Modeling of Finger Photoplethysmography for Wearable Sensors

Sokwoo Rhee, Boo-Ho Yang, and Haruhiko H. Asada
d'Arbeloff Laboratory for Information Systems and Technology
Department of Mechanical Engineering
Massachusetts Institute of Technology
Cambridge, MA 02139, U.S.A.
Email: sokwoo@mit.edu

Abstract This paper describes the development of an opto-physiological model of a finger in conjunction with a ring-type photoplethysmography device (the Ring Sensor). It describes the photoplethysmographic effects due to the relative displacement and rotation of a finger to a ring-type opto-electric device that monitors the arterial pulsation noninvasively and continuously. Numerical simulations and experiments were conducted to verify and evaluate this model.

Keywords : photoplethysmography, motion artifact, physiological modeling

1. Introduction

We have developed a continuous patient monitoring device called "Ring sensor." The Ring Sensor is a photoplethysmographic device in a finger ring shape that noninvasively monitors the arterial pulse of an individual that offers remarkable convenience and advantages. However, the relative displacement and the rotation of the sensor probe to the finger cause the loss of accuracy. The objective of the paper is to quantify the mechanism of the motion artifact of finger photoplethysmography based on an opto-physiological model of the finger and to facilitate the development of the Ring Sensor which is less affected by the relative displacement of the finger to the ring.

2. Approach and Modeling

Our finger model is composed of three major parts that are closely coupled to each other ; Optical model, tissue mechanical model, blood vessel dynamics. Feng, S., Zeng, F., and Chance, B. derived an analytical formulation of the photon path distributions in the presence of a region with different absorption and scattering properties from the surroundings in semi-infinite geometry [1]. This formulation was used in our optical model to describe the relationship between the intensity of light from the LED source and the intensity of light that arrives at the photodetector. As the relative position of the finger to the ring changes due to an external force as is shown in Fig 1, the pressure at the contact surface increases, which results in the increase of pressures that apply to the digital arteries. The pressures applying to the digital arteries can be found by modeling the finger tissue as the elastic material. By using the volume-pressure curve of blood vessel, the volume of the digital arteries can be obtained from the pressures, which is combined with the optical model and gives the output of photoplethysmography.

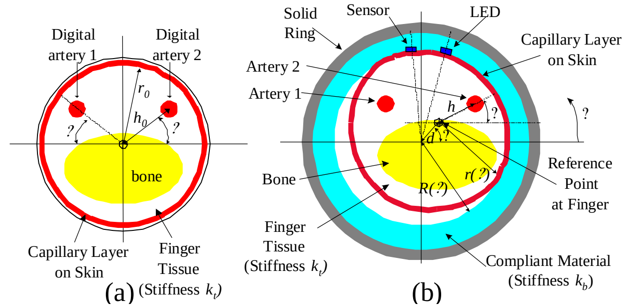

Fig. 1: (a) Uncompressed finger under no external force (d=0). (b) Finger compressed by the ring due to an external force.(d>0)

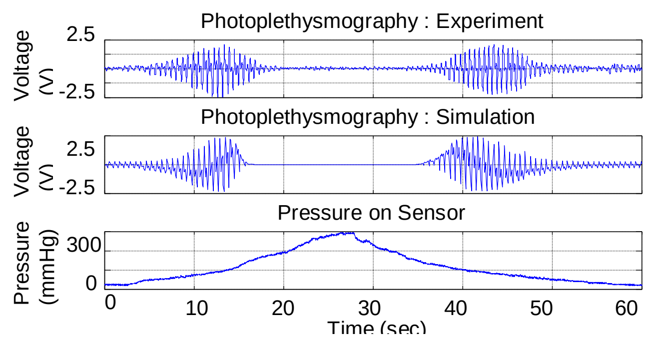

Fig. 2 : Experiment and simulation of photoplethysmography with the variation of pressure on the sensor unit

3. Experiment and Numerical Simulation

Numerical simulations and experiments were conducted at $\alpha=20^{o}$ with varying pressure on the optical sensor, and the results are shown in Fig 2. The numerical simulation of this model shows a good agreement with the experiment result.

4. Conclusion

A finger model for photoplethysmography was developed to describe the nature of the finger-based health monitoring device (the Ring Sensor), and was verified by experiments and numerical simulations. This model will be especially useful in developing an optimum design of the Ring Sensor to minimize the motion artifact.

Reference

[1] Feng, S., Zeng, F. and Chance, B., "Photon Migration in the Presence of a Single Defect : a Perturbation Analysis," Applied Optics, Vol. 34, No. 19, 3826-3837 (1995)