Remote-Controlled Microcontroller-Based Temperature System: An Economical Design

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***Abstract*— Temperature measurement and monitoring are very important for most service and industrial applications. This paper presents the design of a remote-controlled microcontroller-based system. A multi-sensor/ multi-actuator system is proposed and the paper illustrates the steps for the design development. System simulation and the fabrication of a hardware prototype are both presented. Design alternatives are described, and emphasization on the choice of the economical and reliable ones are justified. The IR remote control unit, used in the hardware prototype as to replace keypad for the temperature setting, is described.**

***Keywords*— Automation; microcontroller; sensors; temperature control ; thermistor.**

I. INTRODUCTION

Automatic control or automation refers to the notion of having some equipments and applications working with minimal or reduced human intervention. With Some processes being completely autonomous, automation can help in saving labor, energy and materials and to improve quality, accuracy and precision. An embedded controller is defined as a controller that is embedded in a greater system for some purpose other than general purpose computing.

Combination of various means including mechanical, pneumatic, hydraulic, electrical, electronic devices and computers, are usually used to achieve automation, and different tools such as; computers, information technology (IT), and industrial machinery may assist the design, implementation, and monitoring of automated control systems. Microcontrollers for example, which are dedicated computers, and programmable logic controllers (PLC), which are specialized hardened computers, are frequently used to synchronize the flow of inputs from sensors and events with the flow of outputs to actuators and events. A designer, who may have to choose between microcontrollers and PLCs could consider number of factors, and if cost reduction is among the factors, then microcontrollers will be preferred. In published literature, lots of work reflect the use of microcontrollers in the implementation of various automated embedded control systems [1]-[3].

With automated systems, various physical quantities; such as temperature, can be measured using sensors, where a sensor is a device that measures and converts the physical quantity into a signal. The mercury thermometer, for example is a sensor that converts the measured temperature into expansion and contraction of a liquid which can be read on a calibrated glass tube [4]. The process of recording temperature over defined period of time is referred to as temperature monitoring. In some earlier time, temperature was monitored with the help of data loggers through manual measurements using analog instruments. For recent scenarios and related requirements, the data logger was not able to fulfill the need in terms of time and accuracy, therefore PC based data logging systems [5], were developed and considered a noticeable progress in terms of temperature monitoring. A revolutionary change, however, was later seen when microcontrollers are being used in embedded system designs [6].

Literature related to applications concerned with automated multi sensors, microcontroller-based temperature systems can be found in many published work. In [7], Fisher et al., proposed a prototype system for automating the measurement and recording of soil and air temperature as well as soil moisture status in cropped fields. In [8], multi RF wireless sensors are interfaced to an 8051 microcontroller to serve as indoor environment monitoring system. In addition to temperature, the proposed system in [8] is designed to monitor humidity, O_2 and CO_2 gases. The perspectives and implications of the challenging issue relates to thermal management of computer systems, data processing, and communication equipments is presented in [9]. For such fields of IT industry, and throughout the last few decades, the storage requirements in terms of physical space of storage devices have dramatically decreased, while the energy efficiency for equipments have not dropped at the same rate.

Considering the fact that computer manufacturers put more and more processing power into smaller packages, driven by the impact of Moore's law, which states that semiconductor performance is almost doubled every two years [10], the challenge of cooling becomes more complex, and more critical. Today's communication switches and servers generate as much as ten times the heat generated by systems manufactured ten years ago [11]. This fact makes it necessary to implement new strategies and technologies to provide the cooling for high density systems requiring reliable operation, keeping in mind that the responsibility of hardware manufacturers is limited to exhausting the heat from within their products but not the surrounding space. A this stage, temperature control becomes the customer or user responsibility. Among the strategies proposed are those adopting dynamic optimization of the thermal environment with more sensors placed in closer proximity to critical equipment [12].

Industrial processes operating in a temperature sensitive environment (e.g. manufacturing, fabrication, and power generation) require an infrastructure for continuous and reliable temperature control and monitoring [13], where temperature measurement is an integral part of their control systems. The book of D. Ibrahim [14] provides design principles and application case studies together with techniques for the application of microcontroller-based control systems. In [15]-[17], are researches, which are investigating temperature control systems based on microcontrollers. A typical block diagram of a microcontroller based temperature control system is shown in Fig. 1.

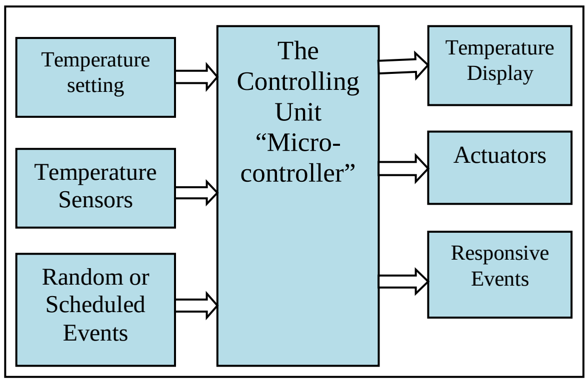

Fig. 1. Block diagram of a typical temperature control system.

As shown in Fig. 1, a temperature control system must have a temperature sensor as a vital part. Temperature sensors are normally having different characteristics depending upon their actual application. Some of them should be in physical contact with the object being sensed, while other types use convection and radiation to monitor changes in temperature. Temperature sensors that are common in applications may be divided as three groups, namely; electro-mechanical, which is normally referred to as thermostats, resistive, whose name in applications is thermistors and electronic, which are the thermocouples. Other types of temperature sensors include semiconductor junction sensors, Infra-red and thermal radiation sensors, medical type thermometers, indicators and color changing inks or dyes [18]. Various characteristics can be offered by individual sensors in terms of precision, cost, and range. Cheap thermostats, which cover wide range of operation are normally lacking precision. Thermistors on the other hand, are reasonably cheap, and featured by repeatability, as well as speed of response to any changes in temperature. Thermocouples are popular because they can measure a wide range of temperatures, however with limited accuracy.

II. THERMISTORS CHARACTERISTICS

Thermistors are generally composed of semiconductor materials, and mostly have a negative temperature coefficient (NTC); where their resistance decreases with increasing temperature. In practice, thermistors, are an easy to use and adaptable sensors with a reasonable accuracy. Their inaccuracy comes basically from their characteristic, where the resistance of the thermistor is changing according to the temperature change in an extremely non-linear way.

Because there are no standardized thermistor curves, as for thermocouple curves, it is therefore necessary to apply some calculations on the thermistor curve to adjust readings and obtain a very close approximation through the use of the following Steinhart-Hart equation [19].

$$T = 1/[A + B \ln (R) + C (\ln (R))^3] \quad (1)$$

In this equation:
T = Degrees [Kelvin]
R = Resistance of the thermistor [Ohms]
A,B,C = Curve-fitting constants

A, B, and C are found by selecting three data points on the published data curve and solving the three simultaneous equations.

To illustrate this let's assume a thermistor having resistances of (25000 Ω, 10000 Ω, and 4000 Ω) at (5 ^{0}C, 25 ^{0}C, and 45 ^{0}C) respectively.

Substituting these values, we can get three equations in A, B and C.

$278 = 1/[A + B \ln(25000) + C (\ln(25000))^3]$

$298 = 1/[A + B \ln(10000) + C (\ln(10000))^3]$

$318 = 1/[A + B \ln(4000) + C (\ln(4000))^3]$

Solution of the given set of simultaneous linear equations brings out the values of A, B and C:

$A = 2.108508173 \times 10^{-3}$

$B = 0.7979204727 \times 10^{-4}$

$C = 6.535076315 \times 10^{-7}$

In application, each time the resistance (R) of the themistor is read, equation (1) is executed using the values of the parameters A,B, and C, and hence the corresponding approximated temperature (T) is obtained. This continuous mathematical process may require resources, in terms of time and memory, that may not be within the microcontroller capability. One solution to this problem, which we have adopted in this paper, is to generate a lookup table through the offline solution of (1) for all the possible thermistor resistances and hence obtain their corresponding temperature values.

A basic electrical circuit, as well as economic and easy way to sense changes in a resistance with minimal components used, is a voltage divider circuit. In such circuit, the thermistor is typically connected in series with another resistance, as shown in Fig. 2. The output voltage V_o of this circuit forms an input to a microcontroller pin. The value of V_o relies on the changing resistance value of the thermistor.

$$V_o = [R_2/(R_1 + R_2)]Vi \qquad (2)$$

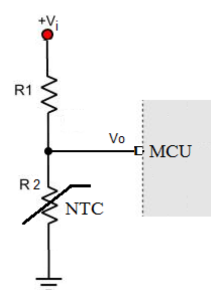

Fig. 2. A typical voltage divider circuit

III. The Proposed system: Design Issues

In this paper, we are considering a real life application, where the temperature has to be measured and monitored with reasonable accuracy at many physically distanced positions. Obviously many sensors may have to be installed in this application, and for a reliable and economical design, with the cost/performance criteria kept in mind, we will require proper choice of parts in terms of cost, size, as well as performance.

After investigating the characteristics of temperature sensors, the thermistors have been chosen due to their competitive characteristics (mainly price and size). As a matter of fact, a high accuracy temperature sensor, whose size is much more than the size of a thermistor, may cost eight times the price of a practical thermistor. This point contribute to the features indicating that an economical design of an embedded temperature control system can be achieved, while requirements of system reliability is not violated.

IV. System Simulation

The proposed circuit diagram of the system, shown in Fig. 3 is developed and simulated by the aid of the Proteus software package. It's assumed in this system, that temperature need to be measured and monitored at four different positions. Fig. 3 is showing it clear that we have not used four separate control systems to perform this task, where instead only four temperature sensors (NTC thermisors) are interfaced to the input pins of a single microcontroller. The 40 pins PIC18F4580 is used as the main control unit in the system, taking into consideration that other types of microcontrollers, with enough number of pins, can also be used.

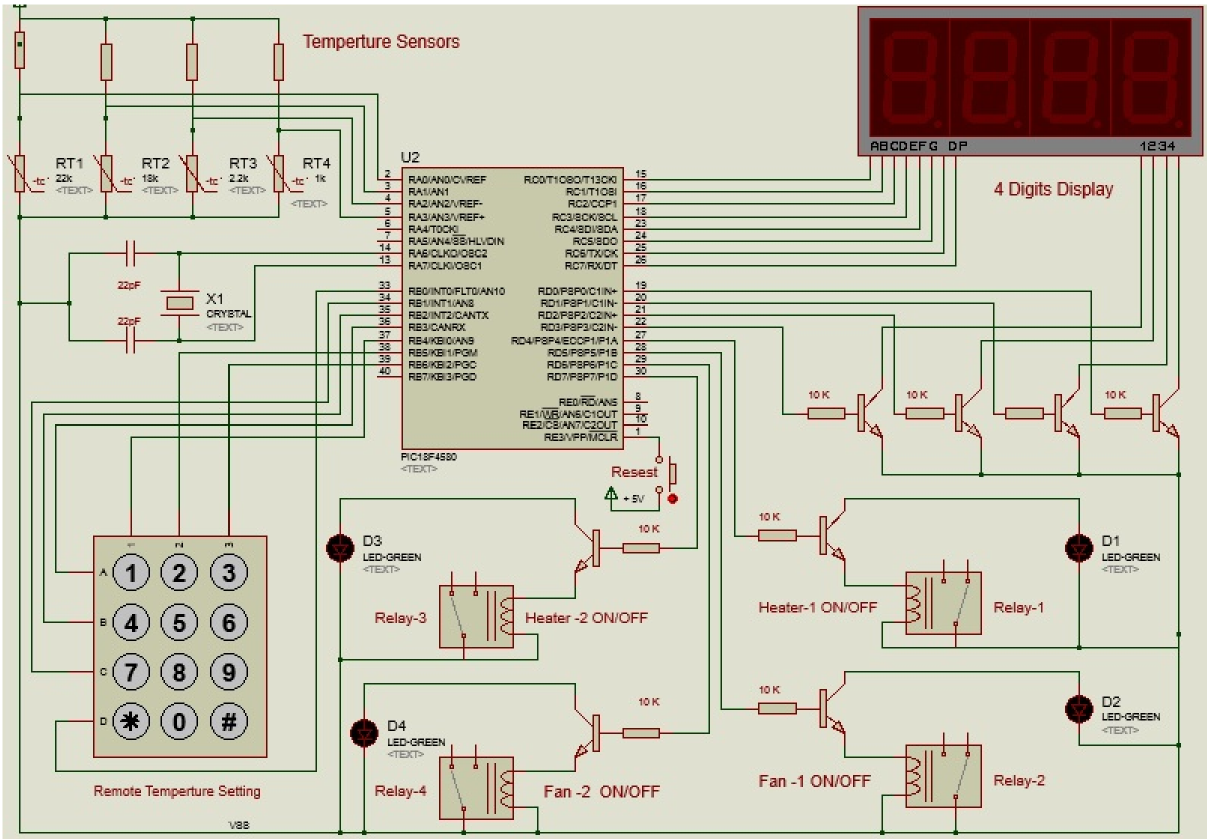

Fig. 3. The multi sensors temperature control system

The temperature is displayed using a 4-digits 7-segments with common input for all the segments, and a separate enable line for each segment. The enable line is used to turn ON and turn OFF a particular segment. At this point, it's reasonable to recall that a character LCD may be used as an alternative display method with advantages of requiring less number of pins to interface with the microcontroller, and simpler way of programming. The 7-segments display is favored here, however, because good readability of the displayed digits is more required.

A. Temperature Setting

For the system to automatically control a temperature, it should have a continuous process of measuring and monitoring. The measured temperature is normally compared with some stored threshold values (possibly maximum and minimum). In Fig. 3, a (3x4) keypad is used to set the threshold temperatures for the different sensors. The use of this keypad requires an interface with the microcontroller via 7 input pins. In fact the keypad is only used for the purpose of simulation, where in line with the objective of this research, we have used, in the fabricated hardware prototype a more practical alternative for temperature setting. Replacing the keypad with an IR (Infra Red) remote device has noticeably minimized the utilization of microcontroller pins. We, in fact, could not simulate the IR receiver because it is not available within the database of the Proteus package. In section five of this paper further exploration regarding the remote control will be introduced.

B. Actuators

Fundamentals of automatic control dictates that some action should be taken if the routine monitoring of the system has come to such a decision. Turning an actuator ON, triggering another subsystem, putting a machine into operation are among a list of possible actions. In the automatic temperature control, a fan may be turned ON if the environment needs to be cooled or alternatively a heater may be put ON to raise the temperature. Both types of actions are simulated in the system as shown in Fig. 3. More fans and/or heaters may in fact be controlled, where their actions may be a response to various sensors based on the way system programs are designed and implemented.

V. The hardware implementation

The design outline introduced in the section four of this paper, is used to produce a hardware prototype for our IR remote controlled automatic temperature system. Minor changes to the simulated system illustrated in Fig, 3, are made and the same tool (i.e. Proteus) is also used to develop and produce a proper PCB layout. One thermistor, rather than four, is used in the implementation, and instead of the (3x4) keypad, a miniaturized IR receiver for infrared remote control is interfaced to perform temperature settings. The IR receiver used is the TSOP1738, which is basically a 3-lead frame package being an assembly of a PIN diode and preamplifier. The hardware assembly is shown in Fig. 4.

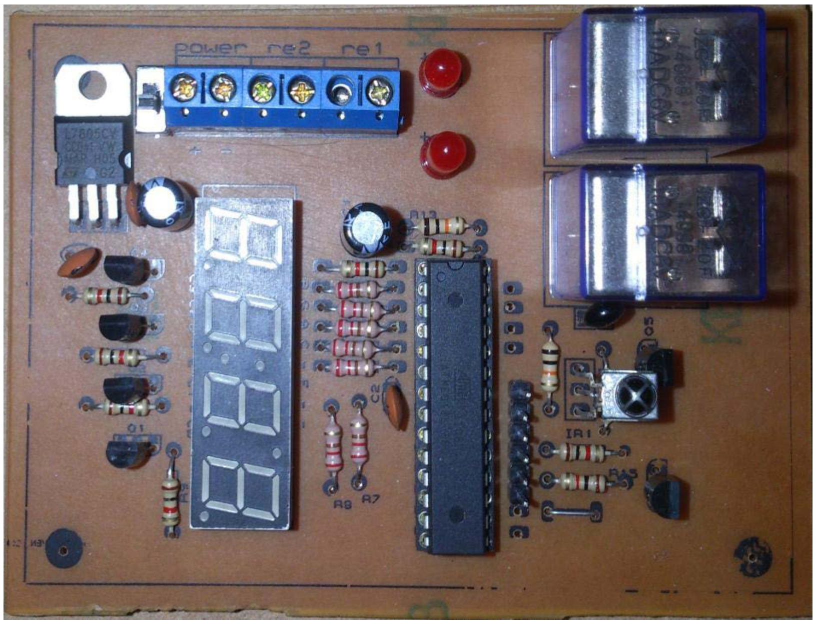

Fig. 4. Hardware assembly of an automatic temperature control system

Transmission systems adopting infrared remote control technology, and only requiring small data rates, are now widely used in application to eliminate keypads [20]. Standard types of IR transmitters are working in the frequency band between 30kHz and 56kHz. The TSOP1738, which is used in our prototype has a carrier frequency of 38kHz. Many commercial transmitters are having similar carrier frequency and hence any of them may suit our application. We, however, required to carefully consider the coding system [21] adopted by the manufacturer of the selected IR transmitter [22]. Timings, storage, as well as synchronization requirements are considered in programming the microcontroller taking into consideration the standard message format of NEC code, as the transmitter used is actually adopting this protocol. The remote control is used to set the threshold temperature values such that the system perform automatic measurements and monitoring to keep the temperature environment within the desired temperature via functioning the proper action (e.g. put the fan or the heater ON or OFF). Hardware reset of the system can also be done using the proper pin. Necessary lab testing were carried out to make sure that message transactions is reliable and performed as per the NEC encoding.

VI. Conclusions

The paper has presented the temperature measurement and monitoring for a proposed service or industrial application with multi-sensor/ multi-actuator system. The PIC18F450 with 40 pins is used as the main control unit. The system is displaying the temperature using 7 segments LEDs because they offer better readability with respect to LCD. Thermistors are used as temperature sensors due to their suitable characteristics. The Proteus software is used to aid the development of the system in terms of editing, simulation, and PCB layout production. An IR remote control with 38 kHz carrier frequency subsystem is integrated with the temperature control system to perform temperature settings replacing the use of a keypad.

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