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Research Article

Internet of Things Information System and Clothing Computer Renderings Digital Art

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The Internet of Things (IoT) is developing rapidly and is integrated into all aspects of life. Clothing is an indispensable part of meeting the basic needs of the human body, and its traditional functions include warmth, health care, decoration, and beauty. While as a special type of clothing that integrates multidisciplinary technology, smart clothing has a wider scope of action. With the update and iteration of science and technology, many technologies that originally belonged to nonclothing disciplines have also been applied to the clothing field. Accordingly, for the special clothing category of smart clothing based on embedded system, a set of design process that can be used for this category of smart clothing was proposed. Using this design process, an intelligent fire suit that can be used to protect the personal safety of firefighters and assist firefighters to cooperate was designed and implemented. Starting from the daily working environment and working characteristics of firefighters, this firefighting obedience analyzed the design points from the perspectives of clothing comfort, warning, toxic and harmful gas monitoring, and firefighters' cooperation. After testing, the test results of the outer layer fabric, waterproof and moisture-permeable layer fabric, and thermal insulation and comfort layer fabric of the fire suit all met the corresponding national standards; the monitoring sensitivity of harmful gases was high; it could achieve a "good" warning effect in a dark environment. Compared with ordinary firefighting suits, it was more comfortable under the subjective and objective test and scored 0.669 higher under the seven-point scale; its interactive performance met the actual needs. The clothing has complete functions and a complete feedback mechanism, which has a positive effect on ensuring the personal safety of firefighters.

1. Introduction

With the development of science and technology, smart clothing has gradually developed from the initial concept product to the direction of physical production. The initial smart clothing research focused on the field of military security. Since the late 1990s, the research on smart clothing has gradually developed into the field of health care, among which the most prominent is the smart clothing for body temperature monitoring. In the 21st century, smart clothing has truly entered the life of ordinary consumers, and this stage is also the initial stage of research on smart clothing. At present, the research on smart clothing is limited to the design and development of a specific category of smart clothing, and the design of clothing also focuses on functional design and implementation and involves less about the overall design process and design concepts of clothing. This paper mainly studied and discussed the design of smart clothing based on embedded system. The design theory and specific case design and production of this type of smart clothing were carried out from two aspects of embedded system and smart clothing, which provide ideas and case guidance for future smart clothing design based on embedded technology.

Computer renderings are an expression of a design language. Clothing transfer is a complex computer vision problem; Zhang et al. proposed a novel attention fusion model based on semantic features for clothing transfer, which can provide fine synthesis, high global consistency, and illusion of image authenticity [1]. With the rapid development of computer network technology, digital computer technology has been widely put into practical use. Tang et al.'s analysis was based on the application of digital technology in architectural design and computer analysis of works of art [2]. Suarez et al. proposed a method to render pen and ink shadows in real time in large scenes, in which goal is to come up with a solution that starts with a 3D model containing realistic textures and materials to generate shaded renderings [3]. Contracted by Carnegie Mellon University with the National Energy Technology Laboratory and co-funded by the Northeast Gas Association, Andreazzi C has completed the overall system development, field testing, and magnetic leak sensor evaluation program for the next-generation Explorer-II (X–II) robotic nondestructive evaluation and primary visual gas detection platform [4]. The above scholars have used computer renderings well, but they have not fully explained the experimental process.

IoT is the Internet where everything is connected. With regard to the growing number of applications of IoT, Razzaque MA believed that these proposals for the future envisaged by IoT focus on wireless sensor networks (WSN) [5]. IoT, a dynamic global information network of Internet-connected objects, is becoming an integral part of the Internet of the future. In this issue, Perera et al. studied more than 100 smart IoT solutions on the market and analyzed the technologies, functions, and applications used [6]. To reduce the amount of data collected by IoT and improve the processing speed of big data, Xue et al. proposed a sampling scheme for compressed sensing. In order to solve the problem of high computational complexity of the compressed sensing algorithm, Xue et al. used the multiobjective particle family optimization algorithm to improve the search term of the gradient sparse reconstruction algorithm (GPSR-BB), which effectively improved the reconstruction accuracy of the algorithm [7]. The Internet grew out of revolutionary advances in electronics, telecommunications, information technology, devices, and applications. It started out as the Internet connecting people, but by 2008, it was connecting more things than people. Collier saw this exponential growth happening primarily as centralized monitoring and control of the IoT. For various reasons, this traditional approach to networking proved to be infeasible [8]. Although the above scholars have described the usefulness of IoT well, they have not specifically explained a certain aspect.

This study proposed a smart clothing design process based on embedded technology and proposed new concepts and references for the design of smart clothing. The innovation of this study: from the perspective of firefighters' personal safety and work needs, combining design theory and design practice and using this design theory, the design of intelligent fire suits can be extended to other types of intelligent clothing, which provides a discussion idea for the standardization and modularization of smart clothing design.

2. Wireless Sensor Technology Based on IoT Technology

IoT is a new generation of Internet where things are connected and interconnected, and it is also the development direction of industrial informatization in the new era [9]. With the transformation and development of a new round of Industry 4.0 technology, it has effectively promoted the informatization and intelligent development of social production methods and people's lifestyles, making the allocation of social resources more reasonable and production efficiency more efficient, as shown in Figure 1.

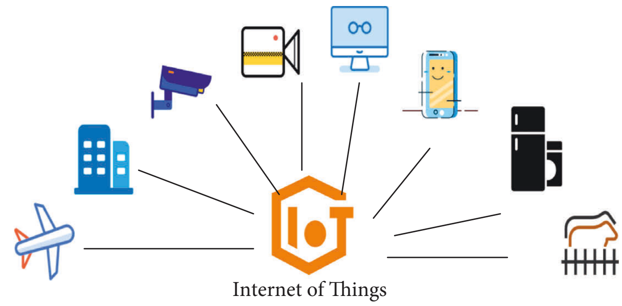


Figure 1: IoT.

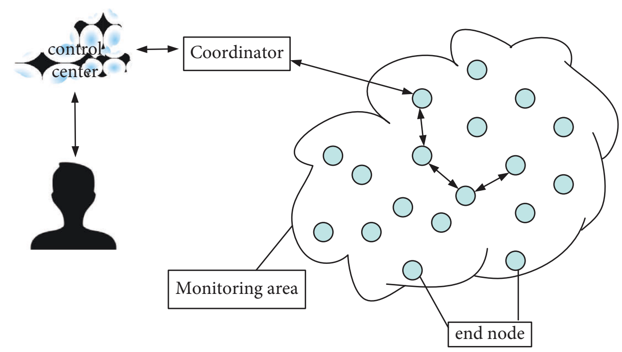


Figure 2: Wireless sensor network architecture.

Wireless sensor network is a network system composed of a large number of dynamic or static nodes deployed in the monitoring area through wireless communication protocols and is an important supporting technology of IoT. As shown in Figure 2, in a large-scale intelligent unmanned storage system, the wireless sensor network can realize the real-time monitoring of the storage environment, goods, and equipment, while the mobile intelligent body can complete the tasks of sorting, handling, stacking, and so on. The combination of the two has become a widespread IoT scenario, which can promote the intelligent and safe operation of the warehousing system.

2.1. Prediction-Based Potential Field Calculation

2.1.1. Dangerous Potential Field Prediction. Generally speaking, in dangerous scenarios, the environmental information monitored by wireless sensor network nodes is based on time-varying data (such as temperature and gas concentration), and the data changes follow certain rules and are time-dependent. Given a smoothing coefficient $\beta \in (0, 1)$, for the data $[y_i]$ of sensor node t_i in the time period $[0, 1]$,

$$\begin{cases} r_s^{(1)} = \beta y_s + (1-\beta) r_{s-1}^{(1)}, \\ r_s^{(2)} = \beta r_s^{(1)} + (1-\beta) r_{s-1}^{(2)}, \\ r_s^{(3)} = \beta r_s^{(2)} + (1-\beta) r_{s-1}^{(3)}. \end{cases} \tag{1}$$

Predict the value y_{s+T} for T periods in the future:

$$y_{s+T} = C_T + D_T T + E_T T^2. \tag{2}$$

Among them,

$$\begin{cases} C_T = 3r_s^{(1)} - 3r_s^{(2)} + r_s^{(3)}, \\ D_T = \dfrac{\beta}{2(1-\beta)^2}\left[(6-5\beta)r_s^{(1)} - 2(5-4\beta)r_s^{(2)} + (4-3\beta)r_s^{(3)}\right], \\ E_T = \dfrac{\beta^2}{2(1-\beta)^2}\left[r_s^{(1)} - 2r_s^{(2)} + r_s^{(3)}\right]. \end{cases} \tag{3}$$

2.1.2. Establishment of Potential Field. In the wireless sensor network, after node t_i receives the navigation request sent by the navigation user, it will calculate the node's risk prediction value $g_f(i)$ according to the user's arrival time. Define the dangerous potential field of node t_i as $d_f(i)$ and the distance potential field as $d_r(i)$; then, there are

$$\begin{aligned} d_f(i) &= \frac{g_f(i)}{g_{\text{threshold}}}, \\ d_r(i) &= \frac{g_r(i)}{g_{\max}}, \end{aligned} \tag{4}$$

where $g_{\text{threshold}}$ is the danger threshold and $g_{\max}$ is the maximum distance.

The total potential field of the node is composed of the danger potential field $d_f(i)$ and the distance potential field $d_r(i)$ according to a certain weight. Define the total potential field of node t_i at a certain moment as $d(i)$; then, there are

$$F(i) = \alpha F_f(i) + (1-\alpha) F_r(i). \tag{5}$$

2.2. Prediction-Based Algorithms. The origin t_i (usually the user by default) starts to send navigation request information to its neighbor node $(M)t_i$ [10]. After the neighbor node t_j receives the navigation request, it estimates the user's arrival time t according to its distance h from the starting point:

$$t = \frac{h}{v}. \tag{6}$$

In formula (7), s is the speed of the navigating user. Based on the arrival time t, calculate the forecast period K:

$$K = \left[\frac{t}{K_f}\right], \tag{7}$$

where K_f is the monitoring period of the node dataset $\{y_r\}$. Then, use the cubic exponential smoothing model to predict its risk value, assuming that the minimum total potential field value fed back by all neighbor nodes $(M)t_i$ is $D_{\min}$:

$$D_{\min} = \min\left\{D(s), t_j \in M(t_i)\right\}. \tag{8}$$

Assuming that the observed dataset $Y = \{y, i = 1, 2, 3, \ldots, k\}$ of k nodes in a space is known, to find the observed value of the $k+1$th unknown node in the space, the mathematical model is as

$$y_{k+1} = \frac{\sum_{j=1}^{k} y_j / f_j^p}{\sum_{j=1}^{k} 1/f_j^p}. \tag{9}$$

2.3. Evaluation Indicators. In the experiment, the following indicators are used to measure the performance of the prediction-based wireless sensor network algorithm.

2.3.1. Average Path Length

$$k_{\text{avg}} = \frac{1}{n}\sum_{j=1}^{n} k_j, \tag{10}$$

where k_j is the length of the navigation path corresponding to user j and n is the number of navigation users.

2.3.2. The Maximum Hazard Intensity of the Average Path. For a path containing m landmark nodes, it is calculated as

$$G_{\max} = \max\left(g_f(j)\right), j = 1, 2, 3, \ldots, m. \tag{11}$$

2.3.3. Average Path Hazard Value. In emergencies, such as indoor fires and toxic gas leaks, the degree of danger is related to the level of danger and the length of time; the user is exposed to in the environment; then, define the hazard value between two signpost nodes as

$$F_{j,i} = \frac{r_{ji}\left(g_f(j) + g_f(i)\right)}{2}, \tag{12}$$

where r_{ji} is the time required for the user to go from node t_i to node t_j and $g_f(j)$ and $g_f(i)$ are the risk values of the user at nodes t_i and t_j, respectively. Define the path risk as

$$F = \sum_{i=1}^{m-1} F_{i,i+1}, \tag{13}$$

where i is the serial number of the road sign node and m is the total number of nodes in the path, that is,

$$F_{\text{avg}} = \frac{1}{n}\sum_{j=1}^{n} F_j. \tag{14}$$

2.4. Local Algorithm of Mobile Agent Based on Sensor Network. Suppose there are three known WSN nodes D, E, and F, whose coordinates are (a_0, b_0), (a_1, b_1), and (a_2, b_2), respectively, as shown in formula (16):

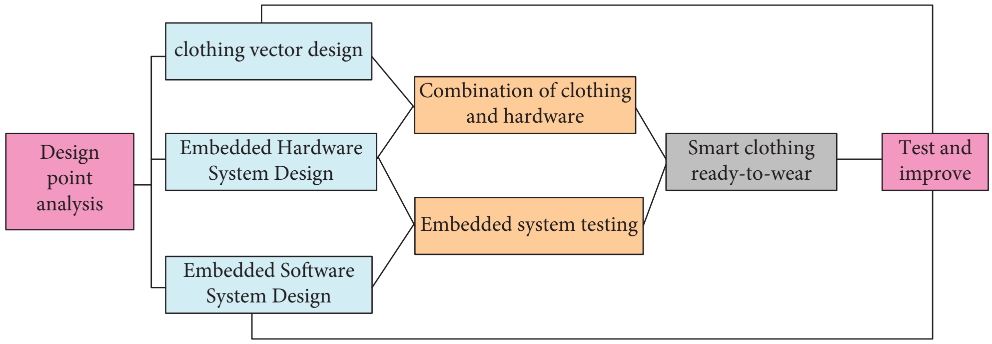


FIGURE 3: Smart clothing design process based on embedded system.

$$\begin{cases} \sqrt{(a_i - a_0)^2 + (b_i - b_0)^2} = h_0, \\ \sqrt{(a_i - a_1)^2 + (b_i - b_1)^2} = h_1, \\ \sqrt{(a_i - a_2)^2 + (b_i - b_2)^2} = h_2. \end{cases} \quad (15)$$

Then, the coordinates of node t_i can be obtained as

$$\begin{bmatrix} a \\ b_i \end{bmatrix} = \begin{bmatrix} 2(a_0 - a_2) 2(b_0 - b_2) \\ 2(a_1 - a_2) 2(b_1 - b_2) \end{bmatrix}^{-1} \begin{bmatrix} a_0^2 - a_2^2 + b_0^2 - b_2^2 + h_2^2 - h_0^2 \\ a_1^2 - a_2^2 + b_1^2 - b_2^2 + h_2^2 - h_1^2 \end{bmatrix}. \quad (16)$$

Then, the relationship between unknown node t_0 and m nodes with known coordinates satisfies formula (18):

$$\begin{cases} \sqrt{(a - a_1)^2 + (b - b_1)^2} = h_1, \\ \sqrt{(a - a_2)^2 + (b - b_2)^2} = h_2, \\ \sqrt{(a - a_3)^2 + (b - b_3)^2} = h_3, \\ \cdots \\ \sqrt{(a - a_m)^2 + (b - b_m)^2} = h_m. \end{cases} \quad (17)$$

Transform the following:

$$\begin{cases} a_1^2 - a_m^2 - 2(a_1 - a_m)a + b_1^2 - b_m^2 - 2(b_1 - b_m)b = h_1^2 - h_m^2, \\ a_{m-1}^2 - a_m^2 - 2(a_{m-1} - a_m)a + b_{m-1}^2 - b_m^2 - 2(b_{m-1} - b_m)b = h_{m-1}^2 - h_m^2. \end{cases} \quad (18)$$

Formula (19) can be expressed as $\mathrm{CX} = d$ by a system of linear functions; among them,

$$\begin{cases} C = \begin{bmatrix} 2(a_1 - a_m) 2(b_1 - b_m) \\ \cdots \\ 2(a_{m-1} - a_m) 2(b_{m-1} - b_m) \end{bmatrix}, \\ X = \begin{bmatrix} a \\ b \end{bmatrix}, \\ d = \begin{bmatrix} a_1^2 - a_m^2 + b_1^2 - b_m^2 + h_m^2 - h_1^2 \\ a_{m-1}^2 - a_m^2 + b_{m-1}^2 - b_m^2 + h_m^2 - h_{m-1}^2 \end{bmatrix}. \end{cases} \quad (19)$$

3. Intelligent Clothing Design Based on Embedded System

3.1. Intelligent Clothing Design Process Based on Embedded System. Figure 3 is a smart clothing design process based on an embedded system, and relevant tests and improvements are carried out based on the ready-made smart clothing.

3.1.1. Analysis of the Main Points of Clothing Design. Clothing can be divided into multiple categories according to different demand objects and application scenarios. The design and development of smart clothing should also be analyzed according to specific needs, and clothing should be designed and produced according to specific needs.

(1) Application Scenario Analysis. According to the specific usage scenarios, the design focus of smart clothing is also different [11]. Users' functional requirements for smart clothing often need to be substituted into specific usage scenarios for analysis, rather than just designed from the perspective of functional requirements. Analysis from the application scene can make a perfect and detailed analysis of the design points of smart clothing.

(2) Confirmation of Clothing Design Points. The design points of smart clothing are confirmed according to the requirements of the demand object and the characteristics of the application scene. The confirmation of the design points should follow the order of function importance, and the conflicting design points should be selected according to their importance; the similar designs can be functionally integrated to reduce the workload.

3.1.2. Garment Carrier Design. The clothing carrier design is the design of the clothing itself in addition to the embedded system in the intelligent clothing system.

(1) Fabric Selection. The selection of fabrics for clothing should be selected according to specific user needs and usage scenarios; the function, safety and environmental protection, comfort, aesthetics, and other factors should be considered when choosing. Therefore, the selection of fabrics for smart clothing should often be based on the specific selection of different categories and parts according to relevant needs.

(2) Clothing Structure Design. Clothing structure design not only improves the overall aesthetics and comfort of clothing but also affects the stability of the embedded system in smart clothing. Through the special clothing structure design, on the premise of meeting the user's original comfort and functional requirements for clothing, it can also provide relevant support in the combination of embedded hardware and clothing [12].

3.2. Example of Smart Clothing Design Based on Embedded System. As a kind of special work clothing, firefighting clothing has high requirements on the characteristics of flame retardant and wear resistance of the clothing carrier and has corresponding national standards for regulations and constraints. Therefore, when designing, it is necessary to pay more attention to the performance requirements of the clothing body and to carry out functional design under the premise of meeting the requirements of the clothing carrier.

3.2.1. Analysis of the Main Points of Clothing Design. Firefighters are also responsible for firefighting and rescue work. From the point of view of safety protection and assisting work, this section intended to design a new type of firefighting suit with multiple functions, which is functionally designed based on the field work environment of firefighters.

(1) Analysis of Firefighters Working Scene. The working scenes of firefighters mainly include fire sites, toxic and harmful gas gathering places, dust gathering places, and small rescue places, among which fire sites are the most common. The fire environment is complex and harsh, and its characteristics include high temperature and low visibility, which have certain requirements for the flame retardancy and conspicuousness of firefighting clothing. Explosive gas or dust gathering places will explode when encountering electric sparks, which has certain requirements for the electronic equipment carried by firefighters. For the rescue of small places, firefighters cannot carry large rescue equipment or intercom equipment, which requires higher coordination and cooperation among firefighters. At the same time, due to the unpredictability of rescue times, firefighters need to be prepared to work for long hours, which also require lightness and comfort of firefighting suits.

(2) Design Points. Because firefighters often need to face the fire scene and other places with high risk factors, it is particularly important to design a firefighting uniform that meets the actual needs of firefighters. According to the design requirements of firefighting suits, this design expounded the design scheme of the new firefighting suits from four aspects: protective performance, comfort and lightness, safety, and interactive functions.

(3) Basic Performance. The most important function of firefighting clothing is to protect firefighters from various types of injuries, and it needs to protect the personal safety of firefighters. Its basic performance can be divided into protective performance, wearing warning performance, and safety performance. Considering the protective performance of fire protection clothing, fire protection clothing must have flame retardancy and heat insulation. Because firefighters work day and night, there may also be smoke, dust, and other substances that affect visibility in the workplace; in order to facilitate the normal operation of firefighters and carry out rescue work, the clothing needs to be recognizable [13]. Concentration detection is required for the explosive gas methane, propane, and toxic gas carbon monoxide that often appear in the fire field. However, the fire environment is complex and may be accompanied by unfavorable factors such as thick smoke. Therefore, from this perspective, it is necessary to locate and monitor firefighters.

(4) Interactive Performance. Existing firefighting uniforms focus on single personal protection, and the research on army cooperation and firefighters' psychological safety is relatively lacking. From the perspective of safety management and troop overall planning, in order to facilitate the coordination and cooperation between firefighters, firefighting clothing should have an interactive function to meet the real-time communication needs of the wearer.

(5) Comfort. Firefighters work long hours, intensely, and often face the fire. In the high-temperature environment of the fire site, there are also high requirements for the thermal and humidity comfort of clothing. Therefore, under the premise of satisfying the flame retardancy and thermal insulation of clothing, it is necessary to improve the wearing comfort and lightness of clothing as much as possible.

(6) Design Research Framework. The functional design was designed and implemented from four aspects: toxic and harmful gas monitoring, positioning monitoring, interactive function, and wireless transmission, so as to achieve the functions of voice interaction, real-time alarm, and web page display. In the test stage, the overall performance of the new fire suit was tested and evaluated from five aspects: clothing protection performance, clothing comfort, clothing conspicuousness, gas monitoring function, and data interaction performance [14].

3.2.2. Garment Carrier Design. The comfort of firefighters' work is directly related to the comfort of their clothing. Based on its special working environment, on the premise of taking into account the breathability and heat and humidity comfort of firefighting clothing, attention should be paid to the flame retardancy and wear resistance of clothing.

Figure 4: Structure diagram of the new fire suit.

(1) Clothing Structure Design. Figure 4 is a structural diagram of the new fire suit. In order to facilitate the operation, the overall structure of the new firefighting suit adopts a split design, and the structure is divided into an outer layer, a waterproof and moisture-permeable layer, and a thermal insulation and comfort layer.

The collar of the shirt can be adjusted according to the needs, and the cuffs and the feet can be adjusted loosely, as shown in Figure 4(a). In order to improve wearing comfort, this fire suit installs a detachable aerogel felt on the back and front of the heat-insulating comfort layer fabric, as shown in Figure 4(b). The aerogel felt is to attach the nanoscale aerogel to the flexible substrate of silica through a special process. Due to the good flame retardancy of the silica matrix, the thermal conductivity of the aerogel felt is extremely low, and the heat-resistant temperature can reach 650°C. The sponge-like or foam-like porous structure of aerogel itself can store still air, which can effectively improve the thermal insulation performance of clothing. Considering the safety of the operation, the trousers adopt a relatively stable strap design, and at the same time, the same elastic band as the cuff is set at the foot opening. To improve wearing comfort, install removable aerogel felt over the insulated comfort layer fabric at the knees of the fire suit trousers.

(2) Fabric Selection. Fire-fighting clothing has higher requirements on the outer fabric, and it needs to have flame retardant, wear-resistant, anti-static, and other properties. In this design, the outer fabric is a new type of anti-static aramid fabric, which is composed of 2% silver fiber and 98% aramid fiber. The waterproof and breathable layer fabric needs to have the effect of fast perspiration and moisture conduction; this part of the fabric is composed of 20% aramid 1414, 80% aramid 1313, and PTFE (polytetrafluoroethylene) film.

The thermal insulation and comfort layer fabric directly touches the skin, which requires a combination of flame retardant performance and comfort. This part of the fabric is composed of stitched aramid base fabric and aramid thermal insulation felt.

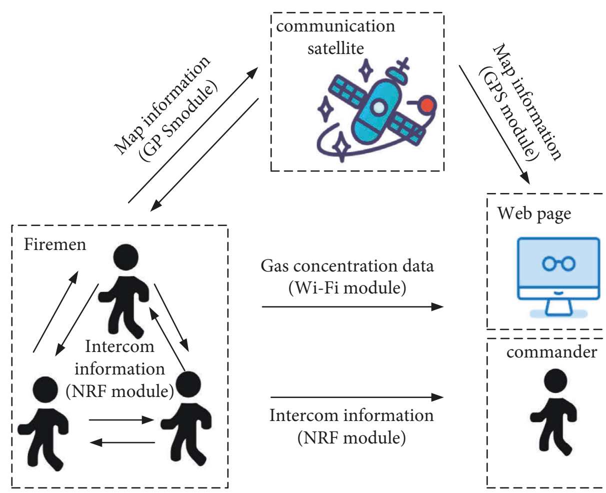


Figure 5: Wireless body area network design.

Figure 6: Hardware placement.

Table 1: Fabric performance test results.

Numbering	Vertical		Weft		Breaking strength (N)		Fabric combination TPP value
	Afterburning time (s)	Damaged length (mm)	Afterburning time (s)	Damaged length (mm)	Vertical	Weft	
A	0	5.8	0	5.6	1733.2	1543.2	
B	—	—	—	—	—	—	32
C	—	—	—	—	—	—	
Standard requirement	≤2	≤100	≤2	≤100	≥650	≥650	≥29

(3) Design of Warning Module. Since firefighters work day and night, the workplace also includes places with high dust concentration and low visibility. In order to facilitate the normal operation of firefighters and carry out rescue work, the clothing needs to be recognizable [15].

3.3. Embedded Software System Design

3.3.1. Working Principle. The wireless body area network in this design mainly includes NRF Module, GPS Module, and Wi-Fi Module. The NRF module is mainly used for voice communication between firefighters; the GPS module is mainly used for the transmission of positioning information between firefighters; the Wi-Fi module is mainly used for data transmission between firefighters and web pages, as shown in Figure 5.

When firefighters are working, the gas sensor in the fire suit system will monitor the relevant gas concentration in the environment and feed it back to the Arduino processor in the form of a digital signal. The processor determines whether the number exceeds a threshold and controls the state of the associated hardware accordingly. The GPS module will collect the positioning information of firefighters and feed it back to the display in the clothing system so that firefighters can view the location information of themselves and their teammates. The NRF module can support barrier-free voice communication between commanders and firefighters, which facilitates smooth work. The Wi-Fi module can be used to transmit the gas monitoring data and the positioning information of each firefighter to the computer web page of the command center, which is convenient for the unified dispatch of the command center.

3.3.2. Combination Design of Clothing and Hardware. Considering the actual wearing comfort, convenience and washability of the clothing for firefighters, the relevant hardware in this design adopted detachable design. In order to monitor the concentration of toxic and harmful gases in the flowing air, the gas sensor and the processor are placed on the front chest. The KY-038 module responsible for the intercom function and the buzzer are placed on the collar and the left/right ear of the mask respectively. In order to view the position of yourself and teammates on the map, the LCD screen is placed on the left glove. Because firefighters often need to face the fire, in order to ensure the stability and safety of the hardware system, the rest of the hardware modules are placed on the back of the jacket, specifically, as shown in Figure 6.

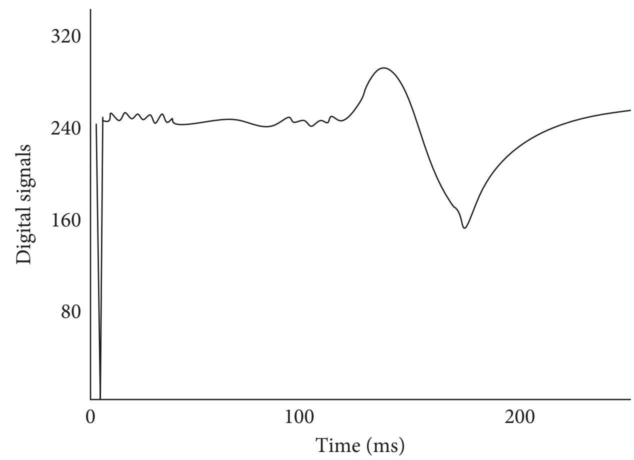


Figure 7: Serial plotter changes.

Table 2: Apparel conspicuous score.

Numbering	Light intensity (*lx*)	The average score
A	0.5	3.6
B	1	3.8
C	5	3.9

3.3.3. Clothing Testing and Improvement. In order to verify whether the comfort of the new fire suit has been improved and to test the safety monitoring function of the clothing, it is necessary to design experiments to test the above contents. The test for the new fire suit is divided into clothing safety test and clothing comfort test.

(1) Security Testing. According to the main points of the above functional design, the safety test of the new firefighting clothing can be divided into three aspects: the protective performance test of the clothing, the test of the harmful gas monitoring function, and the test of the conspicuousness of the clothing.

(2) Clothing Protection Performance Test. The test results of the fabric properties are shown in Table 1. Among them, the samples numbered A, B, and C are the outer fabric, the waterproof and moisture-permeable layer fabric, and the

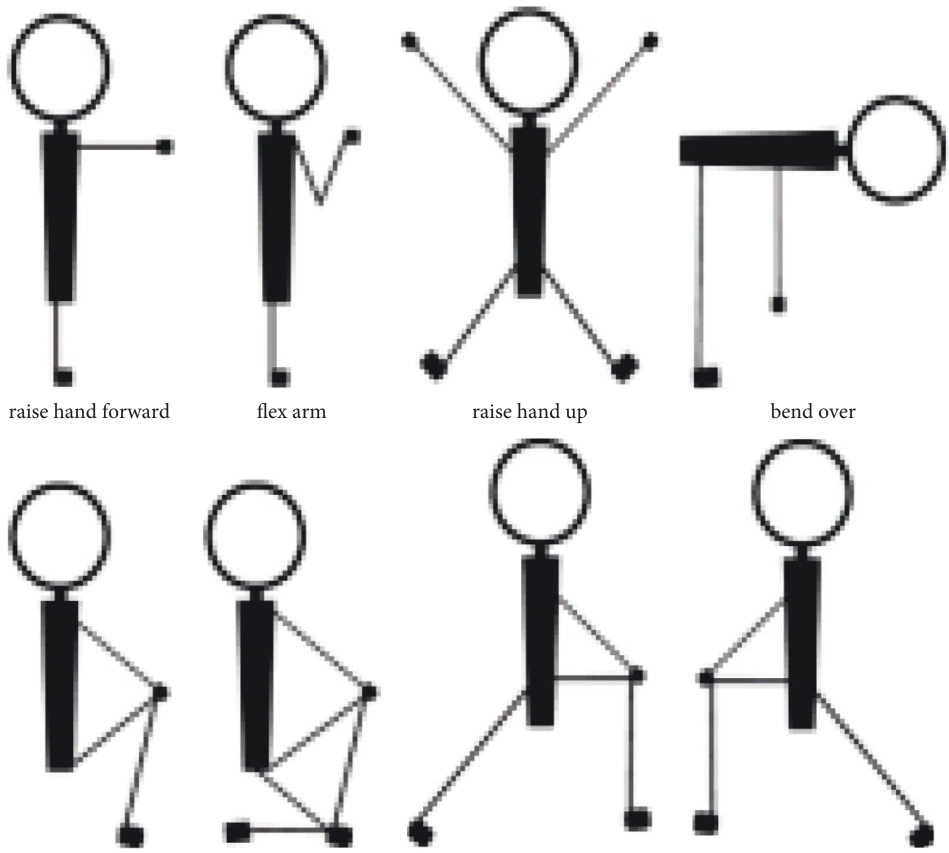


Figure 8: Schematic diagram of gymnastics movements.

thermal insulation and comfort layer fabric, respectively. The test results are in line with the corresponding national standards.

(3) Harmful Gas Monitoring Function Test. After the adjustment time, inject the corresponding gas, the digital signal rises sharply, and the buzzer starts to alarm; after the gas injection is stopped, the digital signal gradually becomes smaller, and after a period of time, the digital signal is lower than the threshold, and the buzzer stops the alarm. Its changes are shown in Figure 7.

(4) Clothing Eye-Catching Test. In order to simulate the dark environment that firefighters may encounter in their daily work, 10 people were selected for this test to evaluate firefighting suits. The results are shown in Table 2.

(5) Clothing Comfort Test. In order to investigate whether the comfort of the new fire suits is improved compared with ordinary fire suits, this study designed a clothing comfort test for the new fire suits and ordinary fire suits. The test is divided into objective evaluation and subjective evaluation. In the objective evaluation test, the relevant performance of clothing is judged by measuring the data of temperature and humidity on the skin surface [16]. Subjective evaluation is based on objective evaluation, and there are additional evaluation indicators for clothing thermal sensation and overall comfort. The test finally compared the results of the subjective and objective evaluations to test the consistency of the subjective and objective evaluations.

(6) Objective Evaluation of Comfort

(7) Objective Evaluation of Experimental Design. In order to simulate the climatic environment of high temperature and high humidity in the fire field, the relevant parameters of the artificial climate chamber are set as the temperature of 35°C, the humidity of 65%, and the wind speed below 0.1 m/s [17]. At the same time, in order to ensure the consistency of the relevant conditions of the two garments, the improved firefighting suit and the ordinary firefighting suit were uniformly washed and dried before the experiment and placed in a climate room for 24 hours in advance.

In order to reflect the characteristics that the work intensity of firefighters increases with time during daily work and to understand the relevant characteristics of clothing when firefighters are resting, do six gymnastics according to the designed movements. The design of gymnastics movements is organized according to the daily activities of firefighters. It is mainly divided into forward extension, elbow bending, lifting, bending over, squatting, kneeling on one knee, and front lunge and back lunge. Specifically, as shown in Figure 8, the time is 10 minutes, and the fifth stage is 10 minutes of sitting [18].

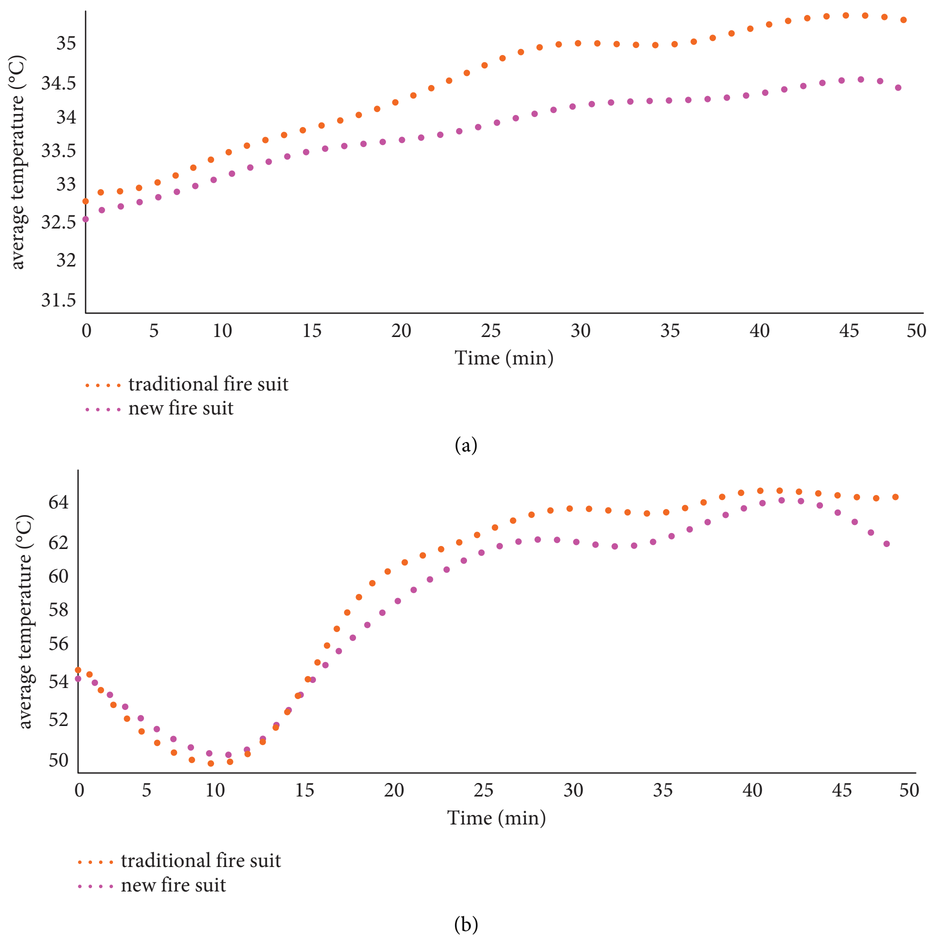


Figure 9: Objective evaluation data of comfort. (a) Sitting stage. (b) Slow walking stage.

Before the experiment starts, the test subjects need to enter the climate chamber 30 minutes in advance to adapt to the environment. The experimental process is the same as the subjective evaluation experiment, but the data are recorded every second. The experimental instrument used MSR145 temperature and humidity sensor to record the temperature and humidity data of the subject's clothing environment.

(8) Objectively Evaluate the Experimental Results. Figure 9(a) shows that, during the test, in the sitting stage, the average temperature of the two garments is not much different, but in the jogging stage, the temperature difference between the two garments increases with the increase of time and exercise intensity. In the fourth stage, the test subjects began to rest, and the temperature of the clothing dropped, and the temperature of the modified fire suit fell faster.

Figure 9(b) shows the variation of the average value of skin moisture on the armpits, front chest, back, thighs, and knees of 10 tested persons over time during the test; it can be seen that, in the stage of sitting still and walking slowly, the average humidity in the clothes of the two garments was not much different, and the change tended to be peaceful. However, as the exercise time becomes longer and the exercise intensity increases, the average humidity in the clothes wearing ordinary fire suits rose faster than the average humidity in the new fire suits. In the fourth stage, the humidity of the new fire suits decreased significantly faster than that of ordinary fire suits, which indicated that the new fire suits had better hygroscopicity and moisture dissipation [19].

(9) Subjective Evaluation of Comfort

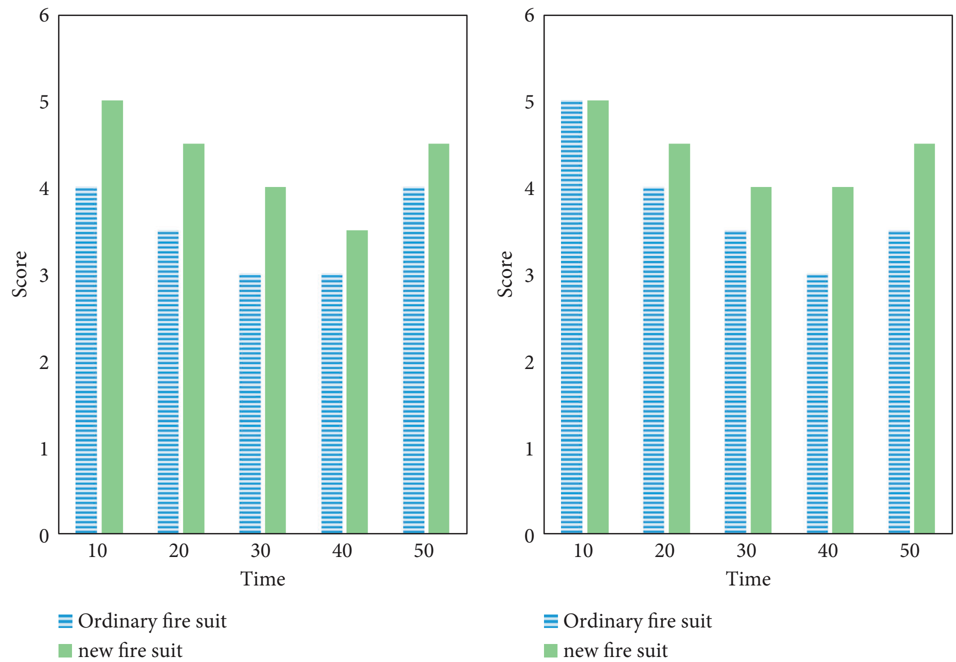
(10) Subjective Comfort Index Confirmation. The questionnaire is formulated according to the classification of clothing comfort, and by listing the comfort indicators and allowing the subjects to select them, the firefighters' attention to different clothing comfort indicators can be determined [20].

Fifty professional firefighters from a city's fire brigade were selected to conduct a questionnaire survey to determine the comfort index. The age, height, and weight of the 50 subjects ($M \pm SD$) were (25.9 ± 3.1) years, (179.1 ± 5.5) cm, and (79.6 ± 7.3) kg, respectively. Before the experiment, the subjects were informed of the relevant requirements and precautions of the questionnaire, and the subjects determined which aspects of clothing comfort they paid more attention to by selecting the variable indicators in the questionnaire.

The results of the questionnaire survey showed that, in the evaluation of clothing comfort, heat, wetness, stuffiness, stickiness, heaviness, restricted movement, hardness, and tightness were the most frequently selected indicators by firefighters.

Table 3: Fritz seven-level semantic difference scale.

Ruler feature	Sensory characteristics	Ruler feature	Sensory characteristics
1	Excellent	4	Moderate
2	Very good	5	Not too good
3	Better	6	Very bad



(a) (b)

Figure 10: Subjective evaluation results. (a) Tester (a). (b) Tester (b).

(11) Experimental Procedure and Experimental Results. The subjective comfort test is consistent with the objective test; see Table 3 for details.

The test experiment of subjective evaluation is also divided into five stages. Figure 10 shows the results of subjective evaluation, and its score is taken from the average score of testers 10(a) and 10(b). It can be seen that the comfort of the new fire suits is better than that of ordinary fire suits [21].

4. Conclusion

This study started with the research status of firefighting suits, and from the perspective of improving the comfort, safety, and interactive performance of existing firefighting suits, on the premise of meeting national standards, the comfort and functionality of firefighting suits were improved and designed. The carrier of the fire suit was designed with a three-layer structure, that is, the outer layer, the waterproof and moisture-permeable layer, and the thermal insulation and comfort layer, and the phase change material was used to improve its comfort. Its functional design is in three aspects. One is to use gas sensors to monitor the concentration of relevant dangerous gases that may appear in the working environment, so as to achieve the purpose of warning and ensure the personal safety of firefighters at work. The second is to solve the problem of the complex working environment of firefighters, using GPS module to monitor the location of firefighters, and to help the Wi-Fi module to send the firefighter's location to the web page and display it on the web page. The third is to enhance the work coordination among firefighters in view of the difficulty in communication between firefighters and between firefighters and the command center during work. After evaluation, the protective performance of the fire suit had reached the national standard, with a score of 0.669 on the seven-point scale, and its comfort had been greatly improved compared with ordinary fire suits. At the same time, the monitoring sensitivity of combustible gas and toxic gas was high, and the interactive function could also meet the work needs of firefighters, which can improve the safety of firefighters at work. At the same time, this design also has some shortcomings: the use time of electronic products cannot be judged because it must be worn out in daily use." I have added it in the original text, please check it out.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that there are no potential conflicts of interest in this study.

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