2021 43rd Annual International Conference of the
IEEE Engineering in Medicine & Biology Society (EMBC)
Oct 31 - Nov 4, 2021. Virtual Conference

Robustness Improvement Design against Convection for Core Body Temperature Sensor by Using Topology Optimization

Y. Tanaka, D. Matsunaga

***Abstract*—This work is about designing a core body temperature sensor using topology optimization. The proposed design showed significantly more robustness against ambient convections in in-vitro experimentation using a phantom with a root mean square error of 0.05 ºC.**

I. INTRODUCTION

Core body temperature (CBT) is the temperature of internal organs located deep within the body, such as the rectum. CBT fluctuates in roughly 24-hour cycles, and it is strongly related to the body's internal clock. A phase gap between the body's internal clock and a social clock can affect sleep quality and exercise performance, possibly leading to serious health problems such as metabolic aberrations. Thus, CBT monitoring is essential for maintaining daily health. While useful, some current techniques are stressful, as they require insertion of a sensor into the rectum. However, sensors that can be attached to the skin have been explored for decades. They mainly utilize a quasi-thermal equivalent circuit that considers the skin temperature T_s and the heat flux H_s from the body core [1]. In conventional sensors with a simple cylindrical structure, ambient convection generates transverse heat flow and increases dissipation of the heat flux H_s, inducing huge systematic errors. To address the problem, we study optimization of the sensor structure by using topology optimization that provides a systematic structure design procedure to maximize or minimize objectives. We propose a way of defining the optimization problem to decrease errors induced by the convection, and we verify our proposed sensor design using numerical calculation and in-vitro experimentation.

II. METHODS

In this work, we utilized aluminum as structural material because it has high thermal conductivity. Its optimum structure in the design domain was obtained by density-based topology optimization. The domain surrounds a sensor domain made of polylactic acid into which thermometers are integrated. The convection was given by a heat transfer coefficient equivalent to the wind speed of 0 to 5 m/s. Fig. 1 (a) shows the sensor scale and definitions of optimization problems. Three objectives are considered: (1) minimized transverse heat flux, (2) maximized average temperature in domain Ω_{Domain}, and (3) maximized heat flux H_s and the resultant structures. Fig. 1 (b, c) shows the estimation error for each optimized structure, and Structure 1, a truncated cone shape, was chosen as the optimum structure for showing the smallest error. The numerical computation was performed by COMSOL Multiphysics 5.5.

Yujiro Tanaka is with the Nippon Telegraph and Telephone Corporation, 3-1 Morinosato-Wakamiya, Atsugi, Kanagawa, Japan, phone: +81-46-240-2774; e-mail: yujiro.tanaka.cw@hco.ntt.co.jp.

III. EXPERIMENTAL

The sensor was fabricated and verified via in-vitro experimentation using a phantom made of 10-m thick ethylene-propylene-diene-monomer rubber, which was placed on a fanning-induced convection hot plate. The response curve between the reference hot plate and the estimated temperatures and the root mean square error (RMSE) at each wind speed are shown in Fig. 1 (d, e). The RMSE was up to 0.05 ºC under convection, and the wind speed ranged from 0 to 5 m/s.

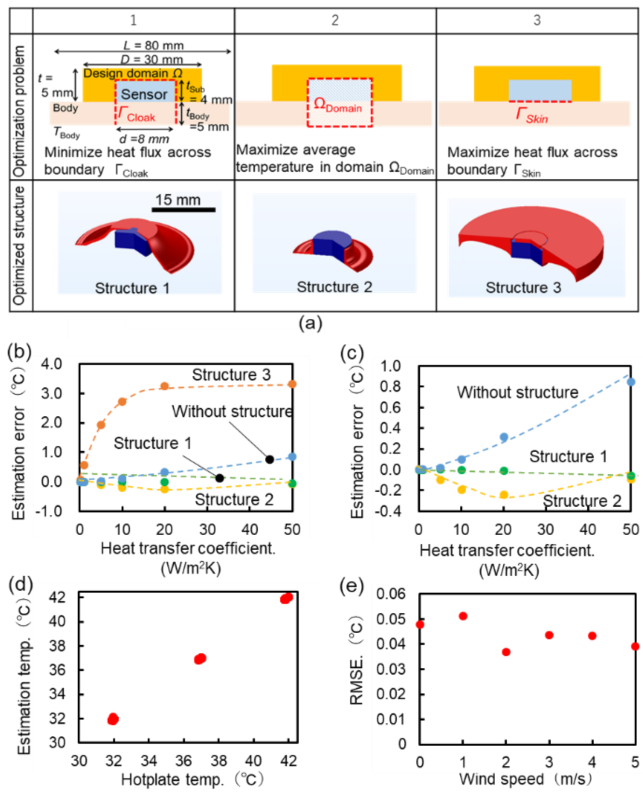

Figure 1. Simulated and experimental results. (a) Definitions of optimization problems and their optimized structures. Red and blue domains are alminum and polylactic acid, respectively. (b) Estimation errors versus heat transfer coefficient. (c) Magnified image of (b). (d) Experimental response curve. (e) Experimental RSME against wind speed.

IV. CONCLUSION

Our proposed sensor showed a robustness to ambient convection. It has high potential to be a CBT monitor that visualizes circadian rhythm in daily life.

References

[1] K. Kitamura et al., Med. Eng. Phys., vol. 32, pp. 1-6, Jan. 2010.