Model and Design of High Temperature and Thermal-proof Garment Using Genetic Algorithm

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ABSTRACT For question one, We adopt the thought of the "environment-fabric-human body" system; For the second question, we consider from the reverse angle; For question three, we also consider the problem from the perspective of human burns based on the idea of question two. Through the PDE toolbox in MATLAB, a three-dimensional distribution image of the temperature of each layer and air layer over time and thickness of each layer is drawn, and a dual-target optimization model is established by using genetic algorithm to search for the optimal thickness that satisfies the conditions. We use MATLAB to obtain the thickness results of Layer II and Layer IV. When the comfort is greatest. Taking into account the body type characteristics of the subject, heat conduction models are established according to different major parts, so as to obtain the optimal thickness of a certain layer of different parts, a greater degree of material saving, and an increase in the number of workers’ comfort.

1. Introduction
When working in a warmer environment, people need to wear professional clothes to avoid Burns. Especially in fire welding, steelmaking and other operations, it is very important to wear thermal protective clothing. This article takes the example of square hot clothing made of third-layer fabric material as an example, and takes human safety and comfort as a starting point to reduce R&D costs. A temperature distribution model and a temperature thickness model are established to design suitable clothing for high temperature operations.

For the first question, in the "environmental-fabric-human body" system, the ambient temperature and the initial human body temperature are constant at 75 °C and 37 °C, respectively, through the literature[2] It can be seen that the temperature on the outside of the human skin is constant at 48.08 °C. Assuming that the heat transfer process from the external environment to the human epidermis is carried out in a direction perpendicular to the skin and fabric, the problem can be spatially.

As a one-dimensional model, according to which we can combine one-dimensional unsteady heat conduction models, list the initial conditions and boundary conditions, and then use the finite difference method to obtain the analytical solution of the partial differential equation. The distribution function T(X, T) of temperature T on time T and space X is obtained. Through the PDE toolbox in MATLAB, three-dimensional distribution images of fabric layers and air layer temperature over time and thickness are drawn.

For the second question, we consider from the reverse perspective that given an external ambient temperature of 65 °C and a four-layer thickness of 5.5 mm, when the dummy test time reaches 60 minutes, the dummy skin external test temperature is just over 44 °C 5 min, but not More than 47 °C.
C. The optimal thickness of the II layer is $L_{\text{min}}$. Based on the heat conduction model established by the problem, we use genetic algorithm to search for the optimal thickness of 12.02 mm.

In response to question 3, we also consider from the perspective of human Burns, that is, when the external ambient temperature is 80 $^\circ$C, the outer temperature of the human skin exceeds 44 $^\circ$C, and just five minutes, the optimal thickness of the second layer and the fourth layer is obtained. The difference is that in this question, we consider the constraints of human comfort, that is, under the dual constraints of safety and comfort, we solve the optimal solution of two layers of thickness. We consider that the thicker the fabric material, the greater the weight. Even if the suit has a good thermal insulation effect, the weight of the general assembly affects the comfort of the employee and thus affects the efficiency of his or her operations. We define the comfort function $\vartheta = \vartheta_2 + \vartheta_4 = 1$, the thickness of Layer II and Layer IV when maximum comfort is achieved under safe conditions, That is, a dual-objective optimization model is established, and the results are 7.4 mm and 6.1 mm using MATLAB, respectively.

2. Restatement of issues

When working in a high temperature environment, people need to wear special clothing to avoid Burns. Dedicated clothing is usually composed of three layers of fabric materials, denoted as layers I, II, and III, where layer I is in contact with the external environment. There is also a gap between layer III and the skin. This gap is recorded as layer IV.

In order to design special clothing, a dummy with a body temperature of 37 $^\circ$C is placed in a laboratory temperature environment and the temperature outside the skin of the dummy is measured. In order to reduce R&D costs and shorten the R&D cycle, please use mathematical models to determine the temperature changes outside the skin of the dummy and solve the following problems:

2.1 Certain parameter values for special clothing materials are derived from[1] Given that the ambient temperature is 75 $^\circ$C, the thickness of the II layer is 6mm, the thickness of the IV layer is 5mm, and the working time is 90 minutes, the temperature outside the skin of the dummy is measured[2] And ... Establish a mathematical model, calculate the temperature distribution, and generate an Excel file with a temperature distribution(file name is problem 1.xlsx).

2.1.1 When the ambient temperature is 65 $^\circ$C and the thickness of layer IV is 5.5 mm, the optimal thickness of layer II is determined to ensure that the outer temperature of the human skin does not exceed 47 $^\circ$C for 60 minutes and does not exceed 44 $^\circ$C for more than 5 minutes.

2.1.2 When the ambient temperature is 80 $^\circ$C, the optimal thickness of Layer II and Layer IV is determined to ensure that at 30 minutes of work, the outer temperature of the human skin does not exceed 47 $^\circ$C and the time exceeding 44 $^\circ$C does not exceed 5 minutes.

2.2 Problem analysis

2.2.1 Analysis of question one
The ambient temperature and the initial temperature of the human body are constant at 75 $^\circ$C and 37 $^\circ$C, respectively, in the "environmental-textile-human body" system. According to Annex II, the external temperature of the human skin is constant at 48.08 $^\circ$C. Assuming that the heat transfer process from the external environment to the human epidermis is carried out in a direction perpendicular to the skin and fabric, the problem can be regarded as a one-dimensional model in space, according to which we can combine one-dimensional unsteady heat conduction models. The initial conditions and boundary conditions are listed, and the differential equation is obtained by the finite difference method. The distribution function $T(X, T)$ of temperature $T$ on time $T$ and space $X$ is obtained.
2.2.2 Analysis of question two
From the reverse perspective, given that the external ambient temperature is 65 °C and the four-layer thickness is 5.5 mm, when the dummy test time reaches 60 minutes, the dummy skin external test temperature is just over 44 °C 5 min, but not more than 47 °C. The optimal thickness of the II layer is \( L_{\text{min}} \).

2.2.3 Analysis of question three
We are also based on the idea of question 2, from the perspective of human Burns, that is, when the external ambient temperature is 80 °C, the outer temperature of the human skin exceeds 44 °C, and just over five minutes, the optimal thickness of the second layer and the fourth layer is obtained. The difference is that, In this question, we consider the constraints of human comfort, that is, under the dual constraints of safety and comfort, to solve the optimal solution of two layers of thickness. We consider that the thicker the fabric material, the greater its weight, even if the suit has a good thermal insulation effect. However, the weight of the conference affects the comfort of the employees, which in turn affects their operational efficiency. We define the comfort function to solve the thickness of the second layer and the fourth layer. When the safety conditions are met and the maximum comfort is achieved,

3. Model assumptions
Assume that the temperature in the "environmental-textile-skin" system is carried out perpendicular to the surface of the skin;
   It is assumed that only heat conduction and heat radiation exist in the system, and heat convection is not considered.
   Assume that each layer of fabric is isotropic;
   It is assumed that the temperature between layers of fabric, between fabric and air, and between air and skin is continuous;
   It is assumed that the temperature of fabric and human skin is 37 degrees.
Assume that the properties of density, specific heat and heat conductivity of fabric materials during heat transfer are unchanged;
   It is assumed that the temperature distribution is uniform in the texture layer at a certain time and thickness;

4. Symbol description
Symbols and Symbolic Meaning see Table 1

| Symbol | symbol meaning |
|--------|----------------|
| T      | temperature    |
| t      | Time           |
| \( c_i \) | specific heat capacity |
| \( \rho_i \) | density |
| \( a_i \) | Temperature conductivity |
| x      | Vertical thickness |
| \( \theta_k \) | Inner Layer Comfort |
5. Establishment and solution of 4 models

5.1 Construction and Solution of Problem-One Model

5.1.1 Problem analysis
In the "environmental-textile-human system", the ambient temperature and the initial temperature of the human body are constant at 75 °C and 37 °C, respectively, and the heat of the external environment is transmitted through the fabric to the air layer, which is a typical heat conduction model. However, there are two types of heat conduction models, steady and unsteady, according to the literature[2] Given the temperature time data, we draw a curve of temperature over time and find that the temperature gradually rises to a constant value over time. Therefore, we judge that this problem is more suitable for non-steady state models. Assuming that heat transfer only considers heat conduction and heat radiation in this problem, that is, heat transfer in the form of heat convection is not considered, and the heat transfer process is perpendicular to the skin, we decided to establish a one-dimensional unsteady state heat transfer model.

5.1.2 Modeling

5.1.2.1 Differential equations and deterministic conditions
For thermal protective clothing, the thickness of each layer of fabric is relatively thin, and the length and width of the area perpendicular to the skin's epidermis are much larger than the thickness of each layer of fabric. There are the following one-dimensional unsteady thermal conduction differential equations:

\[ \frac{\partial^2 T}{\partial x^2} + \frac{\rho c}{\lambda} \frac{\partial T}{\partial \tau} = 0 \]  \hspace{1cm} (1)

Or described as

\[ \frac{\partial^2 T}{\partial x^2} + \frac{1}{a} \frac{\partial T}{\partial \tau} = 0 \]  \hspace{1cm} (2)

The initial condition is:

\[ \tau = 0, 0 < x < L(L = \sum_{i=1}^{n} l_i) \]

\[ t_i = t_{ci} = 75, t_d = t_i = t_a = t_o = 37 \]  \hspace{1cm} (3)

The boundary conditions are:

\[ \tau = 0, x = 0, \frac{\partial T}{\partial x} = 0 \]

\[ \tau > 0, x = l, t_d = t_a \]

\[ \tau > 0, x = L, t_o = t_a \]  \hspace{1cm} (5)

5.1.2.2 Dispersion of the calculated area
In this question, according to the literature[8] we only consider heat transfer along the surface of the human skin, of course, this assumption will cause some error. In order to simplify the model, we establish a one-dimensional unsteady heat conduction model, but "one-dimensional" only means that the heat transfer in space is one-dimensional. Combined with Annex II, it can be seen that the temperature changes over time and eventually tends to a steady state value, which means that the temperature also changes over time. Therefore, in fact, the model we set up solves the problem of "two-
"dimensional" and ultimately requires the distribution function $T(X, T)$. However, it should be noted that the time coordinates are one-way, that is, the time progress is not regressive, and the results of the previous moment will have an impact on the results of the latter moment; But the later results will not affect the previous one. The discrete calculation area with $X$ and $T$ as coordinates begins with $T = 0$ and increases to the $J$ time layer and $J + 1$ layer through one time layer.

5.1.2.3 **Discrete of differential equations**

For any I node, the differential equation can be written as the following formula at $J$ and $J + 1$:

$$
\frac{\partial T}{\partial T_{i}} = d \frac{\partial T}{\partial x_{i}}
$$

(6)

The difference between the left end temperature of the above formula and the partial derivative of time is obtained:

$$
\frac{\partial T}{\partial T_{i}} = \frac{T^{i+1} - T^{i}}{\Delta T}
$$

(7)

Derivatives of the front end term relative to the I point at time

$$
\left( \frac{\partial T}{\partial T} \right)_i
$$

(8)

It's forward differential. We observe that although these two formulas correspond to the right-end difference formula, they have different meanings. In contrast, the right end is the derivative of point I corresponding to the moment’s The backward difference.

$$
\left( \frac{\partial T}{\partial T} \right)_{i+1}
$$

(9)

By replacing the second-order derivative about the right end of the above equation with the corresponding difference, the following two different difference formats, explicit and implicit, can be obtained:

Explicit:

$$
T^{i+1} = fT_{i+1} + (1 - 2f)T_i + fT_{i-1} \quad (J = 0, 1, \ldots, i = 2, 3, \ldots, N - 1)
$$

(10)

All implicit:

$$
T^{i+1} = \frac{1}{1 + 2f} \left( fT_{i+1} + fT_{i-1} + T_i \right) \quad (J = 0, 1, \ldots, i = 2, 3, \ldots, N - 1)
$$

(11)

In the above two formulas

$$
f = \frac{\alpha \Delta T}{\Delta x^2}
$$

(12)

It can be clearly seen from the formula that the right end only involves the temperature of the J moment. We calculate from the initial moment($J = 0, T = 0$). From the initial conditions listed above, the temperature at the next moment can be obtained, that is, the temperature of the fabric layer and the air layer at $J = 1$ moment; The temperature obtained by $J = 1$ is then explicitly calculated to obtain the temperature of each layer at $J \geq 2$. By analogy, the temperature values of each moment and each fabric layer and air layer can be directly obtained by explicit formula.

For the following full implicit right end contains the temperature of different nodes at the same time as the left end of the equal sign, so the temperature values of these nodes must be obtained by solving the algebraic equations.

5.1.2.4 **Dispersion of boundary conditions**

It can be clearly seen from the formula that the right end only involves the temperature of the J moment. We calculate from the initial moment($J = 0, T = 0$). From the initial conditions listed above, the temperature at the next moment can be obtained, that is, the temperature of the fabric layer and the air
layer at $J = 1$ moment; The temperature obtained by $J = 1$ is then explicitly calculated to obtain the temperature of each layer at $J = 2$. By analogy, the temperature values of each moment and each fabric layer and air layer can be directly obtained by explicit formula.

For the following full implicit right end contains the temperature of different nodes at the same time as the left end of the equal sign, so the temperature values of these nodes must be obtained by solving the algebraic equations.

$$T_i^{j+1} = T_i^j$$

$$T_x^{j+1} = \frac{1}{h_A\lambda + 1} \left( T_x^{j+1} + \frac{h_A x}{\lambda} T_x \right)$$

5.1.2.5 Final discrete format

Explicit:

$$T_j^i = T_j \quad (j = 1, 2, \ldots, N)$$

$$T_i^{j+1} = (fT_i^{j+1} + fT_i^j + (1 - 2f)xT_i^j) \quad (i = 2, 3, \ldots, N - 1)$$

$$T_i^{j+1} = T_i^{j+1}$$

$$T_x^{j+1} = \frac{1}{h_A\lambda + 1} \left( T_x^{j+1} + \frac{h_A x}{\lambda} T_x \right)$$

Implicit:

$$T_i^0 = T_j \quad (initial\, value)$$

$$T_i^{j+1} = \frac{1}{1 + 2f} \left( fT_i^{j+1} + fT_i^j + T_i^j \right)$$

$$T_x^{j+1} = \frac{1}{h_A\lambda + 1} \left( T_x^{j+1} + \frac{h_A x}{\lambda} T_x \right)$$

Among them $i = 0, 1, 2 \ldots$. When the second-order precision element balance method is used for discrete, the corresponding discrete format is:

$$T_i^{j+1} = T_i^j + (1 - 2f)xT_i^j + 2fT_i^j$$

$$T_x^{j+1} = (1 - 2f)T_x + 2fT_x + 2fT_x$$

5.1.3 Solution of the model

According to the above method, we find that the final temperature analysis of time and thickness is:

$$T(x, t) = (T_s - T_x) \sum_{m=0}^{\infty} \frac{2\sin \zeta_m}{\sin \zeta_m \cos \zeta_m} \exp(-a^2\tau) \cos(\zeta_m x)$$

For the equation $c = \frac{\zeta}{B_i}$ Root. For each layer of fabric, due to the different material properties, the temperature analysis of time and thickness of the fabric is different, but based on the assumption that each layer of fabric material is isotropic, So it is continuous for the temperature distribution of the entire fabric material and the air layer.

We use MATLAB PDE tool box to draw three dimensional maps of temperature distribution of each layer and three dimensional maps of temperature distribution from thermal protective clothing to human epidermis.

The numerical solution of the four-layer temperature distribution is shown in Figure 1:
By observing the above three-dimensional diagram of the temperature distribution of time and layers of fabric and air, we can get the following conclusions:

From the perspective of time alone, the temperature of the II layer rose fastest in a certain period of time, and the temperature of the IV layer increased by about 10 degrees in 90 minutes.

The temperature of each layer of thermal protective clothing and the temperature of the air layer will eventually rise to a steady state value, with I layer 75 degrees, II layer 63.48 degrees, III layer 52.82 degrees, and IV final 48.08 degrees.

1) The temperature of each layer of fabric material or air layer is transmitted gradually. In this transfer, the temperature is followed by continuous transmission, and there is no unreasonable interruption point in the middle.

2) The temperature of each layer will change over time, further indicating the accuracy of the unsteady state heat conduction model

Based on the above conclusions, we give the following explanation:

According to the physical properties of each layer and air layer of the fabric given in document 1, it is easy to know that the density, specific heat, and heat conductivity of the second layer fabric material are the maximum values in the fourth layer, and it is not difficult to know that the second layer is within a certain period of time., Not only the heat conductivity is the largest, but also the temperature difference of the ascending amount is the largest; On the other hand, the fourth layer, that is, the air layer, is the smallest in terms of both the conduction rate and the rising temperature difference. And in the unsteady state heat conduction model, the temperature eventually rises to a stable value. Numerical solution of temperature distribution in four layers see Fig. 1

![Numerical solution of temperature distribution in four layers](image)

**Fig. 1** Numerical solution of temperature distribution in four layers

The following gives the distribution of temperature at certain times: Results of partial temperature distribution see Table 2

| Time(s) | temperature(° C) | IV lateral | III lateral | II lateral | I lateral |
|---------|------------------|------------|------------|------------|----------|

Table 2 Results of partial temperature distribution
5.2 Establishment and Solution of the Second Problem Model

Based on the analysis and solution results of the issue-one model, it is easy to find that the second problem is actually the inverse process of solving the problem. The first problem is the known thickness of each layer and the ambient temperature conditions. To solve the dynamic distribution of temperature over time at each layer, the second problem is to find the minimum thickness of Layer II given the external temperature and the temperature constraints of the dummy surface. We can use the same method of question one, assuming that the thickness of layer II, according to the Fourier heat conduction principle, lists the general form of the problem two-heat conduction, so as to obtain partial differential equations of the "environmental-textile-human" system, and then increase the boundary constraints. The analytical solution or numerical solution of the differential equation is obtained, and the corresponding critical thickness is found, that is, the thickness of the second layer of the heat service.

5.2.1 Preparation of the model

From the derivation of question one, we can conclude that when the temperature is conducted from the outside to the inside of the human body, the temperature distribution is stepped up. The larger the value of \( a \) of the material, the smaller the temperature difference in the cover layer, and the corresponding thermal insulation performance. The worse, We can use this condition as a known premise to constrain the next model, and play a certain guiding role in the solution of the model, establish a one-dimensional coordinate system perpendicular to the inwards of the skin, and the outer side of the I layer is the unit 0 point, The temperature distribution can be expressed as:

\[
\begin{align*}
\sum_{i=1}^{3} \alpha_i \Delta T_i + \Delta T_1 + \Delta T_2 + \Delta T_3 &= T' - T\big|_{x=0} \\
\Delta T_i \propto \frac{1}{\alpha_i} &= \frac{\rho c_p}{\lambda_i}, i = 1, 2, 3, 4.
\end{align*}
\]

(25)

In the above equation, \( T' \) For external temperature, it is a constant value, \( \alpha_i \) is the conductivity of layer I, and the larger the conductivity, the more likely the object is to be in the heat conduction process.

5.2.2 Modeling

Assuming that the thickness of Layer II is \( x_2 \), similarly, a partial differential equation is established using the one-dimensional unsteady state heat conduction principle as follows:

\[
\frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left( a \frac{\partial T}{\partial x} \right) + f(x), (0 \leq x < 9.7 + x_3)
\]

(26)
\[\begin{align*}
0 < x < 0.6, & \quad a = a_1; \\
0.6 \leq x < 0.6 + x_1, & \quad a = a_2; \\
0.6 + x_1 \leq x < 4.2 + x_2, & \quad a = a_3; \\
4.2 + x_2 \leq x < 9.7 + x_2. 
\end{align*}\]  

(27)

For this problem, for the four-layer material of the anti-heat suit, there is no heat source in this temperature field, so \( F(X) = 0 \). Give the boundary condition:

\[\lambda_i \frac{\partial T}{\partial x} \bigg|_{x=a} = a_i(65 - T)_{x=a} \]

(28)

\[T(9.7 + x, t) = g(t), 0 < t < 60;\]

(29)

According to the unsteady heat conduction problem with internal heat source, the steady state heat conduction problem with homogeneous boundary conditions and an unsteady homogeneous problem can be decomposed into heat source. The solution of the original equation is:

\[T(x, t) = T_i(x, t) + T_0(x)\]

(30)

5.2.3 Solution of the model

For this problem, we first use the PDE toolbox in MATLAB software to find the analytical solution of the partial differential equation. On the basis of the analytical solution, we use the improved genetic algorithm to recycle and make several iterations to obtain the ideal fabric. Layer II thickness, The specific process is as follows.

Step 1 Determines the region of this partial differential equation

The thickness is from 0 to (9.7 + x_2) and the time is from 0 seconds to 5,400 seconds. Due to the finiteness of the visual graphics in the PDE, we reduce the time to the corresponding scale, such as using 0-1 to represent the change in time. After that, type the boundary value condition and divide the area into the mesh as shown in the figure below to facilitate the solution of the subsequent problem and the drawing of the figure.

![Figure 2 The partial subregions](image)

Step2 analysis of numerical solutions

After solving with the PDE toolbox, the numerical solution of the partial differential equation is first obtained. Figure 4 is an image when \( x_2 \) is a certain value between 0.6 and 25. The analysis of the image and model preparation can be found. The thickness of this layer is much thicker than that of other insulation layers so that the two surfaces have enough temperature difference to achieve the insulation effect. The numerical solution of partial differential equations is shown in Figure 4:
Step 3 uses genetic algorithm to solve the optimal value of $x_2$

Based on the initial model assumption, all materials are isotropic materials, and the model is a one-dimensional model. After the establishment of the previous model, a physical problem has been completely abstracted into a mathematical problem, and due to coincidence, this partial differential equation happens to have an analytical solution. The time-varying temperature field function containing the parameter $x_2$ has been found by the PDE toolbox:

$$T(x,t) = (T_w - T_s) \sum_{n=1}^{\infty} \frac{2.56 \sin \zeta_n}{\zeta_n + \sin \left( \frac{\zeta_n x}{2} \right)} \cos \left( 2 \zeta_n x \right)$$

Therefore, we try to use the improved genetic algorithm to solve the minimum value of $x_2$ based on this function. We use the genetic algorithm to write the principle of programming multiple substitution calculations of all values within the $x_2$ range. After verifying whether the temperature does not exceed 47 °C within 60 minutes and the time exceeding 44 °C does not exceed 5 minutes, each feasible solution is retained, and the previous optimal solution is replaced by a new optimal solution. Finally, the optimal solution with a certain degree of rationality is obtained. That is, the thinnest thickness of Layer II that meets the constraints. The specific flow chart for the calculation of the genetic algorithm is 6, and the procedure is shown in appendix 7. See Figure 5 for a map of the optimal solution.
Figure 6 is the embodiment of the genetic algorithm program solution process. After many iterations, the optimal thickness is found out, and the error evaluation of the solution is given, and the function numerical error evaluation is shown in Table 3.

Table 3 Optimal Thickness Solution Results of Genetic Algorithm

| Optimal solution (mm) | Seeking Optimal Solution Error | Find the optimal function numerical error |
|-----------------------|-------------------------------|----------------------------------------|
| 12.02                 | 0.19748                       | -0.3122                                |

5.3 The establishment and solution of the third model of the problem
The third problem solution is similar to the second problem solution, but due to security considerations, the working time is reduced, and under the premise of ensuring the thickness of the second layer, the optimization conditions of the fourth layer are added at the same time, so that the thickness of the two layers is achieved. The model needs to consider two conditions at the same time. The distribution function can be obtained by different temperature distribution conditions, and then the optimal value can be obtained by establishing a double-layer programming model. At the same time, due to the actual situation, the human body needs a certain sense of comfort, so the comfort function $\vartheta(L)$ is introduced here to measure.

5.3.1 Modeling

5.3.1.1 Simplification of objective functions
This question needs to consider two thicknesses at the same time to determine the optimal value, and the temperature conditions have changed. This is to simplify the calculation. We simplify the objective function, assuming that the thickness of the second layer and the thickness of the fourth layer are a constant value. Then it is fitted as a parameter to obtain a relatively reasonable surface equation: Temperature distribution at $80$ °C as shown in Figure 6.

$$T(x,t) = -0.000926x_1 \cos(x_2 \times 4523 \times \pi) - 20.1456 \times e^{-1.2035x_1 - 1.2035^2} + 59.321$$

(32)

5.3.1.2 Establishment of a two-layer planning model
For the second layer of thickness $x_2$: 

Fig. 6 Temperature distribution at $80$ °C
For the fourth layer thickness $x_4$:

$$
\begin{align*}
T(x, 1800) &\leq 47 \\
T(x, 1500) &\leq 44 \\
T(0^+) &\leq 80 \\
x_1 &= 0.6 \\
x_3 &= 3.6 \\
0.6 \leq x_4 &\leq 6.4
\end{align*}
$$

5.3.1.3 Creation of Comfort Functions

The comfort function represents the range of acceptable temperatures in the human body. It represents a relative value of the part that is in contact with the human body and the whole part, and thus measures the high-temperature resistance performance of the clothing. It is related to the thickness of the second layer of clothing requested and the thickness of the third layer of clothing. Once again, we perform a simple treatment. Set it as a positive function:

Each layer of comfort is $\vartheta_i$ ($i = 1, 2, 3, 4$), Among them, outer layer comfort $\vartheta_1 = \rho_j \times C_j \times \delta_j \times x_j$ ($j = 1, 2$). $\rho$, $C$, $\delta$, $x$ indicates the density, specific heat, thermal conductivity, and thickness of the clothing; For the inner layer of clothing, there is a certain change

$$
\vartheta_k = \frac{C_k \times \delta_k \times x_k}{\rho_k} \quad (k = 3, 4)
$$

The final comfort function is

$$
\theta = \frac{\vartheta_2 + \vartheta_4}{\sum_{i=1}^4 \vartheta_i} = \frac{\rho_2 \times C_2 \times \delta_2 \times x_2 + \frac{C_4 \times \delta_4 \times x_4}{\rho_4} + \sum_{k=2}^4 \frac{C_k \times \delta_k \times x_k}{\rho_k}}{\sum_{i=1}^4 \vartheta_i} \quad (36)
$$

The thickness of the object $x_2$ is compared with the thickness of the fourth layer of clothing $x_4$. Considering that the genetic algorithm has different results for each optimization, the obtained value can be taken into the comfort function for testing in order to obtain the relative ideal thickness of the second layer of clothing and the thickness of the fourth layer of clothing.

5.3.2 Model Solving

Considering that question two and question three, although essentially the same, only in the case of the original goal, two additional constraints have been added. If we deal with this separately, we can get the optimal solution. Therefore, this paper still uses genetic algorithm to find the optimal value of the thickness of the second layer of clothing and the fourth layer of clothing, solve it several times, and bring it into the comfort function for testing. The results are as follows: Thickness solution is shown in Table 4:

| Layer Number | Optimal solution (mm) | Seeking optimal solution error | Find the optimal function numerical error |
|--------------|-----------------------|-------------------------------|------------------------------------------|
| II           | 7.4                   | 0.22132                       | -0.12147                                 |
| IV           | 6.1                   | 0.15409                       | -0.27148                                 |

6. Evaluation and Promotion of 5 Model
6.1 Evaluation of the model
The paper discusses a highly specialized heat conduction problem. This model puts forward too many assumptions for the solution of practical problems, and can only guarantee the rationality of the results to a certain extent or within a certain range. For example, the paper model only analyzes one-dimensional heat conduction models, and does not consider the flow of air in the air layer. In the actual problem, the medium-temperature surface is often not an absolute plane, especially for the human body, and it will certainly have a certain degree of bump. And there will be different shapes of heat transfer temperature field models, the figure of the arm and chest, the rate of heat transfer effect temperature distribution is different.

And the model only simply analyzed the radiation and did not make a thorough discussion. As a major form of heat conduction, it should increase its research weight. Considering the effects of radiation will give reasonable answers to questions that the original model can not explain.

6.2 Extension of the model
We should take into account the body characteristics of the person who is dressed, establish heat conduction models based on different major parts, and then carry out more detailed analysis to obtain the optimal thickness of a certain layer of different parts and a greater degree of material saving. Increase the operator's work Shushichengdu.

7. Conclusion
(1) Conclusion 1 Use genetic algorithm to find the optimal value of the thickness of the second layer of clothing and the fourth layer of clothing, solve it several times, and bring it into the comfort function for inspection. The result is the optimal solution of the second layer of clothing 7.4, and the fourth layer of clothing. The optimal solution 6.1.

(2) Conclusion 2 The paper model only analyzes one-dimensional heat conduction models, and does not consider the flow of air in the air layer. In the actual problem, the medium-temperature surface is often not an absolute plane, especially for the human body. There must be a certain degree of bump. And there will be different shapes of heat transfer temperature field models, the figure of the arm and chest, the rate of heat transfer effect temperature distribution is different.

(3) Conclusion 3 Taking into account the body characteristics of the person wearing the dress, heat conduction models are established according to different major parts, and a more detailed analysis is carried out to obtain the optimal thickness of a certain layer of different parts and a greater degree of clothing saving material.

8. Appendix

8.1 Question 2: Genetic algorithm master procedures:
clc
clear all
close all

%%% Set Global Variable
global inputnum hiddennum outputnum net inputn outputn inputps outputps;

%%% First step: raw data processing
% 1.1 Read Data load data input output; %%% Note one: different data formats, different import commands
input=load('input');
output=load('output');
x1=sort(input(:,1));
x2=sort(input(:,2));
y=x1.^2+x2.^2+7;
figure(1);
plot3(x1,x2,y);
grid;
%1.2 Decomposition of training data and test data
input_train=input(:,1:n-800);
input_test=input(:,n-800+1:end);
output_train=output(:,1:n-800);
output_test=output(:,n-800+1:end);
%1.3 Normalization of input and output data
[inputn,inputps]=mapminmax(input_train);%inputn,inputps The normalized data and structure(including the maximum minimum value average, etc.)
[outputn,outputps]=mapminmax(output_train);
%%% Step 2: BP network algorithm and its mean square error
% 2.1 BP Network Structure Parameters
inputnum=2;
hiddennum=5;
outputnum=1;
%2.2 BP network to get network structure, transfer data
[BPoutput,BPerror,BPmse]=GB20_BPFitness(input_train,output_train,input_test,output_test);
%%% Step 3: Genetic Algorithm Optimization
% 3.1 Genetic Algorithm Parameters Initialization
maxgen=50;
sizepop=10;
pcross=[0.3];
pmutation=[0.1];
% 3.2 Genetic Algorithm and its Optimal Individuals
[bestchrom,bestfitness,trace] = GB20_GAXunyou(maxgen,sizepop,pcross,pmutation);
%% % 4: drawing display
figure(1)
plot(BPoutput);
grid;
xlabel('Number of iterations');ylabel(' Function value ');
title(' BP network output signal ');
figure(2)
[r c]=size(trace);
plot(1:r,trace(:,1),'b-',[1:r],trace(:,2),'r-');
grid;
xlabel(' Evolutionary algebra ');
ylabel(' Adaptation function value ');
title(' Adaptability change curve ');
% % Step 5: Error Analysis and Recording
Xerror=sqrt((bestchrom(1,1)-0).^2+(bestchrom(1,2)-0).^2);
Yerror=bestfitness-0;
disp([' The optimal solution for BPGA is: ']);
disp([' The optimal solution error for BPGA search is: ' num2str(Xerror) ']);
disp([' BPGA search optimal function numerical error is: ' num2str(Yerror) ]);
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