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IMPLEMENTATION OF ARTIFICIAL INTELLIGENCE IN CONTROLLING THE TEMPERATURE OF INDUSTRIAL PANEL

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Abstract: Artificial intelligence has been widely used in various applications such as health and safety, smart homes, greenhouses, and industrial application. It has been increasingly utilized in the industry owing to its benefits in terms of enhancing the overall performance of a given system. This study appeared from a real need in many local industries. In this paper, a prototype system has been implemented for artificial control on the temperature of the industrial panel. The paper includes two control systems executed; classical PID (Proportional Integral Derivative) and fuzzy logic with a comparison between them. Fuzzy control algorithm is developing based on Sugeno method inside PLC (Programmable Logic Controller). The connection of PLC with sensors is used by the Modbus protocol. Arduino UNO and Ethernet shield are used to connect the sensor to the router and then to PLC by Modbus.

Keywords: *PLC, PID, Fuzzy, Modbus.*

1. Introduction

Artificial intelligence is a modern technology to provide large applications in health, environment, transport systems monitoring, and other commercial areas. PLC used by many automation processes in industries to increase quality and reliability and reduce the production cost[1]. In the present, "Fuzzy logic" expected to be the more convenient approach for controlling the industrial processes [2].

The usage of the PID control does not achieve optimal device efficiency or reliability of its operation. Where there are excessive delays, study state error may occur: the measurement of the process value is delayed, or the control action does not apply fast enough. In these cases, compensation from lead-lag is needed for accuracy. The controller's response could be defined in terms of its sensitivity to an error, the extent to which a setpoint is overshot by the device, and the oscillation degree of any system. But the PID controller is widely applicable as it depends only on the measured process variable response, not on the underlying process knowledge or model [3].

The word "fuzzy logic" was invented by scientist Lotfi Zadeh with the 1965 that initiate of Fuzzy set theory[4]. Fuzzy logic is a type of multi-valued or multi level logic in which variable truth values may be any real number between 0 and 1 inclusive of both. It is used to handle the concept of partial truth, where the value of truth can range

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from complete true to complete false.[1] In Boolean logic, on the other hand, the value of truth of variables can be only integer values 0 or 1 [5].

The FLC built method used in this work depends on programming the PLC using Structured Text (ST) language. The used PLC should be equipped with an Ethernet port to achieve communication with the Arduino shield for reading the input sensor. Another important thing must be provided for PLC which is the A/D card in order to convert the digital output of Fuzzy to output of the PLC as shown in the block diagram in Fig.1.

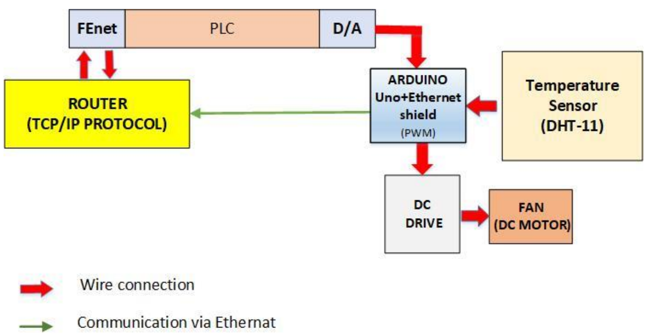


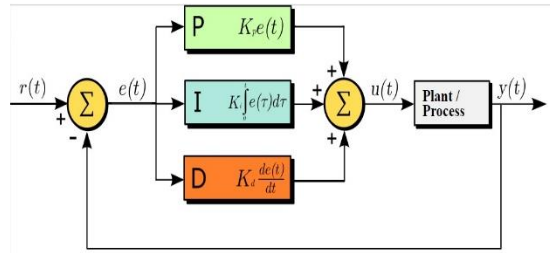
Figure 1. Proposed system block diagram

The temperature has been used as a case study to prove the work of the system. Whereas it is possible to work with any other process such as water level or pressure by making some changes to the settings of fuzzy memberships and Sugeno rulles [4].

The rest of the paper is structured as follows. Section 2 presents the explination for PID controllers. Section 3 explains Fuzzy logic controller system and section 4 describes the design and implementation of the prototype system. Section 5 is to viewing the results and finally section 6 is the concludes and future work.

2. PID Controllers

The PID controller is the device or block that comprise of elements proportional, integral and derivative, is largely used in control of feedback



Figur Error! No text of specified style in document.2. PID structure

for industrial processes. When utilizing PID controllers, it has to design the control system: in such a way, they must be decided first which operation mode to select and then tuning the controller parameters so that their control coefficients are solved suitably. For achieving that target, it will be required to know the process characteristics. As it is the basis for the design procedures, they should have particular criteria to estimate the control system performance. "PID control" is a feedback control method which uses the PID controller as the central tool [3]. The basic formation of traditional feedback control systems is shown in Fig.2, using the block diagram depiction. The process in this figure is the thing to be controlled. The reason for control is to make

the process signal y(t) keep track of the set-point value r(t). To realize this target, the controlled variable u(t) is altered by the governing of the controller.

An example for processes is a heating tank where the heating process for some liquid to reach the desired temperature by increasing the fuel gas burning. The process signal y(t) is the liquid temperature, the flow of the fuel gas is the manipulated signal u(t). The "disturbance" is any factor, other than the manipulated signal, which impacts the processed signal. The error e is formulated by e(t) = r(t) – y(t). The last issue to notice for Fig.2 PID structure is the process signal y(t) supposed to be measured by the sensor that is not shown clearly here with suitable accuracy which regarding as the input to the controller being exactly equal to y(t).

The PID control formula is named in terms of its three component terms, which sum composes the manipulated variable (MV). The proportional, integral, and derivative outputs are gathered to calculate the PID controller output [6]. Specify u(t) as the output of the controller, the final form of PID algorithm is:

$$u(t) = MV(t) = K\rho e(t) + Ki\int_{0}^{t} e(\tau)d\tau + Kd\frac{de(t)}{dt}$$

Where:

Kρ: is the parameter of tuning the proportional gain,

Ki: is the parameter of tuning the integral gain ,

Kd: is the parameter of tuning the derivative ,

E(t) = SP-PV(t) is the error (SP is abbreviation for the set point, and PV(t) is abbreviation for the process variable) ,

t : is the instantaneous time (the present time),

τ : is the integration variable (takes the values from time 0 to the present time).

The above formula is the standard form tuning algorithms for PID controller that most relevant for industry [6]. In this standard form, there is clear physical meaning for parameters. The term proportional error is the present error. The term derivative part attempt to estimate the future error samples (or value), while the integral represents an average of past errors assuming that no altering for the loop control.

3. Fuzzy Logic controller

It represents a branch of artificial intelligence (AI) which transact with thinking algorithms utilized to simulate human reasoning and making the decisions in machines. The fuzzy logic algorithms are used in cases wherever processing data cannot be demonstrated in binary form. For example, "young" and "air cool" cannot represent in binary logic. Where these statements do not show specified data for the age of the person or air temperature (for instance, a 12-year-old boy or air at 18 degrees). Fuzzy logic can interpret such ambiguous statements as logical expressions. In cold air case, PLC (or other controllers) with fuzzy logical abilities interpret both the relationship of coolness to warmth and its level to ensure that "cool" lie in a place between hot and cold. If represent it in binary logic, the hot will be represented by unique separate value (for instance, logic 1) and the cold case will be the other (for instance, logic 0), so it cannot representing the warm temperature [18] (see Fig. 3 (a). Unlike binary logic, the fuzzy logic can be considered a gray logic that expresses in-between values for data levels .

The fuzzy logic associates the level or grade with the range of data (universe of discourse), giving it a minimum of 0 and a maximum of 1. For example, Fig. 3 (b) shows a representation for the temperature range.

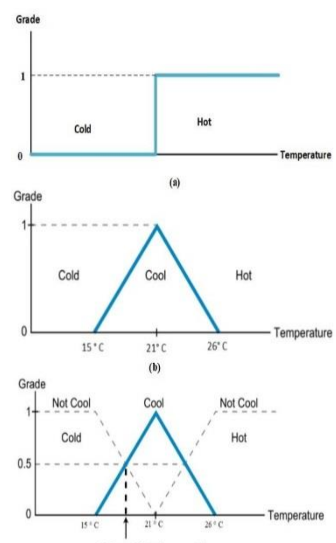


Figure 3. (a) Binary logic demonstration of a separate values of temperature. **(b)** Range of cool air temperature **(c)** dotted lines showing the range not cool

of the cool air, where a temperature of 21 degrees refers to completely cool air (i.e. the value of grade (1)). Any temperature above 26 degrees regarded as hot, and any temperature value below 15 °C is regarded as cold. Consequently, temperatures value less than 15 °C and higher than 26 °C have a cool (0) value, this sense they are at all not cool. Fig. 3 (c) shows another more familiar representation to the range of cool temperature, where the dotted line related that cold and hot temperatures are not cool. At 18 °C, the algorithm of fuzzy logic considers the temperature 50% cool and 50% cold, indicating the level of coolness. While, if the temperature below 15 °C, the algorithm of fuzzy logic is regarded as cold temperature [5]

4. System Implementation

The temperature control considered an industrial system so that more care is needed to provide proper devices for this task. More interesting things to be found in the chosen products are reliability and accuracy. The central controller selected for the framework is from LSIS manufacture, PLC with 12 digital outputs and 16 digital inputs and 2 analog outputs as well as a communication module. As this work would operate in practice, the condition of the analog input or output element can be used for current or voltage, and we make the necessary work arrangement for the industrial facility to protect it from moisture and dust, such as including the instruments in the correct PVC frame. Local control was introduced in the prototype shown in Fig. 4. For the implementation of this control, four digital inputs and three digital outputs and finally, one analog output are used.

There is one 12V power supplies in the panel for DC fan and 24V power supply for PLC. The process in the system is designed by fuzzy control method. The DC-to-DC convertor

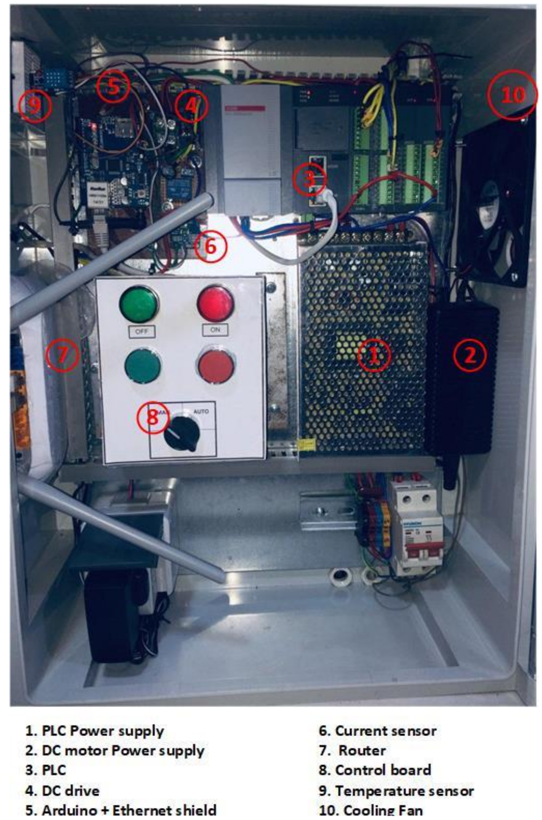


Figure 4. Prototype control panel

working as an interface between PLC process output and electrical motor. Fig. 5 represents the flow chart of the water level control algorithm. The output of PLC (0~5V) is supplied to Arduino analog input A0 which processed by Arduino to obtain PWM at the output. The PWM signal is supplied to DC drive that in turn produce scaled output (0-12V) capable to control the speed of DC fan. This was done by using the mapping statement in C++ code;

Input= Map (ARD Input, 0, 1023, 0, 255);

DC drive the signal of PWM applies directly to the MOSFETs electronic circuit with a maximum capacity of 4A and an output DC voltage of 0 to 12V. For reliable data transmission between sensors and PLC, the Arduino shield is used. To secure the Ethernet connection to the PLC a router device is mounted at the edge of the panel. The PLC is connected to a router and temperature sensor using the MODBUS protocol. To design

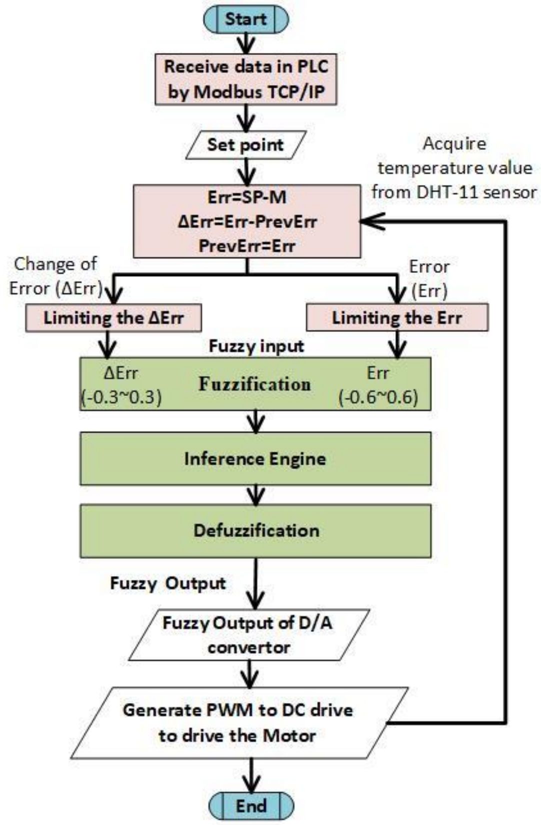


Figure 5. Fuzzy process flow chart

PID controller a PID auto-tuning and PID function blocks have been created in the PLC diagram according to the following setting that obtained by using auto-tuning facility available in the PLC:

Set point=22 C, Cyclic time= 500mSec

The PID parameters are selected based on try and error and they were; Kp=100, Ti= 0.1, Td=20.

Because the actual temperature in the inclosure is higher than the set point, the action of PID controller is selected as the reverse mode.

A fuzzy algorithm with Sugeno rules was developed using (Structure Text) ST to execute the process of fuzzy within the PLC. Seven memberships were selected for both Error (E) and Change of Error (CE) in order to get an accurate and high-performance fuzzy system see Table 1. The rising and falling edges of a timer have been used for taking the sample of temperature and producing the E and CE as a result. The DHT-11 temperature sensor output is used to get the error signal in real-time as below:

E:=Set_Value - Temp_Value

Fig. 6 illustrate the marking of memberships, Error memberships and change of Error (CE).

ENB[1]:=-0.6; ENB[0]:=-0.4;

ENM[0]:=-0.6; ENM[1]:=-0.4; NM[2]:=-0.2;

The above two statements are an example for defining of two membership (NB&NM) of Error. The used fuzzy rules based on the Sugeno approach. The output membership functions of the Sugeno rule, utilized is the singleton. A singleton, or merely a fuzzy singleton, is a fuzzy collection as a membership form that is zero everywhere excluding that unity will be at a specific point in the universe of discourse[7], [8].

The following statements are an example of Sugeno rule programmed in (Structure Text) ST ;

Wi(3,0):=1; Wi(3,1):=0.8; Wi(3,2):=-0.2;

Wi(3,3):=-0.3; Wi(3,4):=-0.4; Wi(3,5):=-0.5; Wi(3,6):=-0.6 ;

Wi' is a matrix abbreviated form named WEIGHT matrix that is assigned to the matrix of two-dimension of the WEIGHT for the inference level. We must write 49 sentences to accommodate all rules as shown in Table.1, which includes 49 rules.

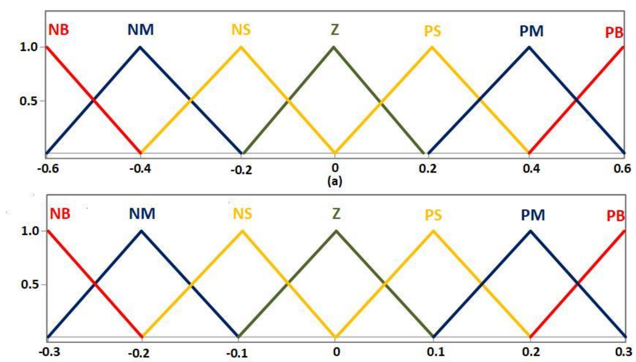


Figure 6. (a) Error **(b)** Change of Error (CE) memberships

Although the signal of error changes over time, it is assumed that "E" will be on any of the member ships of error, so it is important to check the existence of error signal on each member ship and precise value within the member ship.

5. Results and Analysis

Practical tests were conducted to test the competency of both controllers that subjected to research and to come up with a conclusion of which is the most competent dominant in order to be used.

Table (1) Sugeno rules

E / CE	N.B(0)	N.M(1)	N.S(2)	Z(3)	PS(4)	PM(5)	PB(6)
N.B(0)	1	1	1	1	0.9	-0.05	-0.3
N.M(1)	1	1	1	0.9	-0.05	-0.3	-0.6
N.S(2)	1	1	0.9	-0.05	-0.3	-0.6	-0.9
Z(3)	1	0.9	-0.05	-0.3	-0.6	-0.9	-1
PS(4)	0.9	-0.05	-0.3	-0.6	-0.9	-1	-1
PM(5)	-0.05	-0.3	-0.6	-0.9	-1	-1	-1
PB(6)	-0.3	-0.6	-0.9	-1	-1	-1	-1

The room temperature was around 20 °C, while the temperature inside the industrial panel was between 27-35 °C depending on the period of operation of the devices and the extent of their loading.

Fig. 7 shows the temperature change and the Fuzzy Controller's response over time. In this figure, we notice that the blue curve has a maximum value of 12V after making a Scaling for it.

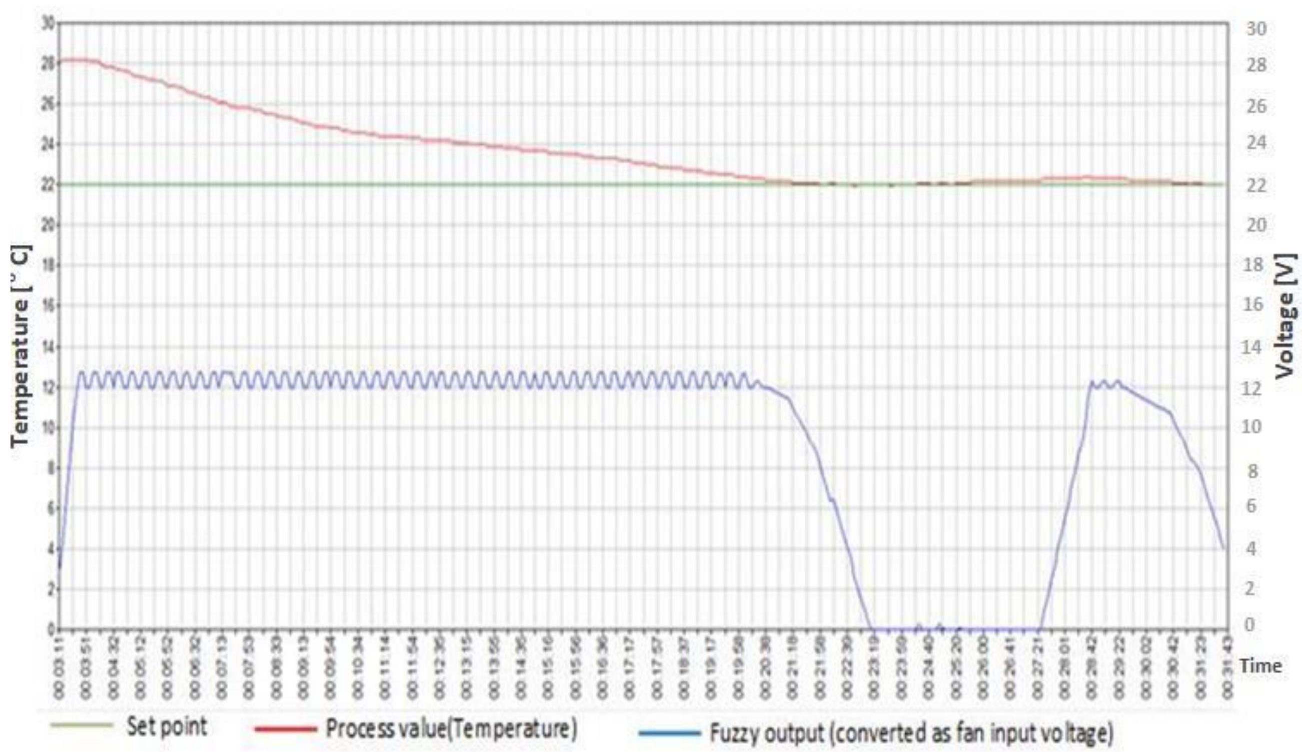


Figure 7. Real photo for variation of temperature and fuzzy response.

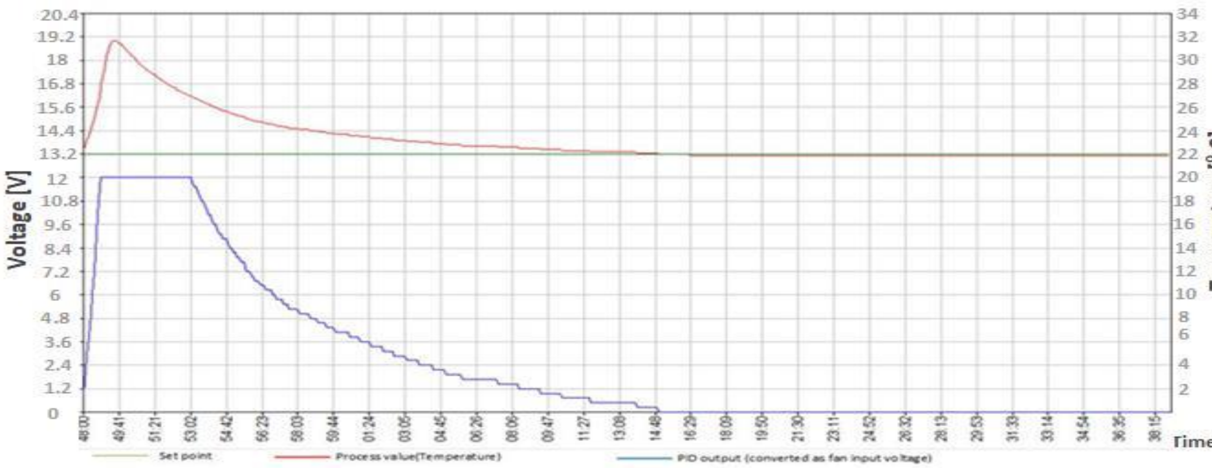


Figure 8. Real photo for variation of temperature and PID response

Fig. 8 represents a real picture of the XG5000 Trend monitor for the PLC, showing the temperature change and the PID Controller response via the D / A module over time. The maximum value that appears for the output of the D / A module is 200 (blue curve), where the real value is 5000mV and scaling has been done to appear consistent to the other curves. Fig. 9 shows a comparison between the response of both PID and Fuzzy Controllers, through which we notice that the Fuzzy has a fast response and a higher accuracy in reaching the set point.

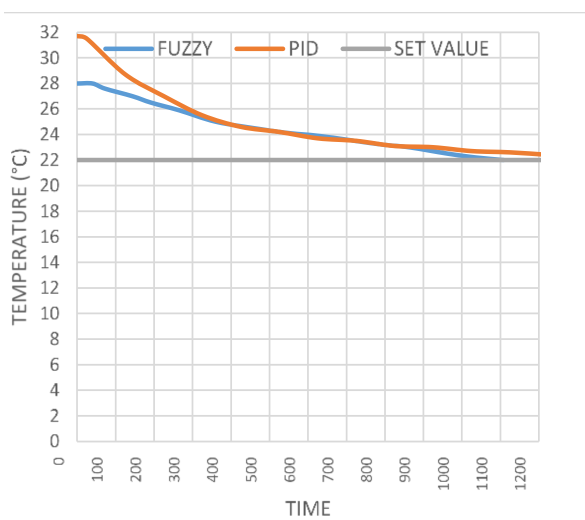


Fig. 9 Comparison between PID and Fuzzy control behavior

Table 2 reveals that the efficiency of Fuzzy is higher than the conventional PID controller. Whereas Fuzzy's settling time, (IAE) Integral

Absolute Error, Integral Time Absolute Error (ITAE), Integral Square Error (ISE) and Integral Time Square Error (ISE) in Fuzzy is less than PID. Therefore, the Fuzzy controller is regarded as the correct choice.

Table 2. comparison between PID and Fuzzy at set value 22 °C.

Controller	Ts (Sec)	IAE	ITAE	ISE	ITSE
PID	1,697	6,910	2,100,750	2,989,350	456,323,750
Fuzzy	1,084	2,749	819,868	694,601	819,868

6. Conclusions

In this work, a prototype industrial control panel was built, and the air temperature inside the board was realized by implementing two types of controls: PID and Fuzzy Controllers.

Practical results have proven that the Fuzzy control system is more efficient and gives accurate and faster results by reaching the setting point than PID control system. In addition to that, the Fuzzy system is characterized by its flexibility in terms of the setting of the Memberships.

When comparing the results obtained in this work with the results in [9], [10] which is somewhat close to our work, we notice that our results are more accurate in both PID and fuzzy controller.

The use of conventional temperature sensors with an industrial controller such as PLC and taking advantage of the using of the Modbus Protocol is of great importance in the research and industrial field alike. It facilitates the process of studying advanced control systems in industrial controllers without resorting to purchasing industrial sensors at high prices let alone not compatible with the research environment. On the other hand, we find that Modbus Protocol can work as a replacement to A / D modules to enter signals into PLC and in some applications driving the output signal. This, in fact, gives us economic feasibility and greater flexibility in transmitting the signal by Ethernet or via wireless.

As future work we can improve the PID control system by using the genetic algorithm for tuning the parameters of PID.

Conflict of interest

There are not conflicts to declare.

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