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New real time temperature monitoring and evaluation system

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The storage of many drugs, serum and vaccines at specified temperature limit is very important. Therefore, it is necessary to read and record the ambient temperature and control the refrigerating device according to the limiting values specified by the user. Taking into account these requirements, a new PIC microprocessor-based temperature monitoring system that triggers the DS18B20 temperature sensor and controls the running of the refrigerator system is designed and developed. At the controlling operation, performed by this system, temperature limits are specified by the user. In case these limit values are exceeded, a warning message is sent to the user through GSM module. Furthermore, the temperature values that are read between the time intervals specified by the user are sent to a GLCD screen and presented in a graphical form. The temperature readings can be transferred to the computer environment as text file through a Visual Basic based interface with using a serial port. At this system which has one year data storage capacity, it is possible that the temperature values can be transferred to the computer by wireless communication facility. Differently from the present systems, recording, evaluation, warning and device control operations are performed in the same system. In the present paper, the system operation and its performance at the fields of application are expressed in detail.

Keywords: Refrigerator, Temperature sensor, Microcontroller, Serial port, Wireless communication

1 Introduction

Today manufacturing in factories is carried out by automatically operating machines. The controls of machines are realized by electronic and computerized systems. It is possible that the mechanical and physical changes in machines can be transferred to the computer system and process them within the computer and perform the control of the same machine or other machines. The sensors are used to transform any physical change into electrical signal and they are transferred to electronic systems. The industrial applications such as counting products, performing quality control, holding the temperature, humidity or illumination within a specified range, etc. are some of the examples of sensor applications. Among the examples, the most important physical quantity is the temperature. Temperature sensors measure the static and dynamic parameters that depend on the temperature[1]. These parameters are length, volume, pressure, electrical resistance, potential difference and colour change and radiation intensity of surfaces. Temperature is measured for control, monitor, security and energy efficiency purpose[2-7]. The temperature control may be necessary for the places such as fixed or mobile frigorific depots, laboratories, computer rooms, nuclear reactors, electrical motors, industrial ovens and boilers[8-11]. Furthermore, it is also necessary to monitor, control and manage the temperature values in the areas such as libraries, museums,health and nutrition buildings. Blood and drug storage environments also necessitate temperature monitor and control because of growth of micro-organisms in such places. Books and historical artifacts may be destroyed by bacterial growth in hot environments.

In recent years, industrial studies have been done on developing low and high temperature measurement systems. There are a lot of examples on temperature measurements such as the real time measurement of surface temperature during the drying stage of the film or mold cover solutions[12], the measurement of operating temperature of an isolated gate bipolar transistor[13], real time measurement of micro-thermocouple array during laser annealing process[14], real time measurement of the temperature of the machine tool[15], the temperature variation on a fiber optic[16], measurement of multi-spectral high temperatures[17], non-contact measurement of surface temperature[18,19], in vivo and real-time measurement of the temperature in acupuncture[20], real-time measurement of concentration and temperature of solution during crystal growth[21], real-time measurement of wall surface temperature subject to hot impinging gas flow in combustion[22], the real-time measurement of welding temperature field and closed-loop control of isotherm width[23], real-time measurement of temperature field with ICCD sensor[24], liquid crystal temperature measurement for real-time control[25], real-time measurement of temperature field by calorimetric method[26], real-time temperature measurement of heating under electrocardiographic electrodes during MR-Imaging[27], real-time temperature-measurement on pcbs, hybrids and microchips[28,29], measuring soil temperature and moisture using wireless mems sensors[30], measuring the mixed air temperature in air-handling units[31].

Measurement system must satisfy the following properties in order to be an appropriate industrial system such as it must be low in weight, compatible with electromagnetic interference, low noise, suitable for wireless communications, high data storage capacity, suitable for multi sensor applications. Taking into account these criteria, in the present work, a new temperature monitoring system which facilitates the operation of a refrigerator in a controlled manner based on the desired inner temperature has been developed.

In order to protect public health, World Health Organization (WHO) suggests the temperature monitoring systems that make measurements and records and also keep the vaccines and similar medicinal products at a specific temperature range. When these suggested systems are examined, it is seen that most of them use non-replace battery, their memory capacity is limited, they have limited activated life, their minimum logging interval is 2 s and their accuracy is not below 0.2°C. In the system developed in the present study, the features of the systems suggested by WHO are enhanced. Furthermore, this developed system can perform motor control of the refrigerating system differently from acoustic and visual alarm.

A temperature sensor called DS18B20 giving digital output is used. In the temperature monitoring system that is developed, triggering the sensor by the clock signal, receiving the data output and determining the temperature value by processing are done by means of a PIC microcontroller. The temperature values determined by this system can be sent to a GLCD screen and transferred to a computer environment through its serial port and stored as a txt file. A new man-machine interface unit has been designed for taking the data into the computer, storing them into the memory and presenting them in graphical form by using Visual Basic software programming language. A facility is added to the system in case the user wants the temperature values read before transferring to a wireless computer. Furthermore, this system has a data storage capacity that can hold them for one year. The system can also stop the operation of another industrial device and brings the values of the temperature to newly determined limits by the user.

2 Temperature Monitor System

2.1 Operation of the System

The block diagram of the temperature monitoring system developed in the present work is shown in Fig. 1.

Figure 1 shows the temperature monitoring system works under the control of a central processing unit (PIC18F452). The unit performs the following operations: activate the sensor and read its output; decide whether the readings can be sent or not by the ASK transmitter; record the readings to the memory (AT24C512) in coordination with the real time clock (DS1307); write the value on the GLCD screen and plot the graph of it; control the load depending on the temperature limits entered by the keypad; activate the buzzer when the memory is overflowed and achieve data flow in a controlled manner from the memory to the serial port of the computer. The flow chart showing the command sequence of the central processing unit is shown in Fig. 2.

As seen from Fig. 2, at the power up of the temperature monitoring system, first of all it is requested to the user to assign the control variables that are used in controlling the refrigerating system. Then, it is asked to enter the values of these variables. If the user of the temperature monitoring system is a medical doctor, then the two variables such as the minimum temperature and the hysteresis temperature have to be assigned in order to preserve the vaccines within the refrigerator. The values of these variables have to be entered as 4°C and 2°C, respectively. The minimum value is the temperature value that it stops

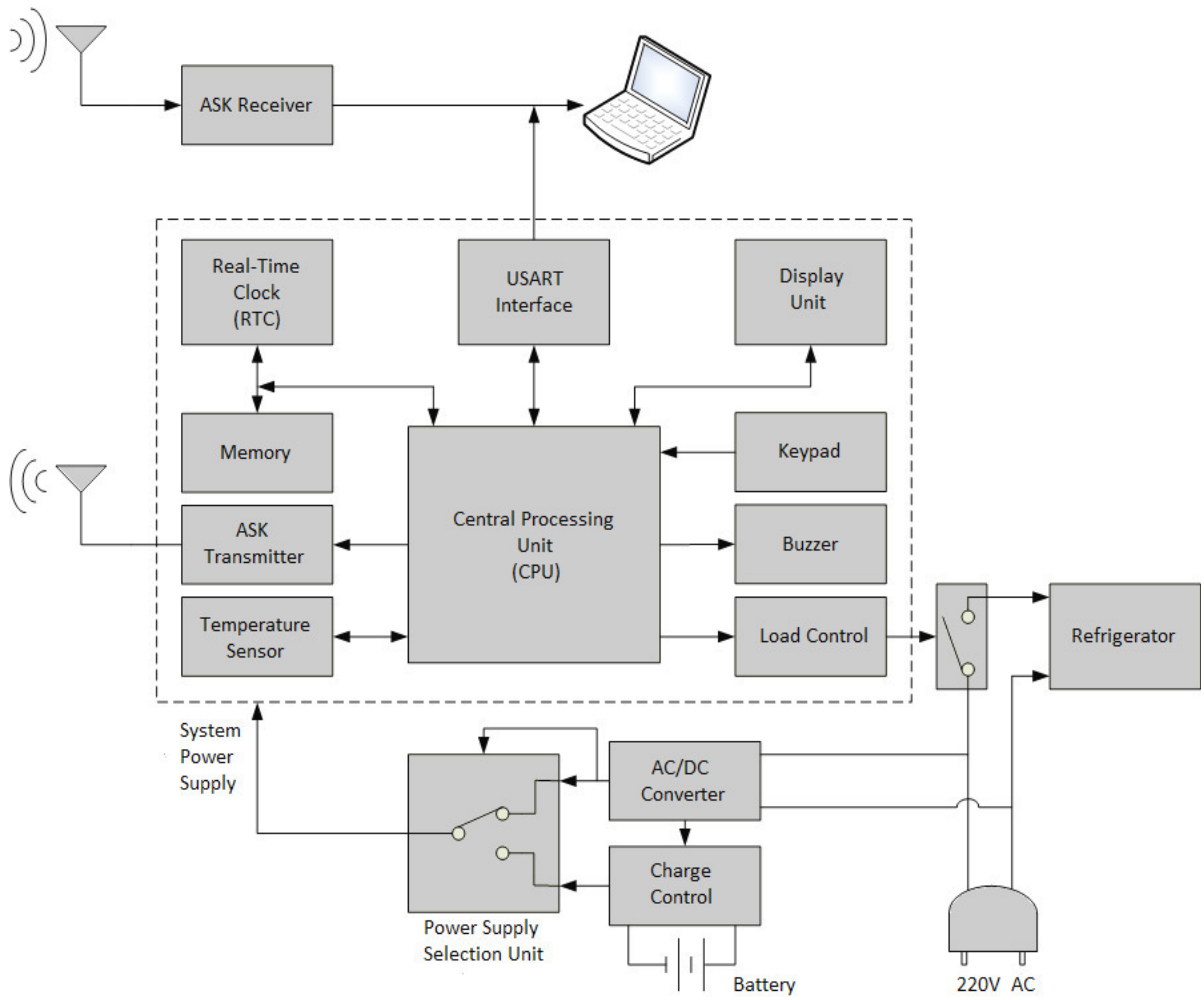


Fig. 1 — Block diagram of the temperature monitoring system

the operation of the refrigerating system, on the other hand, the hysteresis temperature is the value of the temperature that the stopped system at the minimum temperature can start again from that temperature value which is above the minimum temperature.

Figure 2 shows when the energy is given to the temperature monitoring system, first of all, the program assigns the variables which are necessary for the refrigerating system's control. After that, the program reads the ambient temperature value only once and temperature variables which will be controlled have not been entered by the user yet, the values of these variables are accepted as zero. Therefore, the refrigerating system becomes active due to not entering the limiting values. Then, the time is read and the temperature reading is written to GLCD and recorded to the memory.

As long as the user does not push one of the buttons settled in the front board of the system, the refrigerating system stays active. When any button is held down, the program branches to temperature, alarm, time and memory settings. These variables can be chosen with up- down buttons and the values can be entered with right side button. The variables at the temperature settings section are minimum temperature and hysteresis temperature values. The minimum temperature indicates that the refrigerating system will be stopped and hysteresis temperature indicates that above the minimum temperature, the system will work again. At the alarm condition tab, in case the memory is full, it can be arranged that the system will give the alarm or not. At the timing section, the date and the clock information can be entered in detail. Furthermore, with the memory setting section, history

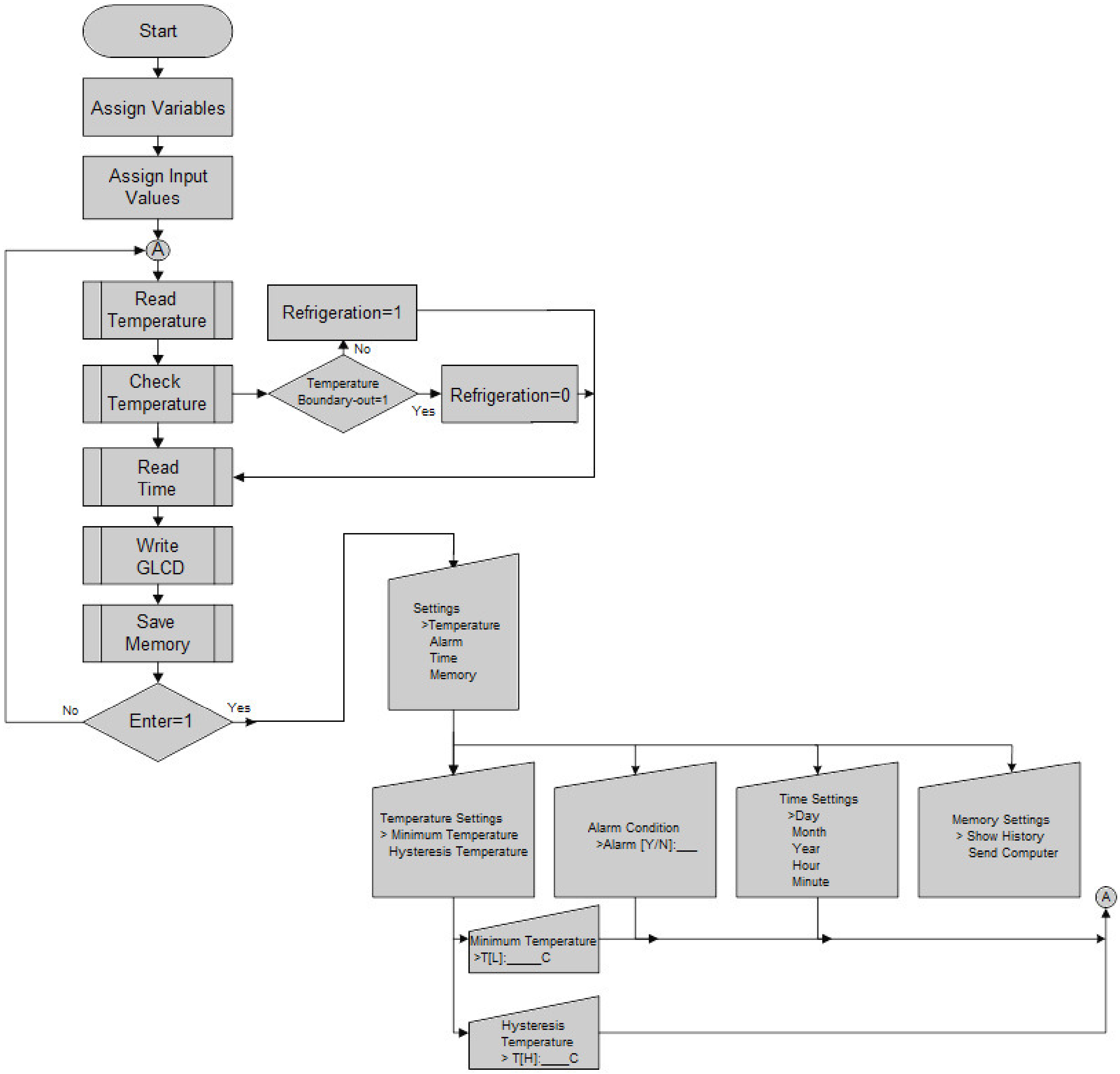


Fig. 2 — Flow chart of the program of central processing unit

of record information can be seen one by one and all records in the memory can be sent to the computer through a serial port.

After the variables are entered, the system reads the first temperature value and then it is controlled that the temperature reading is within the determined limits or not. If the temperature is within the limits, the system cuts the power of the refrigerating system and it reads the time from the real time clock. Then, it sends this temperature value to GLCD and records it in memory. Every recorded temperature value is wirelessly stored in a txt file in computer by means of ASK receiver transmitter. The explicit scheme of temperature monitoring system, the block scheme of which is given at Fig. 1 and seen at Fig. 3.

2.2 Programming Parts of the System, Technical Specifications

2.2.1 Sensor

In the system that we developed in our work, the DS18B20 temperature sensor is used. The pin arrangement and technical specifications of the sensor is given in Table 1. In addition, the block diagram of the sensor is shown in Fig. 4.

The DS18B20 temperature sensor can be programmed through a single line and provide a

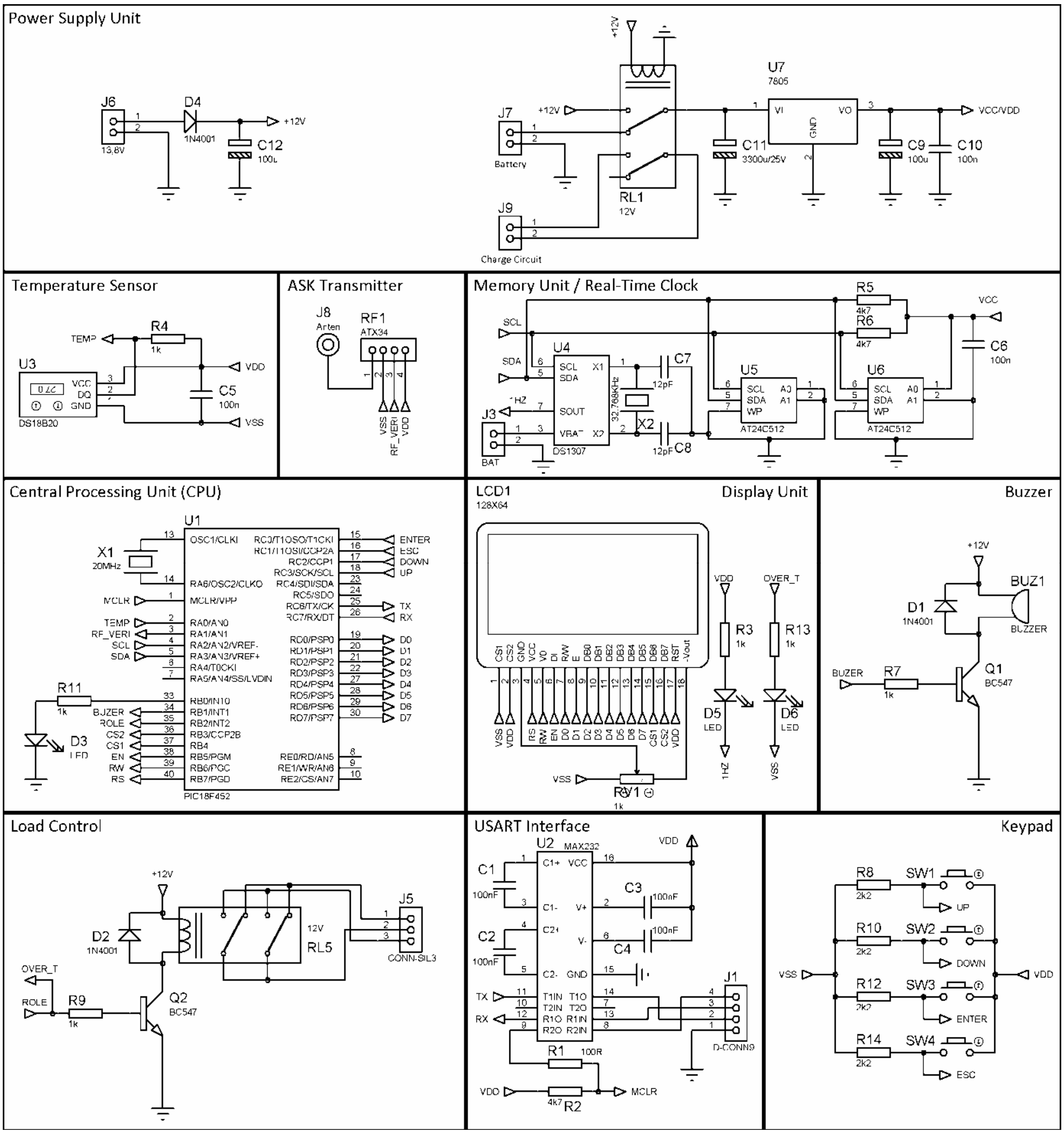
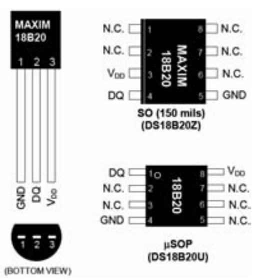


Fig. 3 — Temperature monitoring system circuit diagram

Table.1 — Pin arrangement and technical specifications of the sensor

Pin arrangement of Sensor	Technical Specifications of Sensor
	Unique 1-Wire® Interface Requires Only One Port Pin for Communication Each Device has a Unique 64-Bit Serial Code Stored in an On-Board ROM Multidrop Capability Simplifies Distributed Temperature-Sensing Applications Requires No External Components Can Be Powered from Data Line; Power Supply Range is 3.0 V to 5.5 V Measures Temperatures from −55°C to +125°C (−67°F to +257°F) ±0.5°C Accuracy from −10°C to +85°C Thermometer Resolution is User Selectable from 9 to 12 Bits Converts Temperature to 12-Bit Digital Word in 750 ms (Max) User-Definable Nonvolatile (NV) Alarm Settings

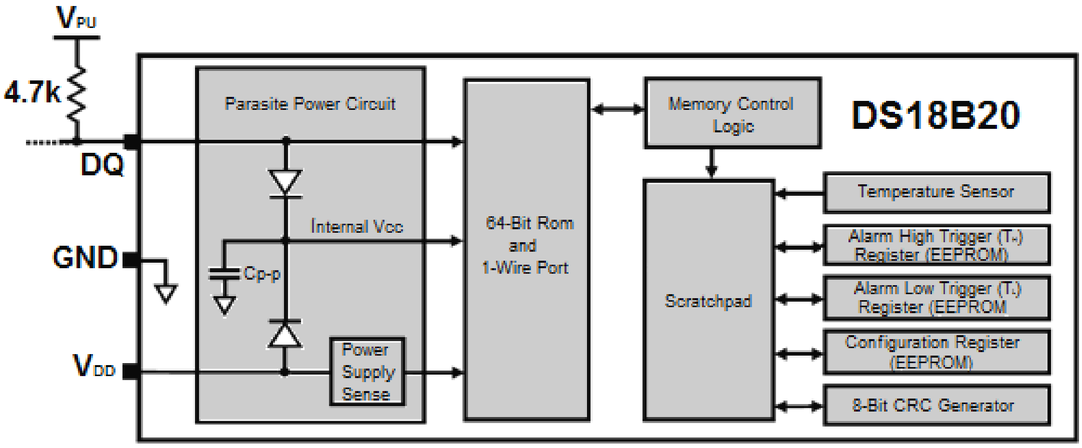


Fig. 4 — Block diagram of the sensor

Configuration Register

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
0	R1	R0	1	1	1	1	1

Thermometer Resolution Configuration

R1	R0	RESOLUTION (BITS)	MAX CONVERSION TIME	
0	0	9	93.75ms	($t_{CONV}/8$)
0	1	10	187.5ms	($t_{CONV}/4$)
1	0	11	375ms	($t_{CONV}/2$)
1	1	12	750ms	(t_{CONV})

Fig. 5 — Configuration register and thermometer resolution configuration

digital output from the single line in contrary to the other temperature sensors such as SHT11 and SHT75 for which there are two separate data lines (SCK, DATA etc.). Therefore, it facilitates the programming process of the unit and also provides easy synchronization with the central processing unit. The sensor can read the value of the temperature either 9-bit or 12-bit resolutions. In our work, we preferred to use 12-bit resolution. In addition, the accuracy of the temperature reading could be reduced to 0.1°C in contrast to 0.5°C by a suitable programming for the temperature range from -10°C to 85°C. In the present work, the temperature reading loop is repeated in every 750 ms (see Fig. 2). In case, the user wants to reduce it to a shorter time, it can be achieved by adjusting Configuration Register settings. But in this case, the resolution will be lowered (Fig. 5). After each loop, the readings are sent to the GLCD. But the recording is done for every half an hour and 48 times in a day. The durations for recordings are optional.

	SCRATCHPAD (POWER-UP STATE)		EEPROM
Byte 0	Temperature LSB (50h)	(85°C)	
Byte 1	Temperature MSB (05h)		
Byte 2	T_H Register or User Byte 1*	⟷	T_H Register or User Byte 1
Byte 3	T_L Register or User Byte 2*	⟷	T_L Register or User Byte 2
Byte 4	Configuration Register*	⟷	Configuration Register
Byte 5	Reserved (FFh)		
Byte 6	Reserved		
Byte 7	Reserved (10h)		
Byte 8	CRC*		

**Power-up state depends on value(s) stored in EEPROM.*

Fig. 6 — DS18B20 memory map

The memory map of the DS18B20 temperature sensor that we use is shown in Fig. 6. The user can program T_H Register (Byte 2) and T_L Register (Byte 3) from this map as seen in Fig. 6.

2.2.2 Real-Time Clock

In our work, the integrated circuit DS1307 is used as the RTC. Since the oscillator used in the circuit is chosen as 32.768 kHz, the RS0, RS1, SQWE bits of the Control Register are set to Logical 1 during programming (Fig. 7).

2.2.3 Memory

In the temperature monitoring system that we developed, AT24C512 two-wire serial EEPROM is used for the storage of the readings. In order to address the AT24C512, an 8-bit digital data is sent by the central processing unit as seen in Fig. 8.

512 K EPPROM is capable of writing 128-byte of data in one page. In addition, each of the 512 K EPPROM can be arranged as 512 pages of 128 byte each. At most 4 EEPROMs can be addressed by a single central processing unit in cable connected

form. When we want to use the total memory capacity of the AT24C512, the A0 and A1of the addressing bits must be set to logical 0. The formats of the digital data for byte write, page write and data read from an address procedure for 512 K EPPROM through its SDA line are shown in Fig. 9.

2.2.4 GLCD

In the developed system, the KS0108 124*64 graphical LCD is used. One half of the GLCD is controlled by the CS1 and the other half is controlled by CS2. The writing operation to the GLCD is performed by the inputs of D0-D7. After the start, the temperature reading is written on the left top corner and the time is written on the right top corner. In addition, a coordinate system appears. Its horizontal axis is the time and vertical axis is the temperature. At every half an hour, the temperature reading is plotted on the graph and recorded in the memory. The horizontal time axis is divided into 48 parts. In such a

Control Register

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
OUT	0	0	SQWE	0	0	RS1	RS0

RS1	RS0	SQW/OUT OUTPUT	SQWE	OUT
0	0	1Hz	1	X
0	1	4.096kHz	1	X
1	0	8.192kHz	1	X
1	1	32.768kHz	1	X
X	X	0	0	0
X	X	1	0	1

Fig.7 — Control register settings of the DS1307

1	0	1	0	0	A_1	A_0	R/W
MSB							LSB

Fig. 8 — AT24C512 Device Address

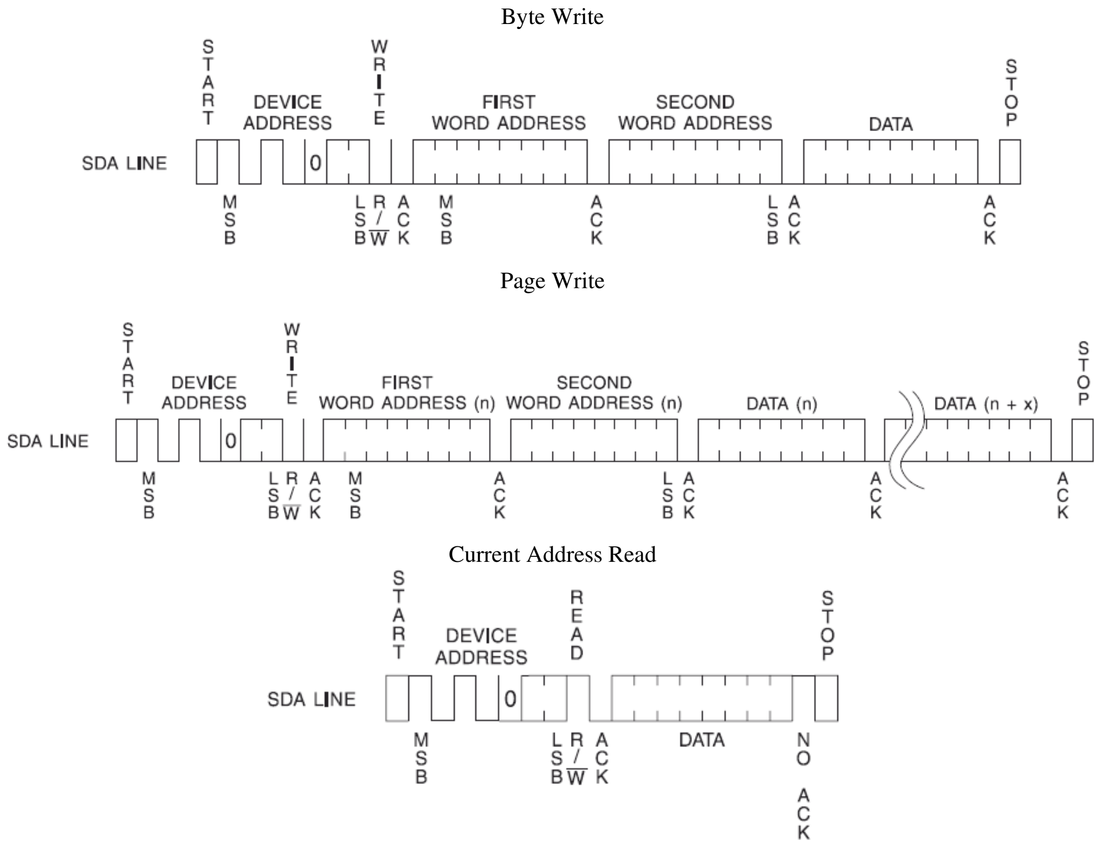


Fig. 9 — Byte write, page write and current address read

way, the user can read a one-day data in the same graph. At the end of the day, the graph is reset and the loop repeated. Since the loop for temperature reading is 750 ms, the temperature readings at every 750 ms is shown at the left top corner of the GLCD, but not plotted on the graph.

2.2.5 Optional Part (GPRS Modem)

The serial port output of the computer used to transfer the temperature value stored in the memory to the computer environment is also used to trigger the GPRS modem or to send a SMS to the user at the value of the temperature set by the user. The internal power supply unit provides power for reading the temperature values and sending SMS to the user during the interruption of the mains supply. However, during the interruption of mains supply system the refrigerator cannot operate, therefore, the temperature value may come to an undesired point. In such a case, the mains interruption can be informed to the user by an SMS. For example, if the user is a medical doctor then an interruption causing the vaccines to stay in a temperature of 7°C over a one hour period may spoil them. In that case, it is necessary to inform the user in time. If the user wants this optional part, then the telephone number of the user is requested after entering the first variables. The GPRS modem in our system is given in Fig. 10 and the general characteristics of it are listed in Table 2.

3 Performance Analysis of the System

Electronics card design of the developed system, layout and rear and front panels are shown in Fig. 11.

Fig. 10 — GPRS Modem

Table 2 — General characteristics of the GPRS Modem

General features

1. Quad-Band GSM (850/900/1800/1900 MHz)
2. GPRS multi-slot class 10
3. Compliant to GSM phase 2/2+
4. Output power: 1-2 W
5. Control via AT commands
6. SIM Application Toolkit
7. SIM Application Toolkit
8. Internet Services: TCP, UDP, HTTP, FTP,SMTP, POP3
9. Supply voltage range: 3.3... 4.8 V
10. Power consumption : 50 µA- 450 mA
11. Temperature Range : –20°C to +85°C

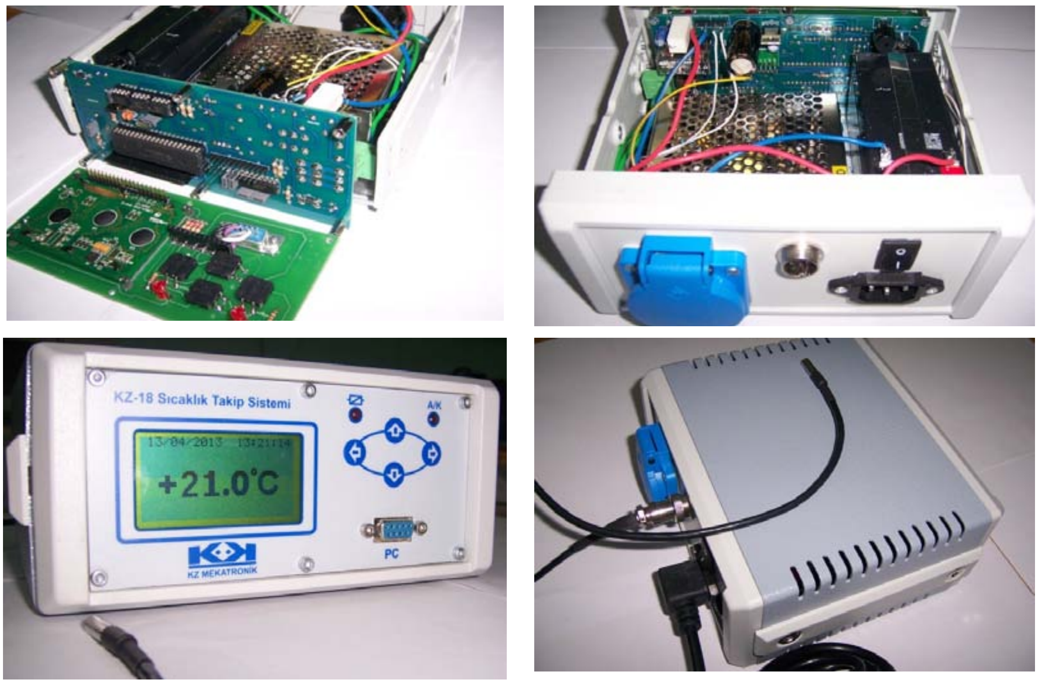


Fig.11 — Electronics card design of the developed system, layout and rear and front panels

Table 3 — Performance parameters of the temperature monitoring system

Performance parameters of the temperature monitoring system	
Sampling time	Min. 93.75 ms 750 ms, Max. 750 ms
A/D Resolution	Min. 9 Bit, Max. 12 Bit
Measurement Accuracy	0.1 ^{0}C
Ease of Use	- Determination of limit temperature values
	- Empty the memory at specified times
Functionality	- Getting data stored in memory in two different ways
	- Sending SMS or call message when exceeding the specified limits
Power consumption	Max. 1 VA
Length of memory	1 year

The socket for refrigerator, temperature probe input, system power supply input and power control switch are placed on the rear panel of the developed temperature monitoring system. When the user makes all the connections and power up the system, the temperature readings on the GLCD screen are updated at every 750 ms. The time, date, alarm, memory and temperature limits are set by the left, right, up and down buttons on the front panel. For this, first of all, the right arrow button is pressed and setting menu is seen. First of all, the temperature limit values are seen in the menu (Fig. 2). Then the alarm, time and memory settings appear (Fig. 2). After all the settings are performed, the system starts to operate according to the settings. The power is made off when the temperature inside the refrigerator system falls to the minimum temperature setting. If the alarm is active, then the low temperature alarm is given. When the internal temperature of the refrigerator system exceeds the total of the minimum temperature plus the hysteresis temperature, the system begins to operate again. Thus, it is possible to hold the internal temperature of the refrigerator system within the desired limits. The performance parameters of the temperature monitoring system are given in Table 3.

The system developed in the scope of this work has three power changes with respect to time and they are shown in Fig. 12. The power consumed by the developed system does not change at all. This shows that the system does not heat during operation.

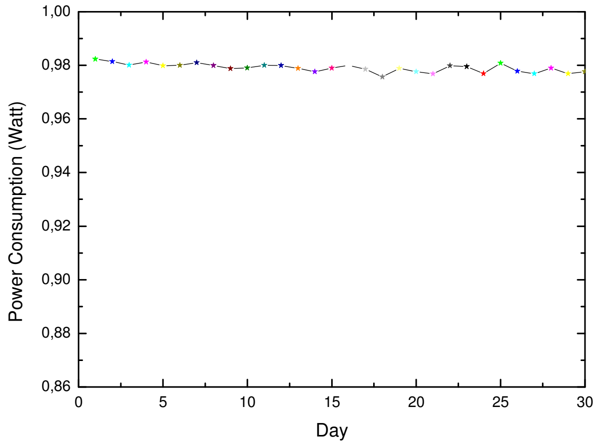


Fig. 12 — Three power changes with time of the temperature monitoring system

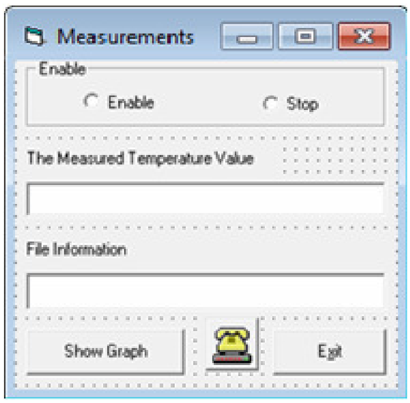


Fig. 13 — User interface on which the sensor readings are written and simultaneously plotted and presented

4 Transfer of Temperature Values to Computer by Serial Port

In the temperature monitoring system that we developed in this work, a Visual Basic based interface is developed to transfer the temperature values taken with the sampling rate of 750 ms to the computer environment through the serial port (Fig. 13). The codes of the program running under this interface are given in Annexure A.

When the *Enable* Option Button is pressed, the 12-bit digital temperature value is taken, converted into the decimal value and written in the textboxes within a 750 ms sampling interval. Furthermore, these

Table 4 — Comparison of developed system and other systems

Specification	Our System	Other Systems [Ref. 32]
Accuracy	± 0.1°C	±0.2°C to ±3.0°C
Activated life	unlimited	12 months to 60 months
Memory capacity	250000 point	4000 point to 38000 point
Minimum logging interval	93.75 ms	2 seconds to 60 seconds
Alarm type	Visual, acoustic and SMS	Visual or Acoustic
Price	150 $ (mains and rechargeable battery)	20 $ to 149 $ (non-replaceable battery) 3600 $ (Mains, battery and solar) 187 $ per year on a 3 year agreement basis (Replaceable batteries) 2100 $ (Rechargeable batteries)
Power source	Mains and Battery	Mains, battery or solar
Min. and max. temperatures	-55°C and +125°C	Except one (3600 $) of them -55°C and +85°C

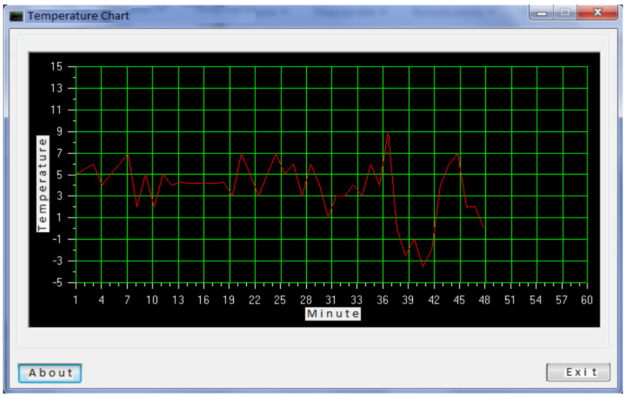


Fig. 14 — Graphical user interface for temperature readings as well as humidity readings in real time

values are recorded into a txt file in a folder determined by the user. When the *Show Graph* command button is pressed, the interface that converts the values into graphical forms appears. In Fig. 14, the graphics related to the temperature values with respect to time are shown as an example.

As seen from Fig. 14, the time scale starts from 1 and goes to 60. At the end of 60 min, the axis shifts to the left and the next values are seen. When the *Stop* Option Button is pressed, data receive and graphics plotting stop. After a while if the *Enable* Option Button is pressed again, the recording process continues from its stopping place and the graphics skip the passing time and plotted again. When the *Exit* command button is pressed, the program is closed.

5 Conclusions

Temperature measurement systems are manufactured according to the some specific purpose. The measurement ranges of each device, sampling time, temperature reading accuracy, data collection may change from system to system. The temperature monitoring system developed in the scope of this work primarily constructed for controlling of the refrigerator systems at a specified temperature range with accurate measurements. Though the results are not given in this paper, it is also tested with systems such as oven, air conditioner, etc and the performance of it is compared with the main device. According to the test works, the comparison of the system with the other measurement systems is given in Table 4.

Restrictions of the developed system:

1 The limits of operation is in between -55°C and +125°C.
2 The distance for wireless communications without data loss is about 100 m.
3 During the mains interruptions, the only operation is to read the internal temperature.
4 The power control system cannot operate in that case.

This system is designed especially for storing vaccines safely in the temperature range 4°-6°C within the refrigerators in the family health centers by the family doctors. The system may give the monthly temperature variations during the audit in a printed form. A normal refrigerator cannot give such a list when needed. In similar systems such as data loggers, the memory capacity is limited for long recording times and they are costly devices as well. Therefore, the temperature monitoring system developed in this study has attractive features to be used in aforementioned applications.

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Appendix A

"VB code to transfer the measurements to the computer"

```
Option Explicit
Private fEnable As Boolean

Private Sub cmdExit_Click()
If MSComm1.PortOpen = True Then
MSComm1.PortOpen = False
End If
End
End Sub

Private Sub Form_Load()
MSComm1.InputLen = 0
MSComm1.CommPort = 1
MSComm1.Settings = "2400,N,8,1"
Open "C:\ Documents and Settings\Yavuz Ege \
Desktop \ Voltmetre\ Deneme_01.txt" For Append As
#1
End Sub

Private Sub optEnable_Click()
fEnable = True
Do Until fEnable = False
DoEvents
Dim BytesToRead As Integer
Dim DataIn As Variant
Dim h As Integer
Dim a As Integer
Dim Tam As Integer
Dim Ondalık As Integer
MSComm1.PortOpen = True
BytesToRead = 1
MSComm1.Output = "A"
Do
DoEvents
Loop Until MSComm1.InBufferCount =
BytesToRead
If a / 2 = Int(a / 2) Then
DataIn = MSComm1.Input
Tam = Asc(DataIn)
End If
If a / 2 <> Int(a / 2) Then
```

```
DataIn = MSComm1.Input
Ondalık = Asc(DataIn)
txtToplam.Text = Tam + Ondalık * 0.1 & "C"
Print #1, Val (txtToplam.Text)
End If
a = a + 1
MSComm1.PortOpen = False
Loop
End Sub

Private Sub optStop_Click()
fEnable = False
Close #1
End Sub
```

Nomenclature

Symbol	
ICCD	Intensified Charge Couple Device
GLCD	Graphic Liquid Crystal Displays
MR	Magneto resistive
ASK	Amplitude Shift Keying
CPU	Central Processing Unit
USART	Universal Synchronous Asynchronous Receiver Transmitter
EPPROM	Erasable Programmable Read-Only Memory
PIC	Peripheral Interface Controller