WIRELESS SYSTEM OF MONITORING OF HUMAN'S TEMPERATURE

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Abstract
Measurement of human's temperature is one of the problems to solve in textronic system that includes textiles joined with electronic and computer technologies. Different parts of human body have different temperatures so it is necessary to use a set of sensors which should be placed in proper points of clothing. Article describes construction of vest with several temperature sensors that measure underwear temperature in different places of human body. Data from sensors was transmitted by radio link to radio receiver. Analysis of placement of temperature sensors in vest was carried out.
Key words: skin temperature, accuracy, wireless transmission, textronic system

Introduction

The textronic system includes textiles joined with electronic and computer technologies [1]. The textronic clothing can be applied mostly for emergency forces (e.g firemen, rescue team of collier, mountain rescuers) and victims of disaster. This kind of clothing includes electronic or textile sensors that measure physiological and ambient parameters, for example humidity and external temperature etc. Information from sensors placed in textronic clothing is often sent to the monitoring station where data are analyzed.
Temperature of human body is one of important parameters, because it decides on life. Critical values of temperature for human are 25°C and 42°C. Decreasing or increasing of temperature from this range causes death. Prototype of textile vest with implemented temperature sensors was made based on experiences of designing textronic measurement systems [2, 4]. Textile form of textronic clothing don't cause discomfort of its using. Temperature of body is difficult to measure and evaluate. It can be measured in few points in ear, under armpit or rectum. Placing temperature sensors in these points is not comfortable in textronic clothing, because temperature of human body has to be measured continuously. Arrangement of temperature sensors follows from regulations [6] and own research [3]. The textronic clothing with temperature sensors is presented in Fig. 1.

Figure 1. Arrangement of temperature sensors in textronic clothing

Senors have to adjoin close skin of human, then temperature is measured appropriately [6]. If there is no conact skin with sensor, temperature is measured in air gap between skin and textile layer. Special gap filler Softtherm produced by MH&W International Corporation Thermal Products Division ensures good contact sensor to skin. Properties of this gap filler are following thermal resistance 1,5 K/W and thermal conductivity 1,0 W/mK [7]. Sensor and gap filler were joined by termoconductive glue Loctite 330 that thermal conductivity is 0,1 W/mK. Connection of sensor with textiles is presented in Fig. 2.

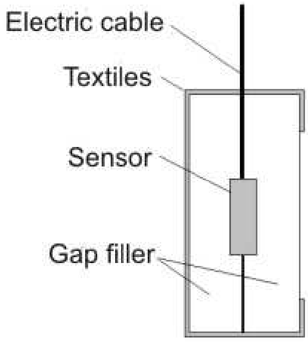

Figure 2. Connection of sensor with textiles

Transmission of signals from sensors in textile structure was achieved by electric wires. Special channels in vest were made for traditional copper wires with isolation.

Monitoring system

Data collected from temperature sensor can be transmitted outside textronic clothing only by radio link. The radio modules for 868 MHz frequency was chosen for transmitting data from temperature sensors, because they work in unlicensed band, maximum radiated power of transmitted signal is 500 mW and maximum range is 4 km in line of sight of transmitter and receiver. These radio modules enable easy enlargement of system, communicate with computer using RS-232 interface, can be supplied from battery, don't require communication with base station and have maximum radio baud rate up to 150 kb/s [5]. Wireless system of monitoring human's temperature is presented in Fig. 3.

Temperature sensors S_1, S_2, S_3, S_4 are connected to input of match system. Signal from match system $U_t(t)$ is measured by A/C converters of microcontroller. The microcontroller acquires data from sensors and prepares it for transmission through transmitter. The data $U_r(t)$ is received by receiver and is compared with sent data $U_t(t)$ in computer. Data from sensor consists of No. of probe and values of measurement and is collected by software. Wireless monitoring system of human's temperature with software was designed and made by Department of Clothing Technology and Textronic, Technical University of Lodz. The software displays measured data in format actual time (hour :minute :second :ms), No. of probe and measured temperature from sensors. The data can be written to the file. Measurement can be started and stopped by pushing "Start measurement" and "Stop measurement" buttons. Trace with probes was drawn in Excel software using text data written to the file.

Pushing of "Start" switch launches a transmission of data from transmitter, probe of measurement starts from No. 1. When "Stop" switch is pushed, transmission and collecting data from sensor is stopped.

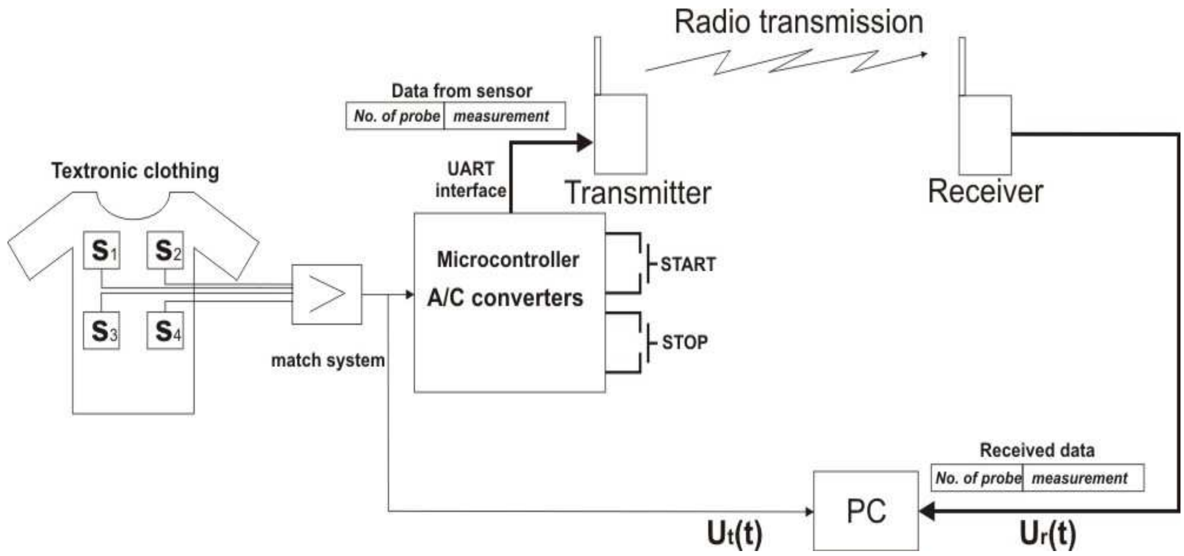

Figure 3. Wireless system of monitoring human's temperature

Parameters of transmission are following:

- power of signal: 25 mW,
- distance between transmitter and receiver: 20 m,
- radio baud rate of data: 38 kb/s,
- interval of time between sending two near probes: 1s.

Thermistor type NTC was chosen for measurement of temperature in textronic vest. This sensor has little value of time constant less than 1s, high sensitivity (Ω/°C) and big value of resistance (higher than 100kΩ in low temperature). Nonlinear static characteristic is disadvantage of thermistor. Two topologies of measurement circuits are presented in Fig. 4 and 5. Table 1 shows parameters of these circuits.

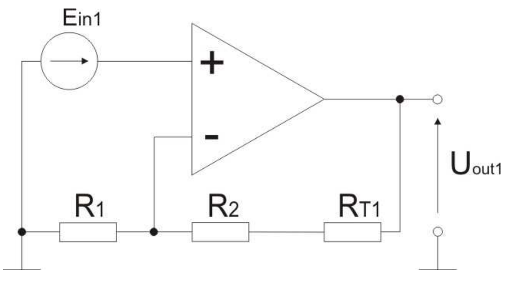

Figure 4. Measurement circuit with PT100 sensor

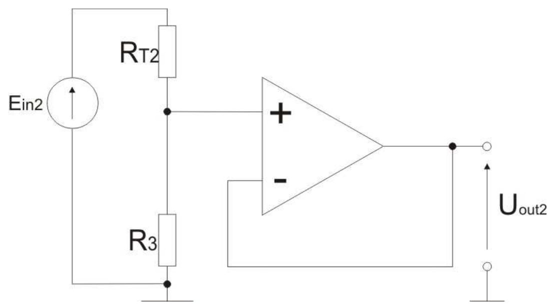

Figure 5. Measurement circuit with thermistor

Table 1. Parameters of measurement circuits

Parameters of circuit with PT100 sensor		Parameters of circuit with thermistor	
E_{in1}	1 V	E_{in2}	2,5 V
R_1	1,2 kΩ	R_3	100 kΩ
R_2	1,2 kΩ		
R_{T1}	PT100	R_{T2}	SEMI833ET
Sesitivity of U_{out1} in temperature range from 20°C to 45°C	0,3 mV/°C	**Sesitivity of U_{out2} in temperature range from 20°C to 45°C**	24 mV/°C

Temperature range from 20°C to 45°C was chosen because it includes critical values of temperature for human life. Using PT100 sensor causes very low sensitivity for range from

20°C to 45°C. Value of sensitivity 0,3 mV/°C is not acceptable for A/C converter of microcontroller that resolution is 0,61mV/bit. Circuit with thermistor (Fig. 5) is appropriate for monitoring of temperature of body, because sensitivity is greater. Special medical thermistor type SEMI833ET of HYGROSENS INSTRUMENTS company was chosen. Basic parameters of this sensor are collected in table 2.

Table 2. Basic parameters of SEMI833ET sensor [8]

Measuring principle	NTC
Measuring range	from - 40 to 100°C
Nominal resistance at 37°C	min. 48561 Ω, max. 51265 Ω
Tolerance in resistance values at 37°C	±0.2%
Response time T_{66} in oil	700 ms
Self heating	1,42°C/mW
Dimensions diamater x length	1,5 x 4 mm

Linearization of static characteristic was necessary. It was achieved by usage R_3 resistance (Fig. 5). This resistance was evaluated experimentally. Result of linearization of thermistor is presented in Fig. 6. Approximation polynomial with correlation coefficient R for linearized characteristics are presented in table 3.

Table 3. Approximation polynomials

R_3	Polynomial	R^2	Sensitivity
kΩ	-	-	mV/°C
100	0,0244x + 0,7547	0,9970	24,32
150	0,0214x + 1,0699	0,9933	21,42
200	0,0188x + 1,2926	0,9903	18,81

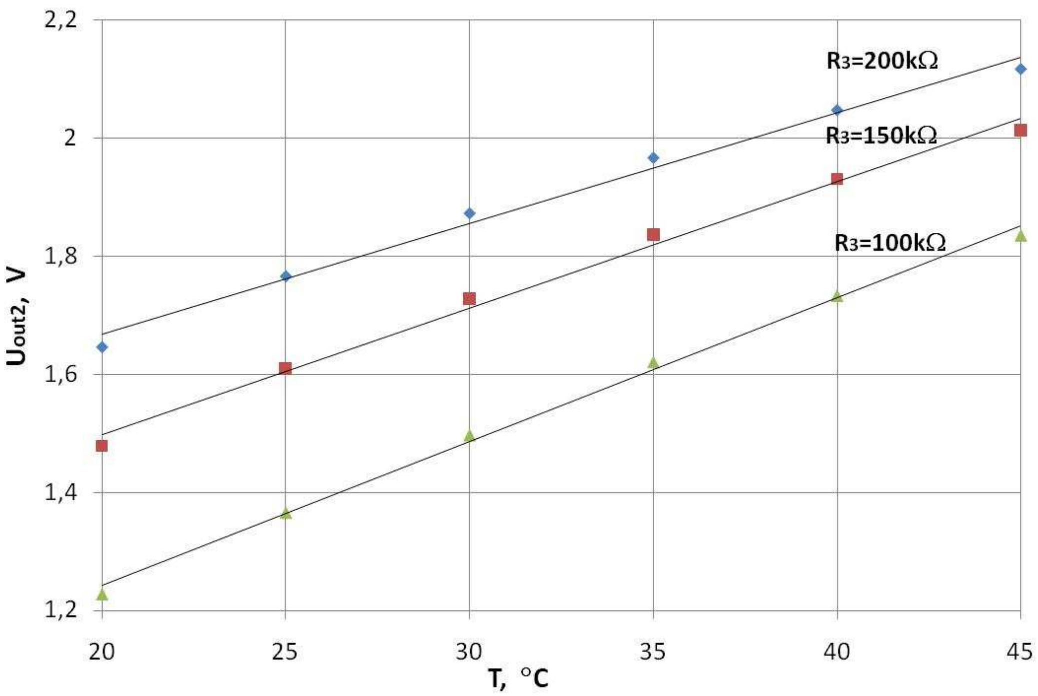

Figure 6. Linearization of thermistor's characteristic

Dynamic and static properties of thermistors with gap filler Softherm was determined. Sensors was removed from vest and placed inside calibration stove presented in Fig. 7.

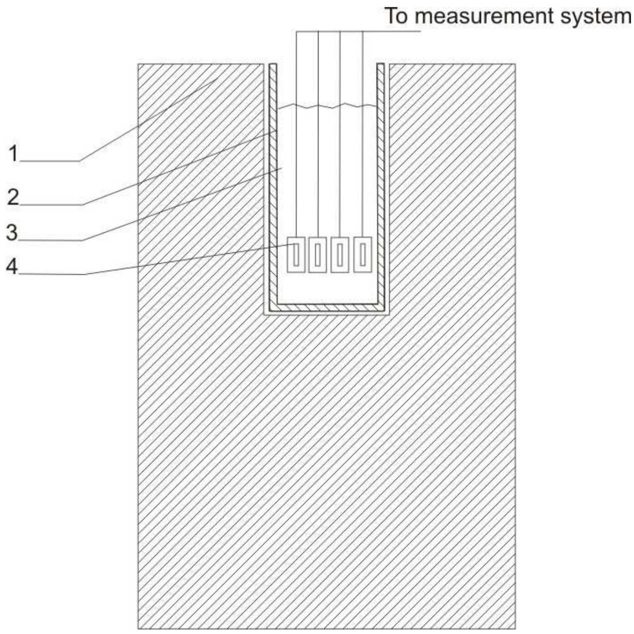

Figure 7. Calibration stove with measured temperature sensors

Measured temperature sensors with gap filler Softherm (4) are covered textile material (3). Sensors are placed inside aluminium cylinder (2). The cylinder is situated in calibration stove MicroCal T100+ (1).
Properties of calibration stove MicroCal T100+ are following:

- regulation of temperature from: -28°C to 150°C,
- stability of temperature: ±0,03°C,
- resolution: 0,01/0,1°C,
- accuracy of reading: ± 0,15°C

Temperature sensors are connected to wireless measurement system presented in Fig. 3. Sent $U_t(t)$ and received $U_r(t)$ data were compared. Research shows that sent $U_t(t)$ and received data $U_r(t)$ are the same and therefore only received data were analysed. Behaviour of all sensors is similar for measuring of dynamic and static properties and therefore characteristics only for one sensor were presented below.
Dynamic properties of sensors was carried out for heating and cooling. Thermistors were heated from ambient temperature T_{amb}=28,2°C to 45°C that was set in calibration stove. After heating sensors were cooled by removing from stove. Dynamic characteristics of temperature sensors for heating and cooling are presented in Fig. 8.

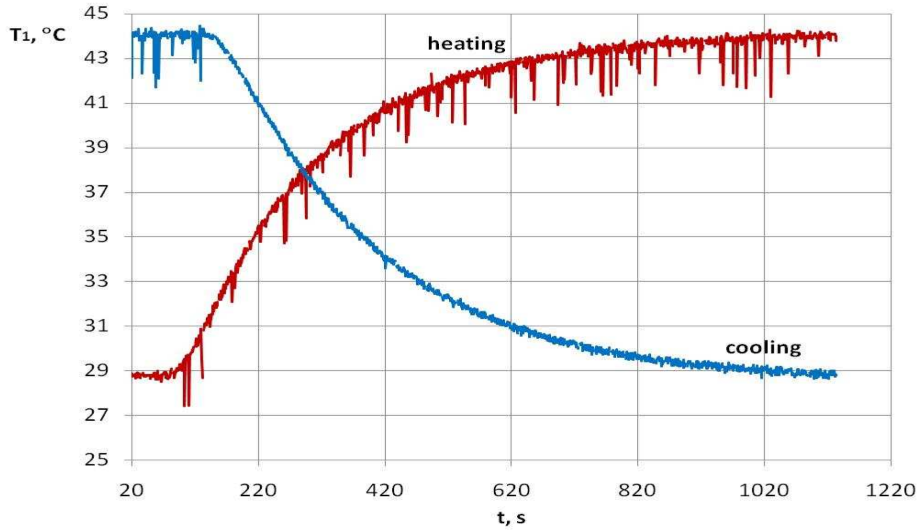

Figure 8. Response of temperature $U_r(t)$ sensor for heating and cooling

Character of change is the same of all sensors for heating and cooling. Table 4 presents results of research of dynamic properties.

Table 4. Results of research of dynamic properties

Sensor	S_1	S_2	S_3	S_4
Time constant	s	s	s	s
Heating	307	358	265	226
Cooling	359	348	312	177

Static characteristics of all four sensors were determined. Research for heating and cooling were carried out by temperature range from 20°C to 45°C. Static characteristics for temperature sensor T_1 are presented in Fig. 9.

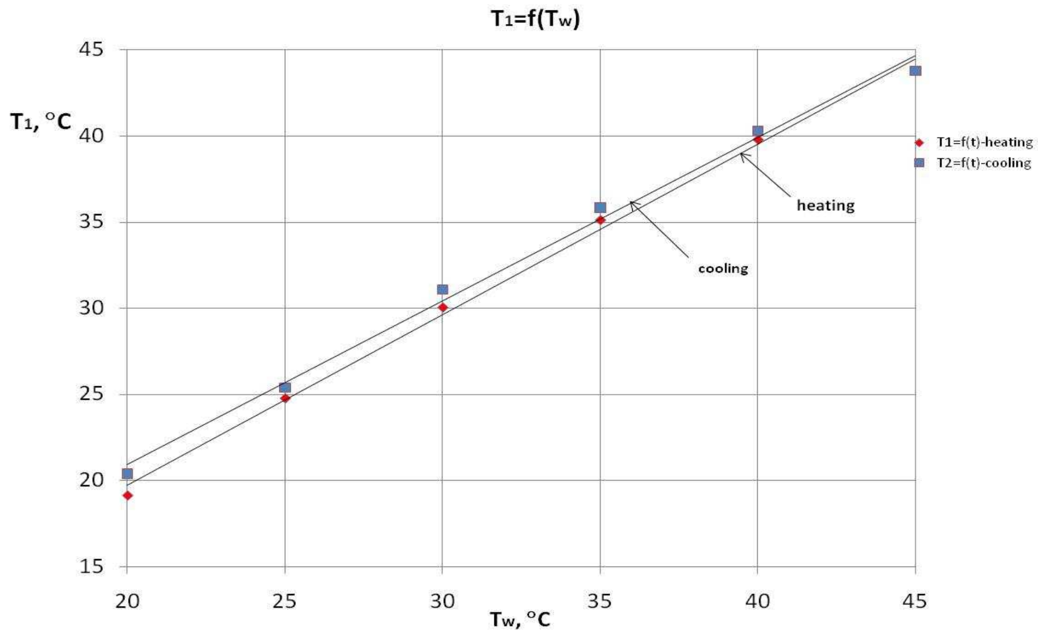

Figure 9. Temperature of sensor S_1 read from receiver in function of reference T_w

Temperature read from display of calibration stove T_w was a reference for measured all four sensors. Static characteristic for all sensors was approximated by line function. Table 5 presents measurement errors of calibration of all sensors.

Table 5 Measurments errors

	Tw	°C	**20**	**25**	**30**	**35**	**40**	**45**
S1	Δ	°C	-0,3	-0,3	-0,4	-0,4	-0,4	-0,5
	δ	%	1,3	1,2	1,2	1,1	1,1	1,1
S2	Δ	°C	-0,5	-0,6	-0,6	-0,7	-0,8	-0,9
	δ	%	2,5	2,3	2,1	2,0	2,0	1,9
S3	Δ	°C	-0,5	-0,6	-0,7	-0,8	-0,8	-0,9
	δ	%	2,7	2,5	2,3	2,2	2,1	2,0
S4	Δ	°C	-0,8	-0,9	-1,0	-1,1	-1,2	-1,3
	δ	%	4,1	3,6	3,4	3,2	3,0	2,9

Δ - absolute error
δ - relative error

$$\Delta = T_a(T_w) - T_w \qquad (1)$$

$$\delta = \frac{\Delta}{T_w} \cdot 100\% \qquad (2)$$

where:
T_a – value of approximated polynomial calculated by reference temperature T_w

Errors were calculated using approximation of line polynomial $y=a \cdot T_w+b$ for heating. After calibration temperature of human body was measured in points indicated in Fig. 1 using textronic vest. Results of these researches are presented in Fig. 10.

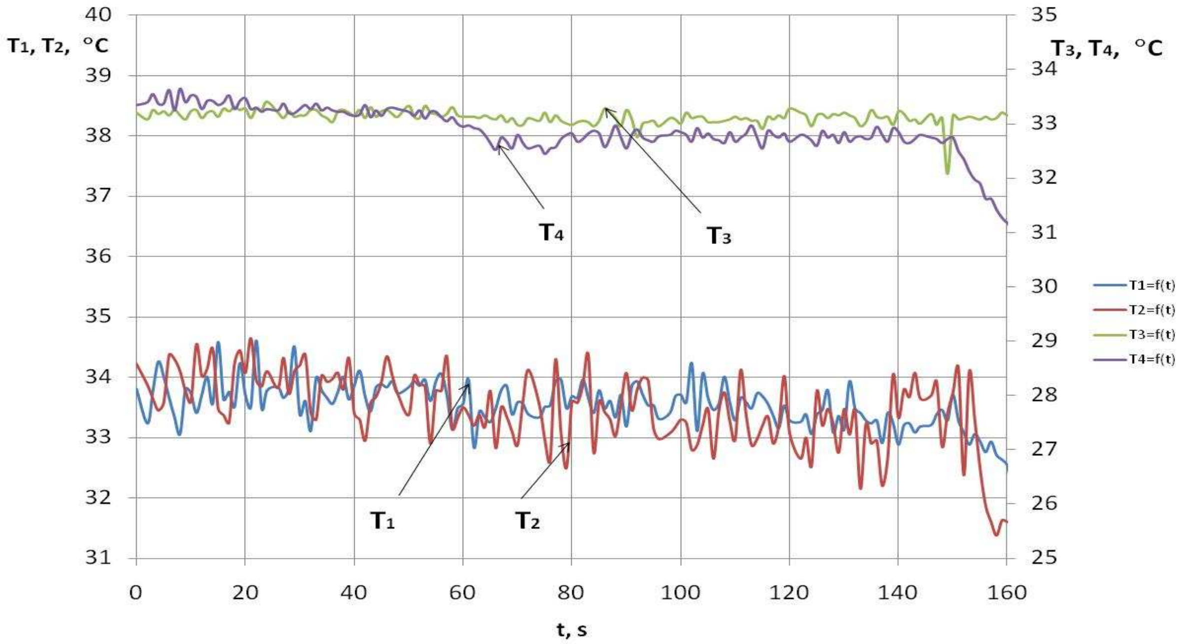

Figure 10. Temperature of human body read from radio receiver, measured by textronic clothing

Conclusions

Measurement of human's body temperature is difficult to evaluate. For example temperature of human body differ in each part of body. Appropriate measurement requires a few sensor. These sensors have to adjoin to the body otherwise temperature of air gap between skin and textile layer is measured. The measurement system cooperating with temperature sensor has to ensure high sensitivity, because temperature of human body is changing in small range. Application of gap filler increases of time constant of temperature sensor up to 359 s what can't be acceptable in case of capturing of quick changing of human temperature. Temperature sensor with gap filler causes hysteresis in static characteristic. Relative errors of temperature measurement decrease with increasing temperature. Research shows that skin temperature is changing even in about 2°C range in certain points of body.

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