Microcontroller based Temperature Controller-implementation of Fuzzy Logic

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This work is in the area of soft computing (Fuzzy Logic) which is an advanced area of computation, which can be applied for control of complex systems wherein mathematical model is not available. Therefore an attempt has been made, to control the temperature of a water bath using Fuzzy Logic Controller. This controller is designed and fabricated (a prototype) using a new microcontroller PIC 16C74 with advanced RISC architecture from MICRO-CHIP. Suitable fuzzy rule base for the system has been prepared and implemented to control the temperature. In this a minimum hardware was required due to the capabilities of the processor. It is observed that the response of the Fuzzy Logic Controller is faster than the conventional PID Controller.

Keywords : Fuzzy logic temperature controller; Microcontroller with RISC architecture; PWM

NOTATION

FLC	: fuzzy logic controller
PID	: proportional integral derivative controller
RISC	: reduced instruction set computer
MIMO	: multi input multi output
PWM	: pulse width modulation

INTRODUCTION

Temperature is the most often-measured environmental quantity. This might be expected since most physical, electronic, chemical, mechanical and biological systems are affected by temperature. Some processes work well only within a narrow range of temperatures. Certain chemical reactions, biological processes, and even electronic circuits perform best within limited temperature ranges. When these processes need to be optimized, control systems that keep temperature within specified limits or constant are often used.

The field of process control has grown rapidly since its inception in the 1959s. It has become one of the core areas of chemical engineering. One of the most important process variables to be controlled is temperature of liquid in many chemical engineering Plants. In brief, how to control the temperature of a water bath is one of the industrial problems. Hence suitable temperature controller for controlling temperature of a water bath is very common requirement of the industries.

Conventional controllers used are as follows

1. On/Off Controller
2. Proportional Controller (P)
3. Proportional Integral Controller (PI)
4. Proportional Integral Derivative Controller (PID)

PID Controller is the present industrial standard, commonly used in temperature control systems. Proper PID control requires that the Proportional, Integral and Derivative settings be tuned accurately, which is not so easy task. Tuning of PID controller involves manual trial and error procedures and is time consuming. It is sometimes very difficult to tune for a few systems. It is also equally difficult or impossible to implement with multi input multi output systems. Also some processes behave in non- linear, complex ways, so that conventional PID controller cannot adequately control them.

Fuzzy Logic Control can cope with such complex problems. It does not depend on precise mathematical values and equations as the PID control does. Fuzzy Logic Controller (FLC) is good for most situations without any modification. It is easier to apply to MIMO systems because control algorithm relies on 'common sense' rather than classical modelling/tuning arbitrary (more or less) numbers fuzzy logic controllers (FLCs) have been reported to perform better than conventional PID controllers.

In this paper, the temperature of a water bath is controlled using fuzzy logic controller (FLC). The software is implemented using new microcontroller PIC 16C74 with advanced RISC architecture from Microchip.

DESCRIPTION OF THE PROCESS

The block diagram of the FLC Temperature Control System is shown in Figure 1.

The function of each block is discussed below.

- Water Bath

  This is a container with suitable inlet and outlet and stores water. The temperature of this water is to be kept constant at desired value.

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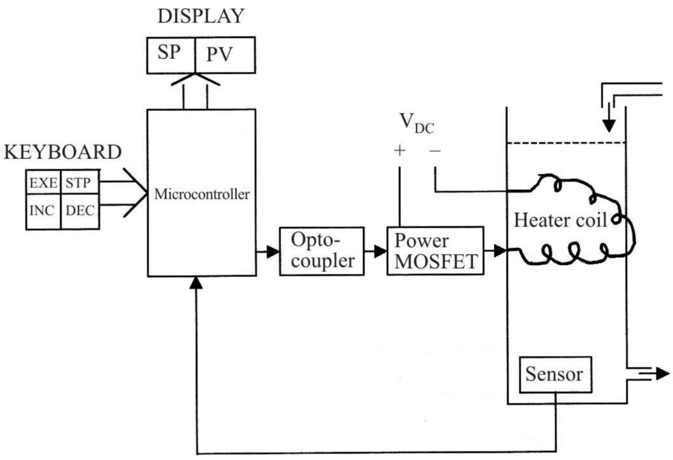

Figure 1 Block diagram of the FLC temperature control system for controlling the temperature of a water bath

- Temperature Sensor

  This is used for the measurement of the process variable, the temperature of the water inside the bath. The output of the sensor, which is proportional to the temperature, is fed back to the microcontroller for initiating necessary steps for taking proper control action.

- Microcontroller with Display and Keyboard Interfaces

  It is the heart of the system. It accepts the analog output of the temperature sensor and processes it further for getting the actual temperature value in digital form.

  The microcontroller is provided with a keyboard interface, which is used to select the controller mode and to input the set point. It allows for the operations such as increment, decrement, execute and stop required by the user.

  The display interface enables to display the set point and the actual temperature of the water.

  The microcontroller calculates the error and change in error. Then depending on the control mode selected, it uses either Fuzzy or PID algorithms from the software to generate the control signal. This control signal is in the form of PWM output.

- Opto-coupler

  It optically couples the PWM output to the Power MOSFET by providing electrical isolation between the two stages.

- Power MOSFET

  It is a switching device through which the required power is delivered to the heater.

- Heater

  The heater coil surrounding the water bath assembly is used to heat the water.

This is general description of the temperature control system for controlling the temperature of water bath. The hardware details are discussed in the Appendix-1 alongwith the circuit diagram.

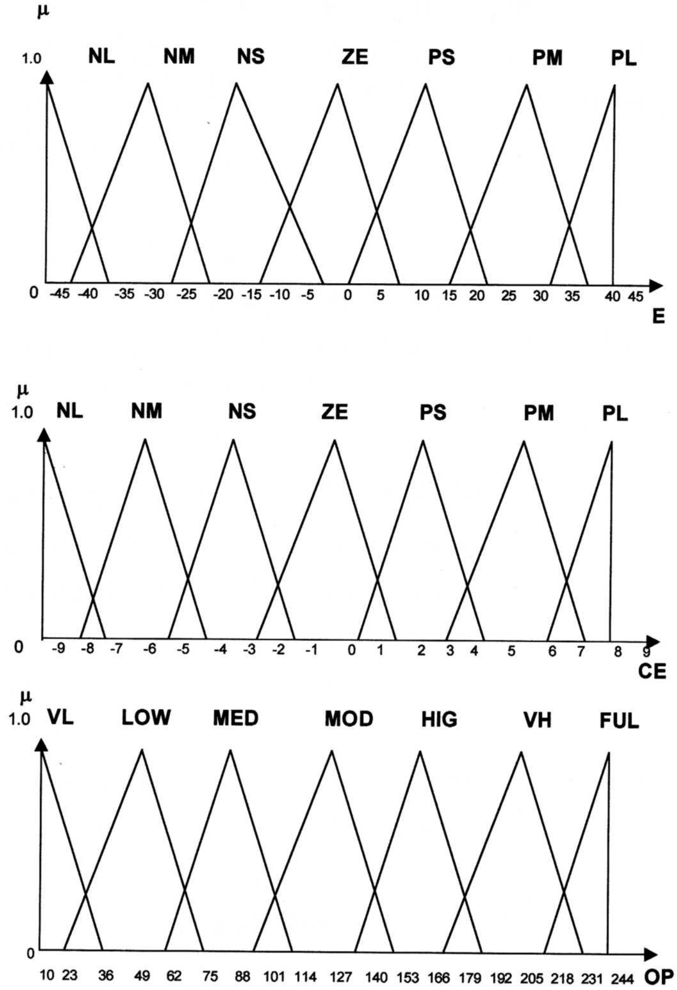

Figure 2 Membership functions of input and output variables

DESIGN OF FUZZY LOGIC

The input variables error and change in error are given as follows.

ERROR = SET POINT - CURRENT TEMPERATURE

ie, E = SP - CT

and CHANGE IN ERROR = CURRENT ERROR – PREVIOUS ERROR

ie, CE = CC – PE

The software is written in assembly language. The input variables are fuzzified, the control rules are evaluated and defuzzified output (computed using Mean-Max Membership Method) is given to the PWM module inside the controller chip. The output variables is the output of the PWM module, which is the control action.

The crisp variables are converted into linguistic variables with a process fuzzification. The input and output variables are divided into seven different ranges, each range corresponds to a linguistic variable. The plot of membership functions is shown in Figure 2.

The table of rules, called rule base is prepared which is based on the experts knowledge. This rule base is the backbone of this

CE/E	NL	NM	NS	ZE	PS	PM	PL
NL	VL	VL	VL	VL	VL	VL	LOW
NM	VL	LOW	VL	VL	VL	LOW	LOW
NS	VL	VL	MED	LOW	LOW	VL	VL
ZE	VL	LOW	LOW	MOD	MED	MED	MOD
PS	MED	MED	MOD	MOD	HIG	HIG	VH
PM	HIG	HIG	HIG	VH	VH	FUL	FUL
PS	VH	VH	FUL	FUL	FUL	FUL	FUL

Input Variables	Output Variables
NL — Negative Large	VL — Very Low
NM — Negative Medium	LOW — Low
NS — Negative Small	MED — Medium
ZE — Zero	MOD — Moderate
PS — Positive Small	HIG — High
PM — Positive Medium	VH — Very High
PL — Positive Large	FUL — Full

Figure 3 Rule base

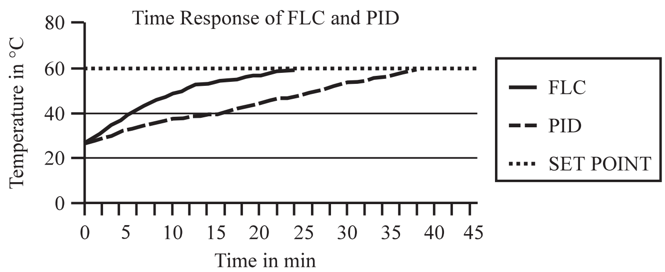

Figure 4 Time response of FLC and PID

system according to which the whole system is operated and the temperature is controlled. The rule base is shown in Figure 3.

For example, one rule out of the 49 rules can be explained as

IF ‘E’ IS NM AND ‘CE’ IS PM THEN ‘OP’ IS HIG.

The Fuzzifier, gives the degrees of membership values and the knowledge base, gives the corresponding output linguistic variable. The fuzzy output variable is converted to crisp value by the process of defuzzification. The defuzzified output is the fed to the further circuit to obtain the control signal.

RESULTS

The implementation of FLC and PID controller has been carried out through software. The time response of Fuzzy Logic Temperature Controller and PID Temperature Controller while controlling the temperature of a water bath is plotted in Figure 4.

CONCLUSIONS

Following conclusions are drawn.

(1) It is observed that the Fuzzy Logic Controller is faster than the conventional PID Controller.

(2) The FLC is useful in reaching the set point faster whereas the PID Controller is useful for maintaining the process variable value at the set point.

(3) Fuzzy Logic Controllers are much closer in spirit to human thinking and decision-making.

(4) FLC can be designed even when the understanding of the system is incomplete, *ie* on situation when it is difficult to construct the mathematical model of the system.

(5) FLC is easier to prototype and implement for most systems without any modifications.

(6) The microcontroller PIC 16C74 with advanced RISC architecture has very powerful set of instructions. The excellent features of this IC, especially the in built PWM module, make it very useful in designing a compact controller.

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APPENDIX I

HARDWARE DETAILS

General Description of Microcontroller PIC 16C74

The general description of this IC is given below.

The PIC 16C74 is a low-cost, high performance, CMOS, fully static, 8-bit microcontroller with integrated analog to digital converter (ADC). It employs an advanced Reduced Instruction Set Computer (RISC) architecture. It has enhanced core features, eight-level deep stack, and multiple internal and external interrupt sources. The separate instruction and data buses of the Harvard architecture allow a 14-bit wide instruction word with the separate 8-bit wide data. The two-stage instruction pipeline allows all instructions to execute in a single cycle, except for program branches, which require two cycles. A total of 35 instructions (reduced instruction set) are available. Additionally, a large register set gives some of the architectural innovations used to achieve a very high performance.

PIC 16C74 microcontroller typically achieve 2 : 1 code compression and a 4 : 2 speed improvement over other 8-bit microcontrollers in its class.

It is a 40-pin chip. It has 192 bytes of RAM and 33 I/O pins. In addition several peripheral features are available including three timer/counters, two Capture/Compare/PWM modules and two serial ports. The Synchronous Serial Port can be configured as either a 3-wire Serial Peripheral Interface (SPI) or the two-wire Inter-Integrated Circuit (i^2C) bus. The Universal Synchronous Asynchronous Receiver Transmitter (USART) is also known as the Serial Communications Interface or SCI. An 8-bit Parallel Slave Port is provided. Also an 8-channel high-speed 8-bit ADC is provided. The 8-bit resolution is ideally suited for applications requiring low-cost analog interface, *eg*, thermostat control, pressure sensing, etc.

Across pin numbers 13 and 14, a crystal X_1 of 3.58 MHz is connected which is used to generate the clock signal for the IC.

At pin number 5 analog reference voltage required for ADC operation can be adjusted by the trim-pot arrangement. It is set to 1.28 V.

Pin number 1 is the master CLEAR or RESET input of active low type. Since it is not used, it is tied to + 5 V through pull-up resistor.

Pin numbers 6, 15, 18, 23 and 24 are not used.

Keyboard Interface

The keyboard consists of four NO type PCB mounted keys. Pin numbers 27, 28, 29 and 30 of PORT D, which is a bi-directional I/O port, are connected with the keyboard. The functions of the keys are as follows.

(1) To select the mode of operation.

This is done by using either INC or DEC keys to display proper code for a particular mode. The codes are as follows.

Display Code	Mode of Operation
22	Fuzzy Control
44	PID Control
88	Transfer Function

After the proper code is displayed, pressing the EXEC key activates the particular mode of operation.

(2) To decide the set point.

The default set point displayed is 60°C. Required value can be chosen by using INC or DEC keys. Pressing of EXEC key twice starts the operation.

(3) To stop the operation.

This is done by the STOP key.

Display Interface

A 4-digit seven-segment LED display (Common Anode type LT 542 × 4), is used in multiplexed mode.

The digit selection is done through PORT B pins 37, 38, 39, 40 (RB4 to RB7). These pins are connected to the common anodes of each display through transistor BC547.

The data to be displayed is made available pin nos 19, 20 21, 22 (RD0 to RD3) of PORT D. These pins are connected to A, B, C, D of the BCD to Seven segment Decoder and Driver IC 7447. The seven segments a to g of all the displays connected together are connected to the decimal output pins 13 to 9 and 15, 14 of IC 7447. Pin nos 3, 4 and 5 are not used and therefore connected to + 5*V*.

Temperature Sensor

The temperature sensor used here is LM35 from National Semiconductor Corporation. It is precision integrated-circuit temperature sensor, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. This is an advantage over linear temperature sensors calibrated in °K, as the user is not requied to subtract a large constant voltage from its output to obtain convenient centigrade scaling. It does not require any external calibration or trimming to provide typical accurcy of ± 3/4°C over a full − 55°C to + 150°C temperature range. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It has linear characteristics with a scale factor of + 10 mV/°C. The sensor is fixed into the top of the water bath assembly so as to dip into the inside water.

Here, it is operated with a dc supply of + 5 V. the output of the sensor is given as a input at pin no 2, which is RA0 or analog input0 of PIC16C74.

Opto-coupler

The PWM output1 at pin no 17 of PIC16C74 is the control signal generated and it is applied as input to the opto-coupler. Here phototransistor opto-coupler IC MCT2E is used. The MCT2E is a NPN silicon planar phototransistor optically coupled to a gallium arsenide infrared emitting diode. This stage optically couples the signal to the next stage by providing electrical isolation between the two stages.

Power MOSFET

The power MOSFET IRF150 from International Rectifiers is used to switch required amount of power across the heater.

Water Bath

The water bath assembly fabricated has a capacity of storing about 1.5 liters of water.

Heater

The heater used for heating of water in this prototype has specifications of 2.5Ω and 400 W. The heater coil surrounds the water bath assembly to deliver heat indirectly.

Power Supply

For getting regulated power supply of + 5 V and + 12 V, voltage regulator ICs LM7805 and LM7812 are used respectively.

The dc dupply of 25 V/20A for heater is derived from the transformer 0-30 V/20 A and suitable bridge rectifier and capacitor filter.

Miscellaneous

Pin nos 33 to 36 (RB0 to RB3) of PIC 16C74 are used to drive the relays.

Pin nos 26 and 25 are the USART Asynchronous Receive and Transmit respectively, connected to IC MAX 232 to allow for RS232 serial interface for the external device, which is not used presently.

APPENDIX II

DESIGN OF PID CONTROLLER

For comparing the response of FLC with the conventional technique, a PID Controller has been implemented through software and the responses of both were plotted. The design of PID Controller is discussed below.

The PID Controller in digital form can be represented by a difference equation. The steps involved in the formation of this difference equation for the given system is discussed below.

(1) The open loop step response of the process is plotted by applying a step input of about 255 W (25 V dc and 2.5 Ω). The plot is shown in Figure II-1. Following observations are made.

(i) Steady-state change in output = 89°C

(ii) Process Gain $K = \dfrac{89}{255} = 0.349$°C/W

(iii) Dead-time θ = 1 min

(iv) Time constant τ = 17 min

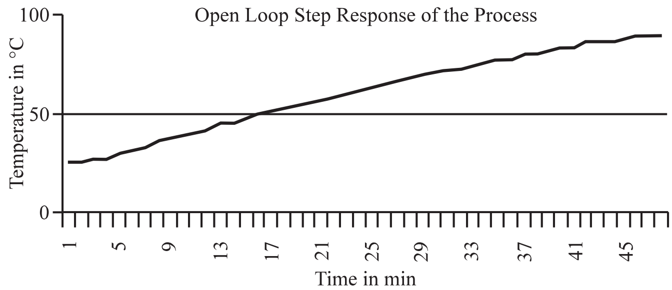

Figure II-1 Open loop step response of the process

(2) Therefore, the transfer function of the process is given by

$$G(S) = \frac{Ke^{-\theta s}}{\tau s + 1}$$

$$G(S) = \frac{0.349\, e^{-s}}{17\, s + 1}$$

(3) The controller settings are determined by Zieglar-Nichols method

$$K_P = \frac{1.2\,\tau}{K\,\theta} = 58.45,\ K_I = 1/2\theta = 0.5,\ K_D = 0.5\,\theta = 0.5$$

(4) The difference equation is

$$u(k) = u(k-1) + \left[K_P + \frac{K_I\,Ts}{2} + \frac{K_D}{Ts}\right] e(k) -$$

$$\left[K_P - \frac{K_I\,Ts}{2} + \frac{2K_D}{Ts}\right] e(k-1) + \frac{K_D}{Ts}\, e(k-2)$$

Putting values gives

$$u(k) = u(k-1) + 89\, e(k) - 118\, e(k-1) + 30\, e(k-2)$$

Since $\frac{u(k)}{255} = \frac{t_p(k)}{255}$

where $t_p(k)$ is the output pulse width, which can be expressed in terms of $t_p(k)$ as follows

$$t_p(k) = t_p(k-1) + 89\, t_p(k) - 118\, t_p(k-1) + e(k-2)$$

This difference equation represents PID Controller and has been implemented through software.