HOOD TEMPERATURE CONTROL IMPROVEMENT FOR NON-CONTACT MEASUREMENT OF THERMAL INERTIA

K. Otsuka*, M. Ogawa**, H. Muramoto***, K. Ota**** and T. Togawa***

*, ** Institute of Biomaterials and Bioengineering,
Tokyo Medical and Dental University, Tokyo, Japan
** Present address: Microvitae Technologies, Grenoble, France
*** Marine Micro Technology Corp., Iruma, Japan
**** Inter-tec Technology Corp., Nishitoukyou, Japan
***** School of Human Science, Waseda University, Tokorozawa, Japan

otsuka.inst@tmd.ac.jp

Abstract: A new ambient temperature controlling method was introduced to the measurement system of thermal property of the skin. This system was constructed with a infrared thermography camera, a hood to control ambient temperature, capacitor charge/discharge unit and a PC to control IR camera and hood (ambient) temperature. The hood temperature raised abruptly by the discharge current to the heaters which were set in the hood and kept for 20 s. The skin thermal inertia, which shows high correlation with blood flow, was calculated with the slope of the temperature change of the skin after increase of the ambient radiation temperature. In the previous system, the hood was constructed with 4 heaters connected parallelly to a bridge circuit and their combined resistance was kept constant so that their temperature was kept constant. However, the temperature of each heater showed drift even though their combined resistance was constant. It was revealed that such drift can cause under estimation of thermal inertia. Thermal inertia of skin was slightly different between previous systems and this seems to be caused by above mentioned under estimation. A new system where each heater was controlled separately was constructed and the temperature of the heaters did not drift.

Introduction

Infrared thermography gives the information of the blood circulation as well as the distribution of skin surface temperature[1-3]. However, rather time-consuming procedures such as exposure to low temperature are often required to obtain circulation data. We have been developing a system where the ambient temperature is controlled and the emissivity of the subject, emissivity-corrected temperature and thermal inertia are obtained simultaneously[4-7]. For thermal inertia showed strong correlation with skin blood flow, thus our system provides distribution of skin circulation within 20-30 sec [8, 9].

In our system, ambient radiation temperature increases from T_{aL} to T_{aH} within very short time (Fig. 1. vertical arrow) and then keep constant. The apparent radiation temperature (readings of thermography T_r) of the subject increases abruptly from T_{rL} to T_{rH} because of the reflection of the ambient radiation. Thus the following equation is obtained:

$$W(T_{rL}) = (1 - e)W(T_{aL}) + e\,W(T_s) \qquad (1)$$
$$W(T_{rH}) = (1 - e)W(T_{aH}) + e\,W(T_s) \qquad (2)$$

where $W(T)$ is the amount of radiation energy from a black body with a temperature T to the IR camera. T_s and e are the temperature of the subject and its emissivity, respectively. Thus emissivity and T_s can be obtained from T_{rL}, T_{rH}, T_{aL} and T_{aH}. T_r increases gradually since the T_s increased with the ambient radiation. The slope of the T_r against the square root of the time after change in ambient radiation (Fig. 1) and determined by the energy of ambient radiation and thermal inertia (square root of the of the product of thermal conductivity, density and specific heat of the subject) [10, 11].

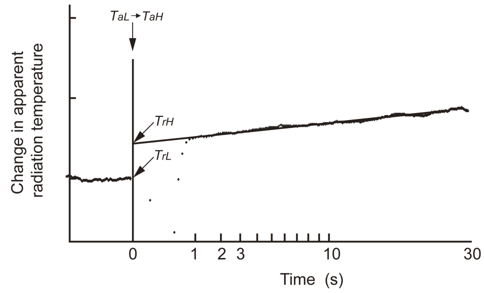

Figure 1: Schematic view of change in apparent radiation temperature of the subject.

The abrupt change of the ambient radiation temperature was realized with a hood with heaters on the inner surface attached to the infrared camera and the discharge of the large capacitors that enabled rapid increase of ambient radiation (Fig. 2).

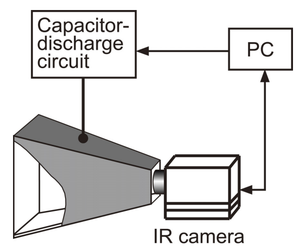

Figure 2: Schematic drawing of the system

ISSN: 1727-1983 © 2005 IFMBE

The heaters were set in a bridge circuit and the temperature of the heater was controlled by keeping the resistance of the heater constant. In the previous system, four heaters were connected in parallel, thus their combined resistance was kept constant.

In this system, it was inevitable that the resistance (and then the temperature) of each heater showed drift even when their overall composite resistance was kept constant (Fig 3 right).

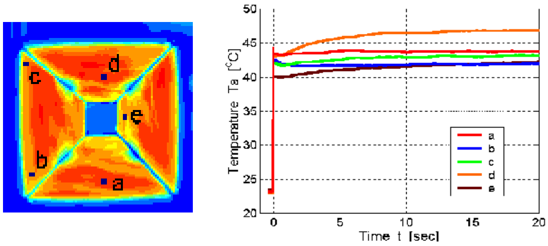

Figure 3 left: Temperature distribution of the hood of previous system. Right: Time course of temperature drift of the hood

In this study, 1) we considered whether such drift affects the measurement and 2) developed a new hood temperature control system to avoid this drift.

Materials and Methods

The basic structure of the system was similar to the previous system shown in Fig. 2. A new hood and control system was developed. The shape of the hood was similar to the previous system: The hood had pyramidal shape. Four trapezoid (shorter side: 75 mm, longer side: 240 mm, height: 355 mm) heaters were attached to the inner surface of the hood (Fig. 4). Each heater was connected to separate capacitor discharge unit, thus four capacitor discharge units were simultaneously controlled the temperature of the heaters. The capacitor discharge units were charged with a voltage of 450-500 V. Charge and discharge of the capacitor as well as temperature keeping were controlled by a PC

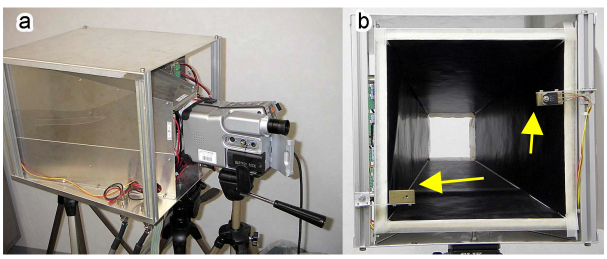

Figure 4: Hood for ambient temperature controlling.
a: The hood attached to the thermography camera.
b: Inner surface of the hood. Arrows indicate the reference plates for calibration of ambient radiation temperature.

The time course of the temperature of the heaters were measured by a infrared thermography camera (Thermotracer TH7102MX, NEC San-ei Instruments, Co. Ltd. Tokyo, Japan) and the data were recorded by a PC via IEEE 1394.

This system was applied to measurement of skin thermal properties of elder persons (71-89 years old). Each of the elderly was informed about this study and measurement of the thermal properties of the inner forearm was carried out under observation of a nurse. The same IR camera as used in measurement of hood temperature was used and the data were recorded by a same PC as hood temperature controlling PC via IEEE 1394.

Results

Figure 5 shows a typical time course of the temperature of this new hood. The temperature of the hood increased about 40 °C within 0.2 s and kept almost constant without any drift. The temperature of the 4 heaters were almost the same.

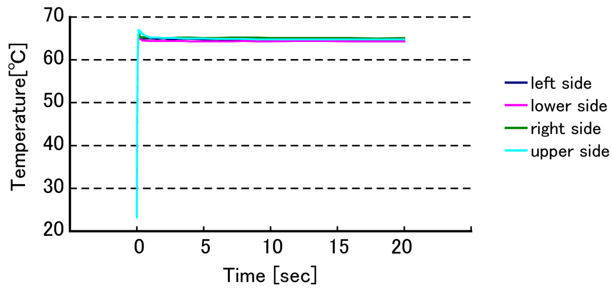

Figure 5: Time course of the temperature of the heaters of the new system.

Figure 6 shows an example of the thermal properties of the skin.

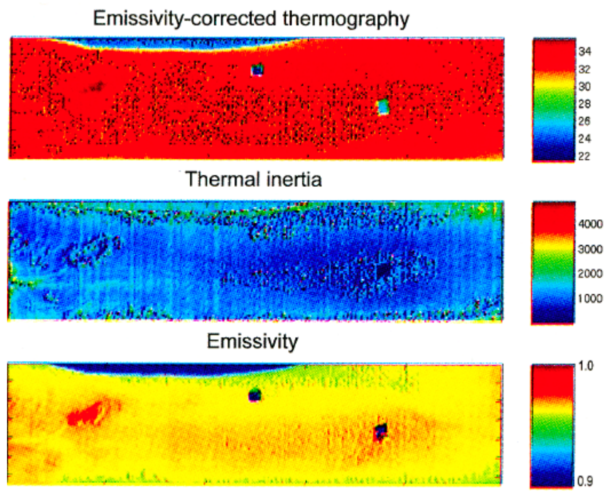

Figure 6: An example of skin thermal prperties of inner forearm.

The thermal inertia of the inner forearm of elder persons are shown in table 1. with the values of previous studies. Three of the old persons showed extraordinarily small value (< 1000) of thermal inertia. Therefore the average of the others is also shown in table 1 (*).

Table 1. Thermal inertia obtained by using changes in the ambient radiation temperature

work	Thermal inertia ($W s^{2/1}/m^2 K$)
Hassan [8]	1410 +/- 148
Huang [9]	1541 +/- 177.8
This study:	
all 10 subjects	1244 +/- 417
selected 7 subjects*	1501 +/- 195

*: Three subjects with extraordinarily small values of thermal inertia (<1000) were omitted.

Discussion

Effect of drift of the hood temperature

Consider a hood with two heaters with a same properties to simplify. Consider the resistance and temperature of the heaters to be R_1 and R_2, T_1 and T_2, respectively. When the resistance of a heater at the temperature T^* is R^* and the two heaters are connected in parallel as in the previous system, the combined resistance were controlled to fill the following equation:

$$1/R_1 + 1/R_2 = 2/R^* \quad (3)$$

Therefore, the resistance and thus the temperature of each heater can drift satisfying the equation (3). When T_i - T^* (i = 1 or i = 2) is small, R_i can be described by this equation:

$$R_i = R^* + a\,(T_i - T^*) \quad (4)$$

where a is constant (a > 0). When the temperature of heater 1 is higher than T^* (i.e. $T_1 > T^*$), according to equation (4), $R_1 > R^*$. Then R_2 is determined by the equation (3) and $R_1 - R^* > R_2 - R^*$. Therefore,

$$T_1 - T^* > T_2 - T^* \quad (5)$$

Since the radiation energy is proportional to T^4, (5) indicates that the increment of the radiation energy of the heater 1 is larger than the decrement of the heater 2.

This discussion indicates that if the temperature of the parallel-connected heaters shows drift as shown in Fig. 3, the ambient radiation temperature becomes larger and larger and thus the temperature of the subject increase more rapidly. There fore, this increment of the radiation energy derives under estimation of the thermal inertia.

Values of thermal inertia

The study by Hassan and Togawa [8] based on the previous heaters (Fig. 3). On the other hand, study of Huang and Togawa [9] based on a different system with two hoods with different temperatures. This Huang's system provided change of ambient radiation temperature by switching them. Thus drift of the hood temperature could not occur in the study of Huang and Togawa [9]. Thermal inertia of Hassan and Togawa [8] was slightly smaller (1410 $W s^{2/1}/m^2 K$) than Huang and Togawa [9] (1541 $W s^{2/1}/m^2 K$). This seems to support the above discussion.

Values of the thermal inertia obtained in this study (1244 $W s^{2/1}/m^2 K$) was smaller than previous two studies. This small average was caused by three subjects with very small thermal inertia (<1000 $W s^{2/1}/m^2 K$). Average of the other subjects' thermal inertia (1501 $W s^{2/1}/m^2 K$) was similar to Huang and Togawa [9] (1541 $W s^{2/1}/m^2 K$). Both Hassan and Togawa [8] and Huang and Togawa [9] measured skin thermal property of young subjects whereas this study was on elder subjects. Thermal inertia of skin correlates with skin blood circulation [5, 8, 9] and kin blood circulation should change by age or other physical condition. Therefore further investigation with more subjects is required to discuss more among the difference of this study and previous studies.

Conclusions

It was demonstrated that the temperature of heaters connected in parallel can drift and such drift of the hood temperature can cause under estimation of thermal inertia. This prediction was consistent with the difference of thermal inertia in previous studies ([8, 9]).

A new system with separate controlled heaters was constructed. This system did not show temperature drift and enabled precise measurement of thermal inertia.

Acknowledgements

This study was supported in part by Japan Science and Technology Corporation (Cultivation Program B (Modeling of Innovative Research Results)) to Marine Micro Technology Corp. We thank Welfare Comfortable House Co. Ltd., for permission and support in the measurement on elder subjects.

References

[1] ABBOT N. C., BECK J. S., HARRISON D. K., WILSON S. B. (1993): 'Dynamic Thermographic Imaging for Estimation of Regional Perfusion in the Tuberculin Reaction in Healthy-Adults', *J Immunol Methods* **162**: pp. 97-107.

[2] FUJIMASA I., Ed. (1999): 'Latest Medical Thermology', Nagoya.

[3] VON BIERBRAUER A., SCHILK I., LUCKE C., SCHMIDT J. A. (1998): 'Infrared thermography in

the diagnosis of Raynaud's phenomenon in vibration-induced white finger', *Vasa-J Vascular Dis* **27**: pp. 94-9.

[4] TOGAWA T., SAITO H. (1994): 'Non-contact imaging of thermal properties of the skin', *Physiol Meas* **15**: pp. 291-8.

[5] HUANG J., TOGAWA T. (1995): 'Improvement of Imaging of Skin Thermal-Properties by Successive Thermographic Measurements at a Stepwise Change in Ambient Radiation Temperature', *Physiol Meas* **16**: pp. 295-301.

[6] OTSUKA K., OKADA S., HASSAN M., TOGAWA T. (2002): 'Imaging of skin thermal properties with estimation of ambient radiation temperature', *Ieee Eng Med Biol* **21**: pp. 49-55.

[7] OGAWA M., OTSUKA K., TOGAWA T. (2003): 'The Measurement of the thermal properties of skin using changes in the ambient radiation temperature', *Rept IBB* **37**: pp. 75-8.

[8] HASSAN M., TOGAWA T. (2001): 'Observation of skin thermal inertia distribution during reactive hyperaemia using a single-hood measurement system', *Physiol Meas* **22**: pp. 187-200.

[9] HUANG J., TOGAWA T. (1995): 'Measurement of the Thermal Inertia of the Skin Using Successive Thermograms Taken at a Stepwise Change in Ambient Radiation Temperature', *Physiol Meas* **16**: pp. 213-25.

[10] TOGAWA T. (1989): 'Non-contact skin emissivity: measurement from reflectance using step change in ambient radiation temperature', *Clin Phys Physiol Meas* **10**: pp. 39-48.

[11] BUETTNER K. (1951): 'Effects of extremeheat and cold on human skin', *J. Appl. Physiol* **3**: pp. 691-702.

.

ISSN: 1727-1983