Fuzzy Logic Temperature Controller for Small Robots

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***Abstract*—Malfunctions in a working robot system are serious factors which can result in deviations from the desired goals. Among these, temperature increase over safe values is one of the most important factors that can limit the usage of available energy. The heat generated from motors and batteries can damage the electrical systems and affect the overall performance. This results in the need to control and maximize the utilization of supplied energy from batteries. In this paper, the authors designed an intelligent system to control temperature thus preventing system malfunction due to overheating in insulated robots, such as underwater robots. This temperature controller works in parallel with the robot motion controller. The proposed temperature control system uses fuzzy logic as a control layer system. It has been adopted to avoid system errors and efficiently use the energy available. The system is developed using fans, heaters and fuzzy logic circuits for achieving an energy efficient robot with long-term high performance.**

Keywords— Autonomous robot, Fuzzy logic controller, PID, PWM.

I. Introduction

In this paper, we present a small robot containing a fuzzy logic control of temperature with thermal insulation from the environment. Fuzzy logic control is a digital control methodology that allows the physical system and of the required control strategy to be developed in a reasonably way. Fuzzy Logic provides a different way to approach a control problem. The method emphasises on the functionality of the system as opposed to developing a mathematical model. Principle of fuzzy logic is built on a set of user-supplied human language rules. Fuzzy systems are designed to convert these rules to their mathematical equivalents. This simplifies the work of a system designer, resulting in more accurate representations of the ways systems behave in real world. Temperature based equipment control is the basic requirement in domestic as well as in many industrial applications.

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.

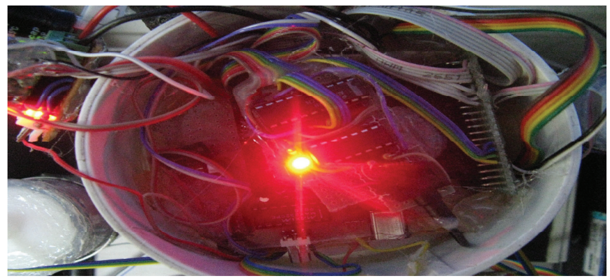

Fig. 1. The Robot with temperature controller on robot board

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 Figure 2

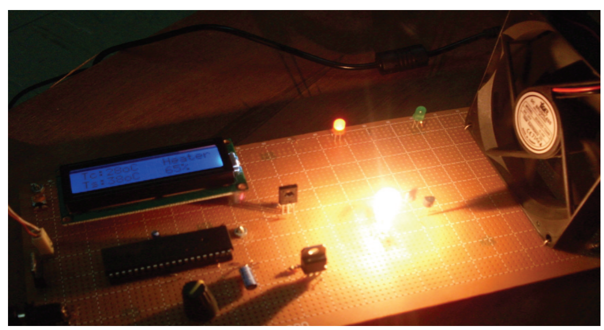

Fig. 2. Microcontroller board

B. Sensors

The LM35 series are precision integrated-circuit temperature sensors which do not require any external calibration or trimming to provide typical accuracies of $\pm 1/4$℃ at room temperature and $\pm 3/4$℃ over a full -55 to $+150$℃ temperature ranges. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and the output voltage is 10mV per degree centigrade [1].

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III. DESIGN OF THE FUZZY CONTROLLER

The fuzzy design process for embedded controller can be executed in three main steps including fuzzifier of the inputs, inferencing the rule based knowledge and defuzzification of the output (Figure 3).

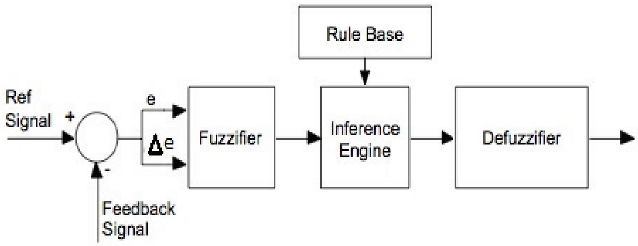


Fig. 3. Three steps for output computation [2].

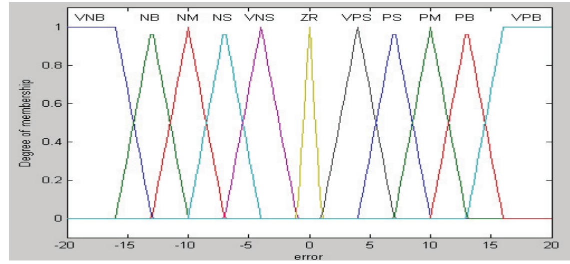
Temperature controllers use the whole range of its universe. Therefore, the maximal values of the error and its change should be equal to the limit of the universe. The universe is in a range of -60 to +60 (the positive sign and the negative sign are demonstrate the balance temperature inside the robot). The choice of the shape of the antecedent MFs are triangular and Trapezoidal with a specific overlap of 50% to ensure that each value of the universe is a member of at least two sets, except possibly for elements at the extreme ends. In the first aspect, the number of the input/output fuzzy sets; is four; temperature sensor is the input and the four fan and four heaters are outputs. For each of the input and output variables, the following eleven linguistic labels are assigned to the membership functions:

VNL = Very Negative Big, NB= Negative Big,
NM = Negative Medium, NS = Negative Small,
VNS = Very Negative Small, ZR = Zero,
VPS = Very Positive Small, PS = Positive Small,
PM = Positive Medium, PB = Positive Big

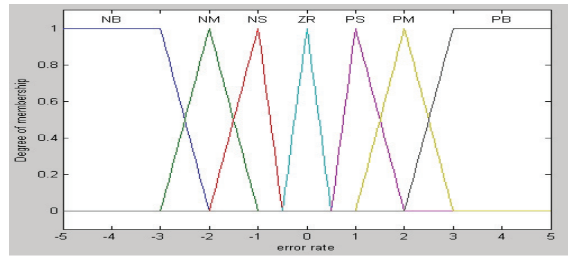
These variables in the premise parts are fuzzy, while in the consequence part is singleton with values between 0 and 1 [3]. The actual Mamdani fuzzy system approach is chosen [4], by using MFs in the input and singletons in the output control system. It is therefore recommended for real-time fuzzy control applications to use singletons in the output resulting in simpler and faster control action ([5], [6]).

IV. FUZZIFIER

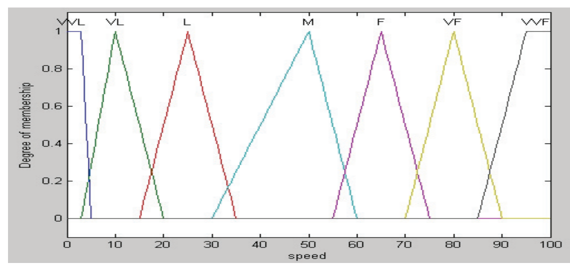
Fuzzy logic uses linguistic variables instead of numerical variables. In a closed loop control system, the error (E) between the desired temperature and the Environment temperature and the rate of change of error (ΔE) can be labeled as Zero (ZR), Negative Big (NB), Negative Medium (NM), Negative Small (NS), Positive Small (PS), Positive Medium (PM), Positive Big (PB). In the real world, measured quantities are real numbers (crisp). The process of converting a numerical variable (real number) into a linguistic label (fuzzy number) is called fuzzification. Figure 5 shows the membership functions that are used to fuzzify the inputs (Figure 4) [7].



Error



Error rate



Speed (PWM)

Fig. 4. Membership Functions of the Fuzzy Logic Controller

V. CONSTRUCTION OF THE RULE BASE

In conventional controllers, there are control laws, which are combinations of numerical values that govern the reaction of controller. In fuzzy logic control, the equivalent term is rules. Rules are linguistics in nature and allow the operator to develop a control decision in a more familiar human environment [8]. A typical rule can be written as follows:

- $E = TS - TC$ IF $E > 0$ Turn On the Heater & $E < 0$ Turn On the Fan
- $\Delta E = |E(K)| - |E(K-1)|$ IF $\Delta E > 0$ Away from the desired temperature & IF $\Delta E < 0$ Near the point & $\Delta E = 0$ is steady
- If Error is very big the very fast speed Fan
- If Error is small $\Delta E \leqslant 0$ low speed fan but if $\Delta E > 0$ high fan speed

Figure 5 shows the rule table for controlling the temperature.

After the rules are evaluated, each output membership function will contain a corresponding membership. From these memberships, a numerical (crisp) value must be produced. This process is called defuzzification [2], [9].

?E \ 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

Fig. 5. Fuzzy Logic Rule Table

VI. DEFUZZIFICATION AND PID CONTROL

Defuzzification plays an important role in a fuzzy logic-based control system. It is the process in which the fuzzy quantities defined over the output membership functions are mapped into a non-fuzzy (crisp) number. There are a variety of methods to achieve this; however this discussion is confined to the process used in this research design. Singleton fuzzy output is chosen due to its quick processing speed [10].

$$Z^* = \frac{\sum_{t=1}^{n} B_n K_n}{\sum_{t=1}^{n} B_n} \tag{1}$$

with B_n the weight of the rule which is fired and K_n the singleton output value for that specific rule.

For feedback control in industrial processes, PID controller which's consisting of proportional, integral and derivative elements, is widely used. It is described by [11]

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

VII. EXPERIMENTS IN ROBOT USING TEMPERATURE SENSOR AND FUZZY PI CONTROL

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.

Rules which have been written for this fuzzy program are as bellow:

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 bellow:

P:Min= -15, Zero = 0, Medium = 18, High = 90.
I: Zero = 0, Low = 15, High = 30.

Fuzzy PI surface has been plotted using MATLAB in Figure 6. The PWM output is based on PI controller equation [12].

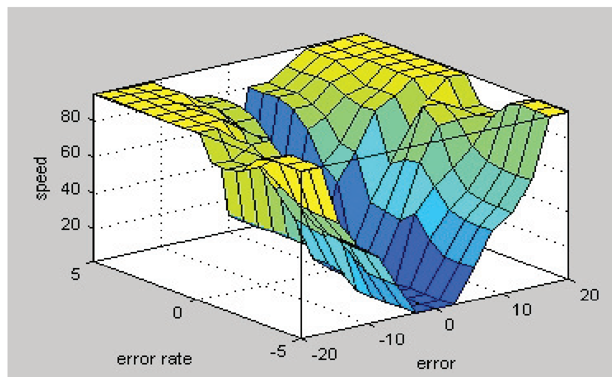


Fig. 6. Fuzzy output surface

The response of the robot with predefined values is depicted in the figure 7.

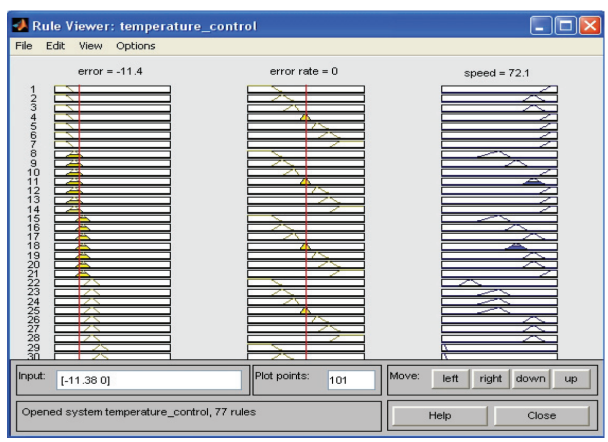


Fig. 7. 77 Rules.

When the robot is subject to a heat shock (about 20 °C), 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 in fig 6, so this part of the fuzzy program has the maximum effect on the response of the robot. As can be seen, the robot is able balance temperature rapidly, at about 78% speed fan, (Figures 8, 9).

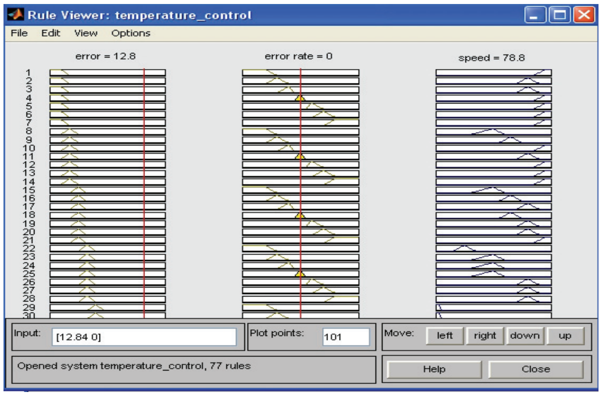


Fig. 8.77 Rules in Temperature decrease (about 15 °C)

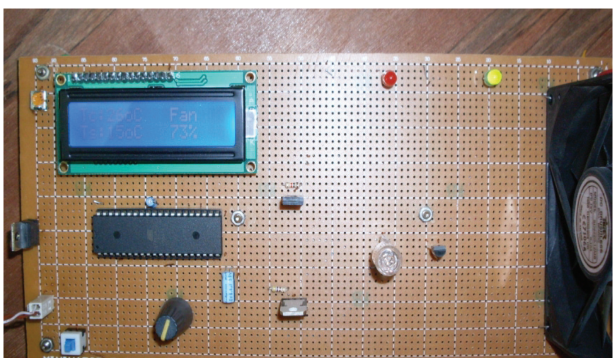


Fig. 9.Temperature shock at about 30 °C

Another experiment has been done to tune the fuzzy variables. When the robot temperature decreases (at about 10 °C), the controller is able to change its critical condition to stable condition as in fig 6. As can be seen, the robot is able to balance rapidly the temperature (at about 65% of the heater power), (Fig.10).

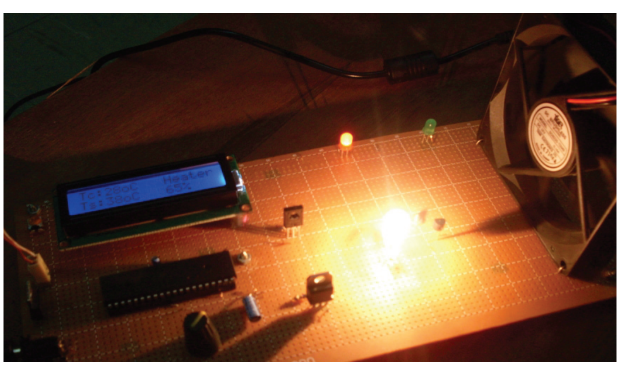


Fig. 10.Temperature decrease (about 15 °C)

Another experiment, when the robot in temperature decreases (at about 7 °C) at the left side of the robot, it is able to change its critical condition to a stable condition (Fig 6). 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 (40% Heater 1, 20% Heater 2, 3 & 5% Heater 4), (Fig.11).

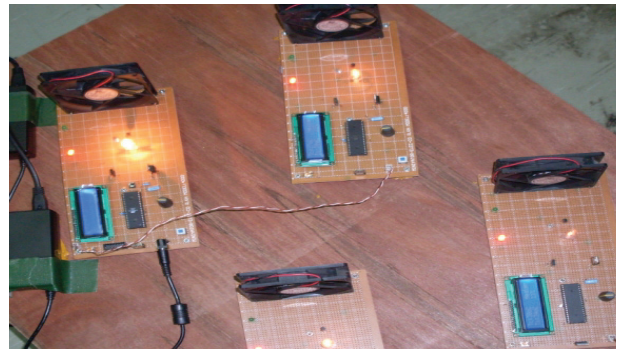


Fig. 11.Temperature decrease (about 10 °C)

VIII. Comments Regarding the Results

Throughout the work, simulations and experiments have been carried out to study the implementation of fuzzy logic for a temperature control system. The simulation also included the study on previous controllers which were state flow controllers. The performance of both types of control techniques were studied in detail. In a first step the user enters a set point temperatures which are greater than the current fan temperature and the heater system will be switched on and active unit current temperature in the fan will reach the set point temperature. Vice versa, if the set point is less than the current temperature appropriate changes will be done by the controller. For second step, fuzzy logic controllers are used to control blower speed. The larger range of temperature difference will result in the increase of the blower speed. If the difference is negative, it means that the set point temperature is less than the current temperature and therefore exhaust fans will be switched on. If the difference is positive, it the heater state will be switched on. When difference is zero both of the states will be switched off by the fuzzy logic controller and the desired state will be maintained until the user changes the values.

IX. Conclusion

In this research work, simulations and experiments have been carried out to study the implementation of fuzzy logic for a temperature control system. The performance of fuzzy logic and state flow controllers were studied in simulations outlining the advantages of the fuzzy logic for a temperature control system.

The proposed control system of temperature for exhaust fan with heater control system can also be later included for an optimized operation.

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