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Design and Prototyping of an ESP32-Based Control Device of Freshness for Climate Clothing

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ABSTRACT

This paper proposes an innovative ESP32-based system to be embedded in cloths for freshness control of the wearer's body. The proposed electronic device consists of a remote control, a data acquisition system and a Peltier module for cooling production. The methodology used to achieve the desired objective relies on the use of our custom workbench, consisting of a Peltier module, an electronic model of freshness production, an analog signal acquisition device with monitoring on a PC/USB terminal. A garment designed according to electronics textile technology was chosen for its heat absorption and restitution properties. The results of this study show that when the electric current is zero, the temperature of the environment is ambient (37°c). In the presence of current, this drops to a certain threshold (28°c), beyond which the temperature varies over time as a function of current. This proves that our system is not only capable of producing the sensations required for human well-being, but can also maintain the equilibrium temperature required for properly evacuating heat through forced convection.

Keywords: ESP32-Based system, data acquisition, freshness control, cooling production, equilibrium temperature

1. INTRODUCTION

The summer seasons raise the question of air conditioning and its comfort in terms of health benefits. Elevated temperatures can have serious consequences the health and comfort of living organisms. It is therefore crucial to track the changes in human health caused by heat. Excessive heat can lead to health discomfort such as headaches, unusual fatigue or exhaustion. These discomforts caused by extreme heat make it more difficult for the body to cool down and maintain its temperature within normal limits. Climate change has led to an increase in the frequency, intensity and duration of heatwaves in 33 European countries, so work has set out a suitable policy for improving the heatwave early warning plan [1]. Studies have examined the combined effects of clothing material properties and wind on the physiological parameters of wearers [2]. A numerical and experimental study is carried out on periodic ventilation processes in fabrics containing phase-change material (PCM) microcapsules. When PCMs are added to textiles, they release heat when the liquid changes to a solid state, and absorb heat when the solid returns to a liquid state [3]. Clothing comfort is determined by a number of clothing properties that affect thermal conditions at skin level. Skin temperature and sensation are the main factors influencing garment comfort, the main signals of which are transmitted to the brain and lead to an overall sensation of comfort or discomfort [4]. To significantly improve the comfort and performance of wearers when exposed to fluctuating or extreme environmental conditions, this paper presents thermoregulating garments with multimodal body heat regulation (i.e., convection, radiation and sweat evaporation) [5], which can automatically adapt to a change in temperature (15°C-35°C) by incorporating mechanically and optically infrared-adapted metallized polyethylene actuators into the textiles. Personal

Thermal Management (PTM) is a promising approach to maintaining the human body's thermal comfort zone while minimizing energy consumption in indoor buildings. Accordingly, recent advances in thermoregulating garments for PTM are reviewed in [6]. Advances in thermoregulating garments have focused on improving control of heat dissipation between the skin and the local environment. Among the adaptation measures and solutions developed to counteract occupational thermal stress, personal cooling garments represent a wearable technology designed to remove heat from the human body, thereby improving human performance [7]. The paper [8] presents an experiment involving different types of sensors and hardware supporting the periodic ventilation process in fabrics containing microcapsules of phase-change materials. The energy requirements of buildings can be considerably reduced through the use of personal cooling garments where only the microclimate around the body is cooled instead of cooling the whole building using heating, ventilation and air-conditioning (HVAC) Systems. The work [9], proposes the development of a battery-free wearable sensing device with integrated temperature and sweat sensors powered by a smart textile that can be used as a personal device involving wireless communication. In addition, we have in [10, 11] cooling vests using a phase-change material to increase the surgeon's thermal comfort. In [12], intelligent microelectronics integrated into textiles in order to facilitate data collection and analysis. Many equivalent instrumentation tools for the propagation of coolness on the human body are also available in smart textile and clothing engineering literature [13-17].

Furthermore, the main aim of this paper is to study a particular approach for absorbing, storing and releasing heat, in order to achieve an overall feeling of coolness on the body from an air-conditioning Electronic Textile garment. It is therefore a set of devices consisting of the basic local digital instrument and the Android mobile application initiated for remote instrumentation needs, which constitutes a valuable new instrument with future vocation. The following sections of this paper are organized as follows: In Section 2, the tools and methods for creating and implementing the proposed Android application are presented. Next, Section 3 presents the testing results obtained, followed by Section 4, which concludes the paper.

2. BUILDING TOOLS AND METHODS

The approach proposed here consists in presenting the electronic tools used to make an e-textile garment and the entire method set up through a structured algorithm for the cause.

2.1. Building tools

The block diagram of the freshness production system initiated in this article is presented in Figure 1 it. The proposed freshness production system consist of a power supply (or battery), a heat production/ freshness block, an ESP32-WROOM-32 card, an adapter or amplifier(buffer), a control block and a radiator.

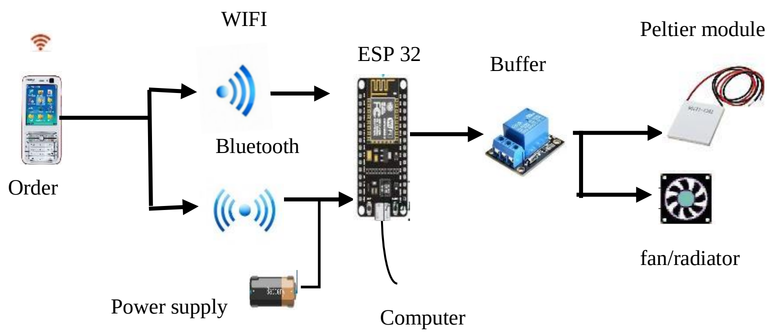


Figure 1: Block diagram of the freshness production system

Table 1 summarizes the technical specifications of the material tools selected for a new prototype of the freshness production system.

Table 1: Features of the Tool Modules

Type	**Tools and software features**
Buffer	VCC: power supply interface, 5 V
Rechargeable lithium-polymer battery	Battery parameters: Lion Power 11,1 V 2800mAh 35C ; Capacity of battery : 28 00mAh ; Continuous discharge rate : 30C, 50C maximum; Battery size: 11.5 x 3.7 x 2.2 cm
ESP32-WROOM-32 card	Power supply: Micro USB-B on computer's USB port; Micro USB-B on USB 5V mains adapter. Processor ESP-WROOM-32 ; WLAN 802.11 B/G/N ; Bluetooth 4.2 / BLE ; Processor Tensilica L108 32 Bits 160 Mhz ; 512 Ko SRAM Memory And 16 Mo Flash Memory ; 32 Digital I/O Pins (3,3V) ; 6 Analog-Digital Pins ; 3x UART, 2x SPI, 2x I2C ; Interface USB Vers UART CP2102.

Transistor NPN	TRANS NPN 40V 30A TO3
Laptop PC	Lenovo 250GHz 260GHz
Fan	SUNON 12 V CC 0,99 W 40 x 40 x 10 mm 13,9 m³/h 7300 tr/min 13,9 m³/h Sunon EE40101S11000U99
Electronic amplifier for coolness fan.radiator	Power: 12VDC 6A; Coolers Model: TEC1-12706; Coolers external dimensions: 40 * 40 * 3.75mm; Maximum temperature: △ Tmax (Qc = 0) above 67 °C; Operating current: Imax = 4-4.6A ; Cooling power: Qcmax 65W;
Peltier Module	Alimentation : 12 Vcc ; Intensity : 6 A ; Power : 51,4 W ; Cord length: 150 mm ;Dimensions : 40 x 40 x 3,8 mm
Arduino C++ platform	Arduino C++ IDE, 1.8.19 version

2.2. Electronic amplifier with coolness fan as load electrical load

Figure 2 stands for the electric circuit of the electronic amplifier device, with associated output fan to be switch ON/OFF via an electric relay.

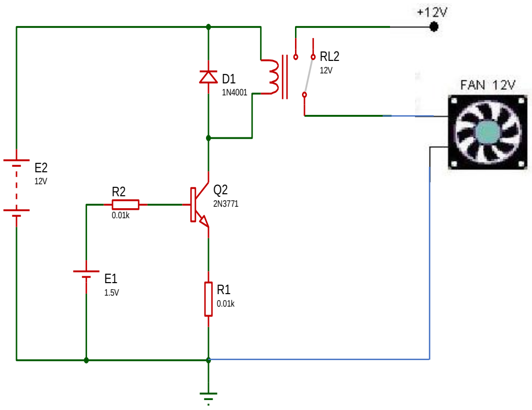


Figure 2: Electric circuit of the electronic amplifier with output fan

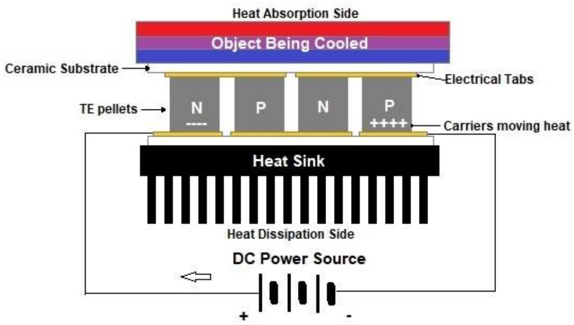
Considering E_1 as the control, transistor Q2 fires at

$$I_B = \frac{E_1 - V_{BE}}{R_2 + R_1(1+\beta)} \quad \rightarrow V_{CE} \approx 0 \qquad (1)$$

$$L\frac{di_c}{dt} + R_1 I_E = E_1 \;\; pour \; E_1 \gg R_1 I_E \qquad (2)$$

The current i_c increases with a slope of $\frac{E_1}{L}$ this is the magnetization phase of the relay coil.
This device adapts the control signal from the ESP32 module via a relay, which transmits the command to the freshness production device.

The internal coolness effet is built around Peltier-effect components, which are thermoelectric modules equivalent to a solid-state heat pump. They are used for heating or cooling, and can also be used as a DC generator, albeit with lower efficiency.



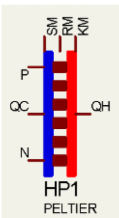


Figure 3: Peltier cooler on the left and its schematic on Proteus on the right [18].

In general, to find out the efficiency of a Peltier module, we use the term 'coefficient of performance' or COP. The COP is the quantity of heat pumped Q_c divided by the quantity of electrical power supplied P_f [18, 19].

$$COP = \frac{Q_c}{P_f} \qquad (3)$$

The *COP* depends on the heat load, the input power and the required DT temperature difference between the hot and cold sides. Figure 4 below shows a normalized graph of COP versus I/I_{max} (the ratio of input current to module Imax given in the datasheet). Each line corresponds to a constant DT/DT_{max} (the ratio of the required differential temperature divided by the DT_{max} specifications of the module).

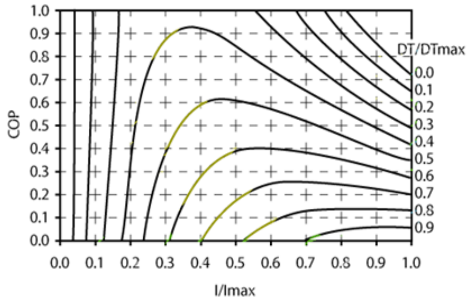


Figure 4: COP curve of a Peltier module [20]

One of the properties that improves the efficiency of a Peltier module is forced ventilation. A properly selected thermal radiator must have the correct R_{Th} value. This is the thermal resistance that heat energy encounters to go from hot (module temperature) to cold (ambient temperature). The smaller the R_{Th}, the larger the radiator. Using a fan for forced convection can be a good solution for achieving a small R_{Th} value with a reasonably sized radiator.

Convection

This refers to the transfer of thermal energy within a moving fluid, or between a moving fluid and a solid wall. This energy transfer is achieved by a combination of two elementary transfer modes: advection and diffusion. Along with conduction and radiation, convection is one of the three modes of heat exchange between two systems, and differs from these in the method of transfer. There are three types of convection: natural convection, forced convection and mixed convection. For the purposes of this work, forced convection is chosen because the heat generated by the Peltier effect is dissipated above a selected temperature threshold.

Forced convection: Forced convection occurs when the fluid flow is caused by an "artificial" device (pump, turbine, fan, etc.). The equation used to calculate thermal convection is [20, 21].

$$\vec{\varphi}_{dif} = -\lambda\vec{\nabla}T \quad heat\ diffusion \tag{4}$$

$$\vec{\varphi}_{adv} = \rho c_p T\vec{u} \quad heat\ advection \tag{5}$$

To obtain the equation for thermal convection, we need to add the formulas for heat diffusion within the fluid (Fourier's law) and heat advection into the fluid [18, 19].

$$\vec{\varphi}_{conv} = \vec{\varphi}_{adv} + \vec{\varphi}_{dif} = \rho c_p T\vec{u} - \lambda\vec{\nabla}T \tag{6}$$

Where

- λ which expresses the thermal conductivity of the fluid.
- ρ which identifies the density of the fluid.
- cp which identifies the fluid's mass heat capacity.
- T denotes fluid temperature.
- u indicates fluid velocity.
- φ which characterizes the heat flux density.

2.3. Digital signal acquisition from the ESP32

The analog signal acquisition device with PC/USB terminal monitoring is an ESP32 board. It is equipped with Bluetooth (version 4.2) and Wi-Fi (802.11, 2.2 to 2.5 GHz), enabling it to target a wide range of applications and making the module versatile, with a control and quality system. Compared to most devices, it offers lower size and cost, a higher degree of pin reconfiguration, higher standard instrumentation bus types and greater flexibility of use. The Wi-Fi allows a wide physical range and direct connection to the Internet via a Wi-Fi router, while the Bluetooth enables the user to connect easily to the phone. What's more, its driver for Arduino IDE-C++ programming is completely free, and its implementation makes it compatible with fast connection boards. An example of wiring diagram of the ESP32 is shown in Figure 5.

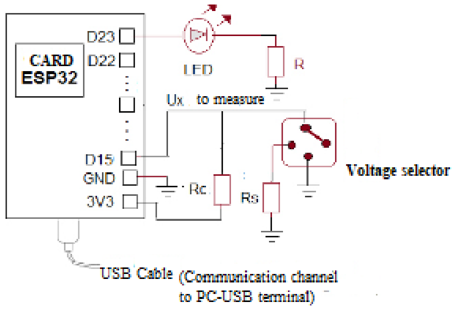


Figure 5: ESP32 schematic diagram [22]

This microcontroller features Wifi and Bluetooth interfaces, ideal for connected objects. Lateral male and female connectors enable the module to be plugged into a quick-mounting plate. The Wifi wireless interface enables the creation of wireless access points. The module is programmed directly from the Arduino IDE (installation of an extension required) and requires a micro USB cable (not included).

2.4. Arduino C++ programming ID

The Arduino IDE software runs on Mac, Windows and Linux. This software is used to create, test and send programs to the Arduino. The online version used in this project arduino.1.8.19.

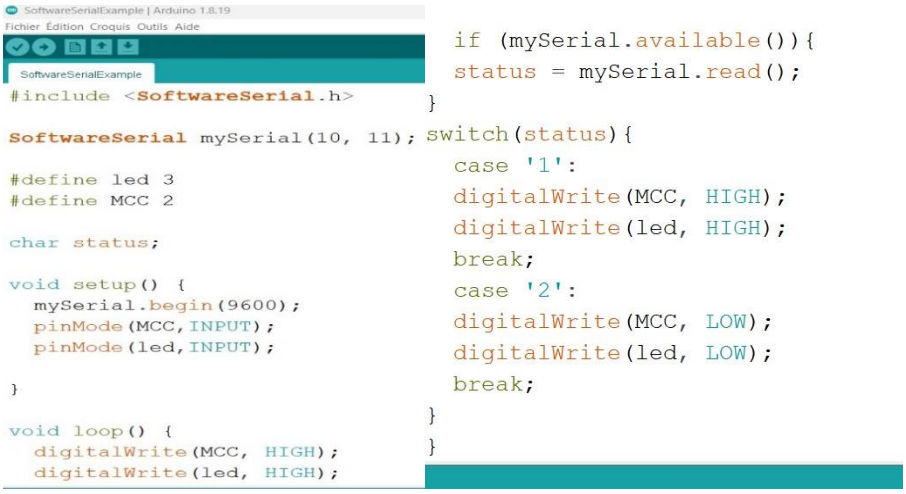


Figure 6: Arduino programming IDE

2.5. Overall virtual electronic scheme

Proteus Professional is a software suite for the electronics industry. Developed by Labcenter Electronics, the software included in Proteus Professional enables CAD (Computer Aided Construction) in the electronics field. The wiring diagram for our device was created using this platform.

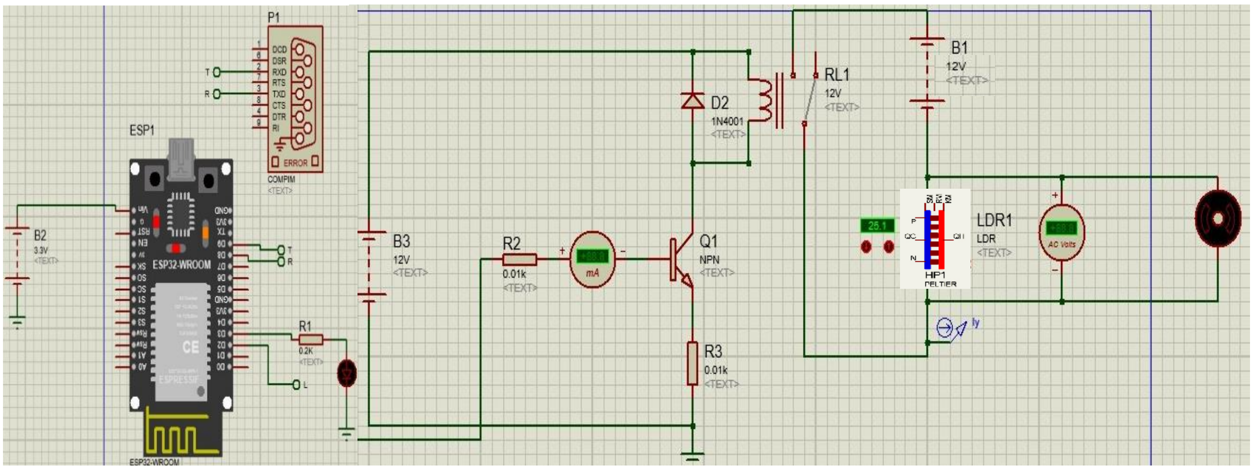


Figure 7: Wiring diagram of the proposed device

The overall virtual electronic scheme presented in Figure 7, only shows the whole building hardware part, of the proposed ESP32-based control device of freshness. The other remaining parts being:

- The C++ executable program, embedded into ESP32 program memory;
- WIFI or Bluetooth media, encapsulating data flux under transmission;
- The remote Smartphone monitor.

2.6. Processing algorithm

The algorithm shown in Figure 8 is a technique for producing a sensation of freshness which combines control, communication, information acquisition and processing methods.

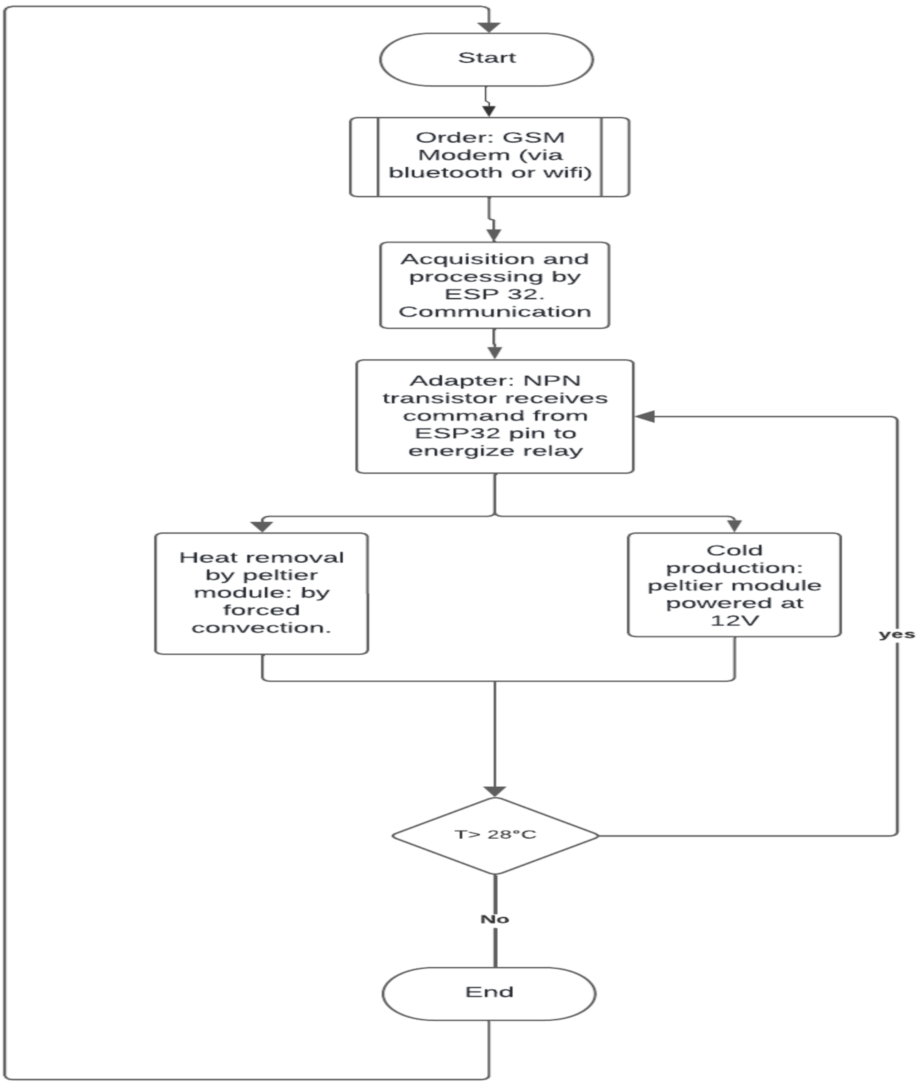


Figure 8: Proposed algorithmic approach

The first step is to install a GSM modem with a control interface and a Wifi or Bluetooth application. For this purpose, we have a Tecno Camon 20 telephone and a serial-Bluetooth application. The GSM modem is connected to the acquisition system via Wifi or Bluetooth using a security code. After connection, a command is sent via a control interface, and is received by by the acquisition system via ESP32 module. Once the information has been processed, the acquisition system is supposed to control the cooling or heating device, but given the ESP32's weak output signals, an adapter (buffer or amplifier) is used. This is designed around a high-sensitivity NPN transistor and an electronic relay with a voltage level equivalent to the device to be powered. The cooling device is built around the Peltier module, whose hot face is bonded to the radiator and a fan to ensure convection of the heat produced by the latter. The temperature of the environment is assessed by that of the garment worn by the individual.

3. RESULTS AND DISCUSSION

This section outlines three outcomes: relevant obtained results and discussions, information acquisition and the power device. The user first switches on the module by pressing ON. With the module powered up, the user sends the command via his telephone to activate the air-conditioning, and the code is analyzed by an ESP32 board. In the event of an error, the module will not operate until the user enters the correct code. He prototyping interactive virtual monitor, displayed on the Smartphone screen of a user, is presented in Fig. 9.

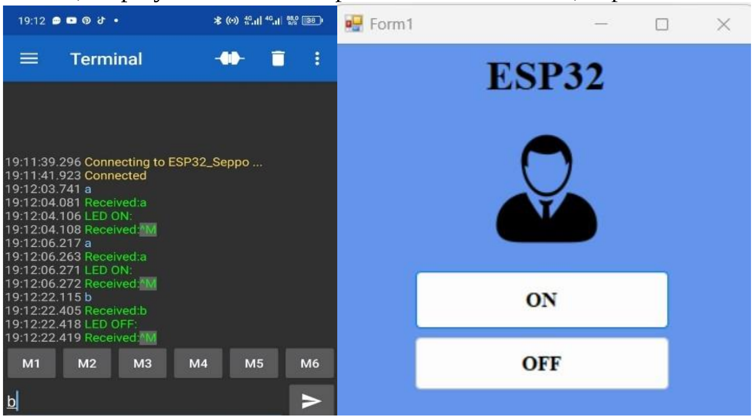


Figure 9: Interactive visual monitor displayed on a smartphone screen

Schematic diagram the experimental workbench realized for testing the proposed new device is shown in figure 10, and the results of this experimental chain are presented in figure 11.

1.Transistor, 2. ESP32 Card, 3. Fan, 4. Radiator, 5. Peltier module, 6. Resistor, 7. Power supply cord, 8. Charger, 9. Switch, 10. Computer.

Figure 10: Workbench, based on the ESP32, for the acquisition of the freshness production device

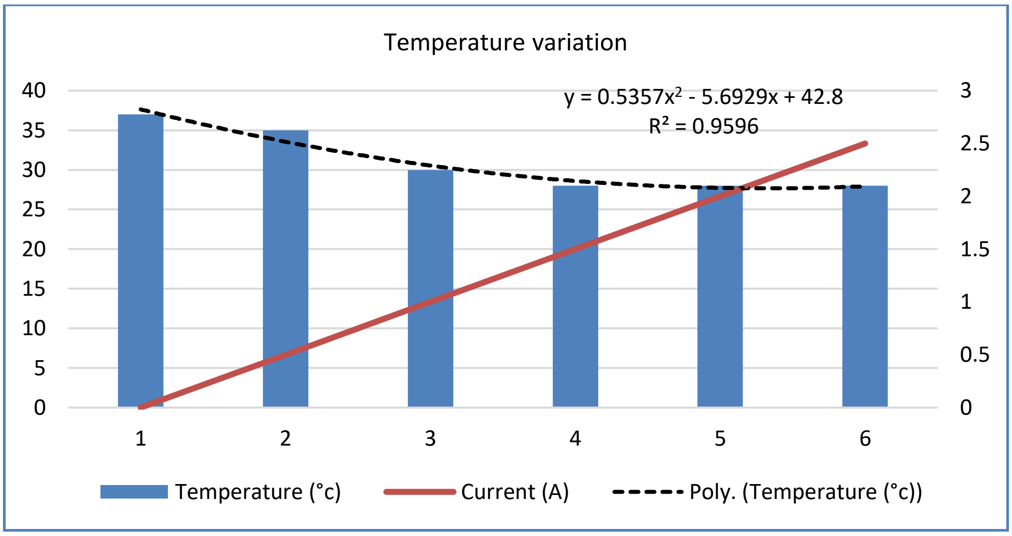


Figure 11: Temperature

Figure 11 shows that the temperature of the medium evolves according to a function of the current flowing through the Peltier module. The equations for the polynomial trend in temperature and the linear trend in current tell us that the temperature decreases as the current increases, and at a certain current value (1.5A), the temperature of the medium remains constant and evolves more as a function of time. All this shows that the system is capable of producing cool sensations (28°c) and dissipating the heat produced by the Peltier module. This low-temperature equilibrium would be nothing less than a comfortable source of well-being for the wearer when incorporated into a thermoregulating textile garment.

4. CONCLUSION

This paper presents a technical and experimental approach for production coolness in an E-Textile garment designed for human well-being and comfort. This approach is undoubtedly a confirmation of the feasibility and quality of the android application for remote monitoring of physiological parameters (body temperature) of a human during periods of high heat. The experimental set-up consists of a control/command unit for commissioning the system and measuring the temperature of the environment, an acquisition/communication unit for information processing and communication between the power and control units, and a heat/cool sensation production unit built around the Peltier module. Particular attention was paid to the judicious choice of equipment for forced convection of heat while maintaining coolness. The results of this work show that, between 37°c and 28°c, the system temperature decreases whereas the electric current increases and when it is below 28°c (1.5A), it no longer decreases as a function of current, but as a function of time. The choice of garment with thermoregulating devices will bring a considerable contribution to the propagation of coolness, for the body well being of smart cloths wearers.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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