WIRELESS DUAL CHANNEL HUMAN BODY TEMPERATURE MEASUREMENT DEVICE

Pelin OĞUZ and *Gökhan ERTAŞ*

Biomedical Engineering Department, Yeditepe University, Istanbul, Turkey

ABSTRACT

Human body temperature is influenced by many factors such as cognitive, emotional and psychological states. Temperature measurements can be done using analogue or digital electrical sensors. High sensitivity and high accuracy in measurements are usually provided by the analogue sensors that require sophisticated circuits for linearization/calibration and also for digitization. When compared with the analogue ones, digital sensors can also provide high sensitivity but lower accuracy although good enough for several medical applications. In this study, a portable device with wireless computer connectivity that provides noninvasive dual channel digital body temperature measurements has been developed. Trials with the device show that it is quite beneficial in measuring body temperature from ear canal. It may also be used to perform temperature measurements from mouth, armpit and anus.

Index Terms— Biomedical equipment, temperature measurement, noninvasive, wireless communication.

1. INTRODUCTION

Cognitive, emotional and psychological states are the factors that have impact on sympathetic activation. To assess sympathetic activation, especially induced by emotions, psychologists usually benefit from skin conductance as a measure [1]. The underlying phenomenon is that narrowing of the blood vessels induces sweating that lead to decrease in skin resistance. Recently, another measure reported has been human body temperature. Normally, body temperature follows strong circadian rhythms over the 24-hour day indirectly determined by sympathetic activations [2]. For instance, in the morning, the increase in sympathetic tone induces narrowing of the blood vessels resulting from contraction of the muscular wall of the vessels and leading to reduced blood flow to the periphery that decreases the temperature. However, in the evening, the sympathetic nervous system exhibits low activity and the widening of skin vessels in the extremities leads to an increased blood flow to the periphery with a sharp increase in temperature at the extremities. On the other hand, it is observed that the temperature measured at the temple instantaneously decreases after the brain starts to solve an arithmetic task [3]. There are also some studies that relate human temperature changes to emotions accompanying music and also solar radiation [4, 5].

Human body temperature is expressed in terms of core body temperature or shell temperature. Core body temperature is measured from the anus, from the mouth, from armpit, from the ear or from the vagina. The temperature measured changes depending on the measurement site but for a healthy human, it is 32.2^{o}C at minimum and 38.2°C at maximum. In addition to this, the shell temperature is measured from the surface of the body aimed and may change in a range of 16 to 42^{o}C [6].

Body temperature measurements can be done using analogue or digital electrical sensors. The analogue sensors are usually thermistors, resistance temperature detectors and thermocouples. These sensors are able to provide measurements with both high sensitivity and high accuracy (±0.1^{o}C) [7]. However, they require sophisticated circuits for linearization/calibration and also for digitization. On the other hand, digital temperature sensors are equipped with on-board thermometers and dedicated circuitry making them easier to implement (i.e. no user calibration, no self heating or linearity correction required). When compared with the analogue ones, digital sensors can provide similar sensitivities. However, their accuracy is low (±1^{o}C) but reported to be good enough for use in several medical applications [8, 9].

To get an idea about energetic balance dynamics, multiple body temperature measurement is needed to be performed simultaneously and continuously. For instance, simultaneous measure of body core temperature, superficial temperature and their difference has been proposed for permanent energetic balance evaluation as “apparatus for disease detection” [10]. This technique has been also tested on diabetic patients and critically ill patients successfully [11].

There is a tremendous demand on wearable devices that provide accurate human temperature measurements and that provide wireless transmission of the measured temperatures. In this study, such a device, that may perform noninvasive dual channel body temperature measurements via its digital sensors, has been developed.

Fig. 1. Physical appearance of the device

2. THE DEVELOPED DEVICE

The physical appearance of the device is as seen in Fig. 1. The device is equipped with two identical temperatures probes, a microcontroller, a Bluetooth module, power supply circuitry and a battery.

2.1. Temperature Probe

The temperature probe is sealed to be waterproof and houses the digital temperature sensor DS18B20 (Microchip Technology, USA). This sensor originally provides 12-bit temperature measurements in 750ms from -10^{o}C to +85^{o}C with a sensitivity of 0.0625^{o}C and an accuracy of ±0.5^{o}C. With some justification, this accuracy is set to ±0.1°C [12]. On its read-only memory, a unique 64-bit serial code has been stored. The least significant 8 bits of this code contain the sensors family code, the next 48 bits contain a unique serial number and the most significant 8 bits contain a cyclic redundancy check byte. The sensor uses this serial code while communicating with any microcontroller. For communication, only one port pin of the microcontroller is required due to the sensor's unique 1-Wire bus interface.

On the 1-Wire bus, all transactions begin with an initialization sequence consisting of a reset pulse transmitted by the microcontroller followed by a presence pulse transmitted by the digital temperature sensor. This lets the microcontroller know that the sensor is connected to the device and is ready to perform a measurement.

2.2. Microcontroller

The core of the device is the microcontroller PIC18F2550 SMD (Microchip Technology, Arizona, USA). This controller is widely used in measurement devices because of its low price, high quality and ease of availability. It has forty pins and thirty-three of these pins can be programmed for digital input/output use. Two of the digital pins are dedicated to universal asynchronous receive/transmit operations and connected to a Bluetooth module providing computer connectivity of the device developed. The microcontroller has been programmed using Proton Development Suit with Proton BASIC compiler supporting several PIC brand microcontrollers.

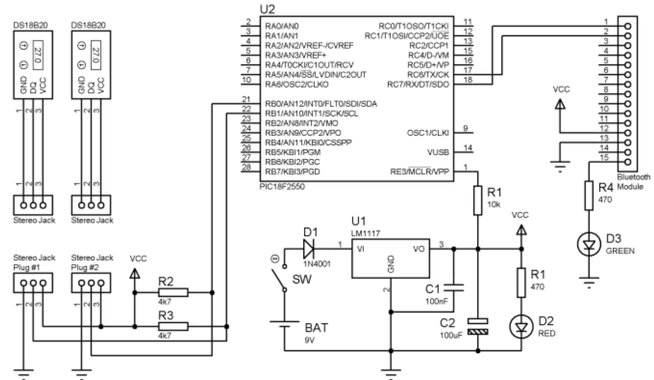

Fig. 2. Electronic schematic of the device

2.3. Bluetooth Module

The device is equipped with an inexpensive and easy to use Bluetooth module (EGBT-04S, e-Gizmo Mechatronix Central, USA). This module provides wireless data transfers between the microcontroller and any personal computer with a Bluetooth receiver. The major terminals of this module are terminal TX, RX and Mode. The TX and RX terminals are for transmission and for reception of data, respectively. These two pins are connected to dedicated RX and TX pins of the microcontroller in the device to ensure proper serial data transfers. The MODE terminal outputs a square wave when the module is not paired but when paired; it outputs a logic high level. Therefore, in the device developed, this terminal is connected to a green light emitting diode (LED) and a current limiting resistor in series: Consequently, the LED is continuously lighted when paired.

2.4. Power Supply Unit

The power supply unit provides +3.3V DC required by all electronic components of the device using a +9V battery and an LM1117 voltage regulator circuitry. The schematic of the device developed showing the connections of the electronic components is seen in Fig. 2.

2.5. User Interface Software

Once the device developed is connected to a personal computer via its Bluetooth module (i.e. paired), at first, a user interface software with serial communication functionality should be run and setup appropriately to allow data transfer (i.e. the port should be selected by the user with a speed of 2400baud, byte size of 8, no parity, 1 stop bit). After this step, the device would perform dual temperature measurements and send the results to the user interface software simultaneously. The values received can be copied and pasted into any spreadsheet program such as Microsoft Excel for further processing or statistical analysis. In this study, the user interface is the serial communicator software embedded into Proton Development Suit.

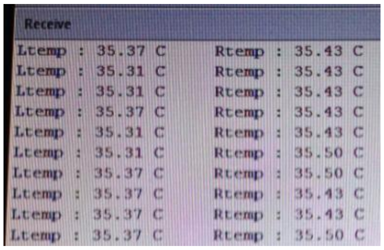

Fig. 3. Screenshot of the user interface software during measurements

3. RESULTS

The device developed has been used to take human body temperature measurements from ear canals. Screenshot of the user interface software while performing measurements on a healthy male volunteer is presented in Fig. 3. Here, *Ltemp* and *Rtemp* are the temperatures measured simultaneously by the "Left" and the "Right" temperature probes placed within the left and right ear canals, respectively. From the ten measurement pairs acquired continuously within eight seconds, the mean left and right ear canal temperatures are calculated as 35.35^{o}C and 35.45^{o}C respectively. There is a considerable 0.10^{o}C temperature difference between the left and the right ear.

The device was tested on eight healthy volunteers (4 male and 4 female). Ten temperature measurements were taken from the left and the right ear canals, simultaneously. The mean of the measurements obtained are as listed in Table 1. When the male group is considered, the mean temperature from the left and the right ear canal temperatures measured is 35.54±0.17^{o}C however it is 35.25±0.32^{o}C for the female group.

Table 1. Temperatures measured

ID	Gender	Mean Temperature (^{o}C)	
		Left	Right
v1	Male	35.56	35.37
v2	Male	35.43	35.75
v3	Male	35.43	35.62
v4	Male	35.81	35.37
v5	Female	35.43	35.43
v6	Female	35.31	35.31
v7	Female	34.75	34.75
v8	Female	35.50	35.50

4. CONCLUSION

In this study, a wearable device that provides noninvasive dual channel body temperature measurements has been developed. The device is equipped with two temperature probes that are waterproof and easy to sterilize offering multiple use opportunity. Each probe houses DS18B20 digital temperature sensor that operates in a range of 16 to 42^{o}C which would be an adequate range when shell temperature changes are considered. No sensor correction, linearization or calibration is needed before/during measurements. Moreover, the sensor waits for a request to perform a temperature measurement and therefore the device developed can detect connecting cable and sensor failure and report such events to the user/healthcare specialist. Measurements are simultaneously transferred to personal computer using wireless communication based on Bluetooth technology.

Measurement trials with the device show that it is easy to use and functional in temperature measurements. The device is quite beneficial in measuring body temperature from ear canal. However, it may also be used to perform temperature measurements from mouth, armpit and also anus. The device performs two body temperature measurements simultaneously and makes it possible to calculate temperature difference. This difference would be a good measure to express energetic balance variations independent of changing environmental temperature and humidity that have a profound impact on human body temperature. However, if desired, an extra sensor can easily be embedded to the device to assess environmental temperature and humidity.

Depending on the application, a great number of temperature sensors may be needed on the palms, beneath the feet or above the liver. Although, the device developed is equipped with just two sensors, it may be easily upgraded to utilize these extra sensors. On the other hand, depending on the application, the interval of continuous temperature measurement may also change. For instance, for circadian rhythms, the interval is long but for emotions, it is short. The device is able to operate these intervals.

There are some future plans to improve the device developed. First, power consumption of the device will be optimized. This would make it possible to continuously monitor body temperature of subjects in their natural environment and to assess circadian rhythmicity of thermoregulation and hence sympathetic activity for several days. Next, dedicated user interface software will be developed to provide online and real-time access to the collected temperature measurements of the subjects with better visualizations and statistics.

5. REFERENCES

[1] L. Brown, B. Grundlehner, J. van de Molengraft, J. Penders, and B. Gyselinckx, "Body Area Network for Monitoring Autonomic Nervous System Responses," in Proc of the 3rd Intern. Conf. on Pervasive Computing Technologies for Healthcare, London, UK, pp. 1-3, 2009.

[2] A.A. Romanovsky, "Thermoregulation: some concepts have changed. Functional architecture of the thermoregulatory system," *Am J Physiol Regul Integr Comp Physiol*, pp. 37-46, 2006.

[3] A. Dittmar, C. Gehin, G. Delhomme, D. Boivin, G. Dumont, and C. Mott, "A Noninvasive Wearable Sensor for the

Measurement of Brain Temperature," in Proc. of the 28th IEEE EMBS Intern. Conf., New York City, USA, pp. 900-902, 2006.

[4] S. E. Rimm-Kaufman and J. Kagan, "The Psychological Significance of Changes Skin Temperature," *Motivation and Emotion*, vol. 20, pp. 63-78, 1996.

[5] K. Blazejczyk, "Influence of Solar Radiation on Skin Temperature in Standing and Walking Subjects Outdoors," in Proc of the 8th International Conference on Environmental Ergonomics, San Diego, CA, USA, pp. 57-60, 1998.

[6] C.A Boano, M. Lasagni, K. Romer, and T. Lange, "Accurate Temperature Measurements for Medical Research using Body Sensor Networks," in Proc of 14th IEEE International Symposium on Object/Component/Service-Oriented Real-Time Distributed Computing Workshops, pp. 189-198, 2011.

[7] W. Chen, S. Dols, S. B. Oetomo, and L. Feijs, "Monitoring Body Temperature of Newborn Infants at Neonatal Intensive Care Units Using Wearable Sensors," in Proc of the 5th International Conference on Body Area Networks (BodyNets), Corfu Island, Greece, pp. 188-194, 2010.

[8] W.V.M. Lichtenbelt, H. Daanen, L. Wouters, R. Fronczek, R. Raymann, N. Severens, and E. V. Someren, "Evaluation of Wireless Determination of Skin Temperature using iButtons," *Physiology and Behavior*, vol. 88, pp. 489-497, 2006.

[9] J. Sarabia, M. Rol, P. Mendiola, and J. Madrid, "Circadian Rhythm of Wrist Temperature in Normal-living Subjects: a Candidate of New Index of the Circadian System," *Physiology and Behavior*, pp. 570-580, 2008.

[10] V.A. Simonov, A.V. Kluchko, V.K. Novikov, and V.P. Coulic, "Electronic Device for Control of The Energetic Balance in Man and Animals (Appliances In Diabetes Mellitus)," In Conf. Proc. IEEE Eng Med Biol Soc, vol. 6, pp. 2270-2271, 1992.

[11] V. Coulic, V. Novikov, J. Devriendt, C. Gillet, A. Bodson, and E. DeKoster, "Use of a Temperature Gradient Measuring Device in Monitoring of Diabetic and Critically Ill Patients," In Proc of the 29th IEEE EMBS Intern. Conf., Lyon, France, August 23-26, pp. 3508-3511, 2007.

[12] Y. Chen, J. Han, K. Wu, X. Wu, and J. Zhou, "A GPRS-based Wrist Type Pulse Wave and Body Temperature Monitor for Children Healthcare," In IFMBE Proceedings (APCMBE 2008), pp. 344-347, 2008.