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Wireless Module for Distance Measurement of Patient's Temperature in Hospitals

D. Tz. Dimitrov
Faculty of Communication Technique and Technologies, Technical University of Sofia,
Kliment Ohridsky str. 8, 1000 Sofia, Bulgaria, phone: +359 2 9652278, e-mail:dcd@tu-sofia.bg

Introduction

One of the important areas of application of wireless communications is telemedicine. A multi-purpose wireless system is described in the paper. It consists two main parts – patient's and base's. Patient's subsystem provides collection of data (biosignals and images) from the patient and transmits them to the subsystem of the base. An appropriate communication protocols provides communication between two subsystems [1].

Description of the wireless module

The system for temperature data transmission consists of two subsystems: **Patient's subsystem**, located by the patient and **Base subsystem**, located by the doctor.

Patient's subsystem provides transmission of bio-signals from the patient to the medical staff on the territory of a given healthcare establishment. The medical staff subsystem provides reproduction, analysis and saving of temperature data received from the patient subsystem into a database. Patient's subsystem transmits signals to the base by means of a temperature sensor SMT16030. Information can be transmitted by means of microprocessor control PIC18F1320 to the medical staff's subsystem. It can communicates with a personal computer and in such a way data could reach the healthcare personal. Patient's temperature reporting is not performed permanently. It can be obtained by special command from computer of the base subsystem. It's a peculiarity of the system described herein, that both subsystems – the first one of the patient and the second one of the base, are completed with a RF module comprising receiver and transmitter, which gave the opportunity to design the system on the principle of time division [6–7].

Patient's subsystem

The patient's subsystems are shown in Fig. 1 and it includes the following major components: microcontroller, transceiver, antenna, voltage regulator block.

AM transceiver. The connection on the radio channel between the patient's subsystem and the base is performed through the transceiver RTL-DATA-SAW [9]. Demodulation and restoration of the useful information signal is performed on reception. The particular module is intended for digital data and could work with amplitude manipulation. After that, the received signal can be sent for consequent processing. The power of emission is selected for the purposes of providing correct information transmission from the desired distance in frame of one hospital. The transceiver of the base system is the same due to the analogous working scheme [4].The digital transceiver RTL DATA SAW can fulfill a semi-duplex bidirectional radio connection with switching between receiving and transmission [2]. Its digital interface is serial. Investigation was done with following parameters: working frequency: 433.92 MHz, power of the transmitter: 8 mW (9dBm ± 2dBm), antenna's impedance 50 Ω.

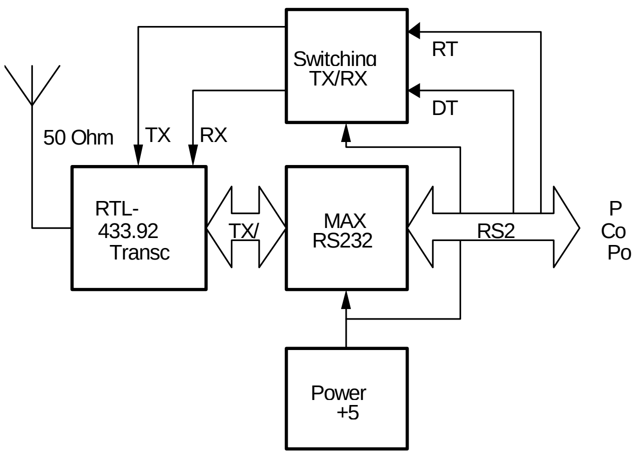

Fig. 1. Patient's subsystem

It's necessary to invert the serial data for connection of RF module to the microcontroller's serial interface. In the other case the module can be in transmission when there is not data in its input. The inverters are built from one 4011 CMOS integrated circuit (for two input NAND elements). During development of the system some unwanted switching of digital output of radio transceiver module has been observed when switching from transmit to receive state. To eliminate this, the NAND in receive part is blocked for about 100 ms by integration circuit connected to its second input. After this the digital out line is stable and depends only by eventual incoming radio signal.

Voltage regulator block. The voltage regulator block operates with a 3V battery and should provide 5V voltage as far as the RF module and the temperature sensor work with that voltage. Because a linear regulator is not appropriate, an impulse regulator is used which provides a much higher efficiency rate and what in its turn would lead to much longer working capacity of the device without changing of the battery.

Antenna. The wireless connection between the two devices could be fulfilled by virtue of an antenna of the type PU 4BA-433. A quarter-wave helical antenna of 433.92 MHz is used. This type of antenna is chosen because combines effectiveness and relatively small size. It can be connected to the radio transceiver module directly.

Base subsystem

The base subsystem is shown in Fig. 2. It consists of the following modules: transceiver, antenna, serial interface RS232, voltage regulator block. This is the section, which receives and transmits the data from and to the patients' subsystems. It is controlled by a personal computer and thus radio-connection for a bi-directional communication is put into a service. The transmitting or receiving state is controlled by RTS and DTR signals of RS232 interface using MOS transistors.

Gate for translation of logical levels. The standard serial port is used to provide communication between the base unit of the device and the personal computer. The physical levels of the logical "0" and "1" with which the transceiver operates, do not correspond to the standard for asynchronous serial interface (RS232). That is why MAX232 level shifter is used to convert the physical levels at the input and output in compliance with the standard for serial interface RS232. This communication is necessary in order to control the device, as well as to extract and process the received data.

Temperature sensor

It's well known that the changes of patient's temperature are enough slow. Its monitoring can be done at great intervals in time (15-30 min. or more) and it depends on the medical representative's judgment. When realizing a module for the monitoring of temperature from a distance, the most important is to use a thermal transducer with a small probability for mistake allowed, a small drift for the parameters and if possible-a lower price. There are different temperature converters and the most precise of them are the resistant converters (platinous and nickel).They have a small drift of the parameters in time, it is easy to make a linearization of the characteristics but unfortunately they have comparatively high price. On the other hand, they require the providing of stable constant electricity through them, which is connected with technical difficulties. The digitalizing of such a kind of information (voltage drop on the converter) has to be done with a precise analog-cipher converter. For more precise measuring of the temperature with such a converter, it is necessary to take into consideration the resistance of the adjoining conductors, which in most cases cannot be ignored. For more precise measurements it is important to be taken measures for eliminating influence of Electromagnetic field (EMF). Another comparatively accessible method for measuring the temperature is using the thermal electric voltage converter (a thermal couple). At the ends of the contact couple made of different substance (thermo element), when there is a temperature difference between the two ends, EMF occurs, called thermal EMF. The thermal couples have low price and are usually used for measuring high temperatures (the linearization when there are low temperatures is hard). They have a smaller frequency of the parameters considering the different examples, a great drift of the parameters in time and last but not least they measure the temperature difference between the connected and the free ends.

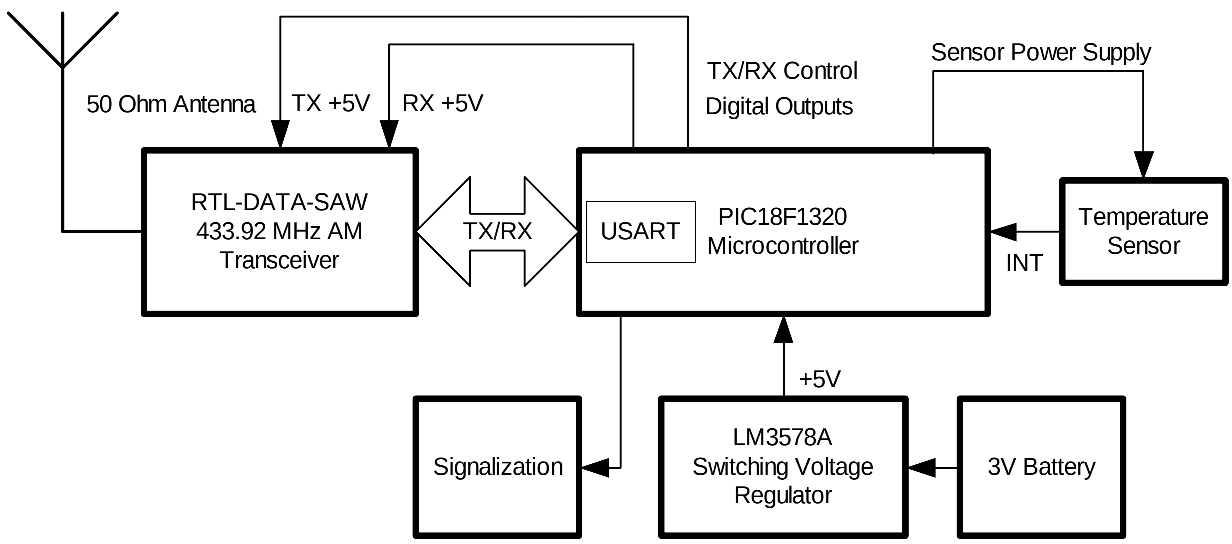

Fig. 2. Base subsystem

In order to measure the temperature by thermoelectric converter, it is necessary that the free ends are situated in 0 °C or the temperature of the free ends is measured by another thermal transducer and on that basis a correction in the measured voltage is done at the free ends and respectively of the measured temperature. These are technical difficulties, which are hard to overcome when developing portable devices.

Another alternative is the semiconductor converters of temperature. They have low price, small proportions and not a great drift of the parameters (for the high-quality ones). Usually, the non-linearity is high, especially at the end of their range. In the given case they are used at a very small temperature range where the mistake for non-linearity is so small that it can be disregarded. When necessary, a linearization can be done. A preliminary conclusion, based on the listed above, that the semiconductor converter is a suitable choice for the given case can be reached.

The precise temperature sensor provides for the measurement of temperature with exactness higher than 0.2 ^{o}C within the temperature span from -30 ^{o}C to 130 ^{o}C and 0.1 ^{o}C in the range from -30 ^{o}C to +100 ^{o}C.

Taking into account the narrow temperature span within which the thermal sensor is used in the specific case, it could be stated that non-linearity in the same is very small. Within the temperature range from 35 ^{o}C to 42 ^{o}C, the non-linearity inaccuracy would be smaller than 0.1 ^{o}C. The drift of the sensor is also very small for the given range (0.05 ^{o}C); hence it becomes clear that the demands in respect to the precision of temperature measurement are satisfied. [3]. Actually the sensor’s output is pulse-width modulation of rectangular pulses, so the duty cycle represents the measured temperature. By virtue of a comparatively short software program, it is possible to measure exactly the times (period and pulse width) of the signal at the output of the temperature sensor (rectangular pulse).

The duty cycle of the output signal is linearly connected with the temperature by $DC = 0{,}320 + 0{,}470t$, where DC is the duty cycle of the rectangular pulses; t is the measured temperature in ^{o}C.

Microcontroller

Microcomputers of the series 18F… are a single-chip, eight-bit microcomputer designed on the basis of CMOS technology. The maximum working frequency for this family is 40MHz. The type of the microcontroller selected provides for utilization of an internal clock-pulse RC generator, which reduces the number of the external components used. Taking into account that for the precise measurement of duty ratio of the impulse from the temperature sensor, it is required that the frequency of this RC generator is stable within a given period of the impulses generated by the sensor (maximum 1 ms), it could be inferred that application of a non-quartz stabilized clock-pulse generator would not degrade the precision of temperature measurement. [8]. Usually the output frequency of RC generators depends mainly by temperature, so the crystal temperature could not vary so much in this short time interval (1ms). The output of the temperature sensor is connected to the external interrupt pin of the microcontroller. So using external interrupt as well as reading the current value of built-in timer module makes possible to calculate the period and the pulse width with high enough accuracy. The microcontrollers of the series PIC18 can process interruptions of low and high priority. As far as an interrupt generated by an impulse of the temperature sensor must be processed without delay (affects the precision of temperature measurement), it is reasonable that an external interruption, generated by the temperature sensor, is selected with high priority. Low priority interruptions refer to reception of data into the USART module.

As the microcontroller should manage external devices of low consumption (the receiver of RF module – 4.5 mA, a transmitter of the RF module 2.5 mA, temperature sensor 0.2 mA), it is possible to connect these devices directly to the I/O pins of the single-chip microcomputer. Each pin of the indicated microcontroller can supply current of up to 25 mA load.

Software

Because the communication in this system requires slow data rate and rare activity, the software for the microcontroller has been developed using high level programming language. This approach reduces the efforts needed for debug. In this case the used compiler is MPLAB – C18 v2.20 (Demo version). The Software is based on interrupt driven routines. The high performance 8-bit PICmicro® microcontrollers offer processing of interrupts with different priority. High priority interrupt can override the low priority interrupt. [8].

The software project uses many standard library functions for serial communications, delays, data conversion and string manipulations. Mainly it consists several software modules: “main.c”, “manchest.c”, “crc8.c”, “int_eep.c”.

Module “main.c”. In this module are located interrupt routines (low and high priority). Interrupt routine with high priority is used to measure the duty cycle of pulses, generated by temperature sensor. This method ensures temperature measuring with high accuracy. As mentioned above the pulse output of the temperature sensor is connected to the external interrupt input of the microcontroller. The routine starts on every pulse edge (rising or falling). Every time the routine changes the edge of this interrupt. Depending of this the stored value in the Timer1 is used to calculate the period and the pulse time of the rectangular pulses, respectively the temperature. To achieve higher accuracy in measuring, long time integration is taking place therefore the period and the pulse time are stored in 4-bytes volatile variables. In this case 10000 periods are used for integration, which means a new valid result is available on every 2.5 to 10 seconds depending by the sensor.

Interrupt routine with low priority is used to capture commands from the base unit. This microcontroller gives opportunity to be woken up from SLEEP state on receiving data state via USART module. The module uses this method for power consumption reducing. In addition if the device does not receive command from base station for more than 15 minutes it will go to SLEEP state to save battery power. To count this timeout Timer0 module is set to overflow on 10 ms. So this interval is used to make a simple clock. Timer0 generates masked interrupt because this 15 minutes timeout is not necessary to be so exact.

According to the communication protocol in this routine the patient's unit receives a string with given length and decodes it form Manchester code. The basic task in the "main.c" is to recognize the received string by checking CRC, and by comparing address field in the string with unique address stored into microcontroller's EEPROM.

Depending on the state main program assembles the packet from current measured data or service message and sends via USART module. After power-up, the module initializes microcontroller's peripherals and during communication controls the TX/RX state of the transceiver module.

This module also takes care for switching the state of RF module with appropriate delays to ensure reliable data transmission.

Module "manchest.c". In this software module functions are located for coding and decoding in Manchester code. In addition the function for decoding is able to detect an illegal Manchester code combination. This is the first check for communication error.

Module "crc8.c". It is responsible for CRC calculation and checking. The used CRC polynomial is $x^8 + x^5 + x^4 + 1$. CRC checking is just comparing of received byte in CRC field with calculated CRC during the receiving process.

Module "int_eep.c". According to datasheet for used PICmicro® microcontroller this module is used to write and read data from on-chip EEPROM. In this memory is located unique address for the unit. When only one patient's unit is enabled the base unit can change its address via radio channel.

Manchester coding. The identification of mistakes is done by Manchester and CRC coding of the information received by the patient subsystem and thus the possibility for wrong data reception is excluded. The combining of the two encodings is necessary as the CRC encoding encounters mistakes, which cannot be found by the Manchester code (two adjacent wrong bits). The even parameter encoding also could disregard such a mistake (11 or 00). Thus the combination of the two kinds of encoding gives a noise-resistant encoding and finds out almost all wrong combinations. In addition, when there are long chains of identical logical levels on the line, practically, there is constant voltage and there is a considerable difficulty for the synchronizing of the transmitting and the receiving part. Consequently, other methods for encoding are more frequently used for transmitting signals. The latter are called impulse and are based on the front of the formed rectangular impulses of electrical voltage on the cable in the physical environment.

Encoding. For a greater noise-resistant data transmission before their transmission begins, they have to be presented in the respective manner. This means that there should not be any long subsequent sequences of logical units and zeroes. This can be achieved through encoding of the information. For that purpose 8 bits of the whole chain of information that should be sent are transferred to the encoding program. Four sequences of processing are done for every 8 bits, out of which 8-bit outgoing sequence of logical units and zeroes is created. Every cycle has been created on the base of highest rank. If the result is not zero, the combination '10' (1001 -> 100110) is added to the initial chain. If it is equal to zero, '01' (1001 -> 100101) is added to the initial chain. After these actions, there is a redistributing to the left of the initial chain and the cycle is repeated.

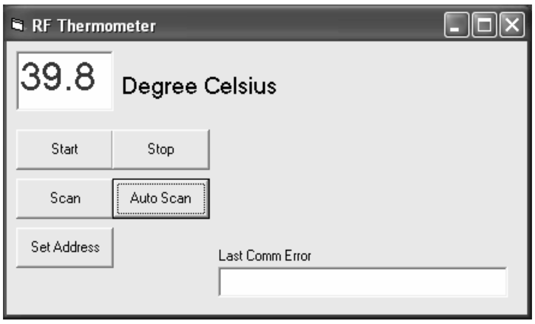

Fig. 3. Software interface

Decoding. After receiving the information from the RF module, they are sent to a subsidiary program for their decoding. The initial chain is processed byte after byte. For every 8 bits 4 chains of processing are done, out of which an 8-bit final chain is produced. In every interaction the state of the two bits of the highest rank is monitored. If they are "01", we obtain "0", and if they are "10", we obtain "1". If the resulting combination is "00" or "11", a Manchester error is generated and the decoding is cancelled. That error can be resulting out of the occurrence of noise during receiving the information, which on its part, can be resulting out of quick movement of the receiver in respect to the transmitter. After completing these actions, the initial change is moved with two bits to the left and the initial chain of the cycle is repeated

Base system software. The base system is driven by Windows application developed using Visual Basic 6. Serial communication is organized on the base of MsComm control. The user interface of the described system is shown in Fig. 3.

Communication protocol

This system has been projected to be multi node. Every node has a unique one-byte address. The maximum number of nodes is 255 (zero address is reserved for the base subsystem). The communication protocol is accomplished on the basis of commands and on principles based on the method of multiple access time division (TDMA) and on packet messages of definite size and format. There could be a time interval for communication for each of the subordinate devices; this is selected and controlled dynamically by the main device, which actually works as an arbiter. The information from more than one patient's subsystem could never be transmitted to the base simultaneously. This bidirectional communication is controlled from the main device, as it sends orders for initiation of temperature data transmission in the form of packets (batches), repetition of wrong packets or termination of request for consequent information. The packets for data exchange are shown in Fig. 4.

PC-Term

Length	Address	Command	CRC

Term – PC

Length	String 1	String 2	CRC

Fig. 4. Communication protocol

In Fig. 4: ***Length*** – gives information to receiver about packet length (one byte); ***String 1*** and ***String 2*** are for information of period and pulse width generated by temperature sensor. They are in ASCII code. The length of these strings can vary; **Address** – 1 byte (1-255); **Command** (one byte): R - Read, S - Start, P - Stop, A – assign a new address.

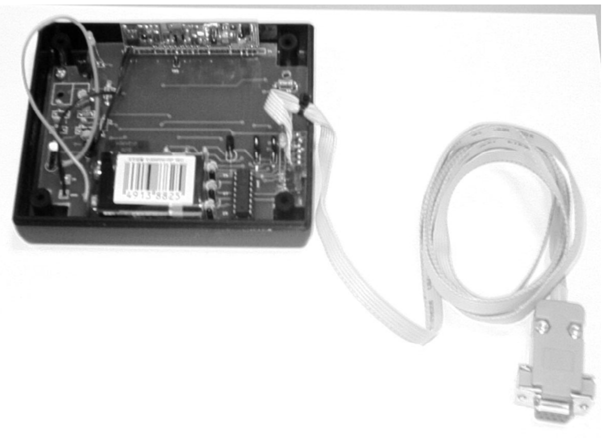

Fig. 5. Base subsystem

To achieve more flexibility it is possible to change the device address over radio channel by issuing “Address” command from the base unit followed by desired address. In this case the others patient’s subsystems must be switched off. The user should take care to avoid more than one subsystem to have same addresses.

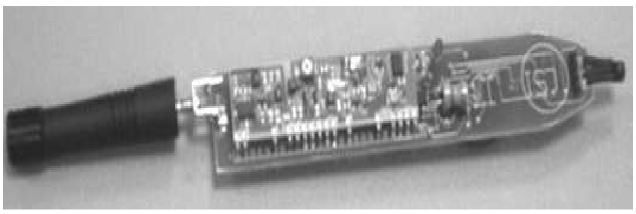

Fig. 6. Patient’s subsystem

Because the amplitude manipulation is not noise resistive the communication should be with high informational redundancy. Cyclic Redundancy Check (CRC) filed protects every packet. On received wrong command the receiver does not answer. In this case the PC software generates a time out error and repeats the command as well as if the base subsystem discovers a communication error of incoming data.

Because of nature of communication over radio channel using NRZ code is not suitable. Manchester encoding removes the DC component of the transmitted bit stream. This technique reduces the throughput of the communication’s channel by factor of 2. The system requires slow data rate. So, its performance is not affected. Manchester encoding also is used to check for some errors (illegal combinations in bit stream like 00, 11 sequences).

The identification of communication error is fulfilled by virtue of Manchester and CRC codification of the information received from patient’s subsystem, and the possibility for wrong reception of data is thus ruled out. [5]

Described and investigated base subsystem is shown in Fig. 5 and the patient’s system is shown in Fig. 6.

Conclusions

The remote temperature measurement is an innovative method in the area of telemedicine.

The module for supervision of patient’s temperature from a distance could find application in a variety of healthcare enterprises or hospitals.

Temperature is not a parameter quickly varying in time, though, in grave conditions, its supervision within shorter periods of 30 minutes could turn out to be very important for the recovery of the patient.

The proposed software of the described module could be organized in such a way as to scan the temperature of all patients as well as to record the data for a long time period and in case of detecting a temperature higher than 37^{o} C to give a warning through a sound signal.

The system is reliable both for the patient and the doctor, as the transmitted information is true and precise and there is no risk of mistakes due to incorrectly distinguished temperature.

A similar system could be designed on the principle of this one, only for the transmission of other types of data – ECG signals, for instance. For this purpose some sophisticated wireless technologies should be used like Bluetooth® or ZigBee®. Especially the second mentioned technology has been developed in last years. It combines low price, low power consumption and possibility to be organized Personal Area Network (PAN) with up to 255 nodes. This is very perspective for different king of wireless diagnostic medical applications over ISM band (2.4 GHz). This could be subject of future developments in this field.

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D. Tz. Dimitrov. Wireless Module for Distance Measurement of Patient's Temperature in Hospitals // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 2(82). – P. 53–58.

System for distance measurements and data collection of patients' temperature in hospitals is analyzed. Microcontrollers and radio-frequency transmitters are used to implement the described module. The wireless system for temperature data transmission consists of subsystems for the patient and for the physician. The module for remote supervision of the temperature of hospitalized patients facilitates work of medical staff. Ill. 6, bibl. 9 (in English; summaries in English, Russian and Lithuanian).

Д. Ц. Димитров. Модуль для дистанционного измерения температуры пациентов в больницах при помощи радиосвязи // Электроника и электротехника. – Каунас: Технология, 2008. – № 2(82). – C. 53–58.

Описывается система для дистанционного измерения температуры пациентов в больницах и накапливания данных измерения. Система реализована при помощи радиопередатчики и микроконтроллеры. Радиосистема дальнего измерения и накапливания температурных данных состоит из подсистемы пациента и подсистемы врача. При помощи этой системы облегчается работа врачей и улучшается обслуживание пациентов. Ил. 6, библ. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

D. Tz. Dimitrov. Belaidis modulis nuotoliniams paciento temperatūros matavimams ligoninėse // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 2(82). – P. 53–58.

Analizuojama distancinio pacientų temperatūros matavimo ligoninėse ir eksperimento duomenų kaupimo sistema. Sistemą sudaro radijo siųstuvai ir mikrovaldikliai. Bevielė temperatūros matavimo duomenų perdavimo sistema susideda iš paciento ir gydytojo posistemių. Nuotolinės pacientų temperatūros stebėsenos modulis palengvina gydytojų darbą ir pagerina pacientų aptarnavimą. Il. 6, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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