Developing a Multifunctional Heating Pad Based on Fuzzy-Edge Computations and IoMT Approach

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Abstract

Many medical assistive devices, such as rehabilitation and heating pads, have developed toward AI IoT functions during the past decade. Heating pads can be used for rehabilitation or to relieve pain while patients use them to relax muscles and enhance blood circulation; however, this assistive device is single-functional. Additionally, older adults usually lack information adaptability in using multifunctional heating pads, and the heating sensors of the pads need to have high stability and low value of temperature error to avoid unstable measurement and unexpected results.

This article proposes a multifunctional heating pad system by fuzzy-edge computations, primarily setting the functions by IoT development board and Bluetooth and the temperature ranges by fuzzy edge technique; users can adjust heating modes based on their needs. Our research team designed the heating sensor in the system to achieve high stability and durability; the IoT development board can calibrate the temperature by digital voltages, which enables the sensor to achieve expected temperatures. The IoT development board and fuzzy-edge technology employed in the system can self-calibrate and maintain the temperature ranges without needing a server to calculate, reaching the goal of edge computations. The experimental result has proved the feasibility of the system.

Keywords: Fuzzy-Edge computations, Internet of things, Artificial Intelligence, Smart healthcare industry, Smart medical

1 Introduction

Today, many countries are gradually aging and have low birth rate societies. The elderly need appropriate medical care or rehabilitation; nonetheless, these jobs require massive medical workforces and resources, but the low birth rate makes the goal run in the opposite direction. Moreover, many older adults live alone, and the development of intelligent health can fulfill the rehabilitation and medical requirements. Among the global countries, when the population aged over 65 years old accounts for more than 7%, 14%, and 20% of the total population, they are called aging society, aged society, and super-aged society. Nevertheless, the aging population is a global issue and an inevitable trend. In 2020, the population of seniors over 65 years old was over 16% [1], increasing the household numbers that require long-term health care [2]; the burdens of medical and personnel costs on the younger generations have also enlarged [3].

Consequently, intelligent health can be the solution to reducing workforce and medical loads. For instance, families can remotely monitor elders' physiological indexes by smart health or control medical equipment, helping older adults to do rehabilitation or checking their medication usage. There are currently various innovative health products on the market, including home care systems [4] and emergency relief systems [5]; unfortunately, the high functional feature sometimes prevents the elderly from using the system familiarly or requires recharge frequently. Furthermore, the lack of information adaptability usually makes older adults give up using the device; hence, an intelligent health device should be designed based on the elder's needs, enabling the product to be universal.

The design of intelligent health products has to consider the following situations: 1. The lack of information adaptability among older adults; most smart-health products contain too many functions, which may lower elders' learning willingness and make them give up using those products; 2. The power consumption issue of intelligent health products; too many functions will increase the power consumption, making smart health products need to recharge frequently. The need to recharge frequently may be an obstacle for the elderly to use, and they may give up using those products quickly. Based on the above issues, the design of smart health products needs to be user-friendly and have higher durability.

Furthermore, the most used heating pads on the market have diverse functions and heating levels; older adults have to buy different heating pads to fulfill various heating purposes, so remembering each product's operation method can be burdensome for them. Additionally, the heating stability and circuit design are vital elements to heating pads; unstable products may cause overheating or not having enough heat, leading to worse rehabilitation performance or even adverse effects. Thus, the circuit design of heating pads should have an automatic correction function to prevent the product from lowering accuracy after frequent use. On the other hand, the Integrated Circuit (IC) commoditization is also essential, making intelligent heating pads universal.

This study designs a multifunctional heating pad developed by fuzzy-edge computations, which primarily

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employs mobile devices to control the operation of the heating pad. For example, users can set the temperatures at a specific range during rehabilitation, and the heating pad can control the temperatures according to older adults' using scenarios. The features of our system include 1. Use a fuzzy decision tree to control the temperatures in various scenarios; 2. The IoT development board is in charge of delivering heating commands, which does not need the server to calculate for reaching the edge computations goals; 3. The designed heating IC can successfully reach desired heating stability; 4. The automatic correction function of the heating IC can send voltage feedback through the IoT development board to correct accuracy. Our research has developed the IC and conducted practical experiments. The experimental result has shown that the designed IC can connect to RS485 for digital corrections and maintain a stable heating temperature, benefiting the use in different scenarios. Furthermore, the fuzzy decision tree in the system constructs various temperature ranges in each scenario, enhancing the multifunctional use of the heating pad. The main contributions of this study are as follows: (1) heating pad malfunction was examined through digital detection; (2) digital voltage correction was performed to eliminate unstable heating voltage or displacement in the heating pad; (3) various temperature ranges for each heating pad use scenario were determined using Fuzzy logic; (4) low-cost chips were employed to facilitate the mass production of heating pads; (5) the heating stability of the heating pad, which was maintained using low-cost chips, was comparable to the performance of high-cost chips.

The remainder of this paper is organized as follows. Section 2 reviews the literature on IoT, Blockchain and fuzzy. Section 3 describes the system model, the categories of the fuzzy decision tree, and the design of the heating pad. Section 4 presents and discusses the experimental results, while conclusions are drawn in Section 5.

2 Related Works

The multifunctional heating pad developed by fuzzy-edge computations in this article offers the elderly intelligent rehabilitation. Literature [6] develops a healthcare system based on Blockchain technology; by storing the information in Blockchain to exchange patient data between different healthcare systems. The system will encrypt information and verify the completeness through Blockchain. The discussion in Literature [7] points out how easy it is for hackers to steal information maliciously through IoT; therefore, it is essential to build a security mechanism to ensure IoT data safety. For instance, many healthcare systems access patient physiological indexes through IoT and encrypt the data by Blockchain; consequently, other medical organizations can decrypt the data by Blockchain and ensure data accuracy. To prevent parallel healthcare systems from hacker attacks, literature [8] stores patient data by distributing the information in Blockchain and integrating the patient data from regional clinics and health examination centers to provide more comprehensive information. Literature [9] mentions that pacemakers need higher protection because radio waves will affect pacemaker's functions; as a result, it is necessary to find the best frequency to stop pacemakers from malfunctioning. Literature [10] stores the patient information of healthcare systems on edge devices; with the encrypted protection of edge devices, the devices will check if these data are correct. If not, the system will transmit the information to a cloud server for storing. The edge computing used in Literature [11] judges whether the IoT information is correct. If yes, the system will keep the information on the cloud; edge computing can help judge if the physiological indexes are normal. Literature [12] compresses the physiological information and transmits it to fog computing or a cloud server for storing, and the fog computing or cloud server will encrypt the data to ensure privacy.

Literature [13] primarily presents an IoT mechanism to track patient locations and physiological information. The system enables hospitals to control patient conditions; the system employs IPv6 over a low-power wireless personal area network, effectively reducing the power consumption of the IoT device and increasing the sensors' power durability. Literature [14] detects the data read from physiological monitors and judges if the patient is encountering life-threatening health conditions by edge computing; if yes, the system will alert the medical staff and effectively integrate the overall physiological information on the screen. The automatic voice disorder detection system in Literature [15] can improve speech disorders; from the research results, the system can show the spectrum distribution of each patient and analyze their vowel performance for doctors to design appropriate treatments. Finally, the sensors in Literature [16] detect brain signal conditions, checking the signals sent from the hands and feet of stroke patients during rehabilitation; the system's signals can help doctors provide appropriate rehabilitation treatments. In [17], Industry 4.0 was applied to monitor oil and gas energy and analyze anomalies in oil and gas inflow and outflow. According to [18], Industry 4.0 requires a reformation of governance because data are key elements and pillars of the processes of the organization. This study proposes a model of reference for implementing an Industry 4.0 data governance system. In [19], a new IoT architecture that employs machine learning to suppress cyber-attacks was introduced for providing reliable, secure, and real-time online monitoring for the induction motor status. This IoT architecture employs advanced machine learning technology to detect cyber-attacks and monitor motor status with high accuracy. According to [20], the operation of a construction supplier company comprises off-site and on-site production elements. Given the highly variable and unpredictable nature of on-site construction processes, rendering synchronizing supply chains to maintain construction schedules poses a challenge. Accordingly, construction supply chains are characterized by high-levels of intermediate buffers and long lead-times. In this study, concepts based on Industry 4.0 were proposed to mitigate these problems.

On the other hand, Literature [21] utilizes a robot to provide medical services; by patrolling between patients, the robot can attain older adults' physiological data and deliver the information back to the doctors for providing suitable medicines or health education. Literature [22] uses a robot to offer emergency medical treatments; when urgent situations such as sudden cardiac death happen, medical staff only has to settle the robot, and the robot will initiate an automated external defibrillator. The intelligent shirt developed in Literature [23] can monitor patients' electrocardiogram and physiological indexes, enabling patients to move around outdoors. Literature [24] utilizes a G-sensor to detect if elders have fallen; the system employs the G-sensor on mobile devices to check older adults' moving speed and their tri-axial acceleration conditions to judge if they have fallen. Literature [25] mainly constructed a drip bottle monitor system by Narrowband IoT (NB-IoT) to control the usage and notify the medical staff for renewing the medicines.

This article designs a multifunctional heating pad by fuzzy-edge computations, connecting the Bluetooth on mobile devices and the IoT development boards to control the system and set the temperature ranges in various scenarios. The designed heating circuit board makes the temperature control more stable, and the IoT development board can self-calibrate the circuit. The approach presented in our research is user-friendly, helping reduce the issue of information adaptability. Meanwhile, the cost-effective heating board can benefit the promotion of the system, making it easier to be universal.

3 The Proposed Scheme

The system model is introduced in 4.1, the categories of the fuzzy decision tree in 4.2, the design of the heating pad in 4.3, and the calibrate method of the heating pad in 4.4.

3.1 System Model

The schematic diagram is shown in Figure 1. Firstly, older adults can connect their mobile devices with the IoT development board through Bluetooth and select desired using scenario; each scenario means a specific heating range for the pad. When the system receives the command sent from the mobile device, it will signal the heating pad to increase the temperature. This study sets various temperature ranges for each use scenario by fuzzy logic, and the heating pad sets the temperatures digitally. The IoT development board will calibrate the temperatures through RS485, ensuring the heating temperatures are within the set ranges. The cost-effective IC designed in the heating pad can improve the penetration rate in the future. The multifunctional heating pad offers the elderly a tool for multiple kinds of use. Apart from maintaining appropriate heating intervals during rehabilitation, heating stability is also an important element for fulfilling users' needs. The experimental result has demonstrated that the design can achieve the above requirements, enriching the smart health goal for using heating pads among older adults.

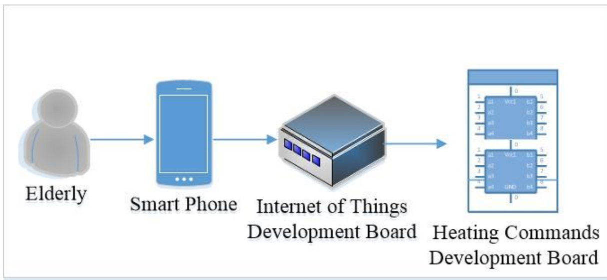

Figure 1. System illustration

3.2 The Categories of the Fuzzy Decision Tree

The research develops different categories in a fuzzy decision tree for various heating pad use scenarios, and each scenario has a specific temperature range, as shown in Figure 2. Set the types of use scenarios as $\langle V,E\rangle=\{Si_1,\dots,Si_n\}$, where V means the tree nodes, E represents the edge between nodes and Si_1 means the set scenario. Different temperature ranges are set for each scenario; for instance, rehabilitation requires the temperatures between a set range; the system should maintain the temperature within the range while operating. When the temperature is higher than the limit, the heating pad will stop increasing the temperature; on the other hand, the pad will start heating when the temperature is lower than the desired range. The fuzzy logic setting follows the Triangular Membership Function as follows:

$$\Lambda_{S_{i,j}}(x;H,C,L)=\left\{\begin{array}{l}0, x\le a\\ \dfrac{x-L}{C-L}, L\le x\le C\\ \dfrac{H-x}{H-C}, C\le x\le H\\ 0,\end{array}\right\}. \quad \textbf{(1)}$$

Where H means the upper limit of the temperature, L means the lower limit of the range, C represents the middle value of the temperature range, x shows the current temperature, and $\Lambda_{S_{i,j}}$ represents the temperature range setting in scenarios. The designed system enables elders to select suitable scenarios when using the heating pad. A specific temperature range is set in each scenario; by following Formula (1), the system can maintain the temperatures within the set ranges, achieving the expected setting temperatures.

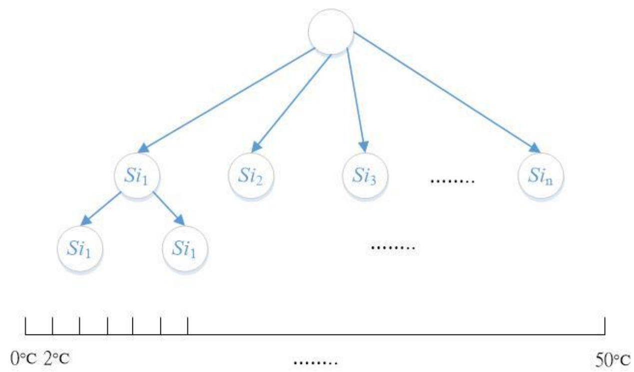

Figure 2. Fuzzy decision tree

3.3 The Design of the Heating Pad

The hardware in our system is the Max6675 IC developed by Maxim Inc., utilizing it in K-type thermocouple to be the temperature detection IC. The IC contains a 12-bit A/D converter and cold-junction compensation functions; the converter can resolve temperatures to 0.25 °C, allow readings as high as +1,024 °C, and have a supply voltage between three to five volts. For example, assume the working voltage is at 3.3 volts, the temperature error between 0 °C and 700 °C is ± 2 °C, and the error is ± 4.5 °C between 700 °C and 1,024 °C; hence, 12 bits means the resolution is 4,095, which means each bit is 0.25 °C, where the cold-junction compensation error is about ± 3 °C. Thus, to correct the internal temperature errors, the system has to take care of three parts, the temperature between 0 ℃ and 700 ℃, the temperature between 700 ℃ and 1,024 ℃, and the cold-junction compensation.

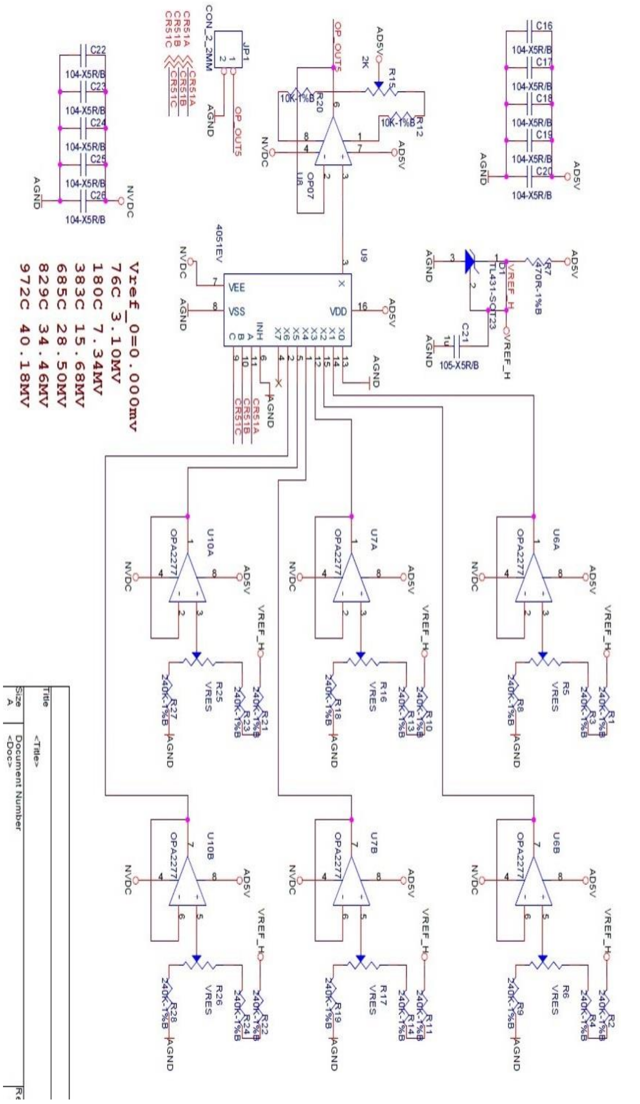

Figure 3. Circuit design diagram

The precondition of temperature correction is to have a standard source generator, an international standard specification for the K-type corresponding scale, and a corresponding table for heat terminal voltage. Assume the standard voltage source is stable without drifting; it also has to have a standard generator inside. The temperature error should be ± 0.25 ℃ at 25 ℃, which means the standard voltage resource should produce four standard voltage points; the highest and the lowest volts are for calibrating the AD linearity error while the other two standard points are for correcting the compared standard value of the middle value between 0 ℃ and 700 ℃ and 700 ℃ and 1,024 ℃. For instance, the middle value of 700 ℃ is 350 ℃, showing that 350 ℃ is the sum of the voltage difference of the temperature and the cold-junction temperature. In other words, when the thermal temperature voltage difference produces 14.000 mV, the K-type relative temperature is 343 ℃, and the cold-junction temperature is 25 ℃; thus, the read temperature range is 343 ℃ + 25 ℃ = 368 ℃, which is around the middle value of 350 ℃. Using 14.000 mV aims to show accuracy as an integer; therefore, as long as the voltage temperature is at around 350 ℃ ± 15 ℃. On the other hand, the second section is to verify the high temperature voltage between 700 ℃ and 1,024 ℃, and the high point locates at 870 ℃. Hence, assume the standard voltage output of 845℃ equals 35.11 mV and add the cold-junction temperature of 25 ℃; the temperature is 870 ℃.

The sensor of the standard temperature source measures K-type cold-junction temperatures. Set the best temperature error between 20 ℃ and 30 ℃ is within ± 0.3 ℃; the resolution should be at least 0.1 ℃. The components of DS18b20 and MCP9804 used in this article are for lowering the temperature error. The circuit design is illustrated in Figure 3.

3.4 The Calibrate Method of the Heating Pad

The IoT development board calibrates the system by COM port. The following shows the calibration and communication command process of the IoT development board through the COM port. The signal communication commands of the IoT development board are:

(1) The temperature sensor IC on the heating pad will transmit the detected value to the IoT development board, and the resolution of the temperature is the first digit to the right of the decimal point.

(2) The IoT development board sends a 0 V voltage value; the heating pad will output 0.00 mV voltage and wait for 10 ms until the signal is stable to send the data back to the IoT development board.

(3) The IoT development board sends a 14 V voltage value; the heating pad will output 14.00 mV voltage and wait for 10 ms until the signal is stable to send the data back to the IoT development board.

If both voltages are shown correctly, meaning the calibration is complete.

Our study compares voltage and temperature by a formula because the hardware, Max6675, shows a linear relationship between its lowest and highest points; therefore, we can develop Formula 2 to simplify the calibrate points that transfer the read voltages to temperatures. This step saves the workload of reading each interval frequently, enhancing the calibration speed on the IoT development board, and the formula is illustrated below:

$$Y = M * X + B. \quad \textbf{(2)}$$

$$M = (Y_2 - Y_1)/(X_2 - X_1). \quad \textbf{(3)}$$

In the formula, Y means the temperature value, X represents the voltage value, and M is the error of the two tests. To derive the unknown B, we then modify Formula 2 as below:

$$B = Y - M * X . \quad \textbf{(4)}$$

The IoT CPU can read the relative temperature and correspond the value with the input voltage; the voltage signal derived from the linear equation in Formula 3 means the normal value of temperature pressure difference of the thermal point produced by the K-type thermocouple. Next, from Formula 4, we can obtain the actual temperature by the relationship between the standard temperature difference and the standard voltage. The circuit design is illustrated in Figure 4.

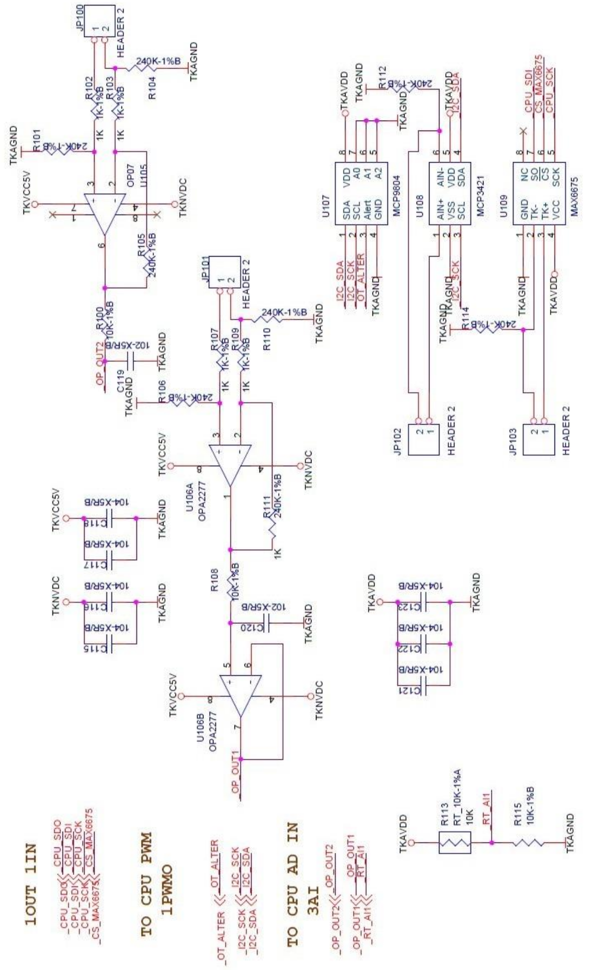

Figure 4. The calibrate method of the design diagram

Figure 5. The smart phone screen

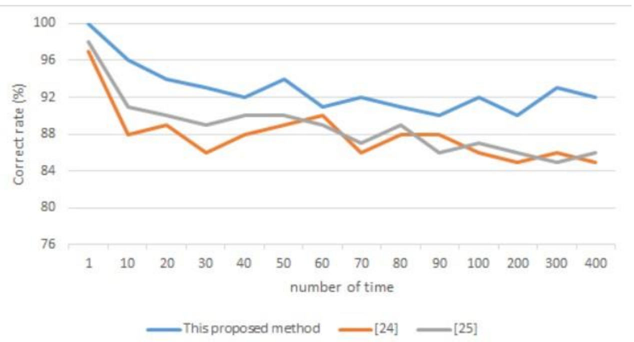

Figure 6. The performance analysis of the fuzzy decision tree

4 Experiment Results

This article develops a multifunctional heating pad by integrating various heating functions through fuzzy-edge computations, offering the elderly more services. Figure 5 demonstrates the actual usage by connecting the heating pad through Bluetooth. From the screen on the mobile device, the user-friendly interface simplifies the operation for older adults, reducing the issue of information adaptability. Additionally, using Bluetooth to operate the heating pad can avoid high power consumption on the mobile device. Figure 6 shows the performance analysis of the fuzzy decision tree. The experimental result proves that the scenario setting can successfully maintain the temperature within set ranges. Table 1 lists the hardware and software tools in this research; moreover, the IC used in the system is cost-effective, which can benefit the future penetration. On the other hand, the designed heating pad possesses a self-calibration function by operating three different ICs. Table 2 proves that the calibrated temperatures of our heating pad have higher stability than other products; outputting voltages through the IoT development board to calibrate temperatures can ensure temperature accuracy. Figure 7 shows Heating IC Board.

Table 1. Development tools

Hardware development tools	Software development tools
Raspberry Pi	Windows 10
Bluetooth	C programming language
Smart phone	Android studio
Heating IC board	
G-sensor	

Table 2. Effectiveness analysis

The calibration IC of the developed system / Black temperature corrector	IC 1	IC 2
50 °C	53 °C	52 °C
100 °C	103 °C	102 °C
150 °C	153 °C	152 °C
200 °C	202 °C	201 °C
250 °C	251 °C	250 °C
300 °C	301 °C	300 °C
350 °C	352 °C	351 °C
400 °C	402 °C	402 °C
450 °C	454 °C	453 °C
500 °C	506 °C	504 °C

Figure 7. The heating IC board

5 Conclusion

Today, many countries are becoming aged societies; many older adults need rehabilitation or relevant healthcare, such as arm and leg care. Considering the differences among various types of rehabilitation or the care of arms and legs, the elderly usually have to buy many heating pads for different use. Our research develops a multifunctional heating pad by fuzzy-edge computations, enabling older adults to select use scenarios on their mobile devices. We have designed the heating circuit board, chosen cost-effective ICs for temperature control, and utilized an IoT development board to calibrate the temperatures and enhance accuracy. The experimental result has proved the feasibility of the design; furthermore, the design genuinely achieves the desired performance and calibration of the circuit board, making the heating pad have multiple functions and increasing heating stability. Thus, the elderly can use the suggested system to reach the goal of smart long-term care. The experiment results indicate that the proposed system can: (1) calibrate and test heating pads using digital voltage; (2) determine the various temperature ranges for each heating pad use scenario using Fuzzy logic; and (3) achieve the same level of heating stability of high-cost chips using low-cost chips.

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