Proceedings of the 6th WSEAS International Conference on Applied Informatics and Communications, Elounda, Greece, August 18-20, 2006 (pp34-39)

Remotely Controlled Supervisory Device For Refrigerators

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Abstract: Many times there are refrigerators and chambers that need to be monitored from a distance. Many reasons may prevent the proper operation of the refrigerator and damage may be caused. A remotely configured, supervisory and data acquisition system for refrigerators is proposed. The design is based on an inexpensive, ultra low power 16-bit RISC microcontroller that implements as many as possible functionalities of the supervisory and data acquisition system. Different type of sensors to monitor the condition of the refrigerator and their interfaces are presented. Communication techniques are analyzed and different designs are presented for data transmission through the telephone line. A microprocessor based design, including hardware and algorithms, is explained. Efficient algorithms were elaborated and their running time on the processor is estimated. The design targets for a reliable and accurate system with reduced power consumption.

Key-Words: -Refrigerator, Monitor, Low Cost, Time-Temperature

1 Introduction

This paper presents the design of a supervisory and data acquisition device to monitor the operation of refrigerators remotely. When the temperature exceeds the limits for some time interval, which can also be defined by the operator, the device will alarm the operator, by calling in some preconfigured telephone number. The programming of all the parameters can be done remotely.

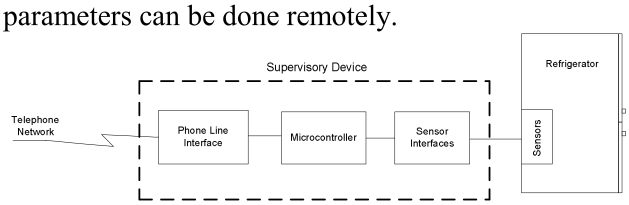

Fig. 1 System Block Diagram

The device consists of: (i) communication part to communicate with the user, (ii) data collection from different sensors part and (iii) the CPU part.

2 Telecommunication Design

The device must have the ability to inform the operator, any time, for the state of the refrigerator wherever he/she may be. It must also be able to receive power from external power sources. For this reason, it must have low power consumption and the ability to take power from a battery. In communication design, we take into account system and communication cost. We come to the conclusion, that it is best to use the wired telephone network for applications that the cost is critical and there is wired telephone access in proximity to the refrigerator. Cellular telephony (GSM), and other wireless communication technologies are of much higher cost.

One method to build the device is using a modem for the communication, and a microcontroller with the appropriate interfaces for the different sensors such as for temperature, chamber/room door state, line power state, relative humidity. The microcontroller will collect the data from sensors and using an alarming algorithm will decide when to inform the remote user for the state of refrigerator through telephone lines using modems.

Functions the microcontroller must execute are:

(i) Interfacing with sensors and data collection
(ii) Execute the alarming algorithm
(iii) Interface with the modem

Another way to build the device is using a microcontroller, two integrated circuits (DTMF encoder, DTMF decoder) and a telephone line interface. In this solution the microcontroller must perform more functions than in above method, which uses a modem. These functions are:

(i) Interfacing with sensors and data collection, (ii) Run the alarming algorithm, (iii) Control of telephone line interface (On Hook, Off Hook), (iv) Dialing, (v) Answering & (vi) Data transmission and Reception.

The DTMF encoder receives from the microcontroller calling number and data in binary format and converts it to DTMF tones. The DTMF decoder receives DTMF tones from telephone line interface, converts it in binary format and sends it to microcontroller.

The third solution to build the device needs fewer components but the microcontroller must execute more functions than the above two methods. In this solution we don't needed the external DTMF encoder & decoder components. The microcontroller will perform the function of these components. It will receive the incoming tones from telephone line interface and it will covert them in to binary numbers using Analog to Digital Converter (ADC) (which included in the microprocessor) and digital filtering algorithms. Also the microcontroller produces the DTMF tones using algorithms and the internal Digital to Analog Converter (DAC), and sends it's to telephone line interface.

3 Hardware Design

This paper presents a design with the MSP430F168 microcontroller of Texas Instruments MSP430 Family. In this design for the production & recognition of DTMF tones is used software algorithms.

The microcontroller needs only a power supply source and a low cost watch crystal (32.768Hz) to operate. The crystal oscillator is used by Timers as time base. This oscillator runs always and is selected a low frequency 32,768 KHz for low power consumption. This frequency is used only from timers and not from CPU. The CPU uses the internal DCO (Digital Controlled Oscillator) to operate. The internal DCO can operate at frequencies from 100 KHz to 8 MHz. To reduce power consumption the CPU is in sleep mode and the DCO is stopped. The CPU wakes-up from timer interrupt, takes measurements, running the alarming algorithm and goes back to sleep mode.

3.1 Power Supply

The power supply is a very critical part of the system in order to have the desired low power consumption. The power supply gives power to microcontroller and to sensors. The main power of device is a battery. Battery is chosen in order to be independent from electricity network.

The system in designed in two power phases.

Phase one, is when the system is off-line. In this phase, the power is taken from battery. The microcontroller is in idle mode and wakes-up every one second, takes measurements from sensors and runs the alarming algorithm every five seconds.

Phase two, is when the system is on-line. In this phase, the power is taken from telephone network. The loop current of telephone network is 12,8mA to 60mA [3] in off-hook mode and his value depends from terminal design. So, it is easy to take a current of about 5mA, which needed by microcontroller for DTMF encode/decode algorithms.

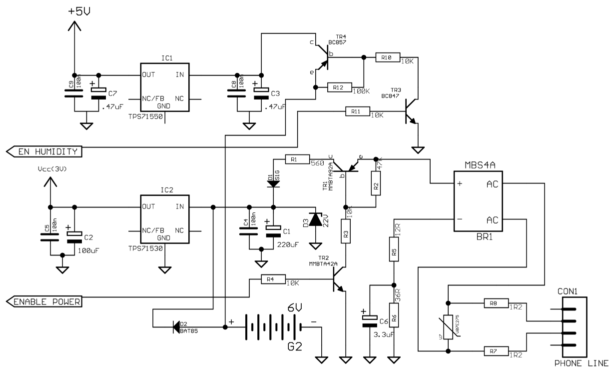

Fig. 2 Power Supply

The power supply is based on TPS71xxx voltage regulators family from Texas Instruments. The big advantage of TPS71xxx is the ultra low quiescent current (ground pin current) and high input voltage range. It needs only 3.2 μA quiescent current and the maximum input voltage is 24Vdc.

3.2 Sensor Interfaces

In order to design the interfaces for sensors, we take in to account the following parameters:

- Power Consumption
- Measurements Accuracy
- Cost

3.3.1 Thermistor Interface

The selected thermistor is NTC type with part number ACCX-002 from RTI Electronics. The ACCX-002 has the following specifications:

- Temperature Tolerance: 0,2%
- Resistance @25 ºC: 3 KOhm
- Temperature measurement range:-40ºC to +150ºC

The power supply of thermistor interface is "ON" when is time for microcontroller to take a measurement, and is "OFF" at the remaining time. For power supply of interface we use a simple digital I/O pin of microcontroller. Any I/O pin of MSP430F168 can supply a current up to 20mA.

This current is enough to power the thermistor interface.

3.3.2 Electricity Sensor Interface

In order to determine the state of power line, is used a transformer. The output of transformer changes linearly, following its input. Therefore, measuring the voltage of secondary winding can be calculated the true voltage of power line. The advantage of this method is the very good isolate which the transformer provides.

3.3.3 Doors State Sensor Interface

In order to determine the state of doors of refrigerator can be used simple magnetic contacts. These contacts needs simple interface with microcontroller and simple installation. The magnetic contact is a switch and it is placed at a proper point on the door. The switch is closed when the door is closed and open when the door is open.

3.3.4 Telephone Line Interface

Another very important part of device is the telephone line interface. This is the piece of the design which couples the telephone network to the analog connections of the modem and provides protection to the network. Also this interface includes the ring detector circuit and audio in/out path.

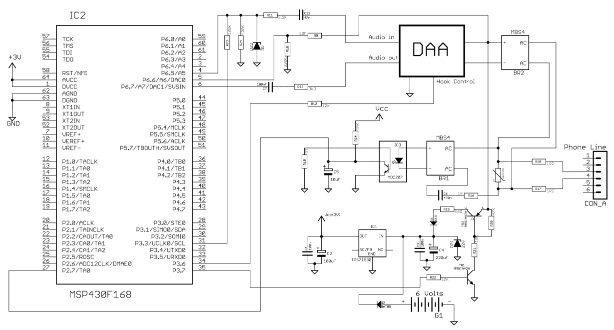

Fig. 3 Telephone Line Interface

The ring detector consists of C6, R16, BR1, IC3, R14, R15 & C5. Fig. 4 shows the response of ring detect circuit. Channel one of oscilloscope is connected at the output of optocoupler (IC3) and channel two indicates the incoming ringing signal.

3.3.5 Signal Paths

The RX signal which comes from telephone line is received by A/D converter input of microcontroller through C12 and R11. The zener diode DZ2 is used as overvoltage protection of microcontroller. The resistor divider R23, R24 is used to bias the input of A/D converter. The TX signal which sends the terminal to the line passes from C7, R13 and applied at the base of complementary Darlington pair TR5-TR6.

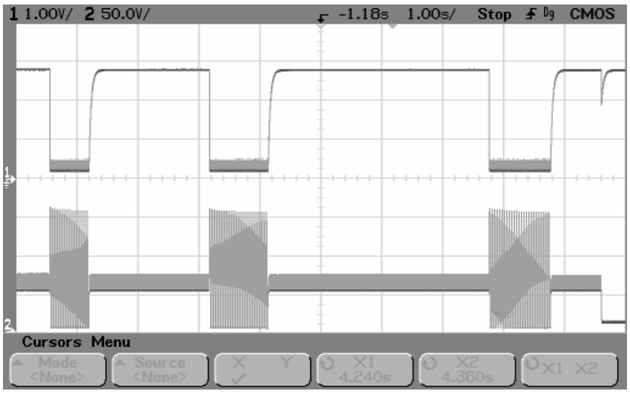

Fig. 4 Ring Detector Waveforms

3.3.6 Telephone Line Voltage Measurement

The device has the ability to know if a parallel connected telephone is in off-hook mode. For this function is necessary to measure the voltage across the line. If the line voltage is bellow than 12V, then a parallel telephone is in off-hook mode. So, a voltage divider which consists of R9 and R10 is connected to the positive end of bridge rectifier BR2. The output of divider is connected to the input A/D converter and the microcontroller takes measurements to know the state of line voltage and of parallel terminal device.

4 Software Design

The used microcontroller is the MSP430F168 [4]. The program is written in assembly language and the debugging is performed “on board” using the JTAG interface of microcontroller. The operations that execute can be divided in three sections:

- Data collection
- Alarming Algorithm
- Communication

In order to reduce the system power consumption, the microcontroller waits in stand by mode most of time. When is time to take measurements wake up by Capture Compare Register 2 (CCR2) of Timer 0. The microcontroller current in sleep mode is only 2μA. After the measurements is running an alarming algorithm. If this algorithm detects any alarm, then sets the master alarm flag and the flag, which indicates the type of alarm. After this, wakes up the microcontroller and the program returns to main loop to start the calling procedure. In figure 5 showed a flow chart of microcontroller processes.

4.1 Refrigerator Temperature Reading

In order to perform the temperature read, the microcontroller executes the following operations: first enables the power supply of thermistor bias and operational amplifier circuit. After that wait 1mSec for current stabilization and when this time expires, enables the ADC and starts a conversion. The next step is to calculate the temperature using the value of ADC and look up table of 512 bytes. With this solution, the microcontroller needs to execute only two instructions to calculate the temperature.
The temperature value needs one byte for storage.

Bit	D7	D6	D5	D4	D3	D2	D1	D0
Bit Function	Sign	2^5	2^4	2^3	2^2	2^1	2^0	2^{-1}

Table 1: Temperature Byte Format

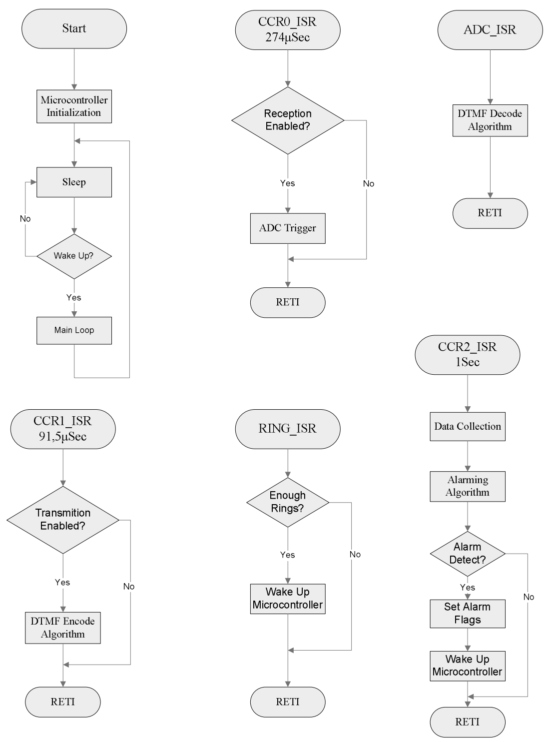

Fig. 5 Basic Microcontroller Operations

4.2 Doors state Reading

The device has two sensors in order to determine the state of doors at any moment. We consider ratio

$$R_d = \frac{DoorOpen}{DoorClosed} * 100\%$$

over a specific time interval Td, to be the parameter to designate that open doors may be responsible for a rise in temperature.

4.3 Alarming Algorithm

The alarming algorithm decides when is the time to inform the operator for the bad operation of refrigerator. The operator will be informed in two cases:
In case one, the user will be informed when one or more sensors designate a malfunction and the content of the refrigerator is still "OK" but the temperature may keep rising in one or more of many situations such as: (i) problems in freezing/heating machines, (ii) problems in electricity supply at the freezing/heating machines and (iii) door left open for longer time.
In case two, the user will be informed when the contents of the refrigerator are bad for human health. In this case, the algorithm waits until the user replaces the contents and presses the recover button on device.

4.4 Communication Control

Except the functions we described in the above paragraphs, the microcontroller is responsible for all communication operations. In communication mode, the microcontroller can do the followings:
(i) DTMF production & recognition, (ii) make & answer a phone call, (iii) receive commands, (iv) send information & (v) hardware control.

4.5 The DTMF Encode/Decode Algorithm

The DTMF is a signal which contains two frequencies (f_l & f_h). The f_l can be 697 or 770 or 852 or 941 Hz and the f_h can be 1209 or 1336 or 1477 or 1633 Hz. The DTMF signal is described by the following equation:

$$f(t) = A_L \sin(2\pi f_L t) + A_H \sin(2\pi f_H t)$$

The DTMF encode algorithm is used to convert digits to analog DTMF signals. These signals are used to make a call and to send data through telephone line. In order to produce these signals the microcontroller uses the Capture/Compare Register 1 of timer A, a sine look-up table and a Digital to Analog Converter. The sampling frequency is XTAL/3=10.922 KHz.
The DTMF decode algorithm is used to convert the received DTMF signals from the telephone line to binary data (DTMF Digits). The binary data may be instructions from user to device. In order to recognize the incoming digit, the software should recognize the two frequencies of incoming signal. One way to do this is using eight digital filters separated in two groups.
The output of each group is connected to a power level detector. This detector determines which of the filters has the higher output power.

5 Communication Protocol

The operator may change the (i) alarming algorithm parameters, (ii) the calling numbers and (iii) the communication settings at the device remotely. The user just makes a phone call to the device from another DTMF telephone. The device will answer in this call and it will send an intermediate tone. The duration of this tone is 500 mSec followed by a pause of 4 seconds. During this time interval, the device waits for instructions. These instructions send using DTMF tones and the operator sends them from his phone keypad.
The receive algorithm starts executing every time an incoming ringing signal arrives. The device may not be connected on a dedicated telephone line.

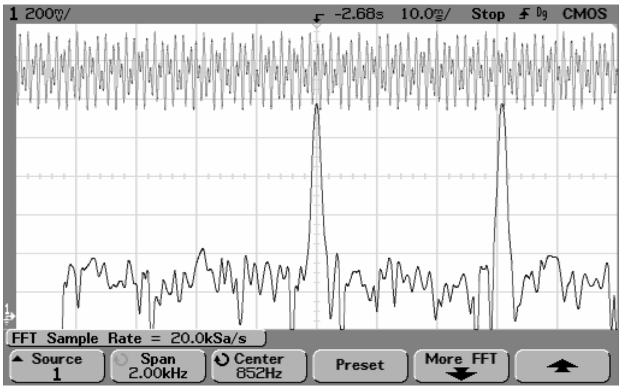

Fig 6: The Spectrum Analysis of Digit “9

After ring detection, the device answers the line and sends periodically a DTMF signal, figure 8, to designate that it is active and ready to receive commands.

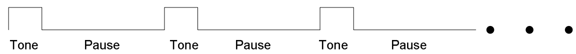

Fig 7: Call Answer Active Signal

At pause duration, the DTMF transmitter is stopped but the DTMF receiver is active. At this time, the user must start a communication session. The first character received, which turns the device in receive data mode, is the asterisk (*). After the asterisk, the device is ready to receive commands using the following format:

Password	Command Type	Data

Using “*” as a delimiters the exact format is: *password*command Id*data fields**.
The implemented commands are showed in table 2. Two asterisks should follow the data field. When the device receives these asterisks, it stores the incoming data into flash memory. Now it is ready to receive another command or to terminate the communication. The communication is terminated any time the device receives three “#”, (###). If the user does not send the termination command, the device automatically turns off the communication mode, one minute after last received character.

ID	Command Description	Data Fields
01	Change Password	*New Password*Reply New Password**
02	Change Calling Numbers	*1st Calling No*2nd Calling No*3rd Calling No**
03	Change Telephone Prefix	*Prefix**
04	Change Rings Before Answer	*Number of Rings**
05	Change First Room Temperature Integral 1st Limits	*First Room 1st Lower limit*First Room 1st Upper Limit**
06	Change Second Room Temperature Integral 1st Limits	*Second Room 1st Lower Limit*Second Room 1st Upper Limit**
07	Change First Room Temperature Integral 2nd Limits	*First Room 2nd Lower limit*First Room 2nd Upper Limit**
08	Change Second Room Temperature Integral 2nd Limits	*Second Room 2nd Lower Limit*Second Room 2nd Upper Limit**
09	Change First Room Door Percentage Threshold	*First Room Door Percentage Threshold**
10	Change Second Room Door Percentage Threshold	*Second Room Door Percentage Threshold**
11	Change Electricity Error Limit	*Electricity Low Voltage Threshold*Electricity Time Limit**

Table 2: Commands Format

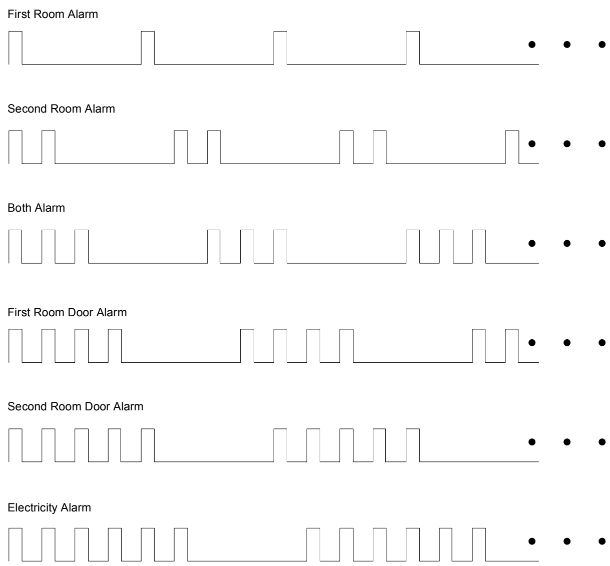

Fig 8: Alarming Tones

When an alarm occurs, the device will call the remote user and inform him for the cause of alarm. The remote user does not need to have a special device to be informed. He will receive a call in his telephone, and the device will send some tones (Figure 8), which represent the alarm. These tones are for (i) designating room

1 temperature errors, (ii) room 2 temperature errors, (iii) room 1 and room 2 temperature errors. The other implemented tones indicates that (iv) the reason of room 1 alarm may be an open door, (v) the reason of room 2 alarm may be the open door and (vi) the electrical supply voltage level is low for a long time.

6 Power Consumption Analysis

The power consumption depends on (i) the current of the sensors condition circuit, (ii) the current of microcontroller and (iii) on the leakage current of the power supply. Each sensor condition circuit draws current only the necessary time needed for an accurate measurement. In table 3 is showed the current consumption of device for each action of microcontroller.

Activity	MCU Current	Sensor Current	Action Time	Repeat Time
Temperature Reading	500 µA	1.56 mA	1 mSec	5 Sec
Doors State Reading	500 µA	181.8 µA	500 µSec	1 Sec
Electricity Level Reading	800 µA	0 mA	4.5 µSec	5 Sec
Temperature Calculating	1.3 mA	0 mA	10 µSec	5 Sec
Doors State Calculating	500 µA	0 mA	100 µSec	1 Sec
Electricity Level Calculating	500 µA	0 mA	100 µSec	5 Sec
Alarming Algorithm	500 µA	0 mA	10 mSec	5 Sec
Power Supply Quiescent Current	-	-	3.2 µA Always	-
Microcontroller Sleep Current	-	-	2 µA Always	-

Table 3: Current Consumption Analysis

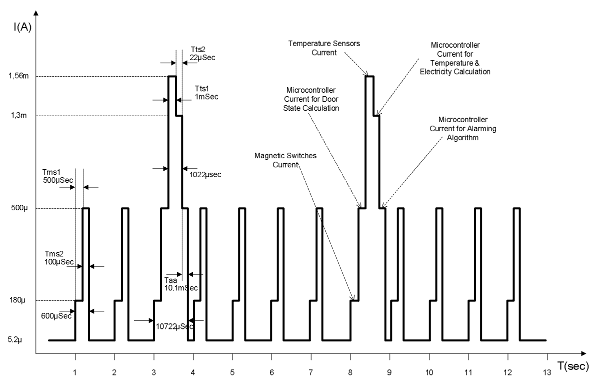

Fig 9: Graphic Analysis of Overall Power Consumption

Using the above can be calculated the overall power consumption of device. The average current on the microcontroller, sensors condition circuit and the power supply is only 7.02 µA. Figure 8 shows the current consumption of device in graphical representation.

7 Conclusion

The theme of this paper was the design and the implementation of an controlled alarming, supervisory and data acquisition system to monitor the operation of refrigerators remotely. Our effort was to build the system using as much as possible the microcontroller, software and hardware, instead of external hardware peripherals in order to reduce the cost and the power consumption of the whole system.

The remote monitoring is performed through the telephone line. The data acquisition system uses differential amplifiers for temperature sensors signal condition. The communication control system uses an optocoupler, transistors, resistors, capacitors and diodes. The power supply is based in an ultra low power regulator with quiescent current of only 3.2µA.

The average current consumption of system, when it is off line, is only 7.02 µA. So, using a small 3.3 V/800 mAh lithium battery the system will operate continuously for 12 years.

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