DESIGN AND IMPLEMENTATION OF A PROTOTYPE FOR NEONATAL INTENSIVE CARE INCUBATOR WITH FUZZY CONTROLLER

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ABSTRACT

The project involves the design and implementation of an intensive care incubator prototype that has a control system embedded in a microcontroller based on the technique of fuzzy logic, capable of maintaining the temperature of the newborn through two operation ways: baby and air. Similarly, it controls the humidity of the chamber according to the gestational age of the patient. The prototype also come with a piece of software developed in Lab View 2010, with which vital variables of the patient are monitored in real-time, that is to say, skin temperature, ambient temperature, humidity, oxygen saturation in the blood and heart rate, using for this, the Zig Bee communication protocol, chosen for its easy implementation and connectivity, and communicates wirelessly with the incubator station. The system has a set of alarms displayed in the main panel of the computer and monitoring software, which works visually and will sound in the event of failures as disconnection of sensor, over temperature, controller failure or supply failure.

Keywords: lab view, prototype, zig bee, fuzzy control, humidity, temperature.

1. INTRODUCTION

The figures are currently in terms of the rate of deaths in newborns, show that four million newborns die each year worldwide, the vast majority in countries without resources and 28% of these deaths are premature. Globally, about 12.9 million babies were born preterm and more than one million infants die in the year for the same reason (World Health Organization, 2005).

In Colombia, more than 130, 000 children are born prematurely each year. In 2008, out of 714, 477 births reported in the country, 18% (130, 932) were premature. 74 babies of 22 weeks or less; 2523 between 22 and 27 weeks, and 28 to 37 128, 335. (Moncada, 2010).

The department of Huila is not foreign to this reality; the censuses show a national infant mortality rate of 28 per 1000 live births that are perfectly comparable with the local situation, where it recorded 23 cases per 1, 000 live births.

The technological contribution to the solution of this problem shows neonatal intensive care incubators that are becoming more sophisticated, but equally represent high costs for intensive care units in remote villages where resources are limited. Among the top brands are Draguer, Fanem, Ohmeda, among others. These teams have servo controls for temperature and humidity; have ergonomic systems for patient comfort and sets alarms that warn the medical staff for any eventuality. Despite high technologies are driving costs too high and always necessary in-situ monitoring by medical personnel.

This project focused on the design and implementation of a prototype of intensive care incubator low cost, using a fuzzy control system of temperature and humidity in two modes: drink and air. It is designed and implemented with double wall technology, in order to mitigate potential losses by evaporation and an aluminum and acrylic mount according to the standards set by international standards.

It also has a wireless communication system that connects the computer with a monitoring station in real time through an application made in lab view, where the controlled variables are displayed and the alarm signals in case of any eventuality. Besides this application has been reported with a database in Microsoft Access, where personal data are stored shift patient and monitored variables.

2. METHODOLOGY

2.1. Structural design INELUS

Given the objectives of the project, the first phases corresponded to the design of an intensive care incubator and then make the appropriate implementation. Technical standards were taken into account, from which one can distinguish the following modules as structural key parts of an incubator: Dome Set, Bed Set, Main Module, or Electronic Control Module and Base Module (National Center Health Technology Excellence, CENETEC, 2004).

They design the structure of the incubator with each of the modules for using industrial design software Solid Edge ST3.

The dome is formed by an acrylic double wall, i.e. the air inside the dome recirculated between two walls, a thickness of 3 mm and a 6 mm, so that there is a better transfer and heat maintenance in the patient, besides there is a better isolation of the medium, mitigating heat losses by convection and irradiation.

The dome also has six gates that serves as access for medical personnel. The bed is the resting place of the patient, which has a lift system with a range of 0-5 degrees and is made of anti-allergic material.

In the central module of the device we find the air circulation system, air filters, and control module are located the airflow sensors, heater and humidifier system.

Finally in the base module we find the accessories support, the movement system and the lifting system. The accessories carrier is simple, made of stainless steel. The motion system is based on four-wheel anti-static and anti-explosive materials that provide ease of movement and safety to the equipment and the patient.

The overall design of the device (Figure-1) is constituted by each of the aforementioned modules, implemented according to the design made individually for each of the aforementioned modules. It was taken into account materials that meet technical standards and also that manufacturing costs were as low as possible.

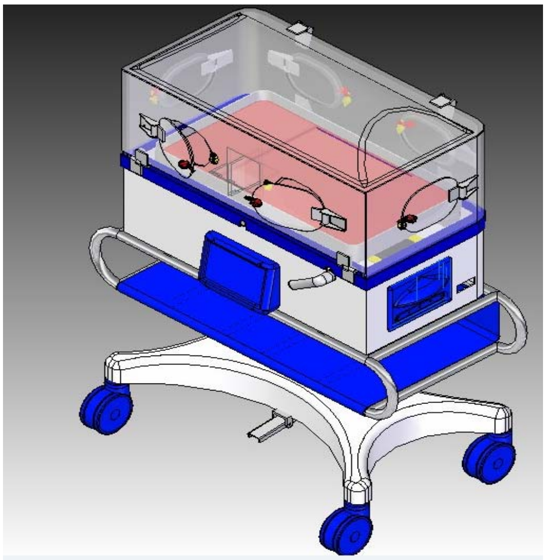

Figure-1. Total assembly.

2.2. Description of hardware

Since the system must perform the acquisition of the signals, performing fuzzy control of temperature and humidity simultaneously calculate the percentage of oxygen saturation in the patient receiving operator commands, display of the state variables in real time and transmit information to a remote station; was designed an electronic control card (Figure-2), which is divided into modules after performing some tests showed that a single microcontroller could not perform all tasks required by the system, due to the memory capacity and processing speed. Besides the amount of inputs required for the acquisition of all signals and outputs from the system response. The main modules are the acquisition and control module, the oximetry module pulse and the module responsible for the alarms, which communicate with each other via communication protocol USART.

Each of these modules comprises a microcontroller, selected according to the complexity of the operation.

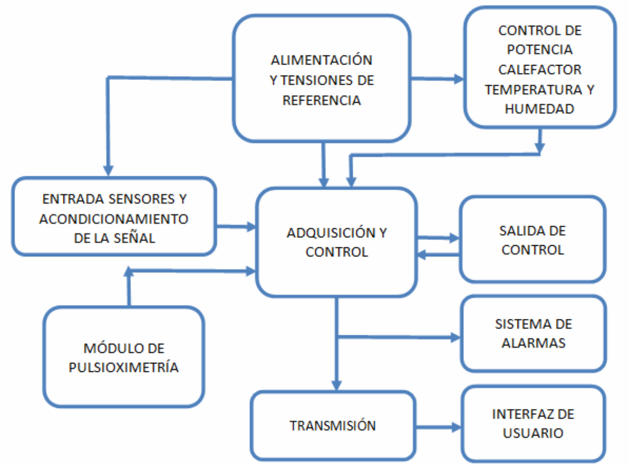

Figure-2. INELUS hardware.

2.2.1. Sensors and signal conditioning

The sensors are involved skin temperature sensor, an air temperature sensor, a humidity sensor HIH 4000-002, a pulse oximetry sensor and a sensor to detect air flow.

The skin temperature sensors (Figure-3) and air temperature (Figure-4), corresponding to NTC thermistors, which have a high sensitivity, making them ideal for such applications where high accuracy is needed in measure, however not lineal (Potter, 1996).

The skin temperature sensor has a resistance at 25 °C. 2.2KΩ To condition the signal division is performed to the output voltage of the sensor signal and is sent directly to the microcontroller where Steinhart modeled Hart, reading is performed that changes according to temperature variation in the resistance of the thermistor.

The air temperature sensor has a resistance of 30KΩ at 25°C. The conditioning was conducted in the same manner as in the case of skin temperature sensor.

Figure-3. Skin temperature sensor.

Figure-4. Air temperature sensor.

The HIH 4000-002 humidity sensor (Figure-5) provides a voltage signal which varies with changes in the ambient relative humidity. On the recommendation of the manufacturer has an op-amp follower configuration for the respective coupling impedance and signal is sent to the microcontroller via where the characteristic equation is given where the producer acquires the exact data of the variable. It was selected for its high degree of accuracy, linear voltage output, fast response time, supply voltage between 4 and 5.8 volts DC and an operating range of relative humidity from 0 to 100% within a temperature range of - 40°C to 85°C, which is adjusted to the range of operation temperature of the project.

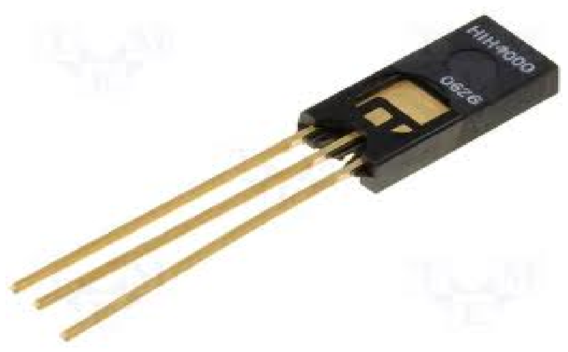

Figure-5. Relative humidity sensor HIH 4000-002.

The air flow sensor detects temperature changes and indicates when the engine is malfunctioning, causing an alarm of the highest priority. It has been used as air flow sensor hot wire anemometer, which is comprised within two NTC thermistors.

For conditioning a comparator circuit with hysteresis inverter has been used. The hysteresis of the comparator is 200mV (Coughlin and Driscoll, 1993). This constantly compares the signals of the two thermistors, so that when the temperature of the thermistor wire is heated above the thermistor very cold wire, to obtain a voltage output indicating the engine failure.

For the acquisition of the signal pulse oximetry was opted the use of neonatal pulse oximetry sensor provided by LIFMED. Type Y (Figure-6), with 6-pin connector Redel (Figure-7).

Figure-6. Pulse oximetry sensor type Y.

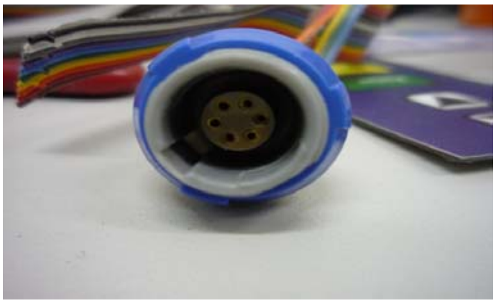

Figure-7. 6-pin Redel connector.

For this signal conditioning circuit conditioning designed (Figure-8), comprising a step of converting current to voltage, a sample and hold stage, a bandpass filter stage with a cutoff frequency of 0.5Hz and 5Hz and a final amplifier stage, a gain of 29.4. These steps were implemented for two signals at the same time because the sensor provides a signal in the red light spectrum and one in the infrared light spectrum (Laborde, 2004).

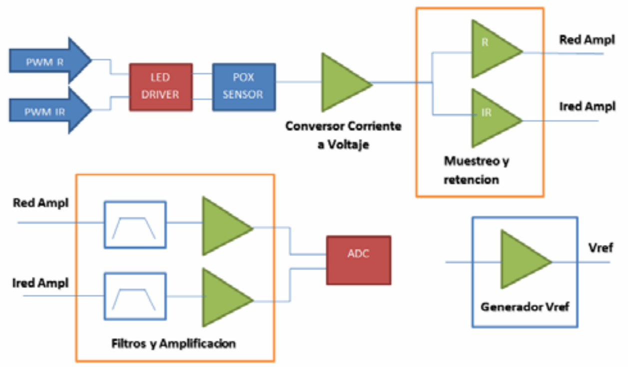

Figure-8. Conditioning circuit pulse oximetry sensor.

The output signal of this stage is sent to the microcontroller in which through an algorithm to calculate the percentage of oxygen saturation in the patient's blood, using the relationship of equation 1.

$$S_pO_2 = 110 - 25 \times R$$

Wherein R corresponds to the ratio of the equation (2).

$$R = \frac{\left(\frac{AC_{rms}600_{nm}}{DC660_{nm}}\right)}{\left(\frac{AC_{rms}940_{nm}}{DC940_{nm}}\right)}$$

2.2.2. Acquisition and control module

For the realization of the fuzzy controller of temperature, the process was the identification of plant using the method of van der Grinten plants as presented behavior (Figure-9) of order one. This system was fed with all the phase, i.e., with a step of 110 VAC. Once the system has stabilized, appropriate measurements were made and from these are determined the corresponding equation system shown in equation (3).

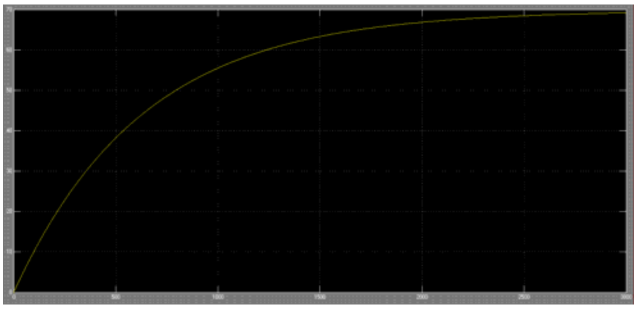

Figure-9. Response time to step.

$$Y = \frac{69.758}{630.26304s + 1}$$

The temperature fuzzy control is implemented with proportional control, since the system behaved ideally with this structure. Was developed following the steps for designing fuzzy controllers, of which take into account the stages of fuzzification, membership functions, the implication, aggregation and desfusificación (Barragán, 2009).

The temperature error corresponds to the input of the system (Figure-10), indicates how far or close is the measure of the required temperature. The output of the system (Figure-11) is composed of three triangular type membership functions as in the inlet. The design was done in Matlab software, college graduate Surcolombiana and using the Fuzzy Logic Toolbox and simulated in Matlab Simulink, considering the characteristic equation of the plant.

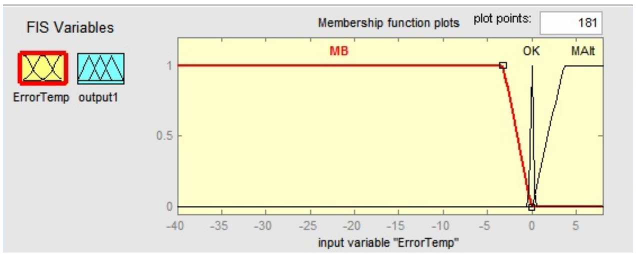

Figure-10. Temperature error.

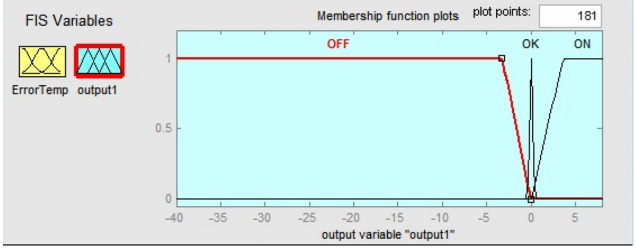

Figure-11. Output temperature fuzzy controller.

In the case of the generation plant relative humidity, the process was conducted with the same method of identification of the plant temperature, however presented a respesta (Figure-12) at the time much slower and with a non-minimum phase behavior. The characteristic equation of the system is shown in Equation 4.

A proportional controller was implemented fuzzy membership functions for Gaussian and triangular ends in the central or ideal input (Figure-13) and output (Figure-14).

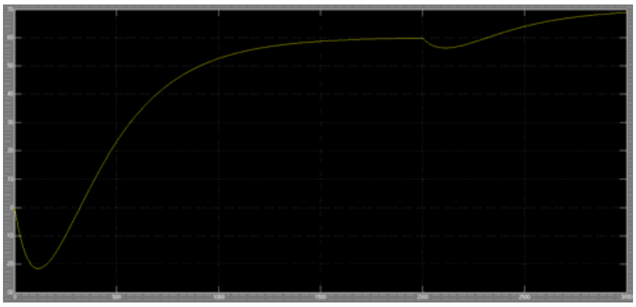

Figure-12. Response time to step.

$$Y = \frac{-23.83\, e^{3}\, s + 79.553}{39.34 e^{3} s^{2} + 430.9 s + 1}$$

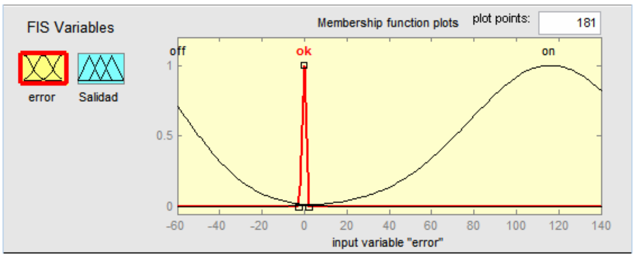

Figure-13. Relative humidity error.

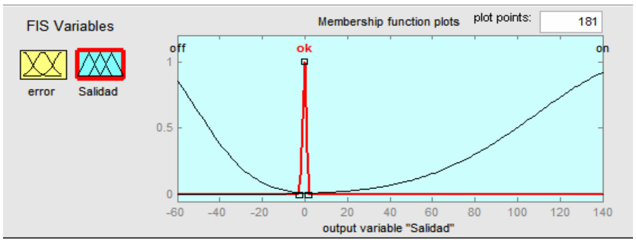

Figure-14. Relative humidity output controller.

The implementation was done using a microcontroller dsPIC 30F4013, which receives the signals from the conditioning stage and performs these functions with fuzzy control of temperature and humidity. Also sent through the protocol 18F4550 microcontroller USART to the actual data of the variables involved in the process, to make it through a graphic display allowing the medical staff to observe the evolution of the process.

2.2.3. User interface module

This module consists of LCD graphic display and a membrane keyboard type, which are managed by a microcontroller 18F4550, through which all data is of interest to the user. Also acquired control data entered by the user via the keyboard and a communication is made by

USART protocol transmission mode with the main microcontroller dsPIC 30F4013. Similarly in this reception mode module receives data from process control to show the user the process data. For any anomaly, gives notice by visual indicators on the front panel.

2.2.4. Communication system

The communication of the incubator with the monitoring station was performed using the ZigBee wireless communication protocol, chosen for its low power consumption, ease of integration, low transmission of data flow and speed up to 250 Kbps Xbee device was used (Figure-15), which is compatible with standard or IEEE 802.15.4 ZigBee communication.

Figure-15. Xbee.

2.3. Monitoring software

The monitoring software (Figure-16), allows a continuous remote knowledge of the state of the various sensors.

Since the project is in a group of research in new technologies Surcolombiana University, the software is designed in LabVIEW 2010, which is licensed by the university, is a graphical programming language that provides the user with a friendly interface and clear the data collected in real time. Besides commercial distribution if it is possible to have an executable file on any computer with a very low cost.

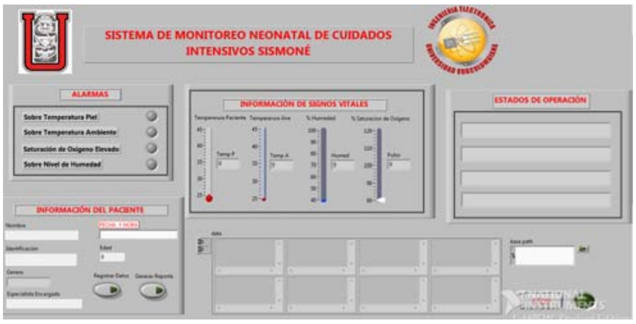

Figure-16. Monitoring software SISMONÉ.

3. RESULTS

For fuzzy structure implemented in temperature plant trials were conducted membership functions in the input and output, involving proportional, derivative and the mixture of both, using Gaussian and triangular functions. Table-1 shows the structures tested to find the best fit to the plant.

Box 1. Actions plant temperature control.

Table-1.

Action	Membership functions at the input	Membership functions in the output	Error
Proportional-derivative	Five triangular functions	Five triangular functions	0.3
Proportional-derivative	Three triangular functions	Three triangular functions	0.3
Proportional-derivative	Five triangular functions	Five triangular functions	1
Proportional	Five triangular functions	Five triangular functions	0.2
Proportional	Five triangular functions	Five triangular functions	2.1
Proportional	Three triangular functions	Three triangular functions	0

Table-1 was implemented with proportional action structure with three membership functions at the input and output. The diffuse surface of this system is shown in Figure-17 and the time response of the plant of Figure-18.

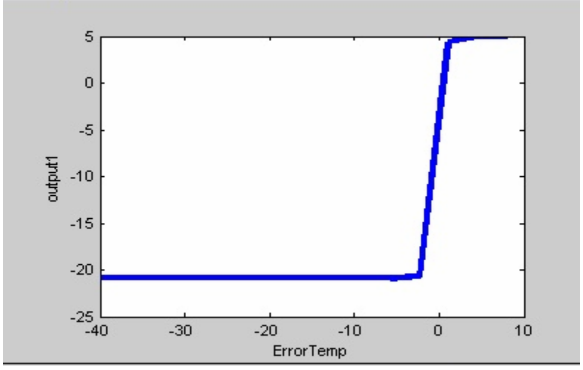

Figure-17. Diffuse surface proportional controller.

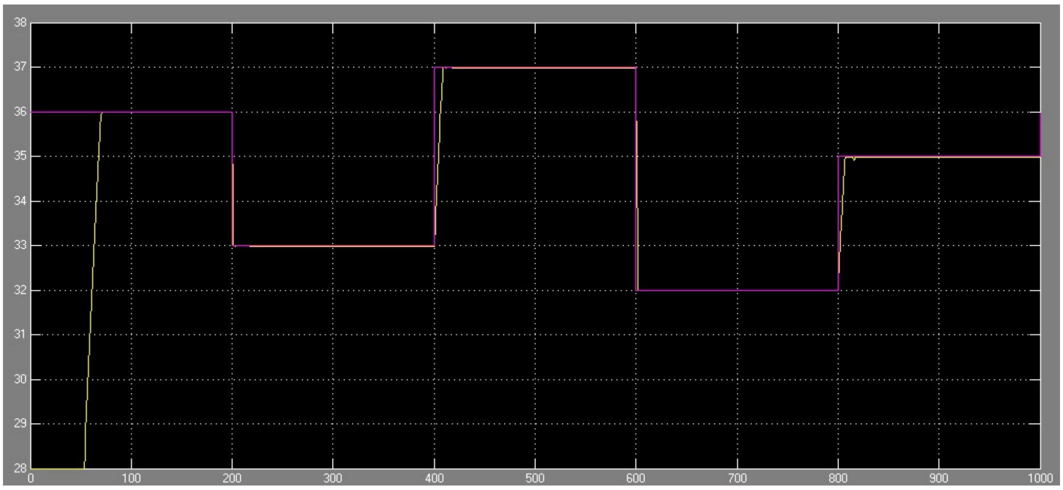

Figure-18. Response time proportional controller.

Table-2 shows the structures tested in the case of fuzzy controller RH.

Table-2. Plant control actions relative humidity.

Action	Membership functions at the input	Membership functions in the output	Error
Proporcional-derivative	Two Gaussian functions and a triangular	Two Gaussian functions and one triangular five triangular functions	0.2
Proportional	Two Gaussian functions and a triangular	Two Gaussian functions and a triangular	0.2

From Table-2 the structure was implemented with proportional action with two Gaussian membership functions and a triangular input and output, since for this system the derivative action made no impact, and required greater complexity in implementation and greater computational cost. The diffuse surface of this system is shown in Figure-19 and the time response of the plant of Figure-20.

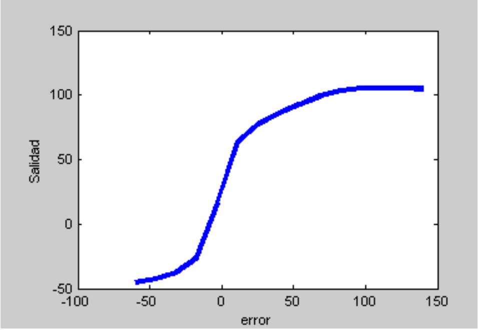

Figure-19. Diffuse surface humidity controller.

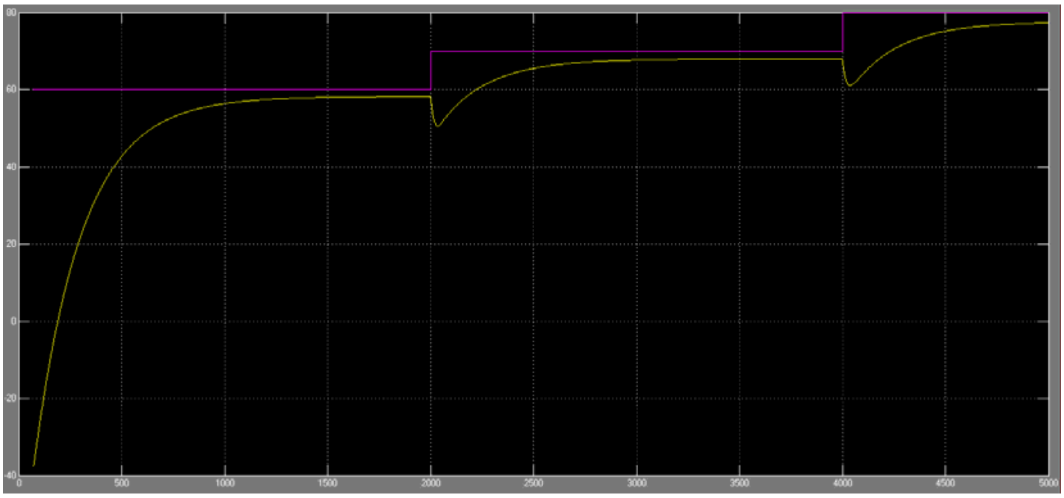

Figure-20. Response time humidity controller.

In practice, once the microcontroller implementation, the behavior of the variables measured by the sensors, taking into account a possible disturbance in the system. The results of this process are shown in figures 21, 22, 23, 24, 25 and 26.

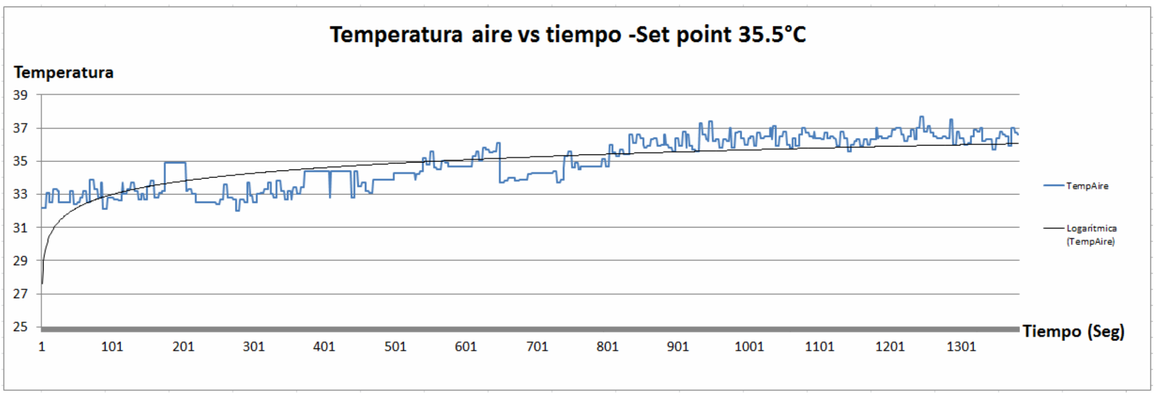

Figure-21. Air temperature vs. time - 35.5°C setpoint.

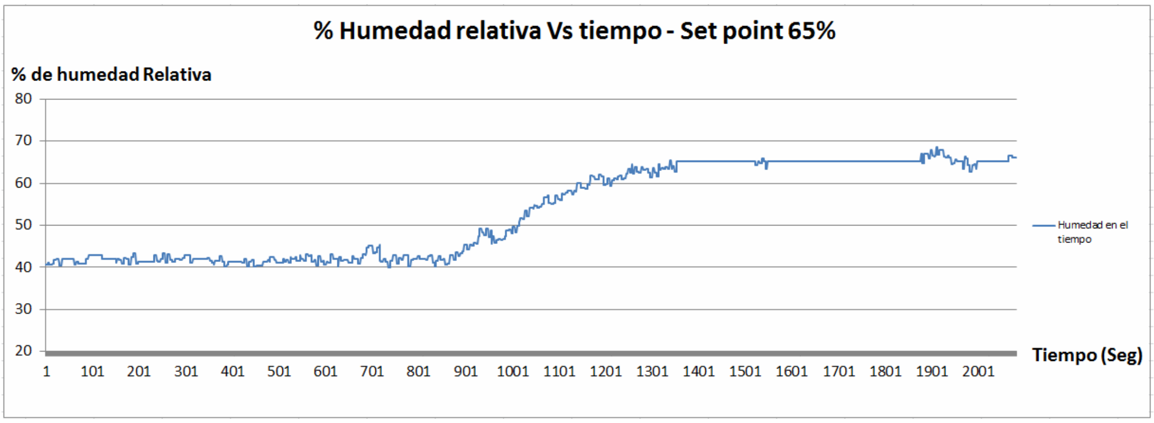

Figure-22. % RH vs. time - set point 65%.

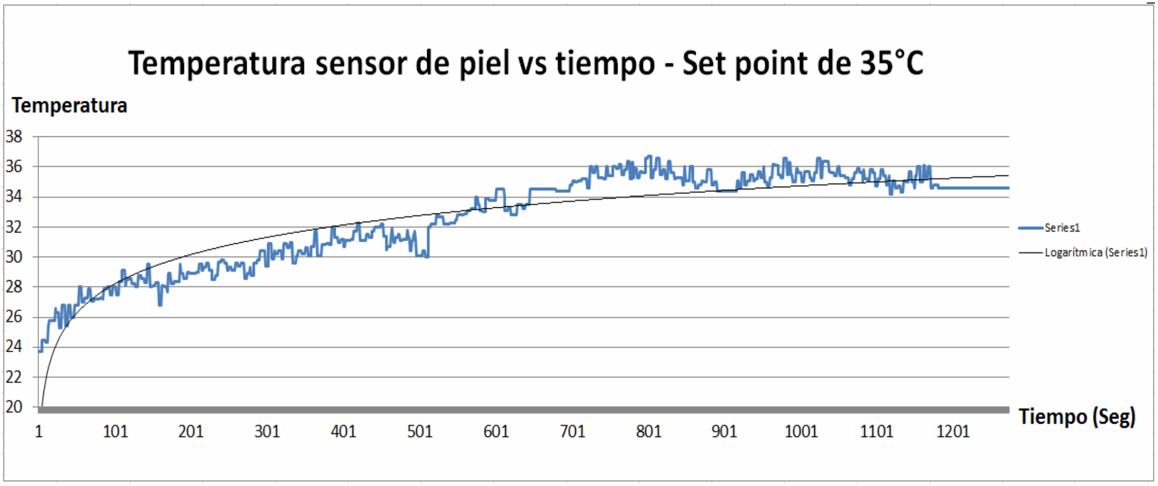

Figure-23. Skin temperature sensor vs time - 35°C setpoint.

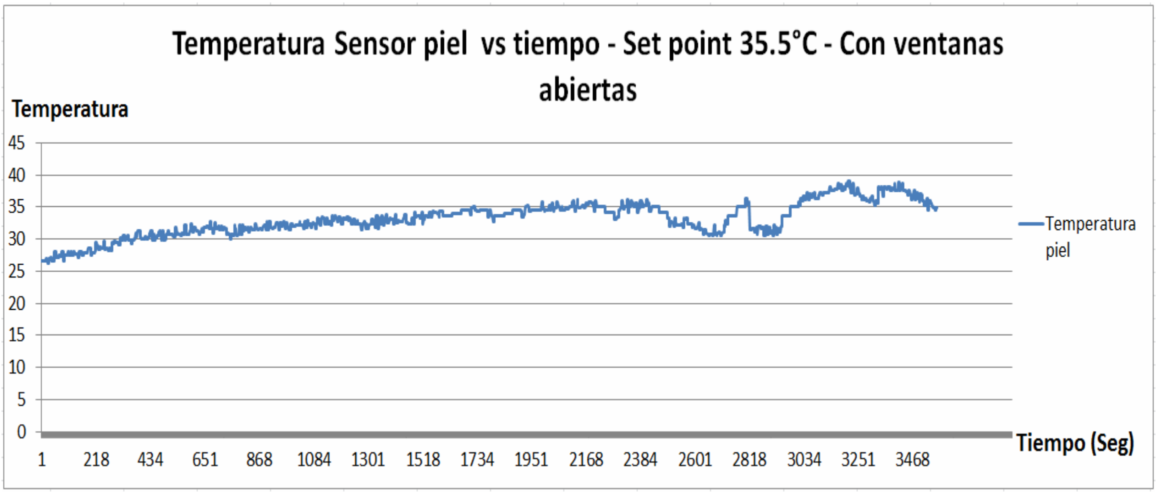

Figure-24. Skin temperature sensor vs time - set point 35°C - open windows.

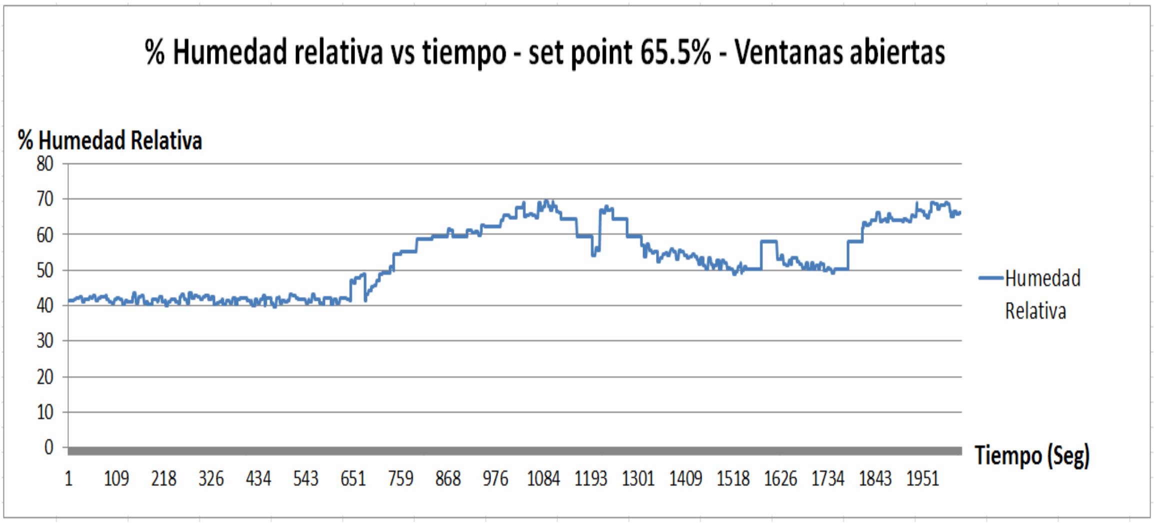

Figure-25. % RH vs. time - 65% set point - open windows.

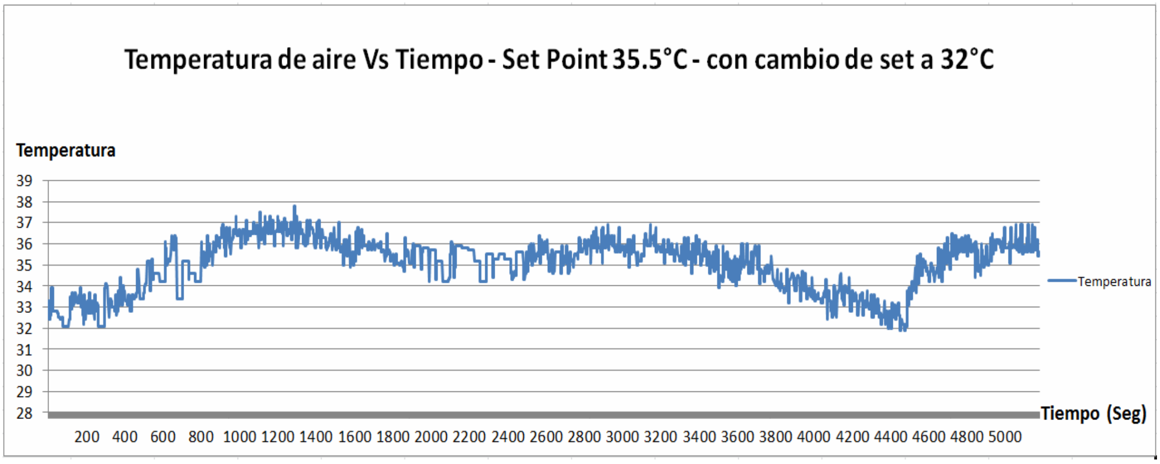

Figure-26. Air temperature vs. time - setpoint 35.5 ° C - with set change to 32°C.

Made conditioning pulse oximetry signal was obtained plestimográfica wave shown in Figure-27. In this case the inverted signal.

Figure-27. Plestimographic wave.

The proposed design implementation resulted INELUS the incubator shown in Figure-28, which has all the required modules and a fuzzy control system for humidity and temperature variables, as well as a pulse oximeter module linked to the computer.

Figure-28. Incubator INELUS.

Finally, after performing the integration of all systems and subsystems electronic level concludes with an acquisition and control card (Figure-29), with which the incubator holds all the tasks.

Figure-29. Acquisition and control final electronic card.

4. CONCLUSIONS

- New technology fuzzy control is presented as an alternative rather than a replacement of the existing classical control techniques. Since in many applications where the system is complex, it is difficult to obtain a mathematical model or when the model requires the expertise of the process, the use of fuzzy control becomes highly relevant.
- Designed and implemented the proposed incubator prototype meeting the requirements required for the manufacture of such equipment. Given a budget that does not affect the quality of the result.
- The use of wireless communication through ZIGBEE protocol provides operator comfort, which you can view in real time the status of the team. At present this type of equipment does not have the module, which is presented as a novelty in these systems.
- Given the characteristics of the system, it was necessary to implement a fuzzy PD controller and that with a single proportional action in the two controlled variables the system responds with good results. So it was only necessary to implement three membership functions at the input and output for the system to respond according to the system requirements.
- Designed and implemented an algorithm to control the temperature and relative humidity, designed under the platform and embedded Matlab dsPIC 30F4013 microcontroller, with which also determined its great potential for the development of mathematical operations that require high precision.
- Involvement was determined that the method developed by Mamdani story is really advantageous not require higher computational cost and is easy to implement in a microcontroller.
- Using dsPIC microcontrollers for the development and implementation of fuzzy controllers in high accuracy applications, provides a great help in the defuzzification process as designed by the center of area method, which gave a reliable performance, its

low computational cost makes it most suitable for implementation in a microcontroller.

- The implementation of a pulse oximetry module in an incubator centralizes much non-invasive monitoring of vital parameters for a patient premature. Ensuring a more consistent and secure monitoring is presented as a new option to deploy commercial equipment.
- The use of monitoring software in LabVIEW 2010 linked to a database for easy access and display information management, allows the operator to access real-time information for possible future research, and can be implemented in equipment commercial use that do not have this.

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