Development of Sensors and Microcontrollers for Small Temperature Controller Systems

Ali Jebelli and Mustapha C. E. Yagoub
School of Electrical Engineering and Computer Science, University of Ottawa, Ottawa, Canada
Email: ajebelli@uottawa.ca, myagoub@eecs.uottawa.ca

***Abstract*—In this paper, a microcontroller-based fuzzy logic controller is introduced to stabilize at the desired temperature, while sudden changes in temperature can be severe. This approach is applied to one onboard microcontroller which is on small board and the control system is able to meet the required respond quickly. The significance of this work is because of using a microcontroller with a fuzzy PI controller as the supervisor, and evaluated through experiments. It is shown that the characteristics of the fuzzy logic, such as flexibility of the I/O selection and saturation of the outputs, provide favorable performance to the control system for temperature system.**

***Index Terms*—fuzzy logic controller, proportional integral derivative (PID), pulse width modulation (PWM)**

I INTRODUCTION

The project deals with temperature based fan/heater controller system implementing fuzzy logic, comparing it with conventional control circuits like an ON/OFF control in which either fan/heater runs at their maximum intensity whereas fuzzy controller works according to the temperature, controls the speed of fan or the radiations from the heater and overcomes the limitations of conventional control circuits. So if the temperature changes, the fan speed or the heater radiation adjusts to keep the temperature at the desired level. In the project a fuzzy logic controller has been envisaged to make conditions adept to a certain temperature range. The fuzzy logic controller acts as a room temperature controller. A microcontroller AVR is designed to act as fuzzy logic controller. This system uses minimum hardware and achieves better performance than a conventional fuzzy controller and can be applicable in various industrial processes where temperature control is vital, and also this paper presents the development of fuzzy controller to control of a low-cost temperature controller.

II SYSTEM DESCRIPTION

A. Microcontroller Board

The robot, shown in Fig. 1, has an ATMEGA16L microcontroller to execute all codes and tasks. This Microcontroller has16-Kbyte self-programming Flash Program Memory, 1-Kbyte SRAM, and 512 Byte EEPROM, 8 Channel 10-bit A/D-converter and JTAG interface for on-chip-debug. It operates at up to 8 MIPS throughput at 8 MHz at 3 Volt. The microcontroller includes PWM outputs for controlling motors and a serial RS232 port for communication with other devices.

Figure 1. Microcontroller board

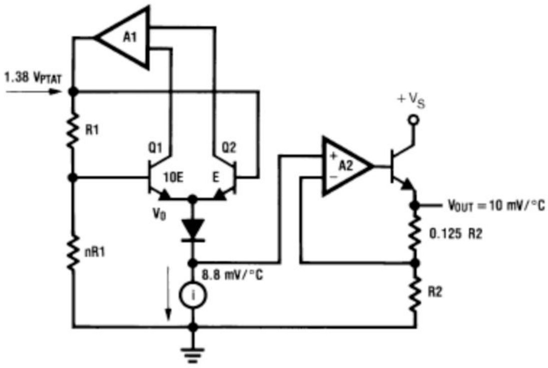

Figure 2. LM35 Sensor Circuit Schematic [1].

The microcontroller integrates many useful capabilities like PWM outputs for controlling the fan or heater speed. It is particularly well suited for this type of application because of its small size and weight and relatively low cost. Apparatus of this temperature control system is shown in Fig. 2

B. Sensors

We used the integrated- circuit temperature sensor LM35 which delivers an output voltage linearly proportional to the centigrade temperature (Fig. 2).

Thus, the LM35 has an advantage over linear temperature sensors calibrated in °K as the user is not required to subtract a large constant voltage from the output to obtain the convenient centigrade scaling. It provides a typical accuracy of ±1⁄4°C at room temperature and ±3⁄4°C over a full −55°C to +150°C temperature

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range, draws only 60 µA from the supply, and has very low self-heating of less than 0.1 ℃ in air [1].

III Design of the Fuzzy Controller

A fuzzy controller is a system that applies linguistic rules to a given input vector to compute an output vector. The fuzzy design process for embedded controller can be executed in three main steps including fuzzification of the inputs, inferencing the rule based knowledge and defuzzification of the output. The three steps to compute the outputs can be illustrated in Fig. 3.

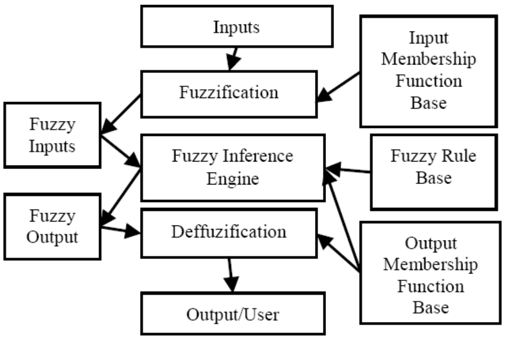


Figure 3. Fuzzy steps for output computation.

IV Fuzzification

The fuzzification step transforms an input crisp value into a fuzzy value representing a degree of membership, called as alpha value. In this research, one approach of fuzzification was chosen namely, the Memory Oriented Fuzzification (MOF), in which the system computes a membership degree for each input off line and stores them in memory.

In this case, the membership function shapes do not influence the computational load of the algorithm. Despite this advantage for high-resolution computations, this approach requires large amounts of memory [2]-[5].

V Fuzzy Sets and Fuzzy Systems

The relationships between the variables are represented by means of fuzzy IF - THEN rules and need to combine fuzzy sets using logical connectives such as AND (conjunction), OR (disjunction) or NOT (complement). For this purpose, the logical connectives from conventional Boolean logic have been extended to their fuzzy equivalents.

Depending on the consequent format, three main types of rule-based fuzzy models can be distinguished:

- Linguistic fuzzy model: both antecedent and consequent terms are fuzzy propositions.
- Fuzzy relational model: as generalization of the linguistic model, relation between antecedent and consequent terms is fuzzy.
- Takagi-Sugeno (TS) fuzzy model, the antecedent is a fuzzy proposition while the consequent is a crisp function.

Because of its ease of implementation, the Linguistic fuzzy model was used in this work. Analytical details on how the rule-base table is designed can be found in [6]-[10].

VI Construction of the Rule Base

One of the drawbacks of using simple fuzzy P control is that in dynamic systems, which are unpredictable, can lead to the steady-state error which is one of the main factors and requires time to reach to desirable situation. One of the solutions to solve this issue is to use fuzzy PI to reduce steady- state error. (In Fig. 4, where E represents the Error and ΔE the Error rate).

The Fuzzy rules for this fuzzy program are as follow:

- E = Ts (Set Point Temperature) – Tc (Current Temperature)
  - IF E > 0 Turn On the Heater
  - IF E < 0 Turn On the Fan
- ΔE = |E(K)| - |E(K-1)|
  - IF ΔE > 0, Away from the desired temperature
  - IF ΔE < 0, Near the point
  - IF ΔE = 0, steady
- IF Error is high, increase the speed of the Fan
- IF Error is small and
  - ΔE ≤ 0, select low fan speed
  - IF ΔE > 0,select high fan speed

Table I shows the rule table, including seventy seven rules.

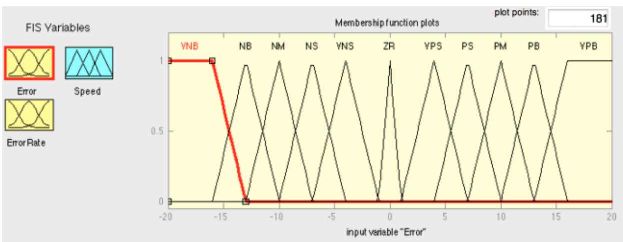
TABLE I. The Decision Table by the Fuzzy Controller

E / Δ*E*	VNB	NB	NM	NS	VNS	ZR	VPS	PS	PM	PB	VPB
NB	VVF	M	M	L	VVL	VVL	VVL	L	M	M	VVF
NM	VF	F	F	M	VVL	VVL	VVL	M	F	F	VF
NS	VF	VVF	VF	M	VL	VVL	VL	M	VF	VVF	VF
ZR	VVF	VF	F	M	VL	VVL	VL	M	F	VF	VVF
PS	VVF	VVF	VF	VF	M	VL	M	VF	F	VVF	VVF
PM	VVF	VVF	VF	VF	F	VL	F	VF	VF	VVF	VVF
PB	VVF	VVF	VVF	VF	VF	VL	VF	VF	VVF	VVF	VVF

The terms in the table are:

NB: negative big,
NM: negative medium,
NS: negative small,
ZR: zero,
PS: positive small,
PM: positive medium,
PB: Positive big

The following regulations were exerted for the fuzzy programs (Fig. 4).



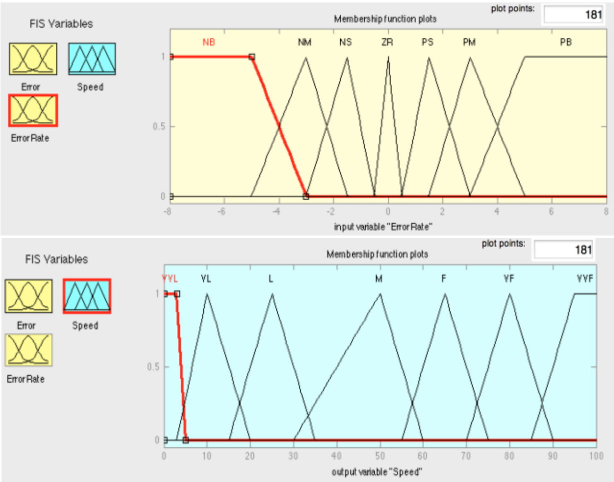


Figure 4. Membership functions of the fuzzy logic controller

VII PID CONTROL

A proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an “error” value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error in outputs by adjusting the process control inputs. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value due to the control action [11].

The PID controller algorithm involves three separate constant parameters and is accordingly called three-term control; P stands for proportional, I for integral, and D for derivative [12]. It is described by:

$$u(t)=k\left(e(t)+\frac{1}{T_i}\int_0^t e(\tau)d(\tau)+T_d\frac{de(t)}{dt}\right) \tag{2}$$

where u the control signal and e the control error ($e = ysp-y$). The reference variable is often called the set point. The control signal is thus a sum of three terms: the P-term (which is proportional to the error), the I-term (which is proportional to the integral of the error), and the D-term (which is proportional to the derivative of the error). The controller parameters are proportional gain K, integral time T_i, and derivative time T_d [12].

VIII PROGRAMMING MICROCONTROLLER USING TEMPERATURE SENSOR AND FUZZY PI CONTROL

One of the issues of the fuzzy control in dynamic systems is that they cannot be forecasted. The balanced error is one of the main factors that needs time to reach the desirable situation. One of the ways is to use the fuzzy PI controller to reduce the risk in the situation of robot’s balance.

The fuzzy program was written using the following instructions:

Fuzzy P rules:

IF Error is Low THEN P-Pwm is Max.

IF Error is Low AND Error rate is Zero THEN P-Pwm is Medium.

IF Error is Zero THEN P-Pwm is Zero.

IF Error is Low AND Error rate is Zero THEN P-Pwm is Medium.

IF Error is High THEN P-Pwm is Max.

Fuzzy I rules:

IF Error rate is Low THEN I-Pwm is Max.

IF Error rate is Low AND Error is Zero THEN I-Pwm is Medium.

IF Error rate is Zero THEN I-Pwm is Zero.

IF Error rate is Low AND Error is Zero THEN I-Pwm is Medium.

IF Error rate is High THEN I-Pwm is Max..

The values for P and I membership functions are as below:

P: Positive Small = -60, Zero = 0,
Positive Medium = 100, Positive Big = 160.
I: Positive Small = 40, Positive Big = 80.

The corresponding Fuzzy PI surface is plotted in Fig. 5.

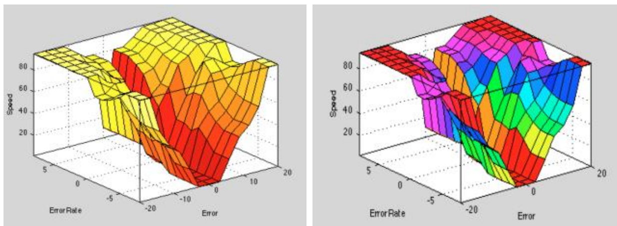


Figure 5. Fuzzy output surface.

IX SIMULATION RESULTS AND DISCUSSION

When the robot is subject to a heat change, it is able in this case to change from a critical condition to a stable condition. This condition happened because of high value of PWM value in output membership function for a sudden change in engine speed, as shown in Fig. 6, the robot has been able to balance temperature rapidly, at about 73% of the fans peed, after a sudden increase of temperature by 13 ℃, and when the temperature change reaches about 4 ℃, the speed of the fan was optimized to 11% (Fig. 7), demonstrating the ability of our control system to adapt the system response to the operating conditions.

As shown in Fig. 8, when the temperature reaches the desired temperature, the robot temporarily turns off the fan and heater by the fuzzy logic controller and the desired state will be maintained until the user changes the values.

Another experiment has been done to tune the fuzzy variables. When the robot temperature decreases (at about 15 ℃), the controller is able to change its critical condition to stable condition as in Fig. 9. As can be seen, the robot is able to balance rapidly the temperature (at about 94% of the heater power), (Fig. 10), and when the temperature change reaches about 12 ℃, the power of the heater was optimized to 65% (Fig. 9), demonstrating the ability of our

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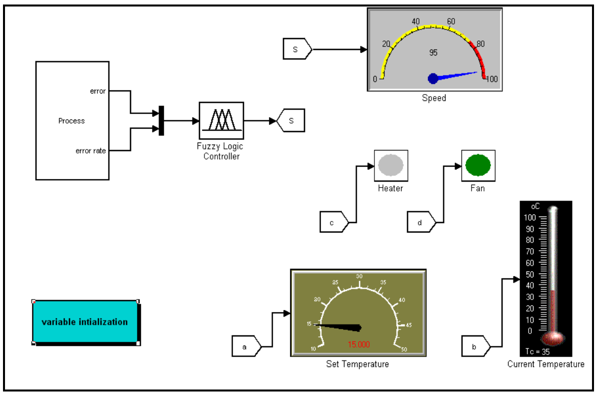
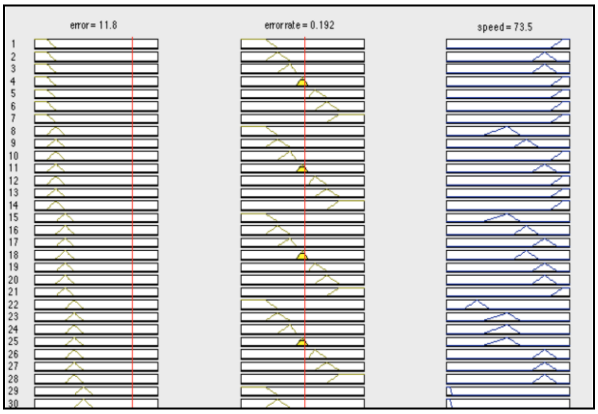
control system to adapt the system response to the operating conditions.





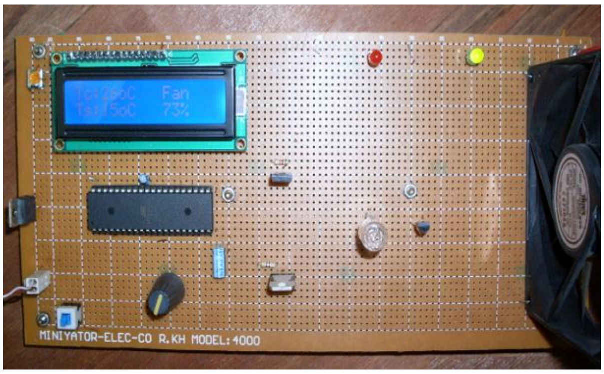
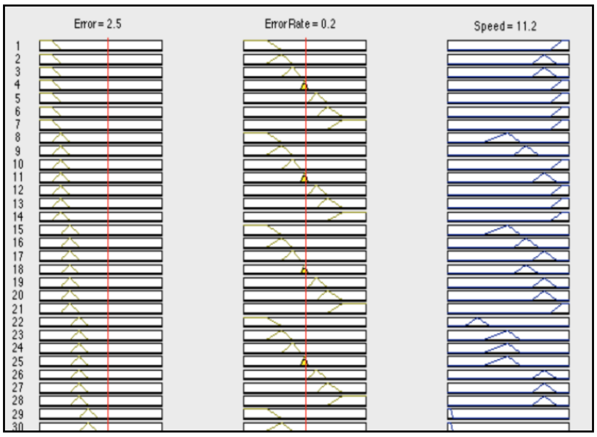


Figure 6. Temperature controller simulation for a 13 ℃ change in temperature.



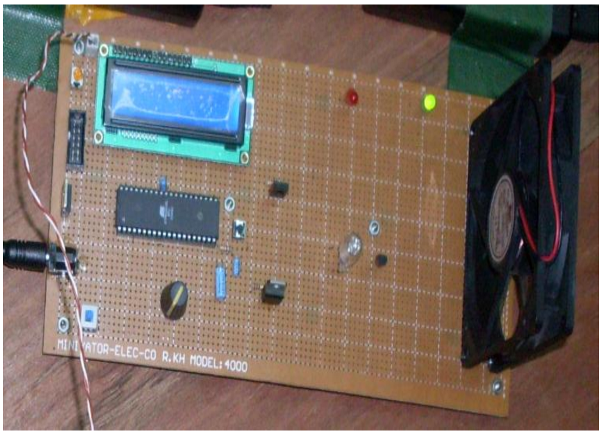
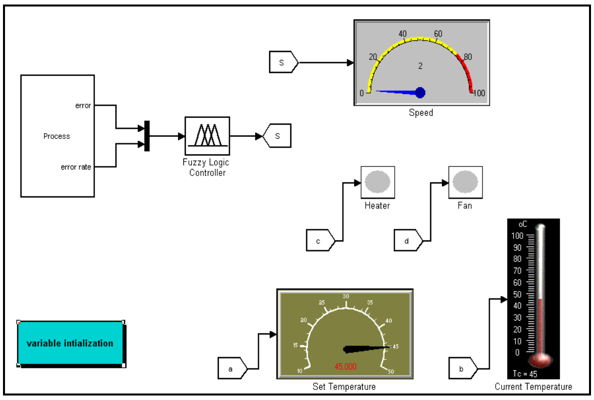
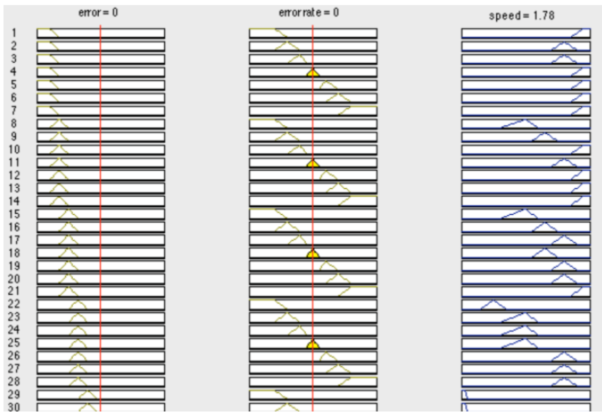


Figure 7. Temperature controller simulation for a 4 ℃ change in temperature.





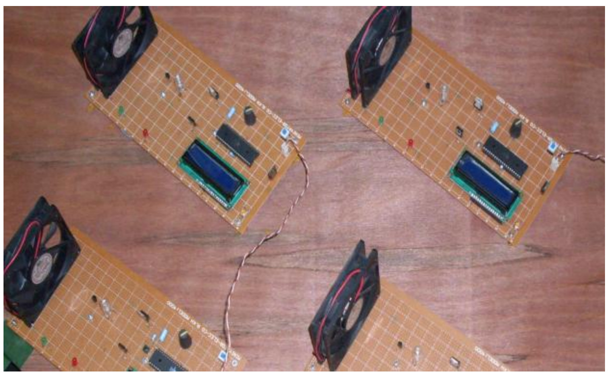
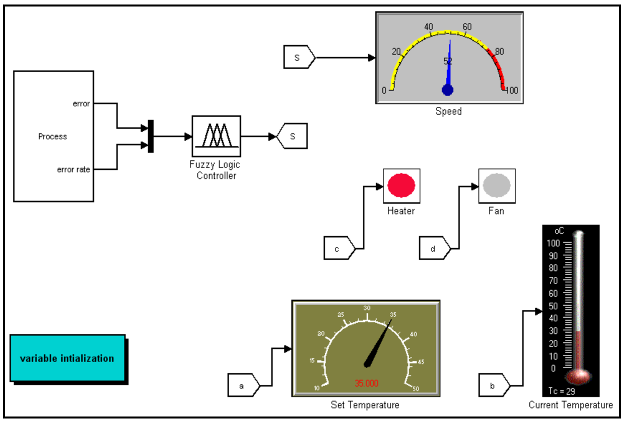
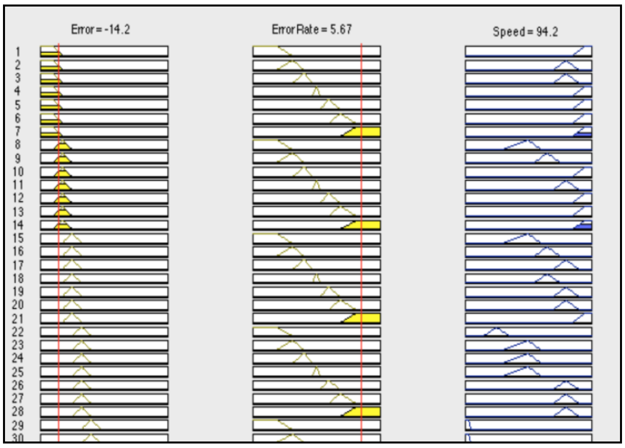


Figure 8. Temperature controller simulation (For temperature change is constant).





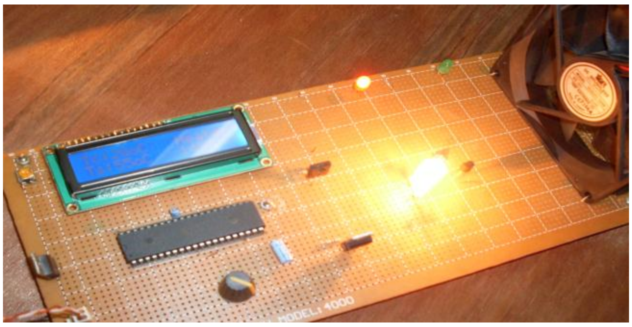
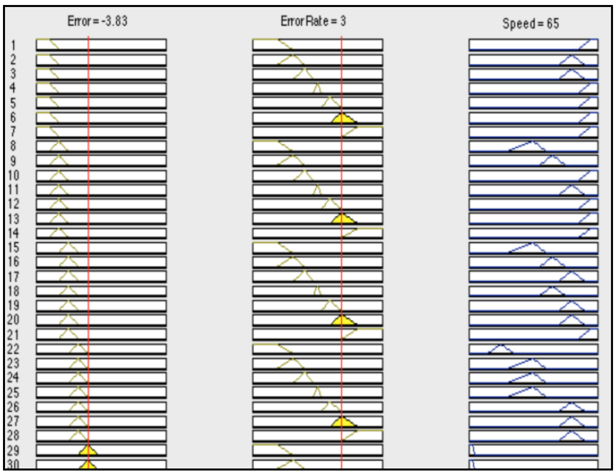


Figure 9. Temperature controller simulation for a 15 ℃ change in temperature.



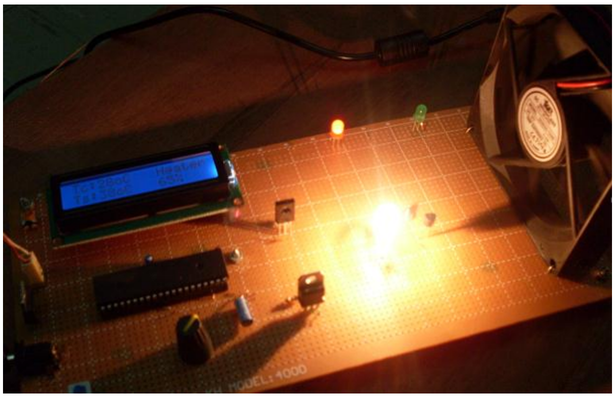
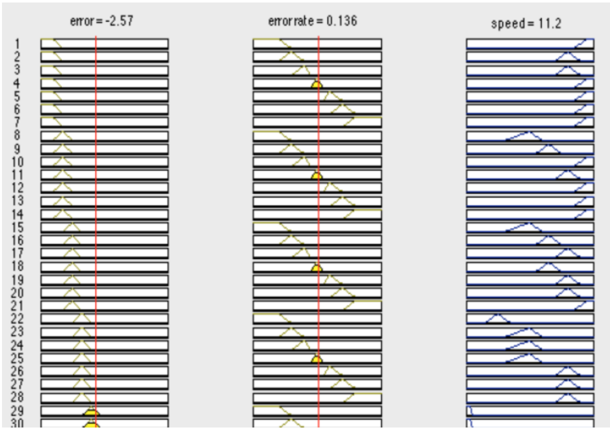


Figure 10. Temperature controller simulation for a 12 ℃ change in temperature.

Also, when the temperature approaches its desired value, the error rate is reduced and the heater power will start to decrease accordingly (Fig. 11).



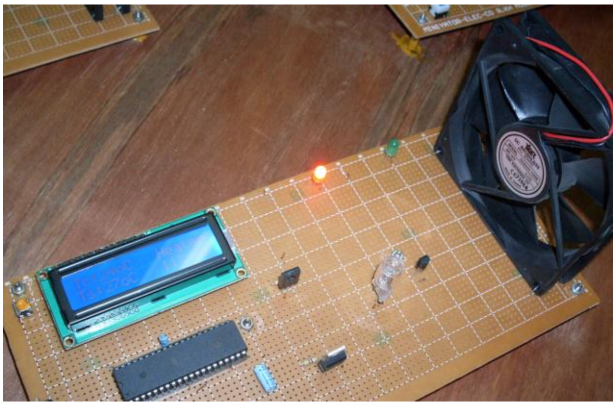


Figure 11. Temperature controller simulation for a 4 ℃ change in temperature.

Another experiment, when the robot in temperature decreases (at about 7 ℃) at the right side of the robot, it is able to change its critical condition to a stable condition (Fig. 12). As can be seen, the robot is able to change the system based on the proposed intelligent planning system to be temperature balanced rapidly based on minimal use of energy (63% Heater 1, 32% Heater 2, 3 & 8% Heater 4), (Fig. 12).

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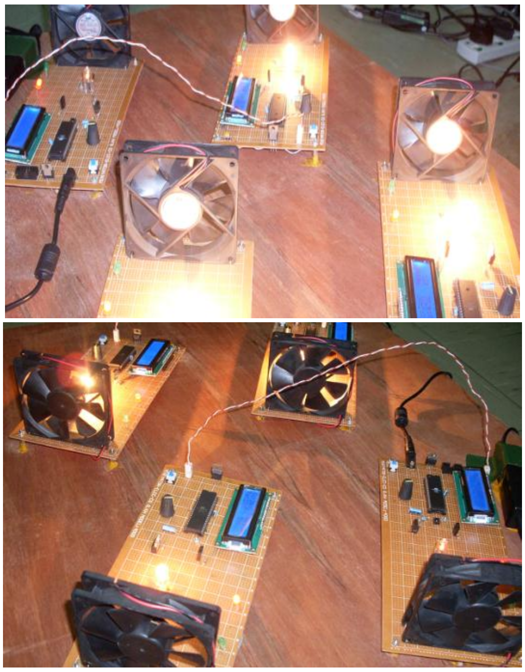

Figure 12. Temperature decrease (at about 7 ℃)

And also, when the robot in temperature increases (at about 7 ℃) at the left side of the robot, it is able to change its critical condition to a stable condition (Fig. 13). As can be seen, the robot is able to change the system based on the proposed intelligent planning system to be temperature balanced rapidly based on minimal use of energy (54% Fan 1, 23% Fan 2, 3 & 6% Fan 4), (Fig. 13).

Figure 13. Temperature increase (at about 7 ℃)

X Conclusion

The proposed of this project is to develop control system of temperature for exhaust fan with heater control system can also be later included for an optimized operation, and the objective of this project is to develop an intelligent temperature control system with heater and cooling control system that can be controlled automatic and it also can be controlled by human. Based on the above test-results, a simple electrical architecture with fuzzy logic and PI control architecture for a small intelligent temperature control system was designed. All functions of the system are obviously realized through its experiments. The models designed are a fuzzy model and PI control containing some behavioral tasks. In order for embedded robot systems to achieve a level of computational intelligence which is adequate for interacting with the real world, they must competent in handling uncertainty, effectively response to dynamically changing environment, and perform the task without fail.

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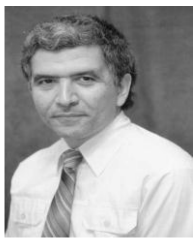
Ali Jebelli is currently a graduate student and also works as a Research Assistant at School of Electrical Engineering and Computer Science, University of Ottawa from 2013. He received his MEng in Electrical – Mechatronics & Automatic Control from University of Technology Malaysia and got his B.S. degree in Electrical Power Engineering from Iran in 2009 and 2005.



Mustapha C. E. Yagoub received the Dipl.-Ing. degree in Electronics and the Magister degree in Telecommunications, both from the École Nationale Polytechnique, Algiers, Algeria, in 1979 and 1987, respectively, and the Ph.D. degree from the Institut National Polytechnique, Toulouse, France, in 1994. After few years working in industry as a design engineer, he joined the Institute of

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Electronics, Université des Sciences et de la Technologie Houari Boumédiene, Algiers, Algeria, first as an Lecturer during 1983-1991 and then as an Assistant Professor during 1994-1999. From 1996 to 1999, he has been head of the communication department. From 1999 to 2001, he was a visiting scholar with the Department of Electronics, Carleton University, Ottawa, ON, Canada, working on neural networks applications in microwave areas. In 2001, he joined the School of Information Technology and Engineering (SITE), University of Ottawa, Ottawa, ON, Canada, where he is currently a Professor. His research interests include RF/microwave CAD, RFID design, neural networks for high frequency applications, planar antennas, and applied electromagnetics. He has authored or coauthored over 300 publications in these topics in international journals and referred conferences. He authored Conception de circuits linéaires et non linéaires micro-ondes (Cépadues, Toulouse, France, 2000), and co-authored Computer Manipulation and Stock Price Trend Analysis (Heilongjiang Education Press, Harbin, China, 2005). Dr. Yagoub is an Editorial Board member of the International Journal of RF and Microwave Computer-Aided Engineering, a senior member of the IEEE, and a registered member of the Professional Engineers of Ontario, Canada.

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