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An Embedded Based Digital Controller for Thermal Process

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Abstract: This paper describes a low cost virtual instrumentation (VI) system to monitor and control the electrically heated water bath temperature. The PIC16F877 based digital microcontroller is used as thermostat which controls and monitors the temperature. The digital controller also allows the user to modify the sensor (PT100) calibration data values if necessary. The developed programmable on/off control function provides on-line display of measuring temperature, set point as well as the control function output plots through the parallel port. This bus interaction is realized in Visual Basic/Assembly Language and uses a 16 bit, 10 μs sampling analog-to-digital converter (ADS 7805) for monitoring and controlling the parameters of the temperature local digital controller.

Keywords: Embedded based digital controller, PIC16F877, Virtual instrumentation, Temperature

1. Introduction

PC based data acquisition systems (DAQ) and plug-in boards and multi-chip sensor boards are used in a wide range of application. Typically, general purpose DAQ plug-in boards are used for measuring analog and digital input and output voltages [1-3]. Controlling the temperature is a classic problem studied in the field of Control Engineering, with various industrial or educational applications. To day, digital controllers have become a vital part of all automatic and semi-automatic machines. The architectural changes in instrumentation and control systems were and are due to the computing and communication capability of the digital controller devices. The advent of intelligent devices like microprocessors provides the ability to implement advance control algorithms/functions in software

using computers. The available software packages and PCs at low cost have enabled the concept of virtual instrument (VI) for measurement and automation of scientific experiments. In order to maintain the desired state of slow and optimal processes we need to keep constant, at prescribed values, such variables as flows, pressures, levels, temperatures, concentrations etc., which demands the design of automatic control systems for them. On the one hand the control systems for these variables differ from one another through their structure and behavior in dynamical state. On the other hand, the automatic control of one of these variables presents, in principle, the same problems, no matter what the process associated with it is, therefore the control systems are treated as subclasses associated with these physical measures: flow, pressure, level, temperature or concentration.

The objective of this paper is to describe a cost effective embedded based digital controller to monitor and to control the electrically heated water bath temperature. The controller is built around the PIC16F877 on microcontroller board. The digital controller provides three primary functions: controlling locally the process functioning as thermostat, reading as well as displaying the digital temperature from the PT100 sensor and maintaining parallel communication with a computer. This system includes a cost effective design solution with minimum hardware and maximum support of software to achieve a user-friendly virtual instrumentation based programmable temperature controller, to control temperature range from -200^o C to 850^o C, with menu driven support for selection of the control functions. The advent of embedded based digital controller combined with user friendly software program assures desired performance, simplicity, flexibility and reliability for temperature monitor and control.

2. Materials and Methods

The digital controller board consists of three modules. The first module PIC16F877 microcontroller is a high performance RISC CPU with low power consumption, 8k words Flash program memory, 368 bytes of data memory (RAM) and 256 bytes of EPROM data memory, Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation, three timers (two 8 bit and one 16 bit), Two Capture (16 bit, max. resolution is 12.5 ns) and Compare (16 bit, max. resolution is 200 ns), PWM modules and a Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection. The second module is Platinum Resistance Thermometers (PRTs) which offer excellent accuracy over a wide temperature range (from -200 to +850 °C). The principle of operation is to measure the resistance of a platinum element. The most common type (PT100) has a resistance of 100 ohms at 0 °C and 138.4 ohms at 100 °C. There are also PT1000 sensors that have a resistance of 25 ohms and 1000 ohms respectively at 0 °C and these sensors offer an accuracy of ±0.3 °C at 0 C. The microcontroller also reads the temperature binary from the sensor. The third module is parallel port transmission/reception, with ADS 7805 which is a 16-Bit 10μs sampling CMOS analog-to-digital converter. The digital controller is connected using parallel port to a personal computer on which the instrument application runs. Desired temperature (reference) is introduced using a computer keyboard locally. This value is transmitted using the parallel port from the computer to the digital controller. The source code for the microcontroller is written in assembly language and front panel is designed using Microsoft Visual basic. The photocopy of overall experimental system is shown in Fig. 1.

The electronic circuit of the microcontroller board circuit and printed circuit board (PCB) is obtained using Diptrace and EasyPCB application. The circuit diagram and components are shown in Figs. 2 and 3 respectively.

Fig. 1. Digital controller experimental system.

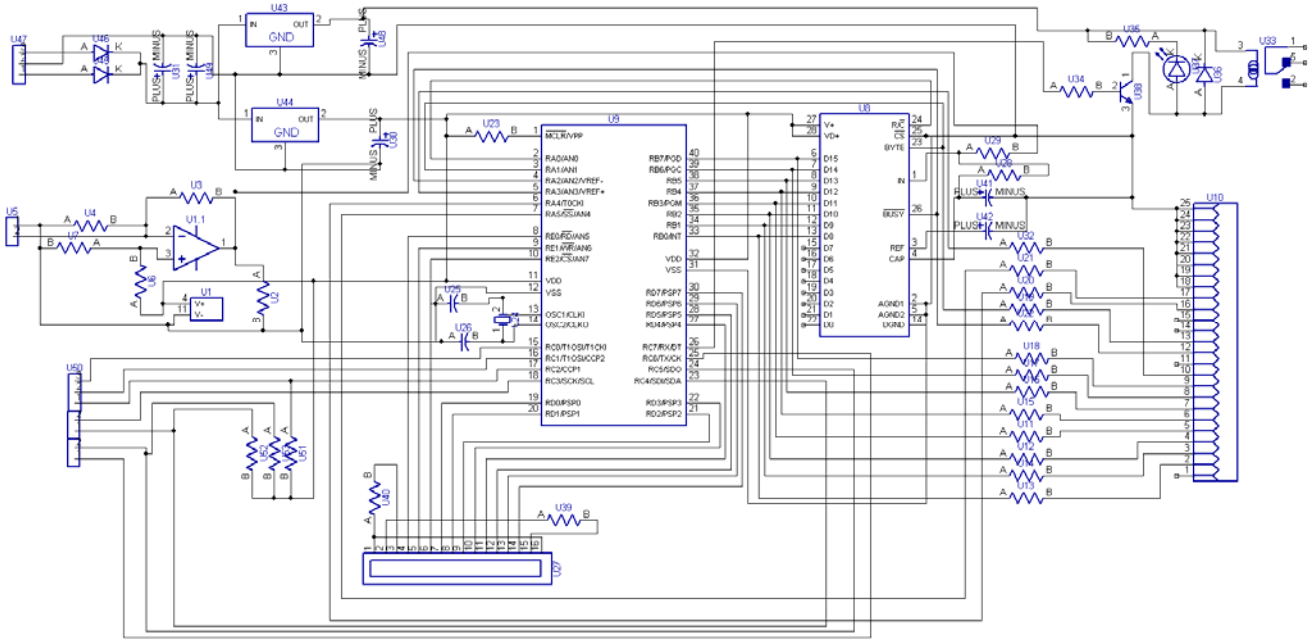

Fig. 2. Digital controller board circuit diagram.

		1	ser2	U31	1000uf	1	CAP300RP
		1	ser2	U32	220E	1	RES400
U1		1	LM324AN	U33		1	relay5
U10	parallel port	1	DB25F	U34	1k	1	RES400
U11	220E	1	RES400	U35	1k	1	RES400
U12	220E	1	RES400	U36		1	1N4007
U13	220E	1	RES400	U37		1	LED
U14	220E	1	RES400	U38	BC547B	1	BC547B
U15	220E	1	RES400	U39	1k	1	RES400
U16	220E	1	RES400	U4		1	RES400
U17	220E	1	RES400	U40	1k	1	RES400
U18	220E	1	RES400	U41	100uf	1	CAP100RP
U19	220E	1	RES400	U42	100uf	1	CAP100RP
U2	4.7k	1	RES400	U43		1	MC7805K
U20	220E	1	RES400	U44		1	MC7812K
U21	220E	1	RES400	U45		1	1N4007
U22	220E	1	RES400	U46		1	1N4007
U23	1k	1	RES400	U47		1	ser3
U24	4MHz	1	ECS-240-20-1	U48	100uf	1	CAP100RP
U25	27pf	1	CAP	U49	104pf	1	CAP100RP
U26	27pf	1	CAP	U5		1	ser2
U27	20X4	1	LCD	U50		1	ser3
U28	4.7K	1	RES400	U51	1k	1	RES400
U29	220E	1	RES400	U52	1k	1	RES400
U3	10k	1	RES400	U53	1k	1	RES400
U30	100uf	1	CAP100RP	U6	10K	1	RES400
U9	PIC16F877A	1	PIC16F877A-	U7	100k	1	RES400
				U8	ADS7805	1	ADS7805P

Fig. 3. Overall microcontroller board circuit components.

3. Results and Discussions

The instrument software application is written using visual basic that can run on Windows 98, 2000 and XP. The digital controller can be accessed directly by the instrument computer, which also has an active part in the control of the water bath temperature. A user friendly calibration of sensor system is also programmed within this digital controller. Thermal process can be monitored with or without the advent of personal computer system through offline measurement system. The offline system is also programmed within that of microcontroller. The instrument application is written in visual basic that has the features including, microcontroller board interfacing through parallel port, setting up the digital controller parameters and displaying and transmitting the state of the controller and the process parameters. The digital controller system is tested with electronic heated water bath temperature system. The Fig. 4 shows the automatic control scheme for the thermal process.

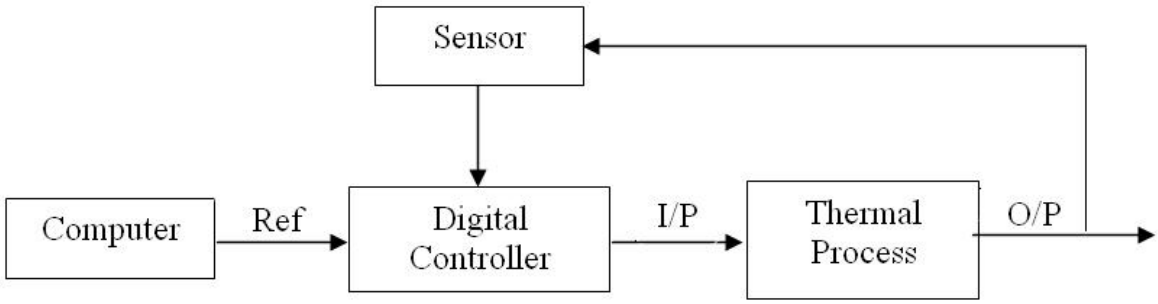

Fig. 4. Digital control scheme for thermal process.

The regulator is implemented in the digital controller which is a relay with non-linear characteristics. The relay outputs are on or off value by comparing the input (i.e.) error signal with the specified thresholds. The analog-to-digital conversion is done using a 16 bit, 10 μs ADC chip, the ADS7805. This chip is cost effective, works well, and has a 16 bit resolution if not 16 bit accuracy. The ADS7805 is a complete 16-bit sampling A/D using state-of-the art CMOS structures. It contains a complete 16-bit, capacitor-based, successive approximation register (SAR) A/D with S/H, reference, clock, interface for microprocessor use, and three-state output drivers. The ADS7805 is specified at a 100 kHz sampling rate, and guaranteed over the full temperature range. Laser trimmed scaling resistors provide an industry standard ±10V input range, while the innovative design allows operation from a single +5V supply, with power dissipation under 100mW. The 8-bit output from the ADS7805 is connected to the data lines of the parallel port. An external clock assesses data from the interface, which communicates without any external hardware for most digital signal processors, microcontrollers and personal computers. It reads the temperature data through the front-end hardware and sets the time triggering firing angle sequence through parallel port and controls the temperature as per the software application. The software front-panel consists of set temperature, temperature scale division, time scale division as well as on-off relay controller which are shown in Fig. 5. The high or low byte output from the ADC can be selected by the BYTE pin on the ADS7805 by the microcontroller.

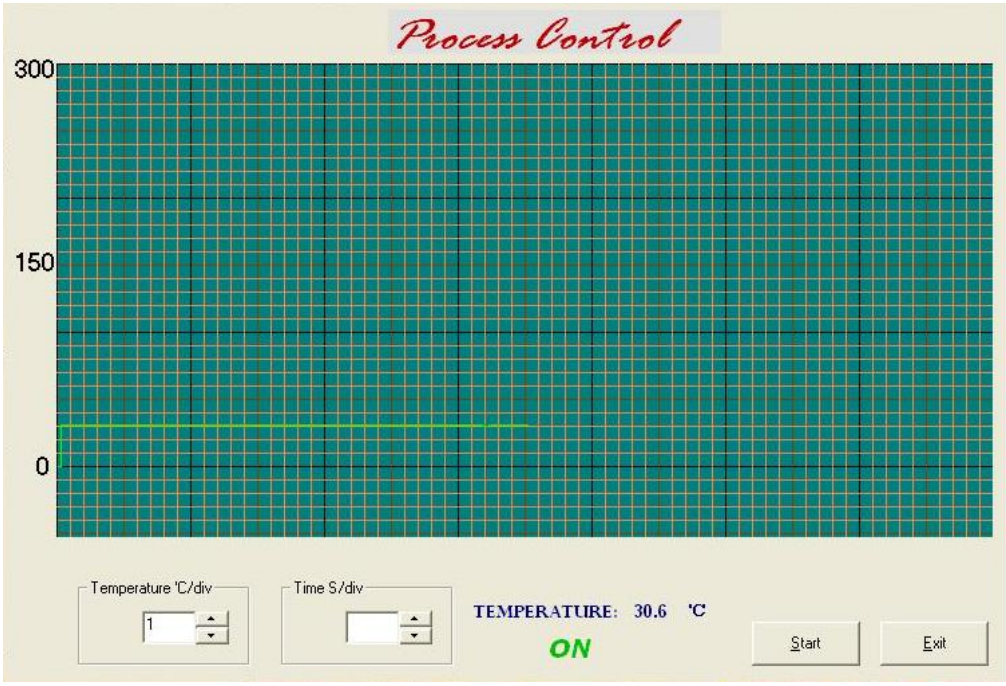

Fig. 5. Front-panel controls with online temperature graphical output.

The developed digital controller has the features such as, it has the provisions for set point tracking and monitoring of system parameters either by online and/or offline functions (i.e.) with and/or without the aid of personal computer and calibration of RT100 can be done at microcontroller itself instead of altering the application program code.

The linearization equation is,

$$R_t = R_0 * (1 + A * t + B * t^2 + C * (t - 100) * t^3), \quad (1)$$

where as 'A' is 3.9083 E^{-3}; 'B' is -5.775 E^{-7} and 'C' is -4.183 E^{-12} (below 0 °C), or 'C' is 0 (above 0 °C).

The local digital controller has built in 20&4 LCD display to monitor and control the temperature values. In future, a controller Ethernet-interface as well as a web enabled architecture work is currently underway on this temperature process as an enhancement of this work.

4. Conclusions

An embedded based local digital controller has been developed as a stand alone controller to control the electrically heated water bath temperature with or without advent of personal computer. The performance of this controller strategy is proved with the real time application of water bath temperature measurement system. The important features of this system are real time control of parameters either by using online and offline mode and user friendly calibration approach. The electrically heated water bath temperature system is considered as case study and local digital controller is effectively interfaced with a transmission rate of 10 μs. Web mediated architecture is under development for the same thermal process.

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

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- Sensor instrumentation;
- Virtual instruments;
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