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Evaluation of Chip LED Sensor Module for Fat Thickness Measurement using Tissue Phantoms

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Abstract— **We tested the feasibility of noninvasive fat thickness measurements by using a diffuse optical method with variable source-detector pairs. A light source module composed of 770 nm low-power chip LEDs and a photodetector were used in this study. The tissue phantoms are composed of a fat and a muscle layer made with gels with appropriate absorption/scattering coefficients. The fat thickness was varied from several to 30 mm. Based on this preliminary study, it is concluded that the noninvasive fat thickness measurement is possible with proper curve fitting procedure.**

I. INTRODUCTION

There are many techniques used to study the lean body mass and subcutaneous fat distribution [1]. The imaging methods such as magnetic resonance imaging (MRI), computer tomography (CT), dual-energy X-ray absorptionmetry (DEXA), and ultrasound imaging, are precise and accurate techniques. But those methods are applicable in vary limited cases due to the high cost and the risk of radiological burden (CT, DEXA). A noninvasive optical approach for measuring the fat thickness has many advantages over these expensive technologies since it costs less and poses no radiation toxicity [2]-[3]. More importantly, it can be incorporated with mobile devices. To develop a portable, miniaturized optical sensor module for targeting the general audience, appropriate source-detector distances (SD) and LED power should be determined within the limited sizes.

For this purpose, we investigated the diffusely reflected light intensity on different SDs and LED power for the variation of fat thickness using the tissue simulating phantoms, which has similar optical properties with the human tissue at the wavelength of 770 nm.

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II. PHANTOM PREPARATION

The fat and muscle layers of the two-layer phantoms were made separately, and then the sliced fat layer with certain thickness was placed over the muscle layer to obtain the two-layered skin model. The thickness of the fat layer varied from 2 mm to 30 mm, while the muscle layer was fixed at 35 mm thickness. The muscle thickness is not important since the light does not reach the bottom surface of the muscle phantom.

Both fat and muscle phantoms were made with gelatin mixed with intralipid solution as a scatterer. For the muscle phantom, the neutralred dye was added to increase the absorption coefficient. The optical properties of the intralipid and neutralred were pre-determined by means of Inverse Adding-Doubling (IAD) from transmittance and reflectance measurements using integrating sphere. The amounts of intralipid and neutralred added in the phantoms were varied to produce the optical properties required and the absorption and the reduced scattering coefficients of each phantom are shown in Table I.

Once the phantoms are made, we measured the optical properties of the phantoms separately to make sure that the phantoms have the similar optical properties as skin.

The absorption and reduced scattering coefficients of the intralipid solution at various concentrations were measured and the results are shown in Fig. 1.

For both optical properties, the coefficients increased almost linearly with concentration increase. The intralipid has the lowest absorption coefficients at around 550 nm and the scattering coefficients decreased with wavelength as expected.

Table I
Summary of optical parameters at 770 nm

Tissue Layer	μ_a (1/cm)	μ'_s (1/cm)
Fat Phantom (Intralipid 20%)	0.064	10.50
Muscle Phantom	0.3	7

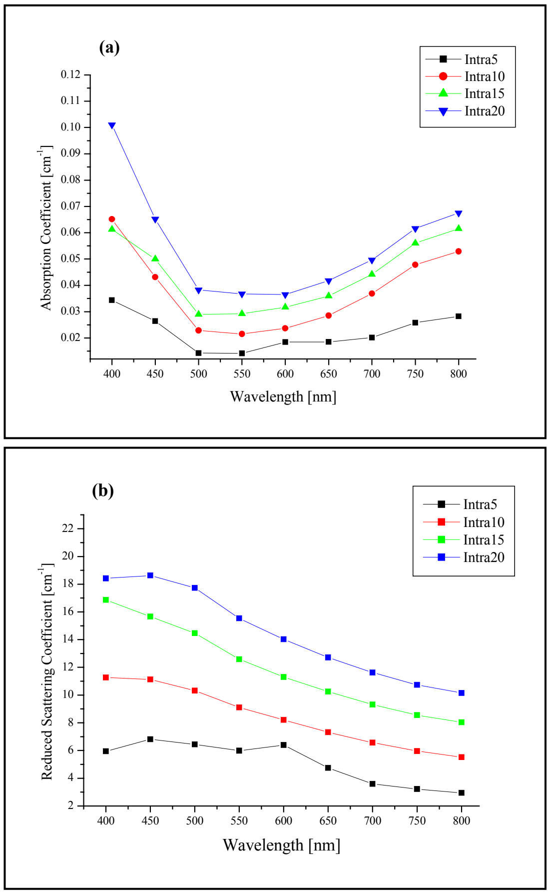

Fig. 1. Optical coefficients of fabricated intralipid solution: (a) the absorption coefficient, (b) the reduced scattering coefficient on the different intralipid concentrations as a function of wavelength.

Figure 2 shows the photograph of fabricated fat and muscle phantoms. The size of phantom contained in large box(small box) which has width 110mm(110mm), length 80mm(80mm) and height 110mm(50mm), respectively. Gelatin was used as the base material for the solid phantoms. The Fat layer was made from 20% Intralipid, 5% milk, 8% gelatin(Sigma Chemical Comp). The muscle layer was made from 5% neutralred, 0.2% tryphanblue, 10% gelatin.

Fig. 2. The Photograph of fabricated fat (left) and muscle (right) phantoms.

III. EXPERIMENTAL SETUP

Figure 3 shows the experimental set-up for evaluating the sensor module with two-layer phantoms, which consist of a fat layer and a muscle layer. Two kind of LEDs with the center wavelength of 770 nm were used in our experiment. One is the lamp LED (viewing angle 20 degree) and the other is t he miniaturized chip LED of surface mount type (viewing angle 120 degree). The frequency of LED pulse operation is about 4.8 kHz and its duty is less than 10%.

In case of the lamp LED, the source distances far from one detector are 5, 10, 15, 20, and 25 mm, respectively. The applied current of each LED was 80 mA.

For the construction of chip LED, it slightly differs from that of lamp LED. The light sources are separated from one Si detector at the different distances of S1(5 mm), S2(10mm), and S3(20 mm). As the SD increases, so the detected intensity rapidly decreased. Then we used the multi-LEDs remaining the same distance from the center of the detector at SDs of 10 mm and 20mm.

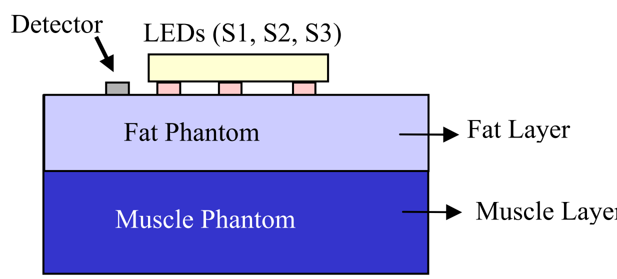

Fig. 3. Schematic diagram for two-layer tissue phantoms experiment.

IV. RESULTS AND DISCUSSIONS

4.1. Monte Carlo Simulation

In our Monte Carlo simulation schematic, each layer of the model structure was infinitely wide. The thickness of the fat layer was varied from 2 mm to 30.0 mm, with a step of 2.0 mm. The refractive indices of the fat and muscle layer both were set as 1.37. The NA and diameter of the source were 0.5 and 2.5 mm, respectively. The separation between the source and detecting fiber were varied from 5 mm to 40 mm. The photon numbers were 10^5. Figure 4, 5 show the simulation results on the detected diffuse reflectance as a function of fat thickness at 770 nm.

Fig. 5 and Fig. 6 indicate the relationship between the fat thickness and the detected diffuse reflectance at 770 nm for the simulation results and the phantom experiment, respectively. When the fat thickness increases, the detected diffuse reflectance increases. This can be explained by the fact that fat has a property of high scattering and low absorption, while muscle has high absorption. It is also shown that the diffuse reflectance of simulation results is similar with that of experimental results.

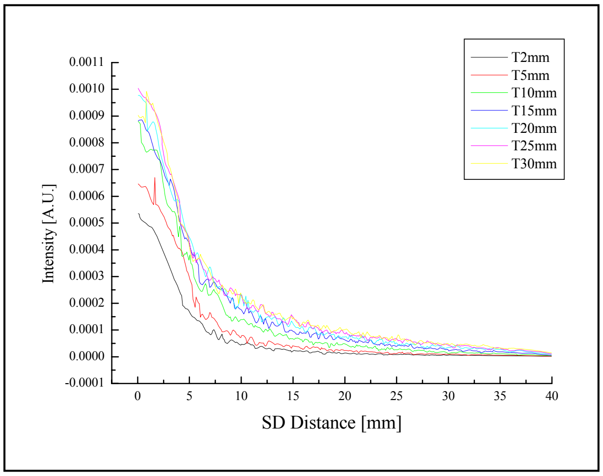

Fig. 4. The simulation results of the reflected intensity for different fat thickness as a function of SDs.

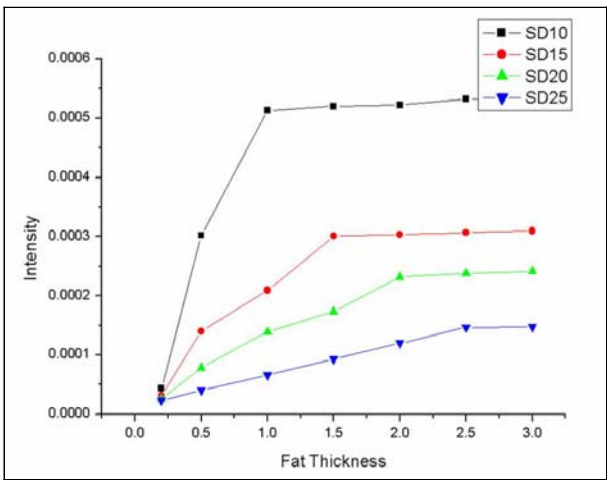

Fig. 5. The simulation results of the detected intensity for different SDs as a function of fat thickness from 0.2 cm to 3 cm.

4.2. Phantom Experiment of Lamp LED

First we investigated the sensor module which consists of one detector and light source of lamp LED (770 nm, viewing angle 20 degree, 3 mm round diameter) at the different SDs. The LEDs is in series arrayed with the same interval of 5 mm from one detector. The maximum distance between detector and source is 25 mm.

At this experiment, the same operation current of LED are applied at the five SDs. Fig. 6 shows the detected intensity for the different SDs as a function of fat thickness.

Because we measured all intensity back-scattered at the same gain, the intensity at SDs of 20 mm and 25 mm is mush lower than those of SD of 10 mm and 5 mm (not shown in the Fig. 6). When the fat thickness increases, the detected diffuse reflectance slowly increase for SDs (15 mm, 20 mm, and 25 mm). This is due to the fact that the fat of human body has a property of high scattering and low absorption, while the muscle has high absorption as shown in Table 1. We can not find the particular things for the SD of 15 mm, 20 mm, and 25 mm according to the increase of fat thickness. The variation of detected intensity is very similar.

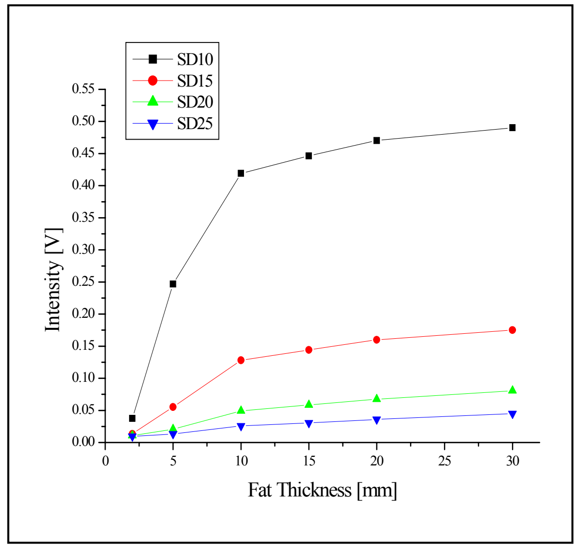

Fig. 6. The detected intensity for the different SDs as a function of fat thickness using Lamp LED.

For the SD of 5 mm not shown in Fig. 6, the detected intensity is rapidly increased until the fat thickness of 10 mm. After 10 mm thickness, it saturated as the fat thickness increase. We can estimate that the measurable fat thickness is maximum 10 mm at SD of 5 mm.

4.3. Phantom Experiment of chip LED

Second we tested the sensor module which consists of one detector and light source of chip LED (770 nm). The light sources (770 nm, chip LEDs, viewing angle 120 degree) are separated from one Si detector at the different distances of S1(5 mm), S2(10mm), and S3(20 mm). As the SD increases, so the detected intensity rapidly decreased. Then we used the multi-LEDs remaining the same distance from the center of the detector at SDs of 10 mm and 20mm. The cycle of LED pulse operation is about 4.8 kHz and its duty is less than 10%.

We adjusted the gain of the amplifier so that the detected intensity (V) at fat thickness of 30 mm shall be included within the range of maximum 3 V. The applied current of each LED was less than 70 mA.

The all back-scattered intensity was measured at LED driving current of 60 mA. Fig. 7 shows the reflected intensity variation as a function of fat thickness at a three different separations between source and detector. As shown in Fig. 7, the used numbers of LEDs is different. The numbers of LED for the SD of 5 mm, 10 mm, and 20 mm are one, three, and five, respectively. The distance from the detector to the multi-LED sources is the same. Also the amplifier gain for the SD of 5 mm, 10 mm, and 20 mm are 1, 1.5, and 5, respectively. As a result, the measured all intensity is within 2 V even though the fat thickness of 30 mm.

The result is very similar with those of lamp LED experiment. For the SD of 5 mm, the detected intensity is rapidly increased until the fat thickness of 10 mm. After 10 mm thickness, it saturated as the fat thickness increase. For SD of 10 mm, we can expect that the maximum measurable thickness shall be approximately 20 mm.

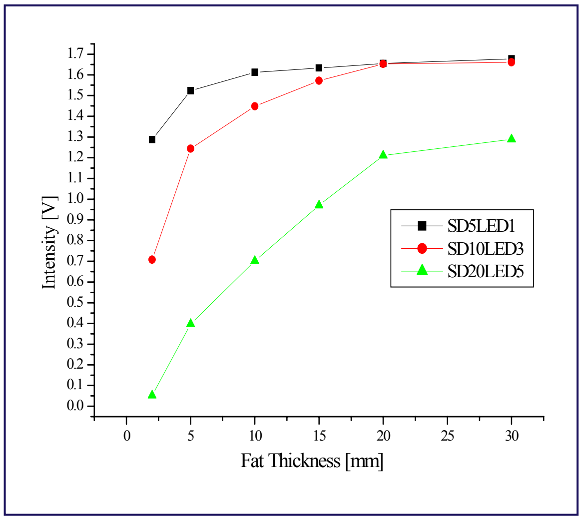

Fig. 7. Reflected intensity variation for the three different separations between source and detector as a function of fat thickness.

Further, when we combine the three SDs of 5, 10, and 20 mm, we expect the fat thickness over 30 mm can be measured. To investigate the influence of LED power, we measured the reflected intensity at different LED power with the three LEDs and the five LEDs for the same SD of 20 mm and the same amplifier gain, respectively.

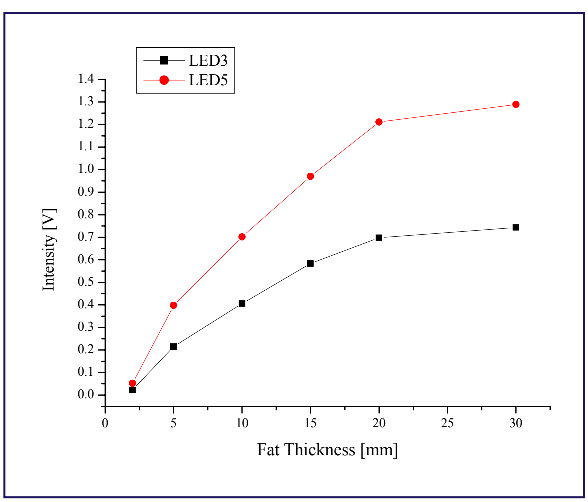

Fig. 8. Reflected intensity variation on the numbers of LEDs as a function of fat thickness at a fixed SD of 20 mm.

At this test, all hardware conditions except for the numbers of chip LED, are the same. As shown in Fig. 8, the reflected intensity from the five LEDs is to some degree larger than that from the three LEDs. It can be seen that even though the space limitation of sensor module is critical parameters, the improvement of the resolution and signal to noise ratio shall be done with the addition of LED numbers. From the reflected intensity fitting results of Fig. 9, it can be shown that each error of fitting results is very low. It is result of each fitting from fat thickness 0 mm to 20 mm and from fat thickness 20 mm to 30 mm. The former is the first order fitting and the latter is the second order fitting result.

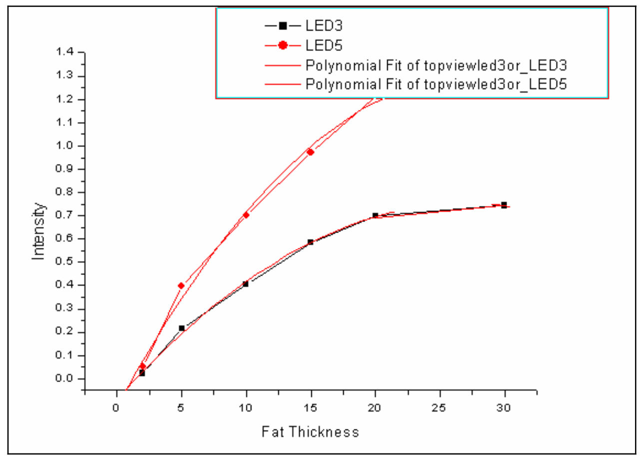

Fig. 9. Reflected intensity fitting results on the numbers of LEDs as a function of fat thickness at a fixed SD of 20 mm.

In summary, we present the possibility of fat thickness measurement by means of the pulse operation of lamp LED and miniaturized chip LEDs (770 nm) using the two-layer tissue phantoms. It is also shown that the simulation results agree with the experimental results well.

Further validation of this study using the chip LEDs with low power compared with that of lamp LED should be more advanced through the clinical testing on human bodies.

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