the programming of the system when being oriented to objects and in the Python language allows changing values in each component which gives maintainability to the code to reuse it, be tested and modified individually.

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