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# Fuzzy Logic Applied to an Oven Temperature Control System

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**Abstract:** The paper describes the methodology of design and development of fuzzy logic based oven temperature control system. As simple fuzzy logic controller (FLC) structure with an efficient realization and a small rule base that can be easily implemented in existing underwater control systems is proposed. The FLC has been designed using bell-shaped membership function for fuzzification, 49 control rules in its rule base and centre of gravity technique for defuzzification. Analog interface card with 16-bits resolution is designed to achieve higher precision in temperature measurement and control. The experimental results of PID and FLC implemented system are drawn for a step input and presented in a comparative fashion. FLC exhibits fast response and it has got sharp rise time and smooth control over conventional PID controller. The paper scrupulously discusses the hardware and software (developed using 'C' language) features of the system. *Copyright © 2011 IFSA.*

**Keywords:** Fuzzy logic controller, PID, Temperature control, and Computer based control.

## 1. Introduction

The need for temperature control arises in various fields such as medical, biological, undersea, industrial and many times in basic scientific research and R&D laboratories. Many physical and chemical reactions are sensitive to temperature and consequently, temperature control is important in several industrial processes.

In many applications, temperature control plays a key role in many processes; in addition, precision and quality control of temperature (with minimum overshoots and undershoots, fast rise and settling times) is desirable. Classical control theory usually requires a mathematical model for designing the controller [1-4]. Inaccurate mathematical modeling of the plants usually degrades the performance of the controller, especially for nonlinear and complex control problems. Hence the process needs an alternative control mechanism that assures precision and quality control for even non linear and time varying systems. Recently, the advent of the fuzzy logic controllers (FLCs) has inspired new resources for the possible realization of better and more efficient control [5-7]. Fuzzy control offers a key advantage over traditional adaptive control systems. Fuzzy control which is based on human expert decision making do not require mathematical model of the plants and is dominant for process control applications [8-15]. Hence the paper thoroughly discusses application of fuzzy logic for an oven temperature control system.

## 2. Measurement Instrumentation

The block diagram of computer based fuzzy logic temperature control system is presented in Fig. 1. An oven with the following specifications (specifications are mentioned in Table 1) is employed for the present investigation.

**Table 1.** Specifications of the Oven.

| Description | Value |
|---|---|
| Watt | 25 W |
| Temperature Range | 0 - 90° C |
| Weight | 200 g |
| Heater Coil Resistance | 40 Ω |

The hardware flow of temperature measurement consists of temperature sensor along with constant current source, instrumentation amplifier, analog to digital converter, digital input output and timer card, and personal computer. A temperature sensor PT100 (specifications are mentioned in Table 2) excited by a constant current source senses the temperature of oven. PT100, connected in feedback path of an op amp, converts the change in temperature into change in voltage [15]. This small proportional differential voltage is suitably amplified by a signal conditioner and converted into equivalent digital data by a 16-bit A/D converter AD 976, which is interfaced to the computer. Computer acquires digital data from A/D converter, calculates the actual temperature using the following curve fitted equation, and displays it on the monitor in terms of degree Celsius.

$$\text{Temperature 'T' in °C} = ((V_T/V_o) - 1)/\alpha,$$

where, $V_T$ is the voltage acquired by the computer at temperature 'T', $V_o$ is the voltage at zero temperature, and '$\alpha$' is the resistance coefficient given as 0.00385 Ω/Ω/°C.

**Table 2.** Specifications of the PT100.

| Description | Value |
|---|---|
| Resolution | ±0.01°C |
| Range | -182.96 °C to 630.74 °C |
| Resistance Coefficient (α) | 0.00385 Ω/Ω/°C |
| Linearity | Highly linear |

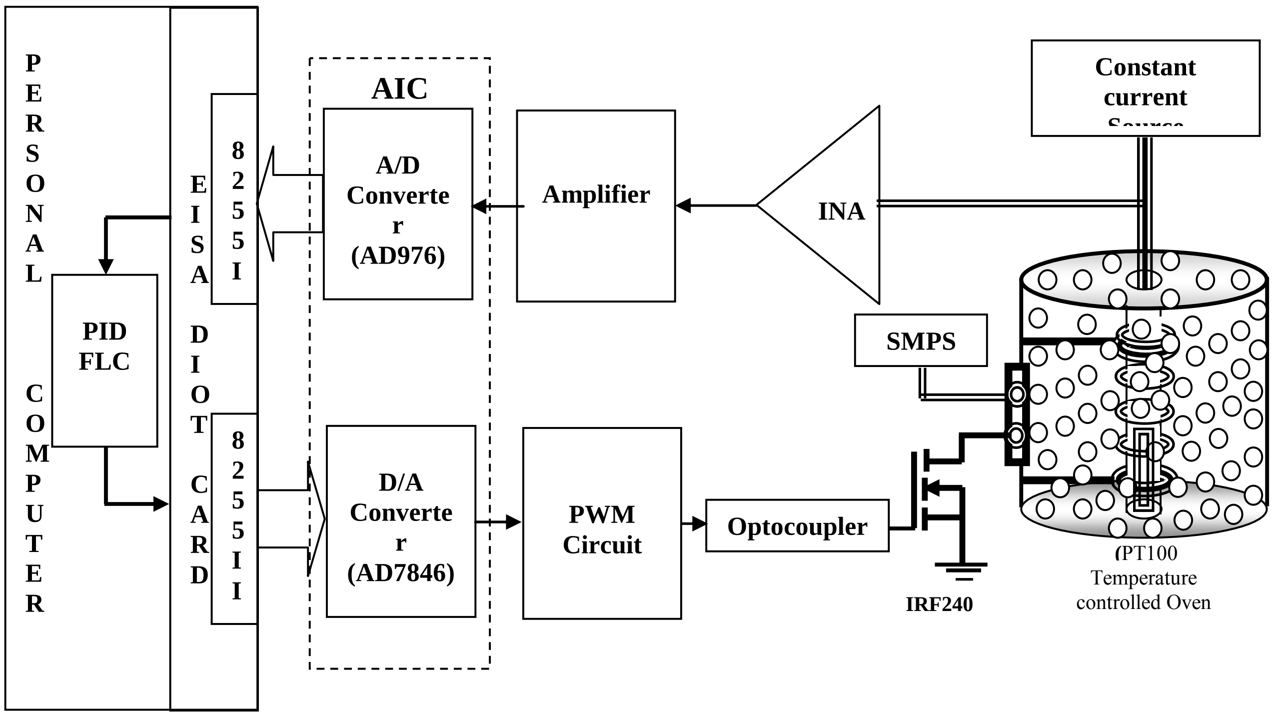


**Fig. 1.** Block diagram of the computer based oven temperature control system.

## 3. Control Instrumentation

The control hardware flow consists of digital to analog (D/A) converter, pulse width modulator (PWM) circuit, opto-coupler, and power MOSFET. After evaluation of the temperature by the computer, it finds the error (by subtracting measured temperature from the reference temperature) and change in errors. These errors are applied to the PID and FLC algorithms, which are discussed later. The controller produces control action according to the errors. The computer then applies this control action, in the form of digital data, to the heater through DIOT card, 16-bit D/A converter AD 7846, PWM generator, and power actuator (MOS FET). The ON time of PWM wave varies with digital data. If digital data is more, ON time will be more and vice-versa. Hence, the power applied to or removed from the heater through actuator will vary with PWM wave. This procedure is repeated till the oven temperature reaches the set value. Thus the oven temperature is controlled at the desired value.

## 4. PID Controller

Improved PID controller algorithm is employed for the present study and is given as,

$$V_n = V_{n-1} + K_p\,(e_n - e_{n-1}) + K_i\,(e_n + e_{n}\text{-}1)/2T + K_d/6T\,[(e_n - 2e_{n-1} - 6e_{n-2} + 2e_{n-3} + 2e_{n-4})],$$

where, $K_p$, $K_i$ and $K_d$ are proportional, integral and derivative constants respectively;
$V_{n-1}$ is the previous control action;
$e_n$, $e_{n-1}$ are the present and previous errors respectively;
$e_{n-2}$, $e_{n-3}$, and $e_{n-4}$ are previous to previous errors.

The best-tuned $K_p$, $K_i$, and $K_d$ values for the above equation are found to be equal to 1000.0, 0.06, and 10.0 respectively and cycle time T is equal to 1.

## 5. Fuzzy Logic Controller

Implementation of a fuzzy logic controller with two input linguistic variables e(k) and ce(k) each with seven bell-shaped membership functions (NL-Negative Large, NM-Negative Medium, NS-Negative Small, ZE-Zero Error, PS-Positive Small, PM-Positive Medium, and PL-Positive Large) is shown in Fig. 2.

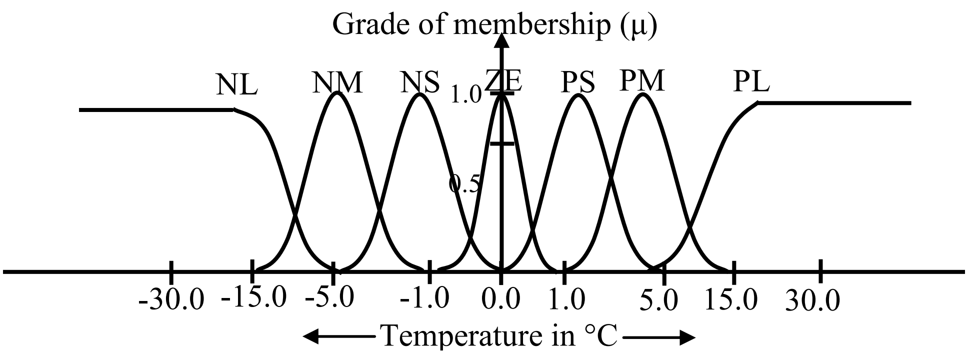


**Fig. 2.** Bell-shaped membership functions for error, change in error and output.

Fuzzification unit evaluates fuzzy sets for given e(k) and ce(k) and passes on to the inference engine. Rule base and decision-making units residing at inference engine generate fuzzy control action using IF and THEN rules. As an example, the following is a possible control rule generated by the inference engine,

**IF** e(k) is the 'PL' and ce(k) is 'PZ' **THEN** cu(k) is 'PM'

Linear control action is evaluated by Mamdani's fuzzy inference strategy and is represented as,

$$R_c : \bigcup_{7}^{i=1} \alpha_i \cap \mu_{ui}$$

where, $\alpha_i$ is the measure of contribution of $i^{th}$ rule to the fuzzy control action and $\mu_{ui}$ is the grade of membership of $i^{th}$ possible control element. The weighing factor $\alpha_i$ is usually expressed as,

$$\alpha_i = \mu_{ei} \cap \mu_{cei}$$

where, $\mu_{ei}$ and $\mu_{cei}$ are the grade of memberships of $i^{th}$ element in the error and change in error fuzzy sets.

Finally all the fuzzy evaluated control rules are defuzzified into a single real value using centre of gravity (COG) method [16],

$$cu = \frac{\sum_{i=1}^{7} \mu cu\,(wi).wi}{\sum_{i=1}^{7} \mu cu\,(wi)}$$

where, $w_i$ is the support member value for the $i^{th}$ element, and $\mu_{cu}$ ($w_i$) is the value of grade of membership function for $i^{th}$ element.

The defuzzified, crisp control action is denoted as cu(k). Further the velocity fuzzy control algorithm computes the control action applied to the process is as given below,

$$u = cu(k) + cu(k-1)$$

where, u is the final control value, cu(k) is present fuzzy computed control action and cu(k-1) is the previous control action.

## 6. Software Development

The software development of a computer based fuzzy logic oven temperature control system is presented in Fig 3 and Fig. 4. PID and fuzzy control algorithms have been implemented using 'C' Language. The software is based on the character user interface (CUI), it displays a text menu, which enable the user to monitor current value of the parameter (speed) being measured and controlled, and the controller parameters. It also features to enter the new set point; to enter filename to store measured data; and tune the controller parameters etc.

## 7. Experimental Validation

Fuzzy logic based controller has been designed and fabricated for oven temperature control system. The experimental system used in real time control application is shown in Fig. 5. The performance and efficiency of the fuzzy controller for temperature control application is evaluated by applying several tests over a wide range of operating conditions. The performance indexes (in terms settling time, steady state error, overshoot, and under shoot) of the proposed controller are studied under no-load application in comparatively with the PID controller.

A plot of comparison of step responses of PID and FLC for temperature control application is presented in Fig. 6 wherein it is observed that the FLC has got better transient and steady state responses. The numerical results are presented in Table 3. From the experimental study it is observed that the FLC has got superior performance over PID controller hence, it is concluded that FLC is the best choice for temperature control application.

**Table 3.** Experimental results of the computer based temperature control system in absence of load.

| **Oven Temperature Control System Results in Absence of Load For a step size of 30 °C (30°C - 60°C)** | | | | | | |
|---|---|---|---|---|---|---|
| **Controller** | **Sampling Interval (min.)** | **Maximum Overshoot (°C)** | **Maximum Undershoot (°C)** | **Settling time (Minutes)** | **Steady-State Error (°C)** | **Remarks** |
| PID | 0.01933 | 0.45 | 0.07 | 5.5873 | 0.19 | |
| 7-member FLC (Bell function) | 0.02283 | 1.76 | 0.07 | 4.0041 | 0.19 | Better |

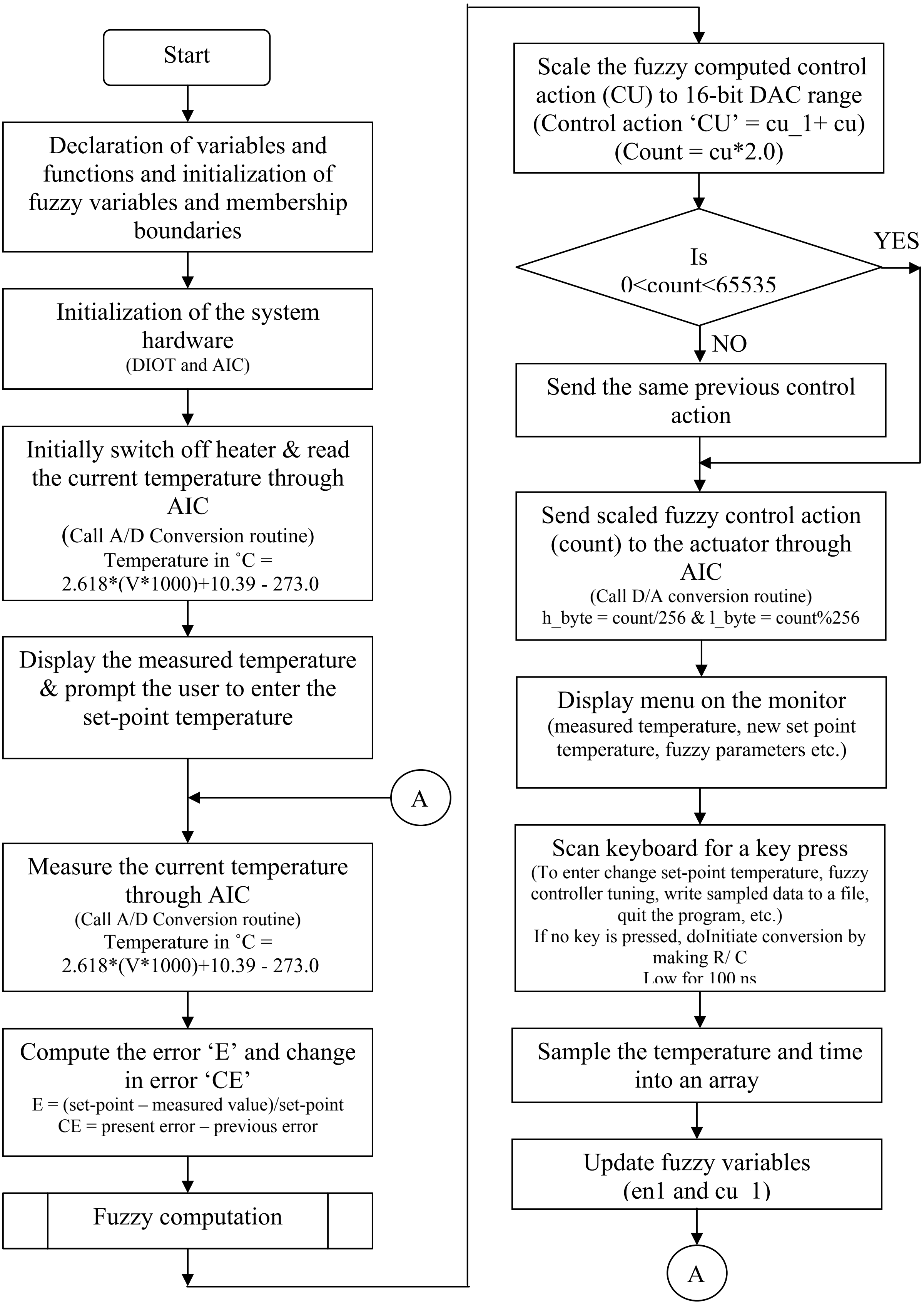


**Fig. 3.** Flowchart of the computer based FLC oven temperature control system.

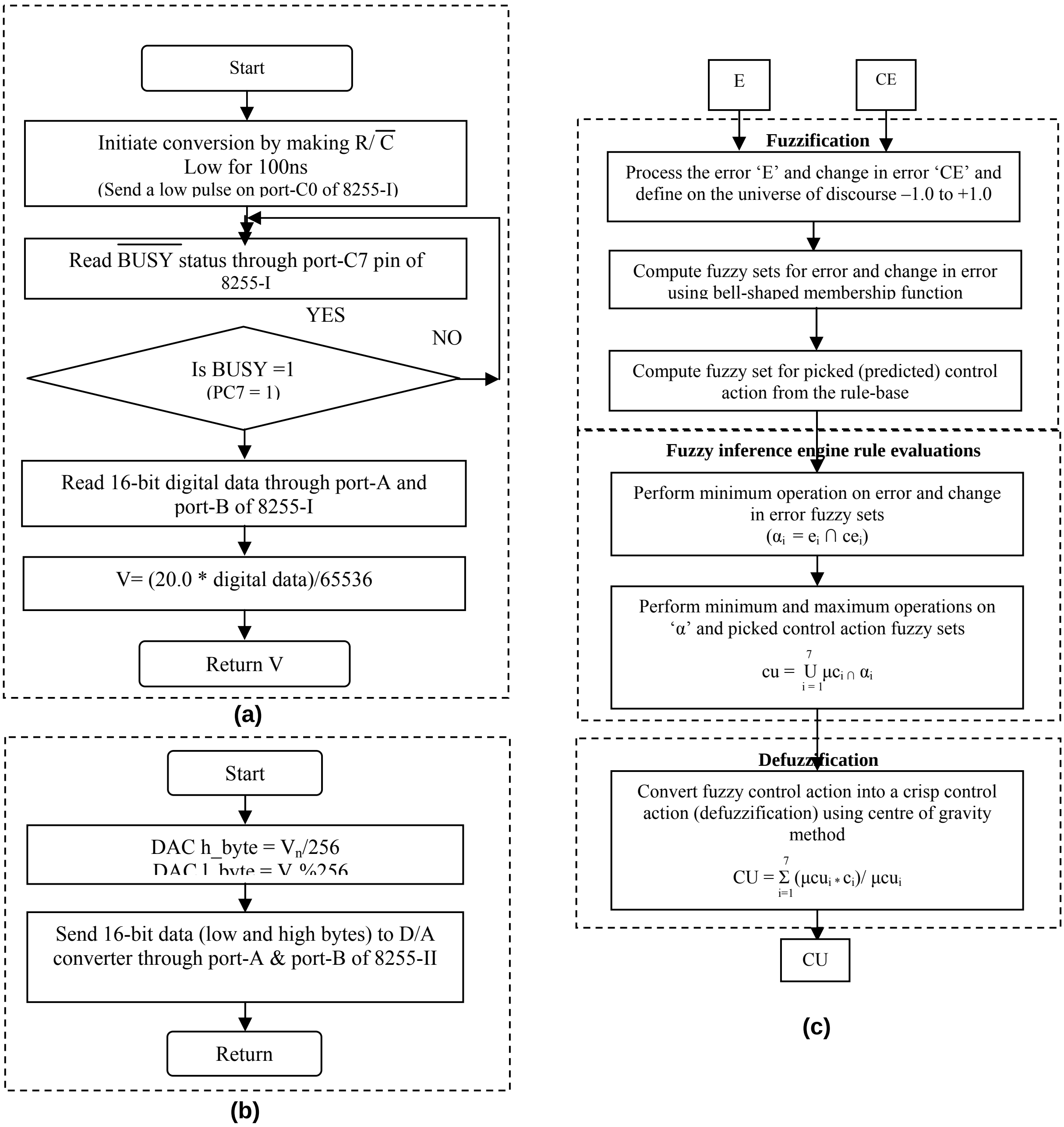


**Fig. 4.** Subroutines: (a) A/D converter; (b) D/A converter, and (c) fuzzy computation.

**Fig. 5.** Photograph of the experimental setup and working model of an oven temperature control system.

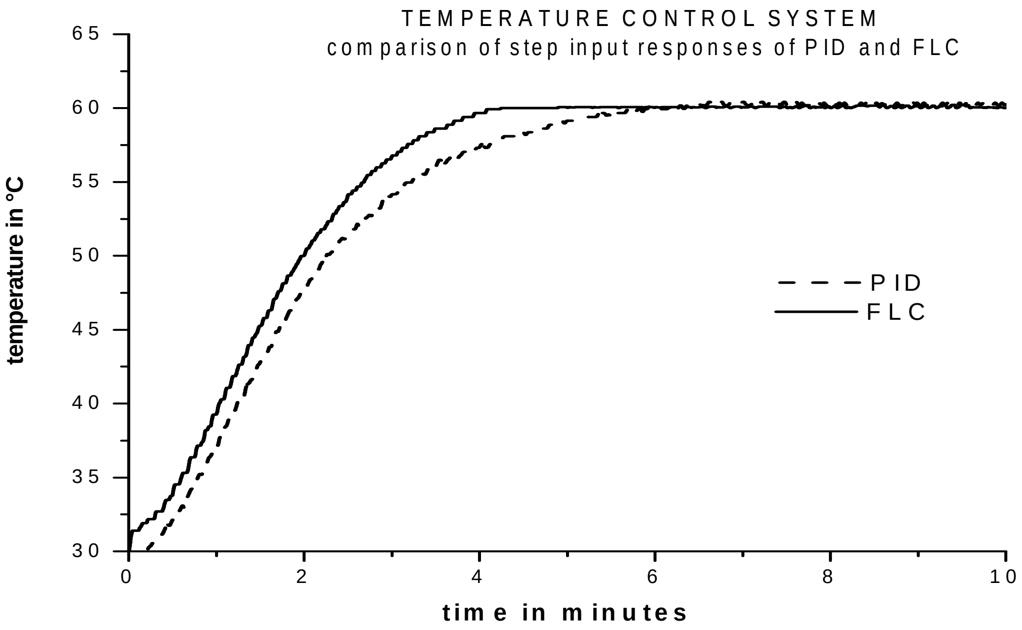


**Fig. 6.** Comparison of step input responses of PID and FLC for temperature control application under no-load.

## 8. Conclusion

Experimental validation of the system concludes that fuzzy controller is better than PID controller. Fuzzy controller exhibits better response in transient state and the steady state response of the fuzzy controller and is also better comparable with the PID controller. Bell shaped membership function is ideal for fuzzification. The computational speed is also reasonable for seven members bell shaped fuzzification/defuzzification.

## 9. Future Enhancement

In future it is intended to study the performance of fuzzy controllers under consideration of load and noise. Work extends to design CYGNAL C8051F020 microcontroller based fuzzy controllers for process control and underwater control applications. And to design fuzzy hardware chips using CPLD/FPGA devices using VHDL software.

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