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A MICROCONTOLLER BASED DIGITAL THERMOMETER WITH TIMER (DIGITHERMO)

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Abstract

Using conventional thermometers for measuring temperature will require a separate instrument for measuring time such as stop clocks, ordinary watches, or digital timers. These thermometers are fragile; prone to measurement errors, contain hazardous material that can burn the skin, eyes, and respiratory tract if spilled.
A microcontroller based digital thermometer with timer (DigiThermo) was designed and constructed. The device employs the AT89C4051 CMOS microcontroller (MCU), interfaced with the CA3162 ADC and a 16 x 1 character LCD display. Temperature is measured with a precision IC linear temperature sensor (LM35D) and time is counted using the MCU's timer circuits. The circuit was assembled on a prototype board, tested, modified and finally assembled on a set of matrix boards, and cased in a portable, stylish plastic casing with the sensor attached to a 28.0 cm long probe.
Results during testing showed that the device displays time count in seconds and temperature in degrees Celsius. The device can be used in the chemistry and engineering laboratories as well as in industrial, agricultural and in other applications requiring simultaneous temperature/time measurements.

Keywords: DigiThermo, Firmware, Microcontroller, Programming, Temperature, Thermometer, Timer.

1. Introduction

Chemistry and Chemical Engineering Laboratories typically employ mercury-in-glass thermometers for measuring temperature and a separate instrument for measuring time such as stop clocks, ordinary watches, or digital timers. However, mercury-in-glass thermometers must be handled with extreme care as they are fragile, contain mercury which is a hazardous material that can cause burns to the skin, eyes, and respiratory tract if spilled from a broken thermometer. These thermometers can explode if mistakenly used in a reaction whose temperature exceeds its range. Again, reading errors, such as errors due to parallax can occur with the use of these thermometers thereby introducing errors to measurements made with them. A similar problem of reading errors also occurs with time measurements depending on the instrument used. Not does the use of a separate timing device inconvenient for the user, it also introduces error in some reaction kinematics measurements. DigiThermo is designed to solve these problems by incorporating these two measuring devices in one. The use of precision temperature sensor and microcontroller to perform computations will eliminate errors thereby enhancing the device's accuracy, increase flexibility and programmability – meaning the product can easily be modified to measure temperature in degrees Fahrenheit, for instance, by changing the application program, rather than redesigning the electronic circuit. It would also eliminate the aforementioned hazards associated with the mercury-in-glass thermometer.

Electronic thermometers have been built which serve as alternatives to mercury-in-glass thermometers. These employ sensors whose electrical properties vary in some way with temperature change. These temperature sensors combined with signal conditioning elements, signal processing elements and data presentation / display elements form an electronic thermometer which could be analog or digital. Digital thermometers [1] are temperature-sensing instruments that are portable, have permanent probes, and a digital display. They are typically battery powered. DigiThermo is designed primarily for use in Chemical Engineering Laboratories and the Chemistry Laboratories for measurement of temperature within the range of 0-100˚C as well as measure time in 'seconds' unit, the standard unit of time used in scientific and engineering calculations. It aims to replace the conventional mercury-in-glass thermometer and other timing devices used in these laboratories.

The design and construction of the microcontroller based digital thermometer and timing device (DigiThermo) illustrates the use of 'C' language in the programming of embedded systems / microcontrollers, the use of dual

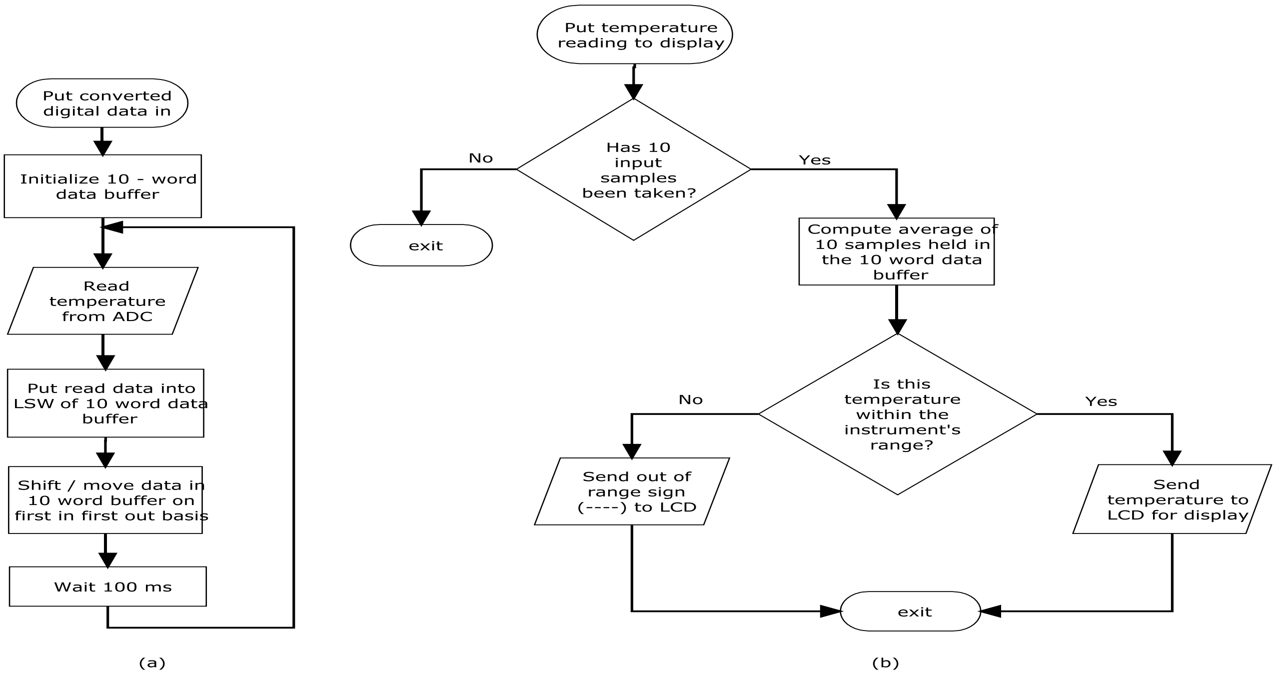

Figure 3: Flowcharts for digital filter implementation (a) convolution (b) sampling.

The driver routines are as follows:
average() – computes average of 10-samples in FIFO buffer
readtemp() – reads the BCD value from the CA3162 ADC
i_LCD() – initializes the LCD using the 4 bit initialization algorithm for the Hitachi 44780 LCD controller
LCDWI() – writes LCD instruction into the LCD in 4 bit mode
LCDWD() – writes ASCII code to LCD buffer
pulseE() – generates LCD enable pulse
pause() – provides a very short delay
delay(n) – delay n milliseconds
delay_1ms() – creates a 1 ms delay with 6 MHz XTAL using timer0
init_timer() –initializes timer1 for a 100 ms tick interval for the sEOS with 6 MHz XTAL
puttitle() – puts the title message to LCD buffer

2.2.4 Microcontroller Programming

The firmware (software) was written using the high level programming language, C. The source code was saved as the file *mythermo.c*. A special C compiler targeted at the 8051 compatible microcontrollers, the SDCC was used to compile the source code. The output machine code was a hex file, *mythermo.ihx* with *.ihx extension. The tool packihx was used to convert this hex file with *.ihx to *.hex producing the packed Intel hex file *mythermo.hex.*

The compiler runs under a dos environment. The following commands were used in the compiling process: “C:\sdcc\bin\sdcc mythermo.c” compiled the source code into the object code: mythermo.ihx while “C:\sdcc\bin\packihx mythermo.ihx” packed the intel hex file into mythermo file with the .hex extension suitable for burning into the microcontroller using the BlowIT programmer circuit. Variables and stack use the area of 128-byte on-chip RAM while the special function registers (SFR) use the area of 128-byte on-chip RAM reserved for them.

Burning of the object code into the microcontroller, that is, the programming of the microcontroller was done using an AT89C4051 microcontroller programmer circuit called *BlowIT 2051*, a burner designed for AT89C2051 Flash Microcontroller by Silicon Studio Ltd and a BlowIT executable modified by Dincer Aydin that supports Intel hex files and is able to able to program the AT89C1051, 2051 and 4051. The BlowIT.exe program runs under real Dos mode.

The object code and the programmer were placed in a removable drive containing a copy of MS-DOS. The microcontroller was placed into a 20-pin DIP socket on the BlowIT burner. The burner was connected to a PC’s parallel port and was powered. The PC was powered and booted into DOS. The BlowIT program was run using the following command:

“A:\Blowit mythermo.hex [1]”

The target MCU, 4051, was selected and the chip was programmed. The BlowIT power was turned off and disconnected from the PC, and the PC was shutdown. The MCU was removed and was ready to be installed into the circuit.

2.3 Principle of Operation of the DigiThermo

When power is turned on via SW_1, the 9V battery provides power to the circuit. This power is regulated by IC_1, the 7805 5V regulator to provide +5V on which the circuit operates. The Microcontroller, the ADC, the temperature sensor and the LCD are all driven by this source.
The reset circuit of the microcontroller (MCU) resets the microcontroller during the first 0.5 s after power has been turned on, as the reset pin is held high during this period until the 10µF capacitor becomes fully charged.
After being reset, the MCU starts executing the control program, mythermo.hex, which initialises the LCD, then controls the functionality of the circuit. The 6 MHz crystal connected to the MCU makes these instructions to be executed at a rate of 0.5 MHz (500,000 instructions/s). IC_2, the LM35DZ temperature sensor, measures temperature producing an output signal of 10mV/°C. This output is filtered by the first order low pass filter formed by R_1 and C_1 and is sent to the ADC chip, IC_3, the Intersil CA3162, 3-digit DVM employing dual slope integration, through its differential input pins 11 for HI and 10 for LI signal. The ADC digitizes this signal at a rate of 4 Hz. Since the ADC converter is capable of providing 0 – 1000mV reading with 1mV resolution, the converter can resolve 0.1 °C (though not absolute accuracy). 3-digit digital output is sent to the MCU's port1 (P1.0-P1.3) via the ADC's multiplex four bit BCD outputs (pins 2, 1, 15, 16) starting from the MSD, LSD, and the NSD respectively. The MSD, NSD, and LSD digit select pins (pins 4, 3, and 5), tied to MCU's pins 11, 7, and 6 respectively, signify when these digits are ready to be read. The control program reads the appropriate digit when any of the pins 11, 7 or 6 is low every 100 ms. The MCU thus samples the ADC at a rate of 10 Hz. It performs digital filtering on the sampled data using FIR digital filters to produce 0.1 °C reading. The temperature reading is sent to the LCD and is updated every 100 ms.
The timer is implemented in the control program making use of one of the MCU timer circuitry, timer1. Timer1 overflows every 100 ms providing a 100 ms time-base producing 1 s for time counting. Each second, the control program sends the second count to the LCD. SW_3 is used to start / stop the timer while SW_4 resets the second counter to zero when pressed respectively. The states of these switches are monitored by the control program, mythermo.hex.
The 16 x 1 character LCD, connected in 4-bit interfacing to pins P1.4 – P1.7 with control signal RS and E to P3.4 and P3.5 respectively, displays time in 1 second unit and temperature in 0.1 °C resolution and can show second count of up to 5 digits while temperature is shown in 3 digits. On power up, the LCD is initialized by the MCU, after which it displays the title message before showing the variables being measured. SW_2 is used to turn on/off the LCD background light. The device is turned off via SW1.

3. Construction

The circuit was first assembled on prototype board to enable testing of the circuit design and easy modification when necessary. All components were connected according to the circuit diagram. C_3 was placed as close as possible to the CA3162E's ground and power pins as suggested in the ADC's datasheet. Other special procedures for handling some other components were adhered to during assembly.

3.1 Calibration of the ADC

Calibration of the ADC was done as follows: ZERO adjustment was done by shorting pin HI and LO to GND and then the 50k POT at pin 8 and 9 was adjusted until the temperature reading was 0.0 °C. A reference voltage source of 391mV was connected to the input of the ADC and the 10k POT was adjusted until the display showed 39.1 °C.

3.2 Preliminary Testing

Preliminary test was done on the fully assembled circuit. This was aimed at ascertain whether it was working and if it performed as expected. The timer and temperature measuring units were tested for accuracy as well as functionality. The timer did not measure time accurately when compared with the timer on a Nokia phone, and the temperature reading was unstable.
This led to a revision / modification of both the firmware and the hardware to tackle the problems discovered. The revised firmware was burnt to the MCU and the circuit was modified to handle the multiplexed output of the ADC much more effectively.
The tests were repeated until a reliable, accurate output was obtained from the .

3.3 Permanent Assembly

The circuit (figure 5) was then transferred to a matrix board where all the components were assembled, connected and soldered into a permanent form. This formed the circuit's mainboard. The layout of components on this board had been carefully planned based on component type, interconnection amongst them as well as the size of the board.

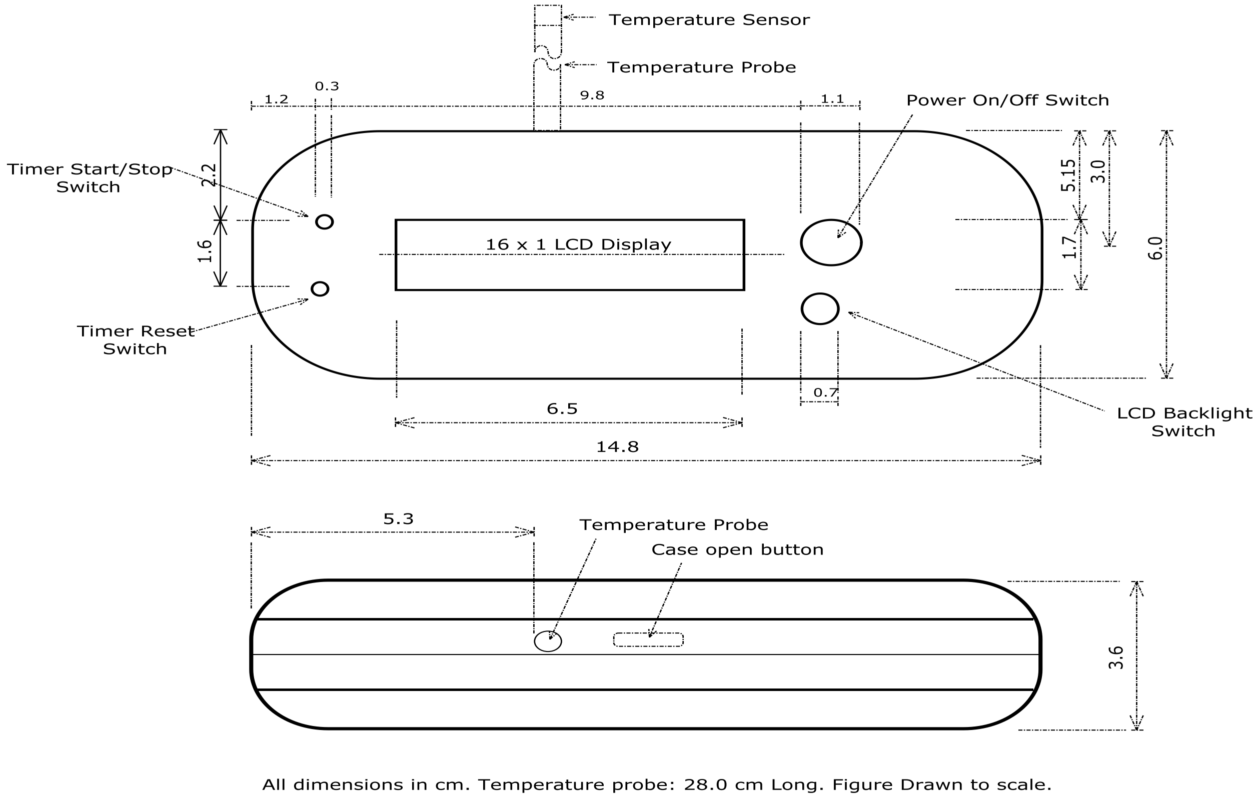

Figure 4: The Casing for DigiThermo

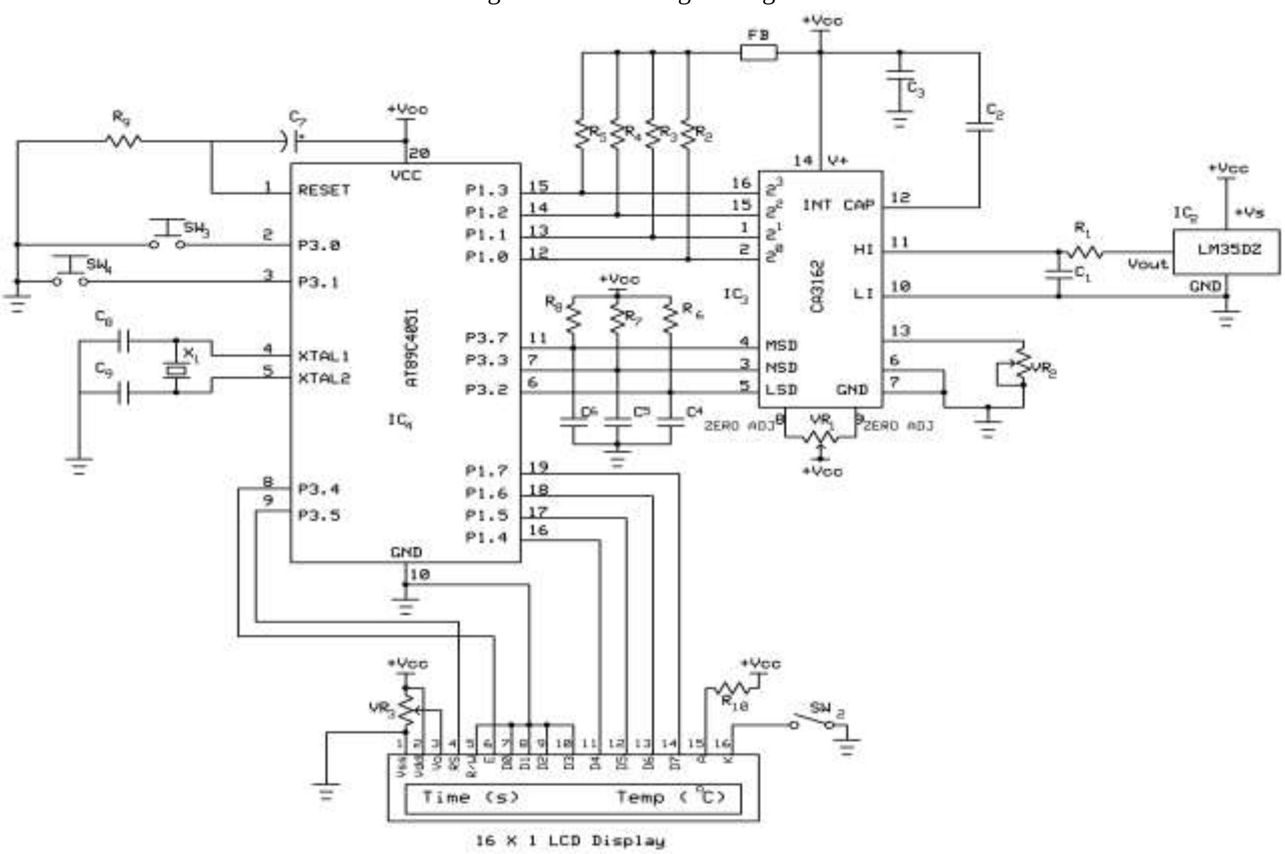

Figure 5: The complete circuit diagram of DigiThermo.

The size of the matrix board was determined by the size of the selected case, which was chosen to make the device portable. The case is a rounded cuboid with dimensions of 14.8 cm x 6.0 cm x 3.6 cm taken across centres (figure 4,6 and 7). A rectangular opening was made on the top of the case to provide a window for the LCD. A plastic transparent sheet, cut to size, was glued underneath the opening to protect the LCD that was later attached just below it to the case using screws. Circular holes were made for the switches on the case. The circuit's four switches were mounted on two small matrix boards with connecting wires to the mainboard. Four plastic round covers were placed over the switches. The switch boards were attached to the upper surface of case on both sides of the LCD using glue. The circuit's mainboard was then fixed into the bottom half of the case. A probe made of rubber tubing and well sealed to keep off moisture and water, was attached to the top of the casing with the temperature sensor at the other end. The probe measures 28.0 cm. This provides flexibility and enables temperature to be measured easily at some distance away from the device itself. Measurement of temperature of fluids is also made easy by this. The LM35's 3 pins were insulated with rubber sheets before being placed within the rubber tubing. The colours of the connecting cables used on the sensor are as follows: orange to $+V_s$ pin, orange with white to V_{out} pin, and green to the GND pin.

A 9V battery was attached to the circuit through a 9V battery connector on the mainboard.

The case was then closed and power was turned on. The ADC was recalibrated. The device worked as expected.

Labels for the switches, as well as the device's name tag, etc were glued at appropriate places on the case. Figure 8 shows the device in its final casing.

4. Results and Discussion

After the final assembly, the circuit was retested and the final results were as shown on Table 1.

The final result obtained shows that the temperature sensor's output is linear. Both the temperature and time measurement aspects of the device are performing satisfactorily.

Table 1: Test and Result

TEST	***METHOD***	***RESULT***
Timer operation	Timer was compared with the timer on a Nokia mobile phone. Both timers were started simultaneously.	There was one to one correspondence with each second count
Thermometer operation	Temperature probe was left to measure the ambient temperature. Later, it was placed close to a heat source, a laptop air vent blowing out warm air. For a second test, the tip of 's sensor was placed on the sides of a hot soldering iron for some time, and then transferred to a cup of cold water containing some ice.	The temperature read 28.0 °C in the first case, and increased to 32.0 °C when it was placed close to the heat source for some time. The temperature reading rose linearly from room temperature to 43.0°C when placed on the soldering iron during the second test and then fell gradually in a linear manner to 5.0°C when immersed in the cold water.

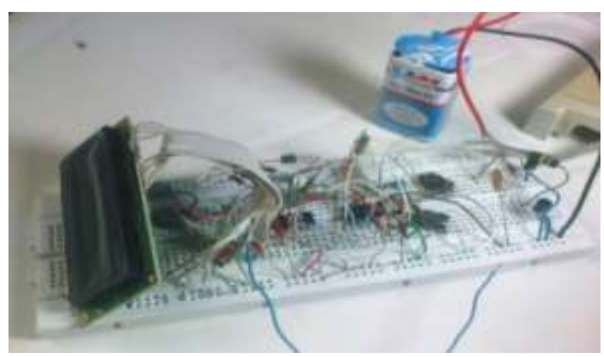

Fig. 6: Preliminary assembly on breadboard

Fig. 7: Case opened showing assembled circuit on matrix board.

Fig 8: Front view of device in final casing.

5. Conclusions

The main aim of this work was to design and construct a microcontroller based digital thermometer with timer. This has been achieved. The device has been tested and is working. This project illustrates the use of embedded systems particularly in instrumentation design and generally in the design of electronic devices. Embedded system design should be encouraged to simplify and provide flexibility for electronic circuits / electronic designs. Those seeking guidance on embedded system design that employ ADC interfacing, specialised LCD interfacing, digital filtering, etc, should avail themselves with this work.

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