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A Circuit Simulating Method for Heat Transfer Mechanism in Human Body

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Abstract—**It is a complicated process producing inner body heat and transferring the thermal energy to body surface. Based on the comparability between bio-heat transfer and current flow in circuit, this paper offers a method to analyze heat transfer mechanism, which using cold water to stimulate body system to produce echo, and applying electrical components to build a circuit to simulate above process. This method considers the production of inner heat source, the influence of organism medium during inner thermal energy transferring to the body surface and the environment temperature. It is a primary attempt to evaluate the distribution of inner body temperature uninjuriously by means of thermographs and provides a new way to analyze bio-heat transfer.**

Keywords—**Bio-heat transfer mechanism; circuit simulation; inner body temperature; thermograph**

I. INTRODUCTION

Organism has its inner heat source—metabolic heat. Organism maintains a stable temperature by means of thermal energy transferring and, when the external temperature changes, makes a proper reaction that adjusting body heat at once to adapt itself to the change. Analysis of metabolic heat and inner body thermal energy transfer comes down to blood perfusion rate, metabolism rate, heat transfer direction and so on. For different individuals the above parameters are different. It is still an obstacle on bio-heat transfer study that these parameters' rules can not be mastered. Since the body can also be looked as a temperature controlling system, we can use engineering means to simulate this control ability.

Cold stimulation is applied to the human body surface, which makes the activity of metabolism to be induced to the body surface, and then we analyze changes of the middle finger temperature from thermographs at different time. By simulating temperature change process, we designs a corresponding circuit, which offers a new path to study bio-heat transfer parameters.

II. METHODOLOGY

1. Principle of cold-water loading:

When body is stimulated by cold, blood vessels contract and blood flow reduces apparently. For compensating the lost heat and keeping inner temperature stable, metabolism will be more active to increase thermal energy. After removing stimulation, the vessels expand, metabolism comes to restore. And there is a negative feedback in body which adapts to the temperature change and stabilizes the temperature of inner body, accordingly, those can be simulated by a feedback in circuit which is used to stabilize the output.

2. Experiment Design

1) Take an infrared thermograph at the beginning, note down the environment temperature;

2) Keep one hand in cold water(10℃) for 60 seconds;

3) Take away cold stimulation; take the thermograph at once;

4) Repeat the above 3rd step four times after designed interval.

Fig.1 shows thermographs of a middle finger at above 6 different time points (the black line in graph is midline of finger):

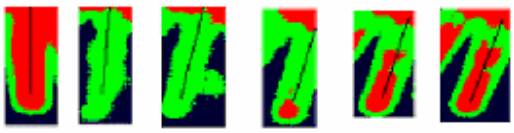


Fig.1 Middle finger thermographs

3. Circuit simulation

According to above principle, we design equivalent circuit to simulate the function of heat energy transferring to the body surface, and use simulink software to display the dynamic process.

Circuit simulating process is:

At stable state (U_a is environment temperature), voltage of capacitance C_1 reach to U_1,voltage of feedback is U_f; loading cold stimulation suddenly, the voltage changes from U_a to U_{a1}($U_{a1}<U_a$), current of C_1 ascends suddenly, C_1 discharges to maintain its voltage; removing cold stimulation, C_1 charges, and voltage of C_1 comes to restore.

See circuit simulation diagram as below fig.2.

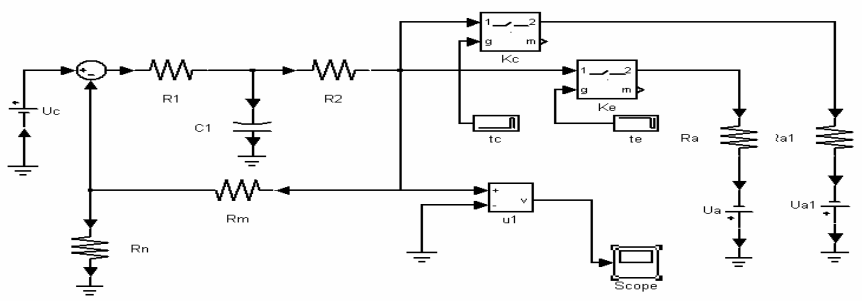


Fig.2 Circuit simulation diagram

In equivalent circuit,

- heat source in body core is constant voltage U_h;
- heat resistance between body core and out layer is resistance R_1;
- heat resistance between out layer and skin is resistance R_2;
- inner body heat capacitance is capacitance C_1;
- R_n and R_m are heat resistance in feedback loop;
- heat resistance between body surface and environment is R_a, Ra changes in different medium;
- heat source in environment is voltage U_a.

Current flow in this circuit can simulate heat flow in body.

Laplace equation for opening circuit is:

$$\begin{bmatrix} R_1+\frac{1}{S\cdot C_1} & \frac{1}{S\cdot C_1} \\ \frac{1}{S\cdot C_1} & R_2+R_a+\frac{1}{S\cdot C_1} \end{bmatrix} \bullet \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} U_i(S)-\frac{U_1}{S} \\ \frac{U_1}{S}-\frac{U_a}{S} \end{bmatrix} \quad (1)$$

$$U_O(S) = \frac{U_a}{S} + I_2 \cdot R_a \quad (2)$$

$$Ui(S) = \frac{U_h}{S} - \frac{R_n}{R_m + R_n} \bullet U_O(S) \quad (3)$$

Calculate Uo(S) from (1), (2) and (3), do inverse-laplace transform for Uo(s) and get Uo(t):

$$U_O(t) = A \cdot e^{-\tau t} + U_0 \quad (4)$$

in which:

$$U_0 = \frac{U_a R_2 + U_a R_1 + U_h R_a}{R_a(n+1) + R_1 + R_2}$$

$$A = \frac{R_a(-R_1U_a - R_aU_h - R_2U_h + R_2U_a n + U_1R_1 + U_1R_2 + R_aU_1 n + R_aU_1)}{(R_1 + R_2 + (n+1)R_a)(R_a + R_2)}$$

$$\tau = \frac{R_1 + R_2 + nR_a + R_a}{R_aC_1R_1 + R_1R_2C_1}$$

$$n = \frac{R_n}{R_m + R_n}$$

Analyze equation (4):

After enough long time out of cold stimulation, the hand should restore to the stable temperature U_0 which is the temperature before loading cold stimulation. We adjust each element in circuit such as R_1, R_2, C_1 one by one. If voltage output curve resembles the actual temperature change curve, we can ascertain values of the R_1, R_2, C_1 and n of individually.

In this circuit model, we suppose:

1) body core temperature U_h is a constant 37V;

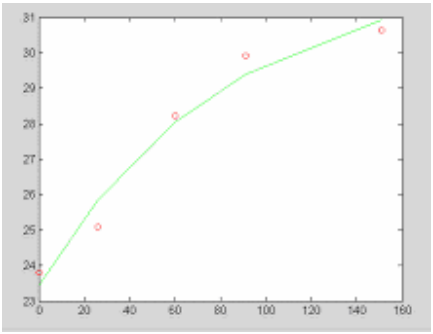
2) individual core temperature difference is not notable; body surface temperature difference is decided by parameters in circuit;

3) heat resistances and heat capacitance won't change with time.

III. RESULTS

We can use the value of τ to evaluate individual ability of body temperature controlling, and apply the value of elements to estimate temperature output curve at different environment temperature.

We compare the results of the data processing of healthy people and diabetics, for diabetes affecting metabolism and lowering ability of body temperature controlling. As results show, the value τ of healthy people is larger than that of diabetics.



x

Fig.3 Fitting curve graph

Given different low-temperature stimulation, the actual temperature curve conforms to the output curve of simulate well.

Simulink in matlab is used to simulate Uo(t) wave ,the following fig.4 is the simulink output wave graph:

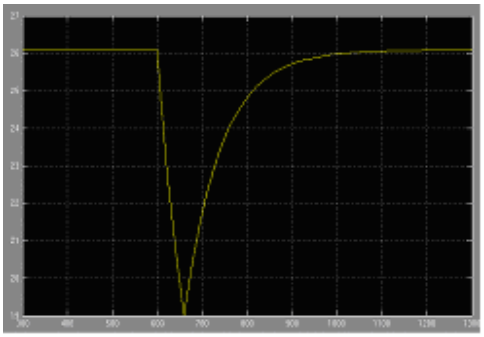
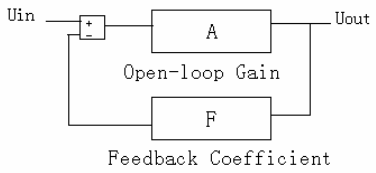


Fig.4 Simulink output curve

IV. DISCUSSION

In further research, circuit model should be subdivided to several levels which can help study organism temperature in different aspects and depth and can help diagnose pathological changes.

Moreover, the human body's metabolism itself is a system, feedback network can be used to simulate the whole metabolism system, then, system block diagram may be useful for analysis, the open-loop gain (A) and feedback coefficient (F) can distinguish individual metabolism level, and the depth feedback coefficient $|1 + AF|$ also reflects the feedback action in circuit, better the feedback action in circuit, easilier the output voltage can be stabilized, better the individual ability of temperature regulation is, and better the individual metabolism is.



Feedback System Graph

V. CONCLUSION

Circuit simulating heat transfer mechanism of human body is a means for bio-heat transfer research. This circuit model can help evaluate the ability of heat transfer of different people and estimate temperature changing trend line after different cold or hot stimulation.

In addition, this method can help identify diabetes degree. In experiment, we analyze the data of people who have heavier diabetes for long time, get small values of τ; while analyze data of the healthy people, big values of τ can be got.

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