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Human body temperature monitoring wireless system

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Abstract. To solve the problems of medical diagnostics, human body temperature measurement has become widespread. In many cases, to make a correct diagnosis, it is required to obtain results of continuous monitoring during a certain period instead of a single temperature measurement. This paper discusses a wireless body temperature monitoring system using a high-precision semiconductor sensor and the RN 4870 Bluetooth module.

1 Introduction

During the last time, medical systems for human health monitoring have become increasingly widespread due to electronic elements and means of communication enhancement. The main problem of further development of human body physical parameters measuring systems are accuracy, speed, power consumption, and information content of measuring signals of the sensors. Mentioned problems reduce the efficiency of using automated diagnostic and decision-making systems, which hinders the development of medical monitoring systems and their wide application [1].

Human body temperature measuring is one of the most frequent tasks of medical diagnostics. Currently, there is a wide variety of devices for body temperature measuring produced by many manufacturers, such as SAAT (Israel), OMRON (Japan), HEALTH INSTRUMENTS (China), and the company "HEY & DI RUS" (Russia). However, existing human body temperature sensors types such as mercury, alcohol, and thermo resistive do not have sufficient speed, and infrared sensors do not have the accuracy in solving real-time temperature monitoring tasks during multiple temperature measurements or during temperature measuring of young children when the specifics measurement conditions require almost instantaneous implementation of this procedure.

As follows from the above mentioned, reducing the time of human body temperature measuring without loss of accuracy is an important task. Developing methods for measuring human body temperature using semiconductor sensors seems promising.

The physical principle of operation of a semiconductor temperature sensor is based on the temperature dependence of the voltage drop at the p-n junction shifted in the forward direction. This dependence is close to linear, which makes it possible to create sensors that do not require complex correction schemes. Diodes or transistors connected according to the diode scheme are used as sensitive elements. To carry out measurements, it is necessary

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to flow a stable current through the sensing element. The output signal is a voltage drop on the sensor [2].

In this paper, body temperature monitoring system using a high-precision semiconductor sensor with wireless communication possible by using of Bluetooth module is considered.

2 Methods

To measure the human body temperature, medical thermometers are used to obtain information about body temperature at the current moment.

However, for differential diagnosis of a patient's disease, the one-time body temperature measurement is not always acceptable. To implement the different methods for disease diagnosis, it is necessary to use instrumental diagnostic methods that allow the determination of localization of the disease and its severity with high accuracy.

One of these methods is the human body temperature monitoring. Monitoring is a constant technological process of measuring body temperature at predetermined intervals. In addition, continuous (periodic) monitoring of body temperature is necessary for some disease treatments to evaluate the chosen treatment strategy. Thermometry as an objective research method can be effectively used for the timely recognition of infectious diseases, infectious and inflammatory processes (endocarditis, pneumonia, rheumatism, etc.), various types of fever, acute surgical pathology, etc. [3].

Based on the mentioned above, it is possible to formulate the requirements for human body temperature monitoring information and measurement system. The requirements are as following:

1) Comfortable location of the system wearable sensors on the human body due to long period of monitoring process (possibly up to several days) is mandatory.

2) High accuracy not only in the measurement procedure but also obtaining the final information directly to the medical personnel, which is affected by distortions and errors in the data transmission channels from sensors to output devices.

3) Considering the trend of the increasingly widespread introduction of telemedicine technologies, an obviously promising information measuring system should be able to connect to telecommunication systems for transmitting current patient temperature data to remote medical centers.

4) The mass-dimensional, energy, and cost characteristics must be applicable for using the system in medical organizations with different conditions.

The following physical principles of temperature influence physical objects' parameters are currently used as the basis for the process of converting human body temperature into data for an information system [4]:

Expansion of liquid materials;

Electrical resistance of materials change;

Thermodynamic electromagnetic field change (thermocouples);

Capacitance of the capacitor change when the temperature changes;

Pressure change;

Inductance change;

A mercury thermometer was created based on the above principle (expansion of materials with temperature changes). It was used for a long time as the main instrument for measuring human body temperature. The main advantage of a mercury thermometer is its simplicity and relative accuracy. The disadvantages include the fragility of the thermometer case and the use of mercury, which is dangerous for health.

Electronic thermometers have replaced the mercury thermometer, which embodied reliability, accuracy, and safety. Electronic thermometers use various temperature conversion principles described above. The disadvantages of electronic thermometers include their cost of production and operation associated with using electrical power sources. The electric power sources require periodic replacement, and old ones are a problem of recycling and environmental impact.

For human body temperature measuring, two measurement methods are used: non-contact and contact [5].

In the non-contact temperature measurement method, special devices for measuring infrared radiation of the body (so-called pyrometers) are used. The main advantages of the pyrometer are non-contact measurement, high measurement speed, and continuity of temperature change readings. The disadvantages are the large error, high operating cost, influence of extraneous sources of infrared radiation, and directivity of measurement.

For contact measurement, depending on circumstances such as age, conditions, and accuracy requirements, various methods are used: Rectally, Vaginally (for women), Oral (buccal), Orally (under the tongue), Axillary (under the arm), an ear and forehead.

Using these methods for a single temperature measurement does not cause inconvenience or problems. But constant temperature monitoring for a long period must satisfy another requirement - measurement accuracy, which depends not only on the accuracy of the temperature measuring device but also on the influence of external factors such as ambient temperature, air humidity, and the material in contact with the temperature sensor during measurement of the temperature on the forehead, in the armpit and inguinal fold, as well as on the human body. The temperature of the human body at different points of taking readings is given in Table 1.

Table 1. Temperature of the human body at different points of taking readings

Measurement method	Min.T ^{0}C	Max.T ^{0}C	Measurement duration (s)
Rectally	36.2	37.7	10-60
Vaginally	36.0	37.5	-
Oral (buccal)	35.5	37.1	30-60
Orally (under the tongue)	35.7	37.3	30-60
Axillary (under the arm)	35.2	36.7	30-60
An ear	35.8	37.1	1
Forehead	*	*	1

**Depends on environmental temperature.*

The results of the research described in [6] the optimal thermometer location placed on the human body was determined. This is the third intercostal space of the axillary. The sensor's location in this place for a long period of measurement does not cause discomfort to the patient.

The human body temperature is affected by ambient temperature. For example, in very cold weather, the rectal temperature can drop to 36.1°C, and the oral temperature is even lower. In extreme heat, the rectal temperature can rise above 37.8°C.

To reduce the influence of external factors and improve accuracy measurement, you need a body temperature sensor heat insulated from external influence and monitor the ambient temperature and its humidity simultaneously with body temperature measurement.

Human body temperature monitoring allows you to trace in time the impact on the state of the body of physical and emotional stress, the influence of external factors (temperature, humidity, pressure, electromagnetic radiation, x-ray, and gamma radiation, atmospheric air composition, etc.), drugs introduced into the human body and their consequences, the impact of food and perform other studies. During body temperature monitoring, the measurement information can be recorded at regular intervals in the electronic memory of an electronic computing device for further processing and research. The stored data can be presented as a table with date, time, and temperature or as a graph of temperature change during time. The results of body temperature monitoring allow you to determine the dependence of body temperature changes during scientific research, disease diagnosis, or treatment.

3 Results and discussion

To develop the human body temperature monitoring information system functional diagram, it is necessary to determine the following items:

Selection of the type of sensors for converting human body temperature into electrical signals;

The number of temperature sensors is enough for accurate average reading with required accuracy calculation;

Choosing a microcontroller for processing signals from sensors;

Selection of the communication protocol for information exchange between the sensor and the microcontroller;

Selection of the data transfer protocol to the measuring information processing device;

Microcontroller software development.

To convert temperature into electrical signals, it was proposed to use a silicon diode thermal sensor with a depleted base region (Fig. 1) described in [7].

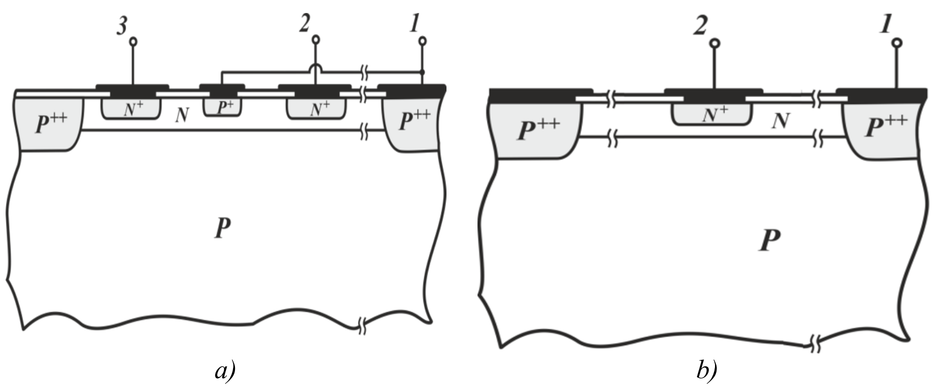

Fig. 1. Structural diagram of diode temperature sensor with region dining area (a) and valuation diode temperature sensor with p-n junction (b)

The mentioned sensor structure selection was made following the following criteria:

relatively accurate temperature conversions, with accuracy not less than 0.1^{0}C;

small weight and size, which is convenient for mounting on the human body;

low cost;

Based on this semiconductor structure of the temperature sensor, it is possible to implement a 1-Wire communication protocol, which requires only two wires for the parasitic power supply of the sensor and three wires for the external power supply.

The RN4870 Bluetooth Low Energy module has been selected for wireless communication between the patient module and the hospital workstation. This module combines a Bluetooth 4.2 baseband controller, a built-in Bluetooth stack, digital and analog inputs/outputs, an RF power amplifier, and an antenna in one solution [8]. The Microchip RN4870 Bluetooth low-power module is a fully certified Bluetooth Smart module that provides reliable Bluetooth connectivity in different conditions. All these advanced features allow you to enable Bluetooth with low power consumption in design with minimal engineering effort.

The RN4870 module uses a built-in Microchip low-power Bluetooth RF chip. The RN4870 provides a control interface based on ASCII commands sent over a universal serial bus. The ASCII command interface on the RN4870 provides an easy transition path for clients currently using RN4870 modules. Interactive ASCII commands allow you to configure the RN4870 without complicated configuration tools. RN4870 supports the roles of both peripheral and central shared access profiles, actively scanning other connected devices instead of waiting for incoming connection requests.

For human development of body temperature monitoring system, the following requirements were taken into account:

Manufacturability of production;

The cost of the finished product;

Operational cost;

Mean time between faults;

Staff skills to work with the product;

Maintainability;

Weight and dimensions of the finished product;

The ability to change the number of connected temperature sensors without significant changes in the control program and product design [9].

The block diagram of the patient temperature monitoring system is shown in Fig. 2.

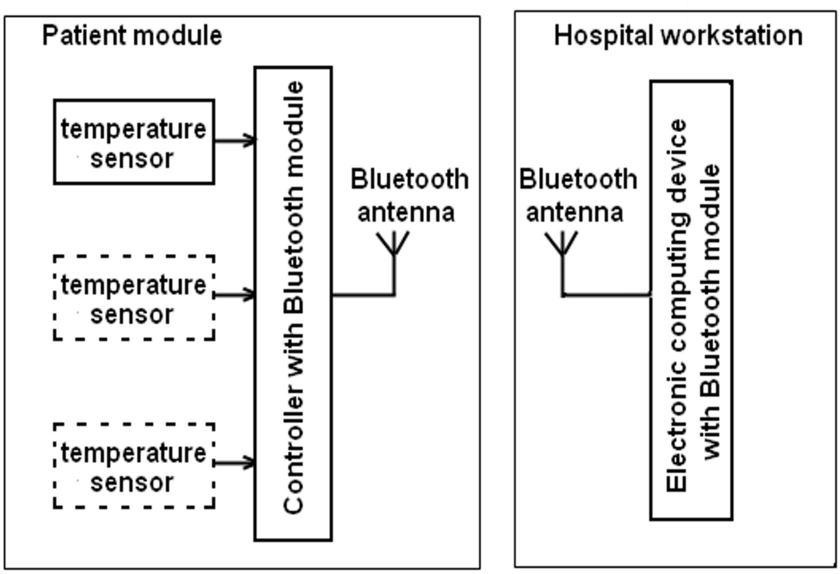

Fig. 2. Block diagram of patient temperature monitoring system

Body temperature measurement time intervals can be pre-loaded in the system memory and then changed by the hospital personnel. The received data is processed by an electronic computing device. A personal computer, laptop, or smartphone can be used as such a device.

One of the requirements for the device is the mandatory use of the operating system with the correspondence software. Android and IOS offer a lot of applications for systems using Bluetooth communication. The number of sensors for body temperature measuring ranges from one to three. The RN4870 module can be used to measure up to three sensors. In this case, the data will be processed individually for each sensor.

3.1 Experimental part

One of the purposes of the research is to experimental data of temperature signal transmission from wearable (patient) module to smartphone analysis.

To check patient module operation, the experimental setup was assembled. The principle of operation of the setup is described in [10]. The purpose of the experiment is as follows:

1) Checking the accuracy of the temperature measured by the analog temperature sensor to a smartphone using a Bluetooth wireless communication line.

2) Checking the dependence of the output signal level on the power supply voltage.

An experimental setup for evaluating the possibilities of transmitting a temperature signal over a Bluetooth wireless data line is shown in Fig.3.

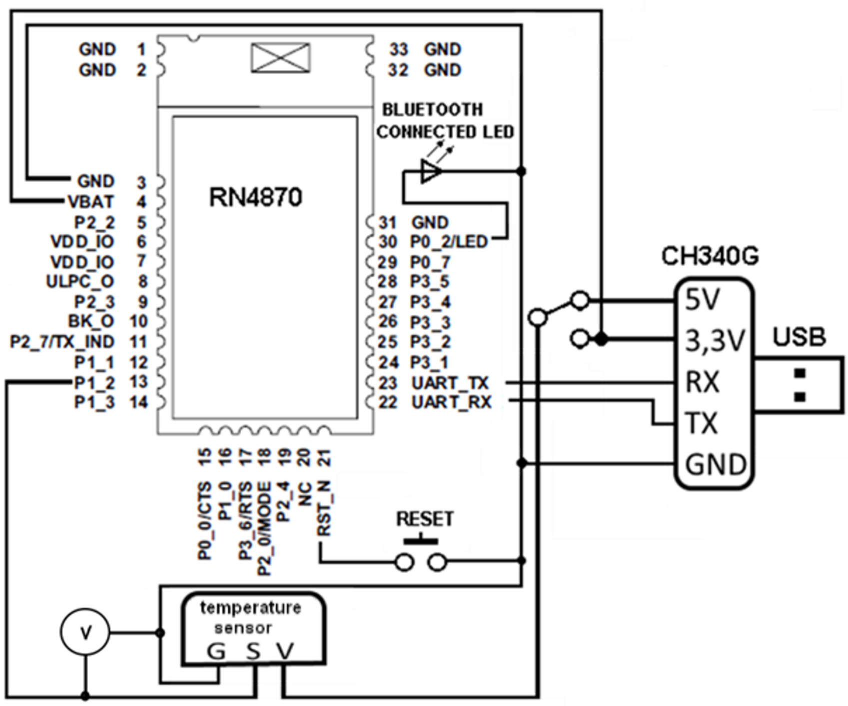

Fig. 3 Experimental setup principal diagram

The following components were used to assemble the experimental setup:

1) The semiconductor diode analog temperature sensor described above measures the temperature from -50 to 150^o with an accuracy of 0.1^0

2) RN4870 controller for converting the analog signal of the temperature sensor into a digital 2-byte signal. The converted signal is transmitted via two channels: via Bluetooth and via UART to the USB input of a personal computer

3) CH340G UART adapter for programming the controller and matching the signal with the USB input of the computer

4) Voltmeter for measuring the analog signal of the thermal sensor (voltage between the signal terminal S and the ground terminal G)

The analog signal from the temperature sensor enters the 16-bit built-in ADC of the RN4870 controller. The sensitivity of the ADC is 0.001 V (to change the digital signal by 1 bit, the voltage must change by 0.01 V).

The experimental measurement data in the temperature range of 34.2-38.2 degrees are given in Table 2. Controller data is a record in a 16-bit system of the voltage value in millivolts. For example, 1AA is converted to a decimal system; we get 426 millivolts (0.426 V).

By the experiment result, the output voltage does not depend on the power supply voltage. Output signal voltage does not drop when the power supply voltage changes from 5V to 3,3V. It means different power supply elements can be used in wearable modules.

Table 2. Experimental measurement data

Controller data	Temperature sensor voltage (V)	Temperature
1A9	0.425	35.1
1AA	0.426	35.2
1AB	0.427	35.3
1AC	0.428	35.4
1AD	0.429	35.5
1AE	0.43	36.6
1AF	0.431	36.7
1B0	0.432	36.8
1B1	0.433	36.9
1B2	0.434	37.0
1B3	0.435	37.1
1B4	0.436	37.2
1B5	0.437	37.3
1B6	0.438	37.4
1B7	0.439	37.5
1B8	0.44	37.6
1B9	0.441	37.7
1B8	0.442	37.8
1B9	0.443	37.9
1B8	0.444	38.0

4 Conclusions

The proposed human body temperature monitoring system is designed for constant temperature monitoring at specified medical personnel time intervals.

The proposed system can be successfully used not only for medical purposes but also in training personnel of special professions (military, accident liquidators, astronauts, etc.).

The system can also be recommended to the athletes' school training staff to control the load of physical education lessons for schoolchildren.

It is possible to recommend using a body temperature monitoring system for several professions, such as public transport drivers, civil aviation pilots, and the air force.

The advantages of the proposed system are compactness, low production and operation cost, reliability, high measurement accuracy, and reliable wireless data transmission over short and medium distances. The power supply of the wearable part of the system is provided by an autonomous battery. Replacing faulty sensors with new ones without any reconfiguration is easily possible. Also, the system is available for use by low-skilled personnel.

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