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MOBILE & WIRELESS HEALTH

An IR Sensor Based Smart System to Approximate Core Body Temperature

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Abstract Herein demonstrated experiment studies two methods, namely convection and body resistance, to approximate human core body temperature. The proposed system is highly energy efficient that consumes only 165 mW power and runs on 5 VDC source. The implemented solution employs an IR thermographic sensor of industry grade along with AT Mega 328 breakout board. Ordinarily, the IR sensor is placed 1.5–30 cm away from human forehead (i.e., non-invasive) and measured the raw data in terms of skin and ambient temperature which is then converted using appropriate approximation formula to find out core body temperature. The raw data is plotted, visualized, and stored instantaneously in a local machine by means of two tools such as Makerplot, and JAVA-JAR. The test is performed when human object is in complete rest and after 10 min of walk. Achieved results are compared with the CoreTemp CM-210 sensor (by Terumo, Japan) which is calculated to be 0.7 °F different from the average value of BCT, obtained by the proposed IR sensor system. Upon a slight modification, the presented model can be connected with a remotely placed Internet of Things cloud service, which may be useful to inform and predict the user's core body temperature through a probabilistic view. It is also comprehended that such system can be useful as wearable device to be worn on at the hat attachable way.

Keywords Infra Red Sensor · Core body Temperature · Distant Measurement

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Introduction

Core body Temperature (i.e. BCT) is one of the most important vitals of human being which is crucial to maintain health factor to keep in a steady state. Human body, normally keeps core body temperature within specific range of operation. In normal condition, a human body tries to regulate its BCT by various means of physiological norms such as sweat, dizziness, sleep, and skin humidity evaporation etc. This situation varies from case to case basis. For example (1) a fisherman is continuously in touch with water that obviously reduces BCT, resulting more energy combustion in terms of food in stomach or burning body fat, (2) a fireman when busy in tacking with fire extinguishing job, his body needs to be cooled down whereby reducing the metabolism and excretion of sweat, and (3) a sports person's body should be kept at a standard BCT per his body structure to allow him to give best performance by regulating glucose consumption and release, hence difference in BCT. In such exemplary situations, it is always beneficial for a person to have prior as well as precise knowledge about his/her BCT which may further help to save his/her life from common injuries such as: hypothermia, hyperthermia, heat stroke or even death.

This study, hence aims at developing and validating a low cost, energy efficient, and portable solution to monitor and measure BCT in continuous and unobtrusive manner. Since majority of the available solutions do conform to mobility impairment or invasiveness, the task behind development of proposed system has never been easy. Towards this goal, a study is designed around a novel sensor system by means of an Infra-Red (i.e. IR) sensor, placed between 1.5–30 cm away from forehead (i.e., non-invasive), which transmits BCT data to a local machine in real-time. The study has been carried upon 37 volunteers in two different phases of activity (1) during complete rest and (2) after an informal walk.

The main goal of this work is to present a novel BCT-formulation which is based on primitive set of theories that have never been tested till date. Per Section II, several literatures exist that have already adopted multiple strategies to tackle the estimation of BCT. Despite of enormous possibility, most of these available proposals either lack in "portability" or in "simplicity". "Wearability" is another very crucial aspect where less importance has been given. Such behavioral lags could be less persuasive with respect to societal needs (i.e. smart healthcare) of pervasiveness in current time. Thus, a novel pedagogy, having more intuitiveness, user-friendliness, real-timeliness, wearability, and distant measurability, is needed.

- To synergize with such aim, this paper contributes as follows:
- To develop and evaluate a novel core body temperature formula;
- To design an IR sensor-based system for measurement and monitoring of human BCT from varying distance;
- To incorporate real-time aggregation of data at the local node;
- To visualize and store the BCT values on an instantaneous terminal;
- To map the temperature fluctuations on a JAVA-JAR based application;
- To statistically analyze the results; and
- To validate the usability of the proposed system's performance by implying on objects and CoreTemp CM-210 sensor.

Rest of the paper is organized as follows. Section II performs a detailed literature review of similar aspects on e-databases. Section III presents proposed methodology and required materials both hardware and software. Section IV discusses on experimental setup and assimilated results from this study. Section V concludes the paper.

Related works

This section presents few related works that have performed body core temperature measurement. The review of such works has comprised of a series of tasks that includes: (1) searching of research articles by (mentioning the key word: "core body temperature") at the IEEE Xplore and Science Direct e-databases, (2) sorting out irrelevant articles from the collected list, and finally (3) selection of most appropriate articles for this study. While performing these methods, few parameters are taken into consideration, such as: (1) key method/s behind the research, (2) type of sensors, and (3) plethora of the system implementation. Ultimately, twenty literatures are included out of this review process which are elaborated in brief as follows.

Mackowiak [1] prescribes various devices that may be useful in detection of fever (i.e. temperature fluctuations) of human body. [2] presents a non-invasive skin touch method to measure core body temperature. Dual-heat-flux technique along with circadian rhythm are used to detect core body temperature [3, 4]. Several researchers employ microwave radiometry and tympanic thermometry to find core temperature [5–8]. Among other techniques, the simplest way is to measure skin temperature by using thermistor or IR temperature sensor [9]. Similar method is used by Gagge et al. [10] and Mendt et al. [11]. Another minimal invasive technique-temperature pill is used to measure core body temperature [12, 13]. Although, this technique is unique, it lacks in many ways such as: high cost, plausible interaction with soluble water or food, and issues in exact localization of the pill in the gastrointestinal track. Sometimes, non-invasive estimation of core body temperature is performed by utilizing computational models on time-series based heart data-rates along with skin surface temperature [14–16]. Several indirect efforts are given in finding core body temperature by measuring heat-flux gradients emitted from test-human skin-surface with help of temperature sensor [17–20].

Besides, current literature, several products are already getting popular in global market that includes (1) Meco IRT550 Infrared Thermometer, (2) Nio Non-Contact Infrared Thermometer, (3) amiciKart® Digital Laser IR Infrared Thermometer, (4) TIPL IR Thermometer, (5) Pixel Infrared Gun Thermometer, (6) Testo 810 (0560 0810)-Infrared Thermometer, (7) Cetpar Infrared Thermometer etc. Although, these products are handy, their average price is more than 35 Dollar. Such huge price is a challenge for under-developed or developing countries. Appending to above, some of these devices require electric-charging, when not in use, thus resulting into high power consumption. Also, the detecting temperature range of such devices are not standardized. It seems that these products are meant for all-in-one usage. Only a handful products exist that cope up with the BCT measurement. Yet, applicability and accuracy might be relevant issues, in this regard.

At this point, it is worth to observe that most cases do not conform to plausibly get applied in to real-life situations. The main reasons behind such notion are as follows: (1) complex wiring, (2) invasiveness/semi-invasiveness, (3) skin touchability, (4) hygiene, (5) reusability, (6) non-real-time, and (7) usage discomfort for the user. Existing systems normally measure core body temperature from invasive/skin-touched probes placed esophagus, rectum or other part of body. They may be difficult for application in everywhere usage which is the need of current time. Smart sensor-based systematic activities are found negligible. Table 1 presents the key comparisons among literature under preview of this study.

Apart from above, the proposed experiment provides data storage, visualization, and thermo-graphic which was never seen in discussed alternatives. Furthermore, the present

Table 1 Comparison among related works

Paper	Method	Sensor Type	Issues related to each implementation
[2]	Non-invasive Touch Skin	Rectal Thermistor (YSI-401), "Dräger" Double Sensor	No system model/flow chart/analysis performed; Only rectal-forehead difference measured
[3]	Dual Heat Flux-Touch	CoreTemp CM-210	Results vary due to inference of circadian rhythm
[5]	Microwave Radiometer for Biomedical Sensing MRBS	Cavity Backed Slot Antenna (CBSA)	Less sensitive to emissivity of the specimen
[6]	Extended Kalman Filter (EKF)-Touch	VitalSense, DS1922L, Squirrel 1000S, Equivital EQ02	No system model/sensor system is presented; 13% inaccuracy is reported
[7]	1.4 GHz radiometry	Thermocouple, GaAs MMIC-CMOS antenna	Non-human experiment performed; deep cm-range penetration into tissues
[8]	Tympanic thermometry	MLX90614-DCA	No analysis of results; Chance of tympanic tissue damage
[4]	Ultradian and circadian rhythmicity using stationary wavelets transform (i.e. SWT)	THM-003 T	Contact temperature measurement; unnecessary arisen of complexity
[1]	Insulated skin temperature	–	Experiment performed for Police, Fire and Rescue, and Ambulance i.e. emergency service personnel; Not valid above 36.5 °C insulated skin temperature
[9]	Heat-flux temperature recordings for monitoring circadian rhythm	YSI 400	Double sensor technique used; constant alteration of body posture causes problem; bed-rest is mandatory while test
[10]	Ingestible temperature pill telemetry system	Tpill	Localization of pill inside gastro-tract; Not suitable for patients in comma, children or emergency situations
[11]	Ingestible temperature pill telemetry system	QUESTemp° 32 Portable Monitor Wet Bulb Globe Temperature	Localization of pill inside gastro-tract; Not suitable for patients in comma, children or emergency situations
[12]	Heart-rate fluctuation	Ingested—Jonah Thermometer Pill	Less accurate; Difficulty in use; Localization of pill inside gastro-tract; Not suitable for patients in comma, children, heart-patients or emergency situations
[13]	Skin heat-flux and heart rate	–	Complex methodology; Not viable for measurement of temperature in motion
[14]	Prediction of core body temperature from heart rate, breathing rate, and skin temperature	–	Multiple variable technique used; Skin touch required
[15]	Zero-heat-flow method	CTM-205	Thermal insulator is placed over a larger skin-surface; Patient needs to be in rest; Skin touch required
[16]	Zero-heat-flux method	NICCT sensor	Patient need to be at rest; Skin touch is required
[17]	Dual-heat-flux method	CTM-205	Constant and vertical heat flow required. Skin touch is required
[18]	Skin heat-flux	Thermocouple and Thermistor	Complex method; Skin touch is required

system implements a novel technique by which BCT can be measured from a varying distance 1.5–30 cm. Certainly, upon specific adjustments, it may open the door of fantastic wearable solution toward BCT measurement.

Proposed methodology

It is a well-known fact that heat is the cause of temperature. Hence, calculated amount of radiated heat from an object could be helpful to estimate the temperature of that object from distant location. In this experiment, two different methods are collaterally used to estimate the core body temperature of a human body. Firstly, a novel derivation is obtained by implying standard convection method where theory of *Newton's Law of Cooling* is extensively used. Later, the final core body temperature formula is devised after performing some addendum in to it. Table 2 presents the abbreviations used in this study.

Approximated formulation of core body temperature

Convection method This experiment approximates the core body temperature by a distant measurement of the amount of heat-radiation emitted from human-forehead. It is known that temperature at forehead is quite less than human core body temperature. In this context, the radiative heat-transfer of forehead is neglected (due to keep the complexity of the solution

Table 2 Abbreviated terms and full forms

Abbreviation	Full Form
Q	Heat transferred per unit time (W)
W	Blood mass flow rate (kg/s)
C	Heat capacity of blood (J/(kg·K))
H	Convective heat transfer coefficient of the process (W/(m^2·K))
A	Heat transfer area of the skin (m^2)
T_c	Core body temperature (°F)
T_s	Temperature of the skin (K)
T_a	Ambient temperature (K)
T_o	Oral temperature (K)
T_r	Rectal temperature (K)
P	Perfusion rate (i.e. blood flow per unit area) (kg/(s·m^2))
SCL	Serial Clock
SDA	Serial Data
PC	Personal Computer
CMOS	Complementary Metal-Oxide Semiconductor
SRAM	Static Random-Access Memory
EEPROM	Electrically Erasable Programmable Read-Only Memory
RISC	Reduced Instruction Set Computer
CBT	Core Body Temperature
ISP	In-System Programming

lower and increase the comprehensibility more and easy), but the convection-wise heat-transfer is retained. Following formulations are hereby derived from the *Newton's Law of Cooling* [21]. The radiated heat-loss of forehead-skin to the environment can be calculated as below [22].

$$Q = H\,x\,A\,x\,(T_s - T_a) \tag{1}$$

Where, Q is heat transferred per unit time (W), H is convective heat transfer coefficient of the process (W/(m^2·K)), A is heat transfer area of the skin (m^2), T_S is temperature of the skin (K), T_a is ambient temperature (K).

Heat radiation-flow from the body-core arterial-source to the forehead-skin is taken place due to blood circulation. Medically, such heat flow is more viable than skin-tissue conduction. Hence, the body-thermal transport via the blood-circulation could be expressed as the following equation:

$$Q = W\,x\,C\,x\,(T_c - T_s) \tag{2}$$

Where, W is blood mass flow rate (kg/s), C is heat capacity of blood (J/(kg·K)), T_C is core body temperature (°F).

Equating (1) and (2) implies:

$$H\,x\,A\,x\,(T_s - T_a) = W\,x\,C\,x\,(T_c - T_s) \tag{3}$$

Dividing both sides of (3) by surface area *A*, we get:

$$H\,x\,(T_s - T_a) = \frac{W}{A}\,x\,C\,x\,(T_c - T_s) \tag{4}$$

(4) may also be written as below.

$$H\,x\ \ (T_s - T_a) = P\,x\ \ C\,x\,(T_c - T_s) \tag{5}$$

Where, P is perfusion rate (i.e. blood flow per unit area) (kg/(s·m^2)), assuming $P = \frac{W}{A}$.

Solving for T_c, we get:

$$T_c = \frac{H}{P\,x\,C}\,x\,(T_s - T_a) + T_s \tag{6}$$

Where, $\frac{H}{P\,x\,C}$ is assumed to be the *weighting coefficient* (i.e. relative to the skin temperature change) that weights the ratio between forehead-skin-surface temperature (i.e. T_s) and ambient temperature (i.e. T_a).

Body resistance method A more intuitive method of calculating $T_c$is to employ body-skin resistance approximation method. This method employs the convention of bodily electrical current to heat-flow and potential difference with synergy with temperature difference. Hence, rephrasing (1) and (2) give following forms:

$$Q = \left(\frac{1}{R_1}\right)x\,(T_s - T_a) \tag{7}$$

and

$$Q = \left(\frac{1}{R_2}\right)x\,(T_c - T_s) \tag{8}$$

Where, T_c and T_s may be considered as constant voltage sources. A more convenient equation out of the earlier two can be expressed as:

$$Q = \left(\frac{1}{R_1 + R_2}\right) x \left(T_c - T_a\right) \tag{9}$$

Using (7) and (9) and solving for T_c we get:

$$\left(\frac{1}{R_1 + R_2}\right) x \left(T_c - T_a\right) = \left(\frac{1}{R_1}\right) x \left(T_s - T_a\right) \tag{10}$$

$$T_c = \left(\frac{R_1 + R_2}{R_1}\right) x \left(T_s - T_a\right) + T_a \tag{11}$$

$$T_c = K\, x \left(T_s - T_a\right) + T_a \tag{12}$$

Where, the K-factor can be equated as:

$$K = \frac{R_1 + R_2}{R_1} \tag{13}$$

Comparing (6) and (11):

$$\frac{H}{P\, x\, C}\, x \left(T_s - T_a\right) + T_s = \left(\frac{R_1 + R_2}{R_1}\right) x \left(T_s - T_a\right) + T_a \tag{14}$$

$$\frac{H}{P\, x\, C} = \left(\frac{R_1 + R_2}{R_1}\right) \tag{15}$$

K-factor with synergy to (13) may now be written as:

$$K = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1} = 1 + \frac{H}{P\, x\, C} \tag{16}$$

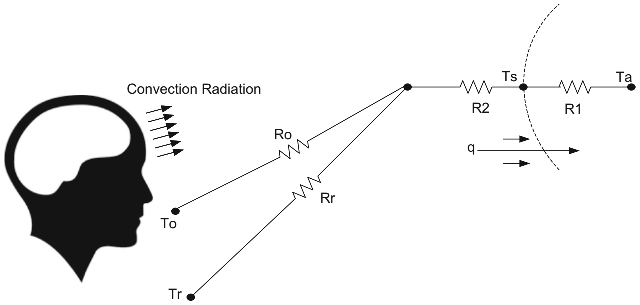

Fig. 1 Electrical modeling of body resistance based temperature approximation

Per [22],

$$\frac{H}{P\, x\, C} = 0.001081\, x\, T_s^2 - 0.2318\, x\, T_s + 12.454 \tag{17}$$

Where T_s is in °F.

Substituting (17) in to (6) we get:

$$T_c = \left(0.001081\, x\, T_s^2 - 0.2318\, x\, T_s + 12.454\right) x \left(T_s - T_a\right) + T_s \tag{18}$$

Per human physiology, body temperature arises from its arterial sources. Accordingly, oral (T_o) and rectal (T_r) diagnostic equivalents can be measured by appropriate K-factor selection, while employing R_o and R_r as conjugal parts (see Fig. 1).

With both approximations, the change in ($\frac{H}{P\, x\, C}$) is seemed to be relative to the skin temperature change. After performing convection and body resistance based approximations, we finally get the human core body temperature (T_c) in °F (in (18)) by the forehead.

In this experiment, human objects are placed at varying distances from the IR sensor. Initially IR sensor is placed 1.5 cm apart from forehead. Later on, this distance was increased up to 30 cm. More than, 30 cm incur significant amount of noise in the BCT values be it analog or thermographic.

Materials

Below mentioned materials are the essential most components of conducted study. Besides, a stand-alone PC, some electric wires, and interfacing circuitry elements are also used which require no such exploration.

MLX90614: It is an Infra-Red (IR) based distant temperature measurement chip which contains both IR sensitive thermopile detector and the signal conditioning ASSP. Moreover, 17-bit internal Analog-to-Digital convertor, low noise amplifier, and a.

- Digital Signal Processing unit make MLX90614 highly accurate for industrial use. Other relevant specifications

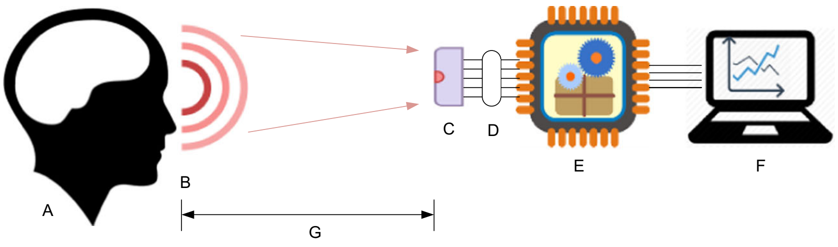

Fig. 2 System model of proposed experiment. A) Human forehead, B) Convection radiation, C) IR sensor, D) Signal amplification-interfacing circuitry between C and E, E) Microcontroller, F) PC, and G) Distance between forehead and IR sensor

are as follows: ambient temperature range: −40 to 125 °C, object temperature range: −70 to 382.2 °C, output resolution of 0.14 °C, working voltage range: 3.3 to 5 v, SCL: serial clock input used for 2 wire communication, SDA: serial data input/output used for measuring object temperature.

- AT Mega 328 Breakout Board: It is an 8-bit CMOS microcontroller based on RISC architecture. This study employs AT Mega 328 based Arduino Uno breakout board for essential computation. Following are key features of such board: 14 digital input/output pins, 6 analog pins, 16 MHz crystal frequency, working voltage range 7 to 12 v, 32 KB flash memory, SRAM 2 KB, EEPROM 1 KB.
- Makerplot: It is a proprietary data acquisition software specially developed for supporting AT Mega based any breakout boards. It allows developer to collect, analyze, and store raw data from associated breakout boards. Developers are also equipped with customized panel (front-end) modification for suitable application development.
- Thermo-JAR: It is a Java-Jar based development used for mapping thermographic images in pixel-wide formation. This is an open-source application made to be run on any Java-enabled system [23].

System model

Figure 2 presents the system model of the proposed experiment. It comprises of seven components as follows. A) Human forehead, B) Convection radiation, C) IR sensor, D) Signal amplification-interfacing circuitry between C and E, E) Microcontroller, F) PC, and G) Distance between forehead and IR sensor. Initially, heat radiation from forehead is received at the (C) where distance is kept static up to (G). (C) is attached with (E) by means of connecting buses. (D) plays a crucial role for interfacing between (C) and (E). (E), in turn is connected to (F) which is a full-fledged stand-alone personal computer. (F) is any PC that runs Makerplot and Thermo-JAR as the data acquisition tool. It is comprehended that relationship between (B) and (C) is as like a horizontally cross-sectioned cone. (E) acts as the brain of the system. It deploys (18) to calculate TC of any human body which is placed in front of (C). The measured temperature is visualized on (F) in real-time.

Flow chart

Figure 3 describes flow chart of proposed system. Initially two packages such as: Makerplot and Thermo-JAR, are checked whether ready to perform plotting and thermographic imaging. If yes, Makerplot is synchronized at 9600 bps to enable for reception of raw data from the system. Simultaneously, Thermo-JAR package is configured per port and 9600 bps. The storage location of received data is hereby selected. Later, the baud rate of the microcontroller-based sensory system is set at 9600 bps to synchronize with Makerplot and Thermo-JAR. Upon successful baud rate setup, MLX90614

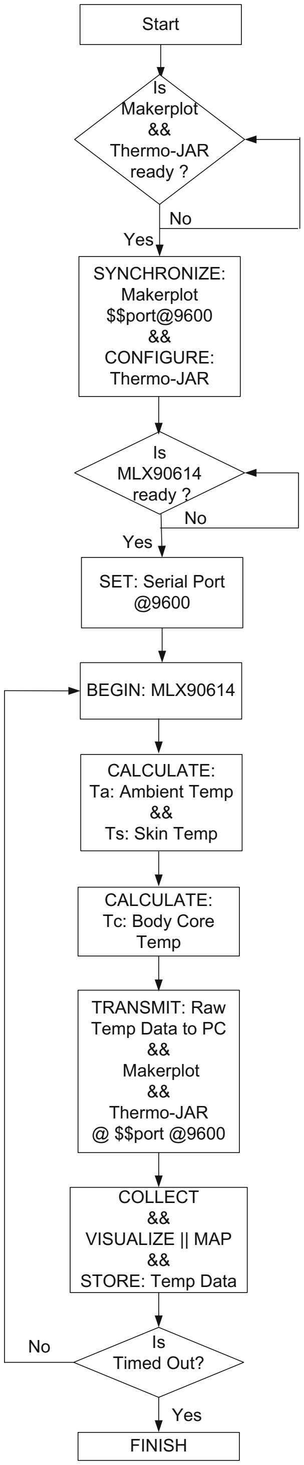

Fig. 3 Flow chart of the proposed system

Table 3 System specification details

Item	Implementation Remarks
AT Mega 328	8-bit AVR RISC-based microcontroller, 32 kB ISP flash memory, 1 kB EEPROM, 2 kB SRAM, 23 general purpose I/O lines, 32 general purpose registers
MLX90614	Industry standard specifications: −40 to 125 °C for Ambient, −70 to 382.2 °C for Object, 3.6–7 V, inbuilt DSP, reverse voltage: 0.4 V, ESD Sensitivity 2 kV, DC current 2–25 mA
SCL	Connected to PORTC5 of AT Mega 328
SDA	Connected to PORTC4 of AT Mega 328
Makerplot	Makerplot V1.7.0 Demo License, Standard Run Interface
Thermo-JAR	Minimum requirements: 1 GB RAM
RxTxComm	RxTxComm.dll, civil.dll
PC	Intel Core i7-7th Generation, 8 GB DDR4 RAM, 1 TB HDD, 8 GB Radeon Graphics Memory, JDK 8 U121
Voltage	3.3–7 VDC
Power	165 mW

is checked whether it is ready to work. In next steps it senses ambient temperature, forehead-skin temperature and calculate core body temperature per formulations prescribed in Section III.A. The calculated value is then transferred to the Personal Computer (i.e. PC), Makerplot, and Thermo-JAR packages for plausible storage, visualization and mapping of core body temperature. Upon, reception of enough temperature data on preset-time period the system stops working. However, it could be run infinitely after certain modifications in the algorithm. The proposed algorithm follows linear behavior where complexity is O(n).

Experimental result and discussion

Experimental setup

The experimental setup follows following constraints. The IR sensor attached with the microcontroller breakout board is ordinarily placed 1.5 cm away from forehead while performing the experiments. Moreover, the IR sensor is continuously moved horizontally from one end of forehead to another. This is done so that average BCT could be obtained which is happened due to varying surface area on forehead. As shown in Fig. 2, the setup contains a PC that runs on Intel Core i7 7th Gen having Windows 10 Professional Operating System, 8 GB RAM, 8 GB Graphics Memory, and *Makerplot* as acquisition tool specially developed for AT Mega series. Both the AT Mega 328 breakout board and *Makerplot* are preset at 9600 bps. Subsequently, a JAVA based heatmap visualizer file is developed (i.e., JAR) to fetch the core body temperature received at the serial port and draw a pixel-wide multi-colored screen. Per Fig. 2, serial communication between (E) and (F) is monitored by RxTxSerial.dll. The tests are performed on 37 volunteers (three age groups: 12 to 18 ×, 19 to 35, and >35 years (46 ± 7.1 years)) in two phases (1) at complete rest, and (2) after walking 10 min' at laboratory and outdoor, respectively. The final specifications of the working system are given in Table 3. After all the data is obtained, the experiment is repeated with CoreTemp CM-210 (i.e, an industry grade BCT measurement sensor by Terumo) (probes placed on the forehead) which shows no significant difference between the average value by both the sensors i.e., IR sensor and CoreTemp CM-210.

Results and discussion

Figure 4 presents the two-different representations of outcomes from this study. The results shown in Fig. 4 advocate for the proposed proof-of-concept essentially performed on author itself. The reason behind such notion is to provide ease understanding over the proposed approach. Fig. (a) and (b) provides the difference between core body temperatures when in rest and after 10 min' walk in outdoor, achieved at JAVA based heap map visualizer. Average value at rest and tired body conditions are measured at 84.64 °F and 92.19 °F i.e., 7.55 °F difference. Minimum temperature range in both situations vary from 81.81 to 90.23 °F and 89.51 to 95.70 °F. The temperature gap is 26.48% higher after exercise than at rest. Green and Red stripes are more vivid after exercise than at rest. Makerplot gives more precise picture of BCT difference in two stages of activity. Black, red, and green lines on Fig. 4(c) and (d) present ambient, object, and core body temperatures, respectively. Figure 4(c) is taken at rest and (d) after 10 min' walk at outdoor. It is seen that CBT at rest and after exercise differs per superimpositions.

As the experiment is conducted in two phases in different deployment sites (i.e., rest phased at laboratory and walk phase at outdoor) there are slight variations in data.

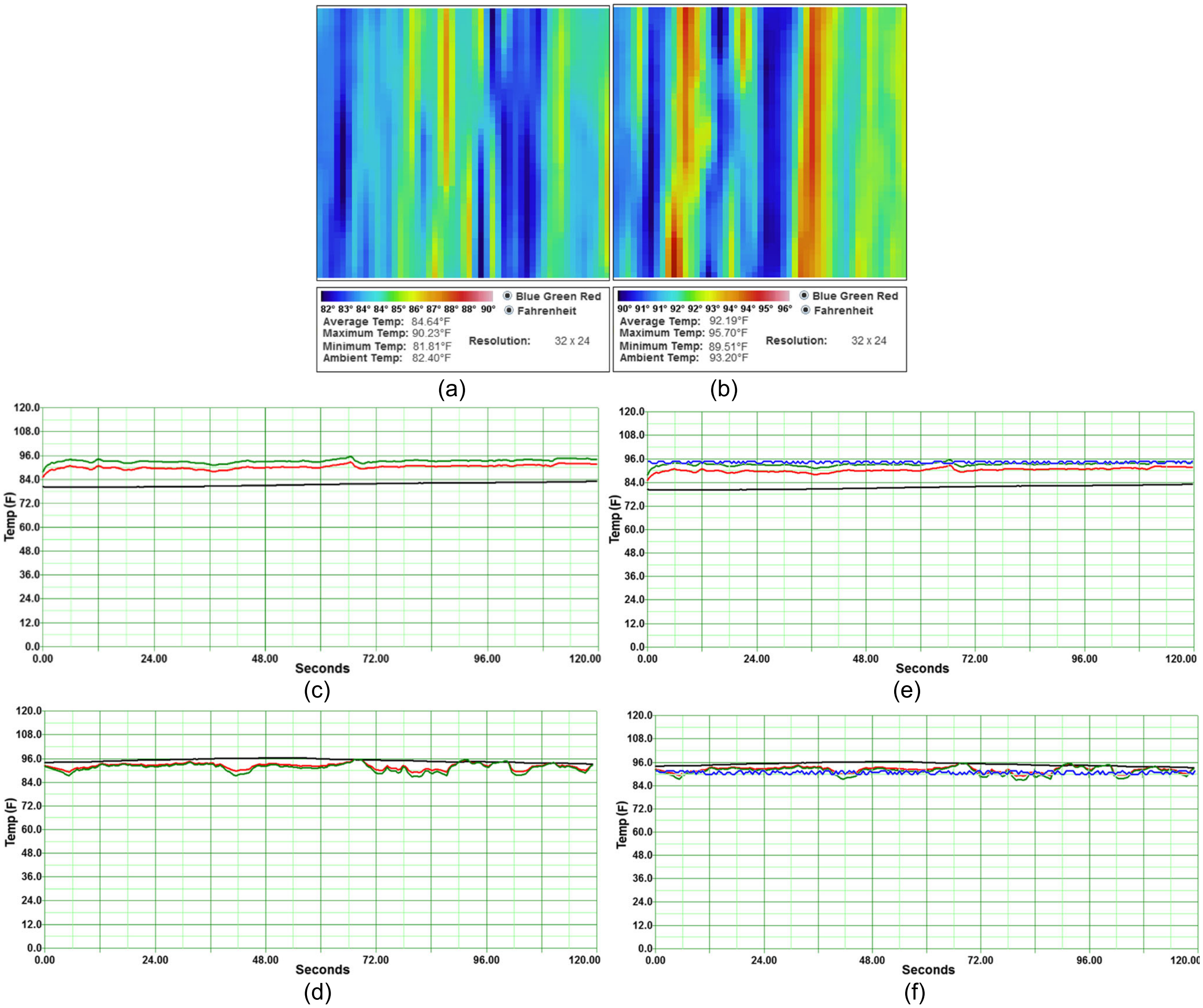

Fig. 4 Experiment results where Black, Red, and Green lines represent ambient, skin, and BCT, respectively. Blue line in (e) and (f) represent the BCT measured by CoreTemp CM-210 by Terumo. (a) Thermo-plot at complete rest, (b) Thermo-plot after 10 min' of walk at outdoor, (c) *Makerplot* output at complete rest, and (d) *Makerplot* output after 10 min' walk at outdoor, (e) Comparative presentation between BCT by IR sensor and CoreTemp CM-210 sensor at rest, (f) Comparative presentation between BCT by IR sensor and CoreTemp CM-210 sensor after walk

Sometimes, temperature lines are stable that is mainly due to fluctuations (i.e., response time) of IR sensor against perceived heat radiation. Figure 4(d) CBT and skin temperature varied more than Fig. 4(c). The reason behind such incident is the change in ambient temperature and sweat drops deposition on forehead. Sometimes, slightly wild wind compelled human body to release latent heat from inner body, hence evaporating the sweat drops.

However, Fig. 4 (e) and (f) present the comparison between the BCT measured by proposed IR sensor system and CoreTemp CM-210 sensor, at rest and after walk, respectively. Blue line (i.e., representation of BCT measured by the CoreTemp CM-210 sensor) is the demarcation over the three colors. Fig. 4(e) and (f) are cumulative images over Fig. 4(c) and (d), respectively.

Table 4, shows the mean and SD of measured BCT. Three different age groups (i.e., 12–18 (15 ± 3 years), 19 to 35 (27 ± 4.7 years), and >35 years (46 ± 7.1 years)) are selected for this study. The reason is simple and straight forward-i.e. people of different age groups have different physiological structure and anomalies. For example, body temperature of a child is usually quite more than an old. Similarly, a middle-aged person has more work ability than an old but less respiration rate than a child. The fitness level of a child is also more than older ones. These are common facts that gradually get inherited into physiological behavior around civilization. This

Table 4 Statistical analysis of measured BCT (°F)

Age group (No.)	IR Based				CM-210 based			
	μ(R)	SD(R	μ(W)	SD(W)	μ(R)	SD(R)	μ(W)	SD(W)
12–18 years (6)	15 ± 3 years							
Male (3)	93.04	0.12	97.14	0.15	93.74	0.16	97.96	0.09
Female (3)	92.89	0.10	96.21	0.08	93.31	0.05	96.81	0.11
19–35 years (14)	27 ± 4.7 years							
Male (7)	92.29	0.11	97.18	0.10	93.40	0.04	97.70	0.15
Female (7)	92.67	0.10	98.10	0.14	92.97	0.09	98.79	0.07
> 35 years (17)	46 ± 7.1 years							
Male (8)	91.98	0.09	95.97	0.19	91.58	0.19	96.47	0.09
Female (6)	89.94	0.11	95.11	0.17	90.98	0.12	96.13	0.13
Mean value	92.13	0.10	96.61	0.10	0.13	92.83	0.10	97.31

study shows that mean value difference between IR based and CM-120 based approaches is 0.7 °F (i.e., average of (92.83–92.13) and (97.31–96.61)). Coincidentally, this numeric gap between Rest and Walk states come out to be equal. In this context, it is worth to note that *R* and *W* stand for *rest* and after *walk* conditions, respectively. It is possible that such difference could be dissimilar in other sets of human samples. As, the mean and SD values of this test are coherent, no further statistical tests (i.e. T-test, F-test etc.) are performed.

It is also noteworthy to mention that the IR sensor was placed between 1.5–30 cm away from human-forehead during experiment. Placing the IR sensor very near to forehead (i.e. < 1.5 cm) did not provide any meaningful results, hence not included in this discussion. Similarly, putting IR sensor very far from the forehead (i.e. > 30 cm) also provided some unstable and erroneous values of the BCT. The main reason behind such incident is the range of the IR sensor. However, to solve this problem, multiple IR sensor arrays could be inculcated into a frame where each of the IR sensors should be placed at different places with respect to certain angle from each other. The results infer that upon suitable pre-calibration, proposed technique would easily uplift itself up to the level of standard one.

In this aspect, a theoretical comparison among surveyed systems and the proposed one is made-i.e. wear-ability which was never seen in earlier designs. Most of the methodologies have involved extraordinary and difficult approaches to study the BCT measurement. Till date, nine different ways have been investigated for increasing accuracy of BCT estimation.

In this study, we compared such literatures per their methodology, sensor type, and related issues. It is found that skin-heat-flux method [3, 9, 11, 17–20] is more cultivated than others. However, two hybrid heat-flux techniques are also seen [14, 15]. This hybrid heat-flux method, skin-heat-flux is adjusted with other values obtained from different parts of body such as rectum, esophagus etc.

Ingestible temperature pills are also in use [12, 13]. Despite of its uniqueness, accurate localization inside gastrointestinal tract prohibits users to practically use it. Besides, cost and health-risk are two main challenges with it.

Radiometry technique is also investigated where a specific range of frequency (normally GHz) is shoot on human body [5, 7]. Per amplitude and reflected frequency of such radiated signal BCT is calculated. The main problem in this technique is complexity of signal generation circuit that in turn incurs huge cost, hence not appropriate for field use. Kalman filter is used in accordance with this drawback but inaccuracy stepped back such idea [6].

Circadian rhythmicity is also chosen as alternative to measure BCT [4]. Patients must be kept is rest-state otherwise valuation of BCT could be abnormal. Basic skin-touched thermopile is also leveraged to validate the actual BCT of human body [2].

Hence, it is worth to comprehend that the proposed solution fits in and around its alternatives, where main importance is solely given upon computational part. Incorporation of low-energy consuming microcontroller enhances the opportunity to be run on just 2–3 AAA batteries. Thus, it reduces the effective cost of utilization in reality. The key attribute of proposed solution is the capability of raw data storage, graphical visualization, and thermo-graphic perception. The stored data could later be used for analysis of prospective occurrence of health-hazards. This solution would leverage portability, usability, and flexibility in one go. Wear-ability is other added advantage of such system.

Conclusion

This paper presents a novel IR sensor-system to measure and monitor BCT, ordinarily placed between 1.5–30 cm away from human-forehead. Results obtained since its experimentation by tools like Java thermos-graphic and Makerplot, provide promising aspects of its usage toward real-time BCT measurement. Achieved results are compared with the CoreTemp CM-210 sensor which is measured to be 0.7 °F different from average value of BCT obtained by the proposed IR sensor system. Being compact and modular in form factor, proposed solution holds two key characteristics (1) energy efficient (due to use of low power consuming microcontroller system) and (2) portability (due to plug-in capability). Upon appropriate modification, this system could be transformed into a wearable one which may further relate to distributed-wearable computing paradigm that in turn would benefit user to predict possible health disorder.

Compliance with ethical standards

Conflict of interest Author declares that he has no conflict of interest.

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