# AN APPROACH OF REDUCING MEASURE TIME OF NONINVASIVE THERMOMETER

## *Application of Curve-fitting Method and Autoregressive Model for Reducing the Measure Time of Dual-heat-flux Thermometer*

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Abstract: Newly developed dual-heat-flux thermometer is expected to be useful in measuring core body temperature noninvasively. However, as it takes more than 30 min to measure, the additional process is needed to reduce the measure time. In this study, we made a dual-heat-flux thermometer to verify its performance and obtained an hour-long data from three subjects. Dual-heat-flux thermometer estimated the core body temperature very well in all subjects. In addition, least squares curve-fitting method predicted deep body temperature well with within 100 sec data. Autoregressive model with 10 sec data also seemed to be suitable method for shortening measure time of dual-heat-flux thermometer.

# 1 INTRODUCTION

Body temperature is a basic and vital signal when monitoring health abnormality. In hospital, all patient monitor devices observe body temperature along with ECG, $SPO_2$, respiration, NIBP and pulse. And athletes could lose their lives due to continuous high body temperature during exercise(Coris et al., 2004). Moreover, body temperature has a strong correlation with various physical conditions. S. S. Yalçın reported that different individual characteristics of children such as hypoalbuminemia showed different RATD (Rectal–Axillary Temperature measurement Difference) values(Yalcin et al., 2010). The menstrual cycle of female is also closely related to the temperature rhythm(Nakayama et al., 1997). Therefore, varied types of thermometers have been developed.

The first method of measuring body temperature was offered by Hippocrates in the 5th century B.C.(Cranston, 1966). He used comparative measurements of heat and cold to distinguish certain diseases. In these days, more complicated and scientific thermometers are employed to measure body temperature. Rectal thermometers, oesophageal thermometers and auditory canal thermometers are the typical thermometers of today(Togawa, 1985). And these types of thermometers are called invasive thermometers because they insert a sensor into a body cavity for checking deep body temperature. In spite of their public use, these devices are not suitable for a long-term monitoring especially when people are awake. Taking a rectal thermometer for example, putting a long and sharp probe in rectum would restrict most movements and cause perforation of the rectum moreover.

The first, innovative noninvasive thermometer was produced in 1971(Fox and Solman, 1971). Zero-heat-flow thermometer is based on the assumption that if heat flow across the skin is zero, skin temperature would be equivalent to deep body tissue temperature. And for making heat flow zero, this thermometer equips a heater which needs AC power

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supply. Recently-introduced dual-heat-flux thermometer is another kind of noninvasive thermometer(Kitamura et al., 2009). However, it doesn't need a heater and AC power supply. Therefore, except for a long measure time of 40 mins, dual-heat-flux thermometer is more promising than zero-heat-flow thermometer when monitoring patient's core body temperature.

In this study, we made a similar dual-heat-flux thermometer to Kitamura K.'s work for reassessing its performance and applied curve-fitting method and autoregressive (AR) model for reducing its long measure time.

## 2 METHODS

We made a dual-heat-flux thermometer and compared it with the measured values of an infrared ear thermometer and an armpit thermometer. For shortening measure time of dual-heat-flux thermometer, curve-fitting method and AR model were applied. We address each of these issues in detail in the following sections.

### 2.1 Principles

#### 2.1.1 Dual-heat-flux Thermometer

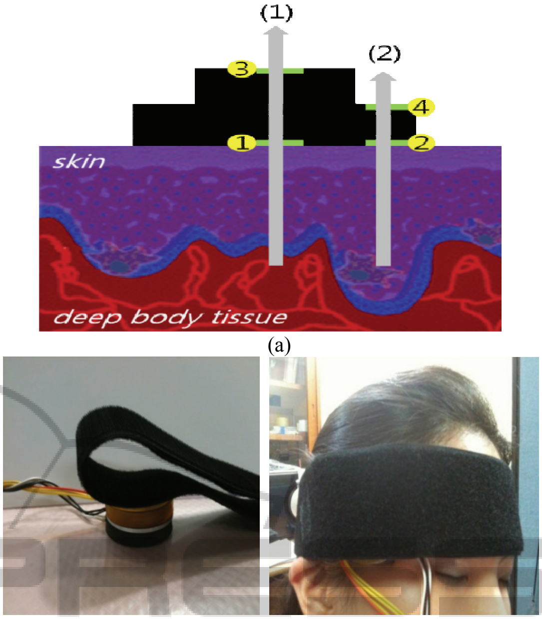
With an insulator on the surface of the body, a heat flow from deep body tissue to skin and another heat flow from skin to outside of the body are balanced. Kitamura K. assumed that the heat flow from the internal body to external is constant and vertical. Therefore, as shown in figure.1 (a), there are two heat flows passing the thermometer and four sensors measure temperatures at each part. In the previous study, based on these presumptions, following equation was obtained by introducing the concept of thermal resistance:

$$T_B = T_1 + \frac{(T_1 - T_2)(T_1 - T_3)}{K(T_2 - T_4) - (T_1 - T_3)} \tag{1}$$

$$K = \frac{(T_B - T_2)(T_1 - T_3)}{(T_B - T_1)(T_2 - T_4)} \tag{2}$$

where $T_B$ represents the core body temperature and $T_N$ indicates the measured value at sensor number N.

To calculate $T_B$, K-value has to be gained in advance through the simulation experiment of Nemoto and Togawa(Nemoto and Togawa, 1988). In the present study, K-value is 0.2679.



(a)

(b) (c)

Figure 1: (a): Two heat flows through the probe (b): A photograph of probe (c): A photograph of the experiment.

#### 2.1.2 Curve-fitting Method

Dual-heat-flux thermometer needs more than 40 min to measure, which makes subjects impatient to remain motionless. Therefore, with data within 100 sec, we tried to estimate the core body temperature using curve-fitting method.

For estimating the trend of outcome and eliminating the noise effect, least squares curve-fitting was used. Least squares method assumes that the best-fit curve of outcome has the smallest sum of the deviations squared from an experimental data. To gain the best-fit curve, we used ORIGIN PRO 8 program which is a powerful tool for analyzing data, especially for curve-fitting.

#### 2.1.3 Autoregressive Model

An autoregressive (AR) model explains that the time series value ($y_t$) at particular point can be predicted by a linear weighted sum of previous data:

$$y_{t+1} = \sum_{i=1}^{m} b_i y_{t-i+1} + \epsilon_{t+1} \tag{3}$$

where b denotes the autoregressive coefficients and $\epsilon_{t+1}$ represents Gaussian white noise with unknown variance. Firstly, to determine the regression coefficient b, we used one subject' data as training data. And as Andrei V. Gribok confirmed that the model trained for one subject is useful to predict the temperature of others (Andrei V. Gribok, 2008), we used the model which was established by 'training data' for estimating the core body temperature of others.

## 2.2 Experiments

Dual-heat-flux thermometer was made as according to the method of Kitamura K. - 4 IC temperature transducers (AD590, Analog Devices Inc, USA), a rubber sponge as an insulator, and a urethane sponge cover for avoiding air current effect. In addition, we replaced copper cap with aluminum cap and removed copper disks and rings to reduce the thermal inertia of the probe.

Core body temperature was measured in three healthy young subjects (26.5± 1.5 years old) and the room temperature was controlled at about 27˚C. Each subject sat on the chair and dual-heat-flux thermometer was fastened on the left anterior temporal region by hair band for an hour. To prevent the increase of brain temperature, some activities like computer games or doing homework which accompany strong brain activity was sublated.

# 3 RESULTS

## 3.1 Core Body Temperature

Besides the core body temperature measured by dual-heat-flux thermometer, auditory canal and axillary temperature were checked by an infrared ear thermometer and an armpit thermometer during the experiment. Table.1. shows measured temperatures of each body part of three subjects.

Table 1: Enumeration of measured temperatures.

| | Core body temperature | Auditory canal temperature | Axillary temperature |
|---|---|---|---|
| Subject 1 | 36.3˚C | 36.7˚C | 36.48˚C |
| Subject 2 | 36.35˚C | 36.8˚C | 36.35˚C |
| Subject 3 | 36.2˚C | 36.9˚C | 36.35˚C |

## 3.2 Application of Curve Fitting

The shapes of each subject's temperature curve were similar. Therefore, one subject's data (subject 3) were used to determine the minimum time that offers relevant result. The model is 'Temperature = $Ae^{B\times Time} + C$'. And as shown in figure 2, the estimation curves drawn within 95sec data and 100sec data are fitted well. For choosing the best-fit curve, estimated core body temperatures and residual sum of squares are listed (Table 2).

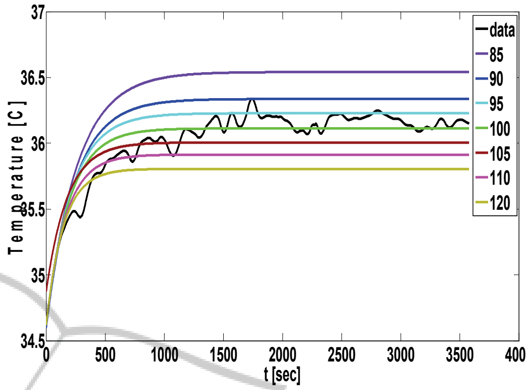


Figure 2: Estimated curves with different measure time.

Table 2: The results of curve-fitting method.

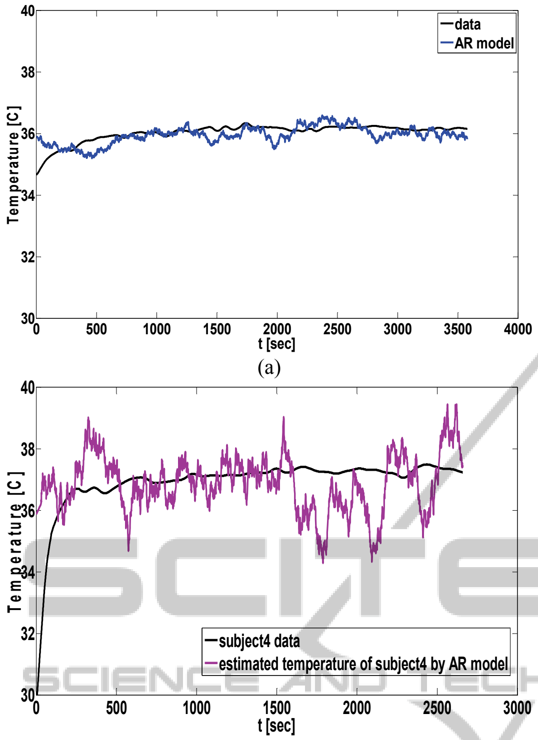
| Measure time | Estimated core body temperature* (dual-heat-flux thermometer) | Estimated core body temperature** (curve-fitting method) | residual sum of squares |
|---|---|---|---|
| 90sec | 36.2˚C | 36.34˚C | 170.57 |
| 95sec | 36.2˚C | 36.23˚C | 74.80 |
| 100sec | 36.2˚C | 36.11˚C | 40.78 |
| 105sec | 36.2˚C | 36.01˚C | 90.51 |

* Estimated core body temperature of subject 3 by dual-heat-flux thermometer is 36.2˚C, as shown in Table 1.

** Estimated core body temperatures of subject 3 by curve-fitting method were determined as the temperature of time =∞.

## 3.3 Application of Autoregressive Model

To seek more progressive way of reducing measure time of dual-heat-flux thermometer, we set up the 10th order AR model. In other words, as the sampling frequency was 1Hz, we used only 10 sec data for estimating core body temperature. The whole autoregressive coefficients were obtained from training data (subject 3). By drawing the curve contiguous to experiment curve, AR model suggests a possible approach to estimate the core body temperature in 10 seconds (Figure 3(a)). On the contrary, the prediction curve of cross-subject model was not fitted well with another individual's data.



(a)

(b)

Figure 3: (a): Core body temperature estimation using the same-subject AR model (b): Core body temperature prediction using the cross-subject AR model.

## 4 DISCUSSION

Core body temperatures measured by dual-heat-flux thermometer and other thermometers showed a narrow difference. Therefore, we could confirm the performance of non-invasive thermometer.

Curve-fitting method offered the possibility of cutting down the measure time of dual-heat-flux thermometer to 100 sec and AR model to 10 sec. In addition, as the AR model was not appropriate for cross-subject temperature estimation, we would consider other probability models in future work.

Finally, the probe is still inconvenient because many wires are surrounding the probe. Thus, we are supposed to transform the existing dual-heat-flux thermometer in telemetry way.

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