Design and Development of Temperature Control System for Photoacoustic Studies

*Sapna[1], P. Bhaskar[2]

[1]Research Scholar, Dept. of Instrumentation Technology, Gulbarga University, P.G. Centre, Raichur, KA, India

[2]Professor, Dept. of Instrumentation Technology, Gulbarga University, P.G. Centre, Raichur, KA, India

Abstract - ***In the photoacoustic(PA) spectrometer applications, temperature control system is essential to study the phase transition of the samples as a function of temperature. In this paper, an attempt is made to design & develop C8050F020 microcontroller based temperature control system for photoacoustic spectrometer. The algorithm is developed in embedded 'C' in KIEL µV4 IDE. The temperature of the PA cell is measured by using Pt-100 temperature sensor. The temperature of the PA cell is controlled by using PID algorithm. Phase angle firing control technique is employed to control the power applied to the heater. The phase angle is controlled by the on-chip timer of the microcontroller. The PID controller is tuned to the best values to obtain desired output. The present temperature control system increases the temperature of the PA cell at the rate of 0.1^0 C/Min. This heating rate is enough to detect the phase transitions of the samples.***

Keywords: Temperature, PID, PAS, KIEL, C8051F020.

I. INTRODUCTION

Temperature is one of the most widely measured and frequently controlled physical variables in the industry. This is because quite often the processing and manufacturing of the desired product is possible only if the temperature is accurately measured and maintained. Further, it forms an important governing parameter in thermodynamic heat transfer and a number of chemical reactions/operations. The need for temperature control arises in various fields such as medical, biological, industrial, frequently in basic scientific research and R&D laboratories. Many physical and chemical reactions are sensitive to temperature and consequently, the temperature control is important in several industrial processes. Temperature control also finds application in cryostats that are used to perform experiments at very low temperatures in the field of spectroscopy, X-ray diffractometry and optical microscopy. Temperature control plays a key role in many industrial processes; in addition, precision and quality in control of temperature is desirable. Hence, several investigators [1-8] have designed and fabricated different types of temperature controllers. But the attempts to use microcontroller with improved features like C8051F020 microcontroller to control temperature are rather scarce in spite of several advantages that are associated with the use of such microcontroller.

Principle: The block diagram of microcontroller based temperature controller is shown in Fig 1.0. The temperature of the photoacoustic cell is sensed by Pt-100 and the output of the sensor is suitably modified using a signal conditioner. The signal conditioner produces an analog voltage which is converted into digital data by on-chip A/D converter of the microcontroller. The microcontroller computes the error by subtracting the measured temperature from the desired temperature (set point). Then the PID equations are solved by the microcontroller.

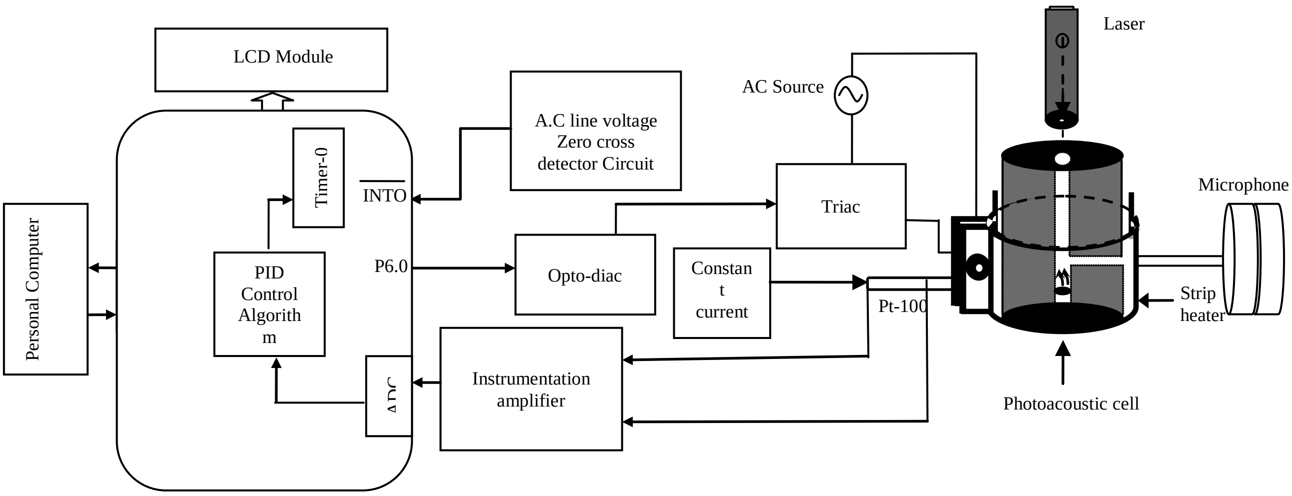


Fig. 1 Block diagram of C8051F020 microcontroller based temperature control system

The output of control program is a digital data which is used as a count value for the on-chip timer, when the timer interrupt occurs the TRIAC is switched ON through P6.0 and opto-diac. The amount of heat, added to or removed from the strip heater connected to the PA cell is decided by the ON-time of the PWM signal generated by the timer. The process is repeated till the desired temperature is attained. After reaching the desired temperature, the set-point is linearly incremented by 1° degree, and then above process is repeated. This gives linear increase in temperature of PA cell up to the desired range as specified in the program.

II. TEMPERATURE CONTROL SYSTEM

Hardware features:

The schematic diagram of microcontroller based temperature control system is shown in Fig 2.0 and the photograph of the system designed and fabricated is shown in Fig 2.1. The system consists of the following elements.

- Temperature Sensor
- Constant current source
- Instrumentation amplifier
- Microcontroller board
- Zero-crossing detector
- Opto-isolator
- Final control element.

2.1 Temperature sensor

The platinum resistance thermometer is used for the present study to overcome the significant limitations of the conventional transducers such as non-linearity, low output, narrow range etc, Pt-100 operates on the principle of change in electrical resistance of platinum wire as a function of temperature [9-10] it is mechanically and electrically stable. One of the important features of Pt-100 is that the relation between temperature and resistance is linear, the drift error with ageing and usage are negligible.

The relation between temperature and resistance of the platinum wire is given by the following relation

$$RT = Ro\,(1 + AT + BT^2)$$

Laser Source

$$\approx Ro\,(1 + AT) \qquad \text{--------- (i)}$$

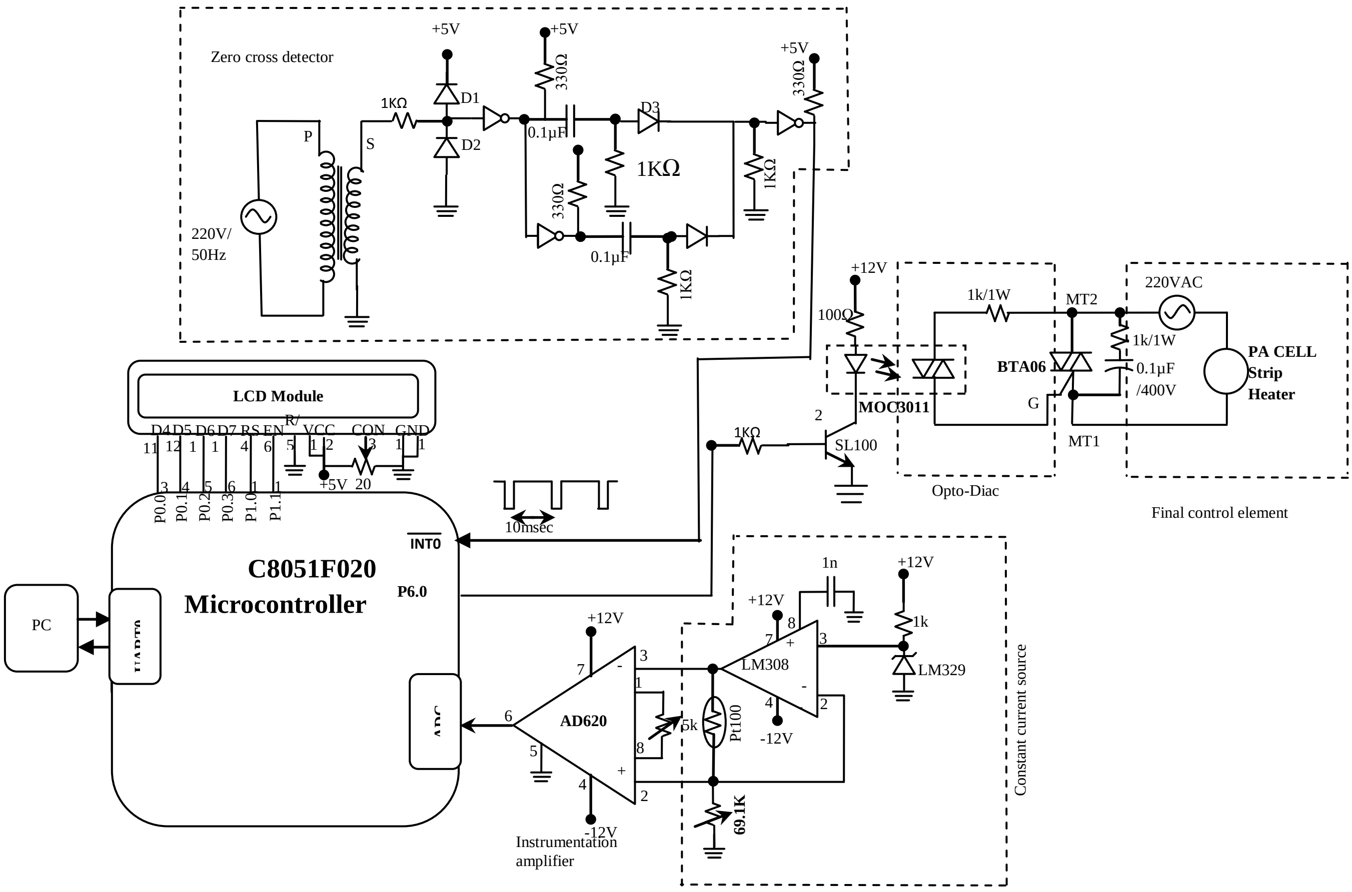


Fig. 2.0 Complete schematic of microcontroller based temperature control system

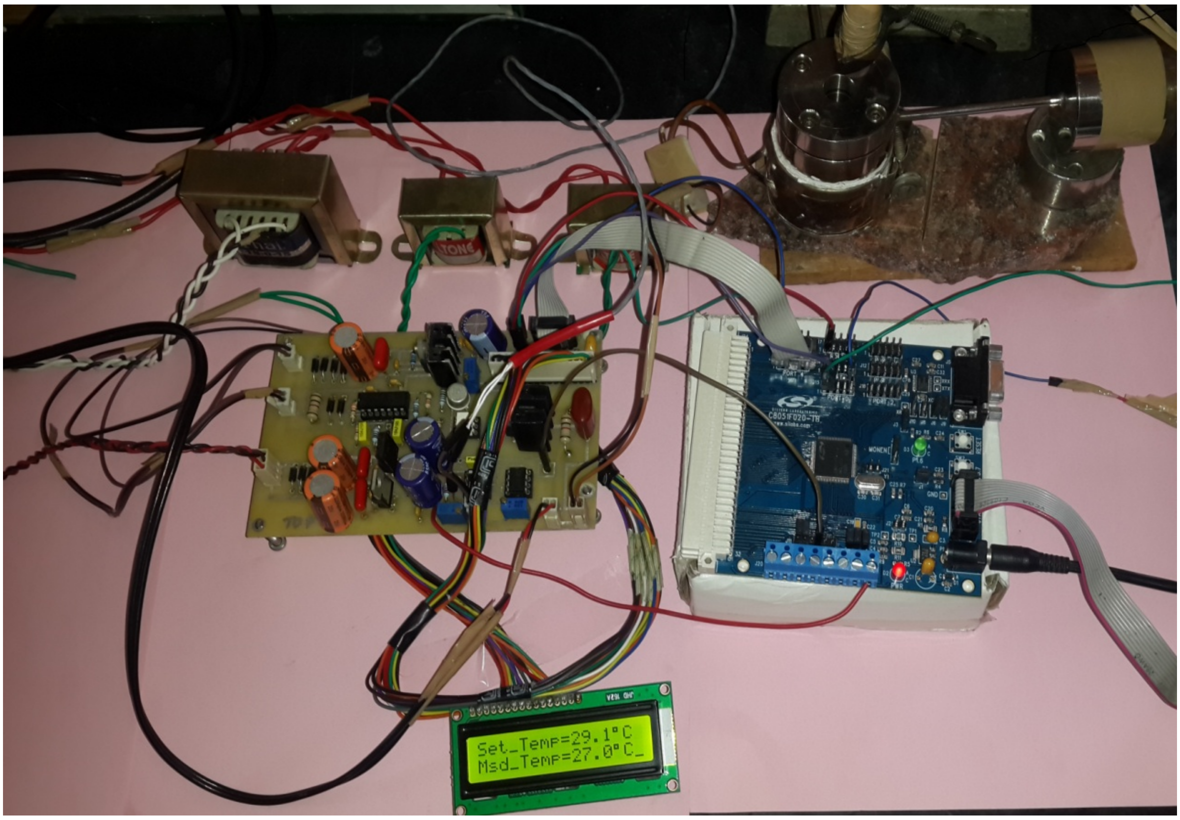


Fig. 2.1 Photograph of microcontroller based temperature control system

where all the second and higher order terms are negligibly small. The platinum resistance transducers are used for temperature measurement in the range of – 220^0 C to 750^0C and it has a temperature co-efficient of resistance as 0.0 389 Ω / ^{0}C.

R=V/I = 6.9V/100µA = 69.0k ---- (ii)

2.2 Constant current source

The signal conditioning circuit is employed for converting resistance changes of the sensor into voltage changes. A constant current source has been designed using operational amplifier [11]. This will eliminate the lead-wire error of Pt-100. A stable voltage sources is constructed using LM329 that gives a constant voltage of 6.9V. This reference voltage is applied to the non-inverting input of op-amp. The Pt-100 acts as a feedback resistance and the resistance R_s determines the amount of current flowing through Pt-100. Since the potential difference between input terminals of the operational amplifier is zero. Hence the voltage at the inverting terminal is also equal to 6.9V. Therefore the current flowing through the resistance (R_s) is equal to $6.9/R_s$. Since the input impedance of the amplifier is very high, the current flowing through Pt-100 is equal to the current flowing through resistance R_s. R_s can be calculated by the equation (ii)

A 100K multi-turn potentiometer is used as R_s and it is adjusted to the value 69.0K this gives a constant current of 100 µ*A*. The current should be as small as possible to avoid the self heating of the sensor.

2.3 Instrumentation Amplifier

When the current passes through the temperature sensor Pt-100, it produces a differential voltage given by the following relation

ΔV= 100µA * (Resistance of Pt-100)

The differential voltage output of temperature sensor is very small, hence it has to be amplified so that further processing of signal can be made possible this voltage is amplified through a differential amplifier AD620 of Analog Device [12] make. The AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set gain of 1 to 10,000. Further, more AD620 features 8-lead DIP packaging it offers lower power (only 1.3mA max current) making it good fit for battery powered portable (or remote) applications.

2.4 C8051F020 microcontroller Board

The microcontroller used for the present study is C8051F020TB from cygnal Integrated products, Inc., Austin, USA. The photograph of C8051F020TB is shown in Fig 3. The microcontroller contains high-speed pipelined 8051-compatible Cip-51 Microcontroller core (up to 25 MIPS), 12-bit 100 Ksps 8-channel ADC, 12-bit DACs with programmable update scheduling, 64k bytes programmable FLASH memory, 4352 bytes of on chip

RAM, and two UART serial interfaces implemented in hardware, Five general-purpose16-bit timers and 64-Digital port I/O's.

Fig 3.The photograph of C8051F020TB microcontroller board

2.5 Zero cross detector

The circuit diagram of zero crossing detector is presented in Fig.2. The 12V transformer followed by the resistor and diodes produces a square wave at the input of an inverter A, which is synchronized with the ac line voltage but restricted to legal TTL levels. The RC and diode networks around the outputs of inverters A and B form positive differentiators. These differentiators produce a positive spike at every zero crossing of the ac mains. The 7405 is an open collector hex inverter provided to assure adequate drive current for the differentiator and the opto-isolator MOC 3010. At each zero crossing of the line, inverter C pulses and these pulses will interrupt microcontroller. At every interrupt the count from the output of PID is loaded into the on-chip timer-0 of the microcontroller. Then the counter decrements at every clock pulse until the count loaded in the timer-0 overflows at the rate decided by the on-chip clock i.e. 2MHz. This produces the pulse width modulated output to control the triac which in turn controls the power applied to the heater connected to the PA cell.

2.6 Opto-isolator

To isolate the AC power from DC powered boards, an opto-isolator MOC3011, of Motorola make is used. The MOC3011 contains LED and an opto-diac. The opto-diac conducts in both the directions of ac cycle and it triggers triac in both positive and negative cycle of ac signal in accordance with PWM signal.

2.7 Final control element

The final control element is nothing but an actuator which controls the power or energy supplied to the system to bring the physical parameter to the desired level. In the present study, a triac (BTA06) is used as final control element. Triac can conduct in both directions and is normally used in ac phase control. It can be considered as two SCRs connected in anti-parallel with a common gate connection. Since, triac is a bidirectional device its terminals cannot be designed as anode and cathode hence designated as MT1 and MT2. If terminal MT2 is positive with respect to terminal MT1, the triac can be turned ON by applying a positive gate signal between gate G and terminal MT1. It is not necessary to have both polarities of gate signal and triac be turned ON with either a positive or negative gate signal. Here, the triac acts as a switch. When it is OFF, no power is allowed to pass through it to the load. When it goes ON, the load receives line voltage. This is quite adequate for simple ON or OFF operations.

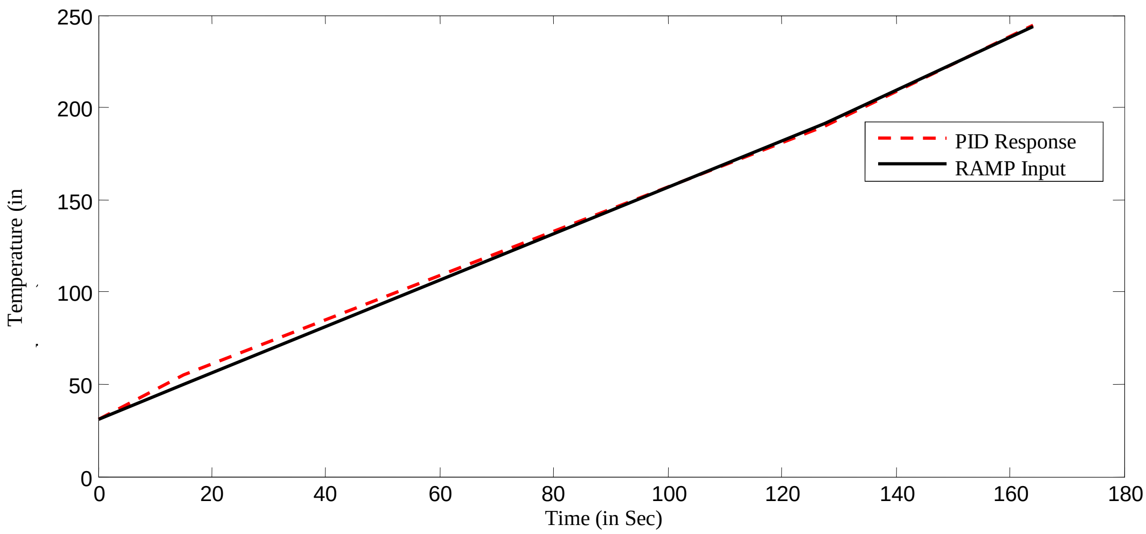


Fig. 4. PID controller response for ramp input

But to provide proportional control of power to the load, phase angle firing control technique has been employed. The firing angle is decided by the output of PID controller. With the help of zero cross detector the power applied to the heater (PA cell) is synchronized with line voltage, the timer is used to control the power based on the PID output.

I. WORKING OF THE SYSTEM

The temperature of the photoacoustic cell is measured by using Pt-100 temperature sensor. Pt-100 produces change in resistance with change in temperature. This change in resistance is converted into change in voltage by using constant current source. The voltage corresponds to temperature is converted into digital data by the on-chip ADC of C8051F020 microcontroller. The digital data is converted into actual temperature by substituting it in the equation

Temperature = (2.657*voltage)-273.0.

Derived from the temperature v/s output voltage graph of Pt-100 ($y = mx+C$). The present temperature of the photoacoustic cell is displayed on the LCD module. The microcontroller compares the actual temperature with the set value and error is calculated. Then error is applied to the PID control algorithm. The control algorithm is implemented by writing embedded 'C' program. The output of the algorithm is fed into on-chip timer-0. The output from P6.0 of the microcontroller is connected to the opto-isolator (MOC 3010) which controls the firing angle of the triac. The firing angle is decided by the count in the timer-0 of the microcontroller which is proportional to the solution of PID equation. The usual method of controlling an alternating voltage (ac mains) is to vary the firing angle of triac. The small count in the timer-0 takes large time to overflow, this produces small conduction angle (and hence small ON-time) and a small output power to the load conversely a large count in the timer-0 will take less time for counter to overflow causing a large conduction angle (large ON time). Hence, larger power is applied to the load. This variation in duty cycle controls the firing angle of the triac and hence an amount of energy supplied to the heater. Thus the later maintains the temperature of the photoacoustic cell at the desired value. The PID temperature controller designed is found to regulate the temperature of the photoacoustic cell with in ±0.1°C.

II. RESULTS & DISCUSSION

The PID controller is implemented to control the temperature of the photoacoustic (PA) cell to study the amplitude and phase variations in the samples. A ramp input is applied to the PA cell where the temperature is varied from initial room temperature of 25.00 °C to final temperature of 250.0 °C with a slope of 0.1°C/Min. The PID response with respect to ramp input is shown in the Fig. 4. It is quite evident from the graph that, the controller exhibit good tracking response with linear characteristics.

SOFTWARE FEATURES :

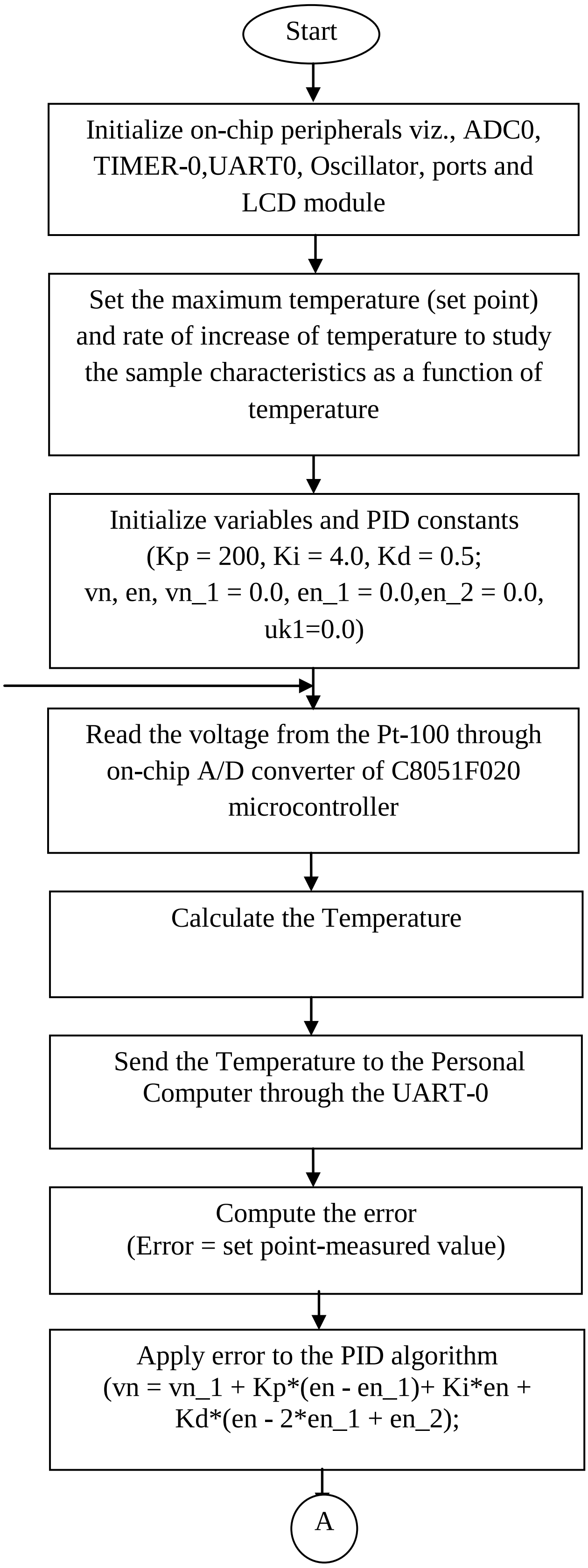
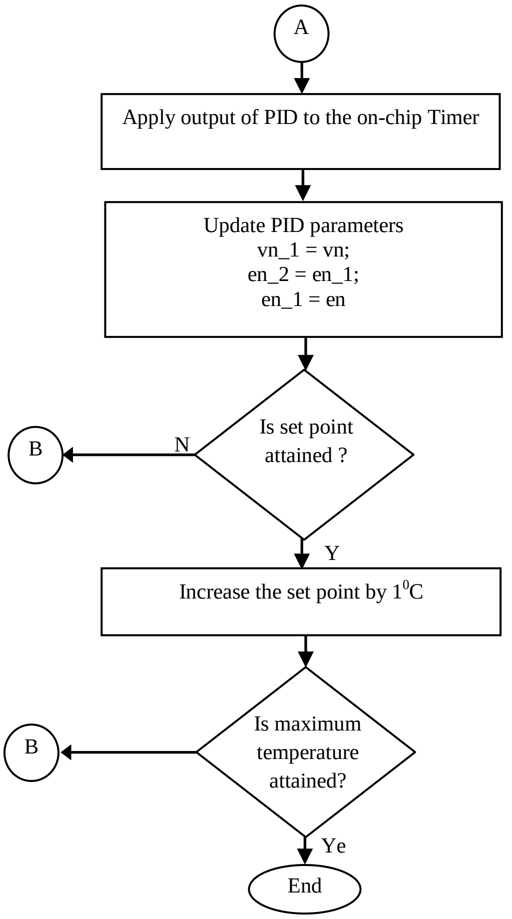


Fig. 5 Flowchart of temperature control system



V. CONCLUSION

In the present work C8051F020 microcontroller based temperature control system for the photoacoustic studies is designed and fabricated. The presently designed temperature control system exhibits good tracking response their by precise control of temperature is achieved. The temperature is varied at the rate of 0.1^{o}C/Min and can be employed for phtoacoustic spectrometer applications.

REFERENCES

[1] V. Natraj, C. Nagaraja Murthy and M.V. Lele, J *Instum.Soc. India*, vol. 21, no. 1, pp.28-35, 1995.

[2] E.J.Kompass, *Control Engineering*, vol.36, no. 9, pp.155-158, 1989.

[3] L.S. Smith, *Conf. on Computer Control of Real-Time Processes*, USA, 1990.

[4] B.N. Chatterji, "PID Contollers," *Students'J. IETE*, vol.35, nos.3 & 4, pp. 169-175, 1994.

[5] R. Yusof, S. Omattu, and M. Khalid, in *Proc. of the 3rd IEEE conf. on Control Applications,* vol. 2, pp.1181-1186, USA, 1994.

[6] W. Daca, and B. Wilkowska, in *Proc. of the 2nd Int. Symp. on Methods and Models in Automation and Robotics*, vol. 2, pp. 837-840, Poland, 1995.

[7] S. Kaliyugavaradan, in Proc. of the IECON'97 23rd Int. Conf. on Industrial Electronics Control and Instrumentation, vol. 1, pp. 155-158, 1997.

[8] Dun Wang, Zhiniu Huang, Guobang Chen, Jianyao Zheng, Jiangping Yu, Yayu Li, Min Shen, Hongyan Chen, Ruiliang Xu, Guang Wen Cui & Ruimin Liu, in Proc. of the 6th Int. Cryogenic Engineering Conf., vol. 1, pp. 77-80, UK, 1997.

[9] J. Michael Jacob, Industrial Control Electronics – Applications and Design, PH, England Cliffs, 1988.

[10] Christopher T. Kilian, Modern Control Technology – Components and Systems, West Publishing Co., 1996.

[11] P. Bhaskar, "Design and Development of computer based instrumentation system for photoacoustic studies", Ph.D. Thesis, SKU, Anantapur, AP, India, 2000.

[12] www.analog.com/en/spciality-amplifiers/Instrumentation-amplifier/ad620 /products/product.html

[13] Michael Jacob J. "Industrial control electronics- applications and design", Prentice Hall, England Cliffs, 1988.

[14] Bhagyajyothi, "Studies on Development of Advanced version Lock-in Amplifier", Ph.D.Thesis, GUG, Raichur, KA, India, 2014

[15] www.ti.com/product/lm311-n.

BIOGRAPHY

Sapna completed her M.Sc. and M.Phil in Instrumentation Technology, from Gulbarga University. Presently, she is pursuing Ph.D. under the guidance of Dr. P. Bhaskar, Professor, Department of Instrumentation Technology, Gulbarga University Post Graduate Centre, Raichur. She has published 2 papers in journals of national/international repute and presented 2 papers in national/ international conferences.

P. Bhaskar received the M.Sc., M.Phil., and Ph.D. degrees in Instrumentation from Sri Krishnadevaraya University, Anantapur, AP, India, Currently, he is a Professor in the Department of Instrumentation Technology at Gulbarga University Post Graduate Centre, Raichur, KA, India. He has published more than 52 papers in journals of national/international repute and presented over 22 papers in national/ international conferences. He has also authored a book on 8051 microcontroller. His research interests include Scientific Instrumentation, Embedded Systems, and Intelligent Control Systems. He is a member of the Instrument Society of India.