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Optical Fiber Near Infrared Spectroscopy for Skin Moisture Measurement

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1. Introduction

Skin covers the entire human body and function as shield from various types of external stimuli, damage and also from loss of moisture. The main characteristic factors for protecting the body and assisting in motion are the softness and pliability of skin (Obata and Tagami, 1990). These factors are dependent on the amount of moisture available in the stratum corneum, which is the outermost layer of skin. Modification in the amount of water content of the stratum corneum may lead to significant consequences to the functional properties of human skin. It is essential to retain sufficient moisture in the stratum corneum for healthy skin since the water level in this superficial layer of the human skin are of the utmost importance in determining many of its properties (Suh *et al*, 2005). Many instruments have been developed for studying skin physiology and among these applications, measurements of moisture in stratum corneum or sometimes also referred as hydration is one of the fundamental in the study of biophysical properties and function of the skin barrier (Fluhr et al, 1999). The most well-established technique to measure water content in skin is based on measuring electrical properties such as capacitance and alternating current conductivity on the skin surface (Arimoto *et al*, 2005). However, optical fiber near infrared spectroscopy technique has emerge as a popular substitute to conventional measuring methodology in various field of study including environmental monitoring, agricultural and food product quality analysis and also in medical, particularly skin health analysis. This mainly due to the technique which is seen to be able to produce measuring instruments that are non-destructive, portable, low cost, fast and easy operation besides having high precision and reproducibility. The integration of optical fiber probe into the spectroscopy system has added the flexibility of measurement and the fiber design itself can serve into raising the efficiency of measurement. For skin moisture measurement, one of the advantages of applying optical measuring technique is that the interface of optical fiber probe does not necessarily have to be made to contact the skin surface. Therefore, non-occlusive measurements can be made. To cater for the increasing interest in the development of optical fiber spectroscopy system, this chapter will present the existing application of upper range of NIR (1100-2500nm) and the possible application of lower range of NIR (700-1100nm) particularly 970nm in the measurement of skin moisture content.

2. Overview on skin pathology and moisture content

Human skin consists of epidermis and dermis and covers the entire body and function as protection from various types of external stimuli, damage and from moisture loss as well as assisting in motion through the skin softness and pliability (Obata and Tagami, 1990, Woo *et al*, 2001). These characteristics are reliant on the amount of moisture available in the stratum corneum, the outermost layer of skin (epidermis) and are controlled by the barrier function that maintains adequate water content in the skin layer. Therefore, changes in the water content of the stratum corneum have important effects on the functional properties of human skin. To sustain a healthy skin, it is very important to maintain sufficient moisture in the stratum corneum (Suh *et al*, 2005). Stratum corneum is about 10-40μm thick and is composed of partially flattened and keratinized layers, except on palms and soles. It is also moderately dehydrated cells in a lipid matrix. Below the stratum corneum is the epidermis with about 100-200microns thickness. Below epidermis is the dermis with about 2-4mm thickness. Skin is more hydrated at the deeper layers. In general, the increase in tissue hydration rate can be influenced by the increase in relative humidity (Martin, 1993). If the health of the stratum corneum is not maintained during environmental changes, the efficiency of the barrier and moisture-maintaining functions of the skin may drop. Consequently, the skin will become easily dried, roughened and even more at risk to infection. Therefore, it is crucial to sustain adequate moisture in the stratum corneum for healthy skin (Woo *et al*, 2001). It is not necessarily to characterize dry skin as lacking in moisture. Dry skin is more often considered to have a rough and uneven surface that efficiently scatters light, leading to a dry and matte appearance of the skin. Climate, cleansing age or heredity may lead to normal dry skin. Water loss in skin can be reduced by applying moisturizer that function by creating a barrier to surface evaporation. This will create a smoother, softer feel to the skin and to improve the appearance of the skin (Martin, 1993). Skin moisture and thickness may vary according to anatomical body site, age, gender and sun exposure. The thickness of the skin for adults may vary from a few millimetres at the eyelid until up to a centimetre at the foot sole. Majority of the current methods used for evaluating skin and diagnosing skin diseases are subjective, time consuming, expensive and invasive. Improvement in non-invasive and objective diagnostic methodology would be valuable from an economic point of view as well as to quality in health care (Boden *et al.*, 2008).

Abnormal changes in the skin are common indicator of many diseases. There is a growing interest in the development of non-invasive methods for diagnosing various illnesses through skin measurements (Boden *et al*, 2008). Since the last three decades, skin bioengineering is a growing field in cutaneous research. Various instruments have been introduced for skin physiological analysis and in experimental trials. The measurement of stratum corneum hydration is one of the primary importances in the study of the biophysical properties and function of the skin barrier (Fluhr *et al*, 1999). Two non-invasive skin characterization techniques suggested for the diagnosis and monitoring of various markers of diseases are near infrared (NIR) spectroscopy and skin impedance (IMP). These two techniques have been applied for diagnosis of neuropathy, blood glucose levels, microcirculation in patients with diabetes and radiotherapy induced erythema (Boden *et al*, 2008).

NIR spectroscopy application for the measurement of water content in skin has long been developed. For clinical diagnostics and for the evaluation of the efficacy of cosmetics products, an exact water content measurement technique is required. For instance, an easy

measurement method of water content is essential for atopic cases (Arimoto *et al*, 2005). Hansen and Yellin (1972) have applied NMR and IR to determine that at water content lower than 10%, the water present was tightly bound, most likely due to the polar sites of the proteins. At water contents in between 10-40%, they found less tightly bound water and suggested it was hydrogen-bonded to the protein-bound water. For water content greater than 50%, the water resembled the bulk liquid. The effectiveness of skin moisturizers is generally verified through indirect measurements of hydration such as high frequency electrical conductivity, TEWL (transepidermal water loss), biomechanical measurements and subjective clinical evaluations. However, all these techniques suffer from low precision and no well-understood relationship to water content (Martin, 1993).

3. Skin moisture measurement

There are several techniques that have been conventional used as skin moisture measuring devices. According to Suh *et al*, 2005, a various techniques have been developed for measuring stratum corneum water content, including electric conductance such as by transepidermal water loss (TEWL) which measures the rate of evaporation of water from the skin surface, attenuated total reflectance (ATR) fourier transform infrared or ATR-FTIR and confocal raman spectroscopy. However, TEWL is very sensitive towards environmental changes and requires several minutes to retrieve stable readings. This can be seen through sample measurement conducted using DermaLab TEWL module (Cortex Technologies, Hadsund, Denmark) as shown in Figure 1. The probe comes together with humidity and temperature sensor. The measurement will stop and the final result will be displayed when the value of standard deviation (SD) reaches the user-defined value which for this example is 0.3.

Fig. 1. TEWL measurement.

ATR-FTIR measurements on the other hand rely on the ambient conditions and are limited to the uppermost stratum corneum. ATR-FTIR method is neither rapid nor portable (Suh *et al*, 2005). ATR measurements on the other hands require occlusion of the skin, which can

affect the measurement of water content. The magnitude of contact between the internal reflectance element and the skin is not constant, especially after the skin is treated with a lotion which may alter the refractive index of the skin upon hydration, hence affecting the depth of penetration of radiation (Martin, 1993).
Arimoto *et al* (2005) stated that the most established technique to measure water content in skin is through the measurement of electrical properties such as capacitance and alternating current conductivity on the skin surface. Table 1 shows the current available commercial instrument for skin moisture measurement and its parameters.

Instrument	Technique	Frequency	Unit
Corneometer CM 820	capacitance	40-75 kHz	Arbitrary Units (AU)
Corneorneter CM 825	capacitance	mean frequency of 1 MHz (1.15 MHz - very dry medium; 0.95 MHz - very hydrated medium)	Arbitrary Units (AU)
Skicon 200	conductance	3.5 MHz	psiemens (pS)
Nova DPM 9003	impedance based capacitance	up to 1 MHz	Arbitrary Units (AU)
DermaLab - Moisture Module	impedance-based capacitance	100 kHz	μsiemens (μS)

Table 1. Parameters of different instruments for moisture measurement (Fluhr *et al*, 1999).

The skin moisture sensor design consists of two metal plates which are isolated by an isolating medium, called a dielectric, as a capacitor. When a voltage source is connected to the capacitor, electrons will start to flow from one plate over the terminal to the other plate. The capacitor will store the electric charge. The quantity of charge stored is called capacitance. The capacitance of the capacitor will increase when material is introduced between the capacitor plates. Vacuum has a dielectric constant less than 7 while water dielectric constant is approximately 81. Therefore, the changes in the amount of water in the measured skin lead to a modification of capacitance of the measuring capacitor. For CM 825 system from Courage and Khazaka, its probe is electrically isolated from the measuring electronics and hence eliminating the influence from ground capacitance and salty skin surface. Total electrical opposition to the flow of an alternating current is defined as impedance. Resistance (R_x), capacitance (C_x) and frequency (f) contribute to the impedance (Z) through the following equation (Fluhr *et al*, 1999):

$$Z=(R_x^2 + [1/2\pi f C_x]^2)^{1/2} \quad (1)$$

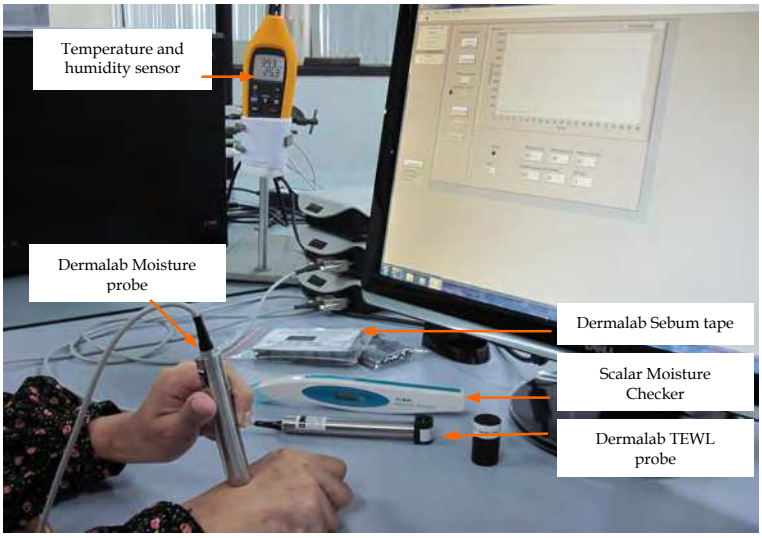
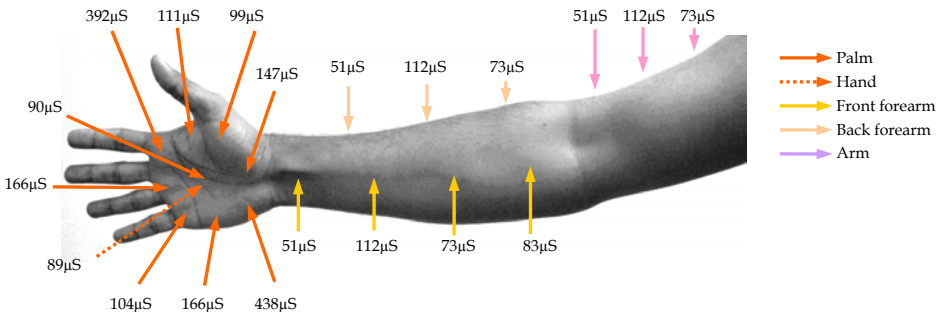


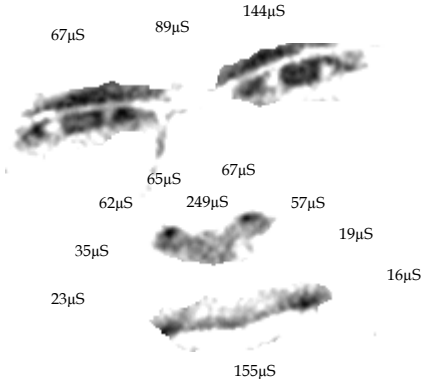
Fig. 2. Skin moisture measurement technique and other skin analysis modules in Spectroscopy Laboratory. Universiti Sains Malaysia.

Electrical conductance is measured when a constant frequency alternating current is applied to skin. The skin moisture is then calculated from the electric conductivity that is dependent on the water content of the skin (Woo et al, 2001). Conductance is identified to correlates well with the superficial portion of the stratum corneum even the electrical field on the stratum corneum is non homogeneous (Tagami, 1994). Nonetheless, this technique has limitation. Moisture measurement using electric conductance devices are easily affected by the amount of electrolytes in the skin and by the contact area of the probe's surface on the skin. These devices are also influenced by external temperature and humidity. This requires the devices to be kept at a constant temperature and humidity. Besides, the amount of electrolyte that the skin contains can alter the conductance value with no regard to water content (Woo *et al*, 2001). Figure 3 shows the skin moisture distribution across a person (a) right upper limb and (b) face measured at room temperature of 22^{o}C and relative humidity of 44.1% using Dermalab moisture module from Cortex Technologies (Hadsund, Denmark). Cortex Technologies suggested moisture content below 150µS as very dry, between 150-300 µS as dry and above 300µS as skin with sufficient amount of moisture.

There is a non linear relationship between electrical conductance and water content. However, this is depending on the binding state of water molecules to the keratin chainsthat is described by the water sorption isotherm. Berardescal stated that there has been regular in the literature to define three types of water according to their strength of binding to the keratin namely *"tightly bound water"* for water contents from in between 0% and 7%, *"bound water"* between about *7%* and *35%* and *"free water "* which is above 35%. This division is generally helpful and can be considered simplistic on the basis of more detailed theory. Due to the variation in water binding strength, there is no direct proportionality between total water content and electrical conductance. Substances or treatments that interact with the keratin-water network may modify conductance without changing the water content of the sample (Berardescal, 1997). Berardescal (1997) disagree with the approach to refer to the electrical *"capacitance"* of the skin without specifying the stimulating frequency and other



(a)



(b)

Fig. 3. Skin moisture distribution across a person (a) right upper limb (b) face.

experimental settings used to make the estimate. "*Capacitance*" term generally referred by many literatures in similar study is not actually electrical capacitance in the usual scientific and engineering sense since it is frequency dependent, in contrary to the true electrical capacitance.

Dermalab moisture module has the capability of showing the result of moisture measurement in two ways, either a single instantaneous data or continuous measurement. For the continuous measurement where the probe is pressed onto the skin for a few cycle of measurement, the measured data will show increment through time as shown in Figure 4. This is due to occlusion which enhances stratum corneum hydration (Zhai and Maibach, 2001). The application of NIR spectroscopy through optical fiber probe has shown a promising solution to this problem since the measurement of moisture can be performed without the need for the probe to be in contact with the skin surface or with very minimum contact pressure.

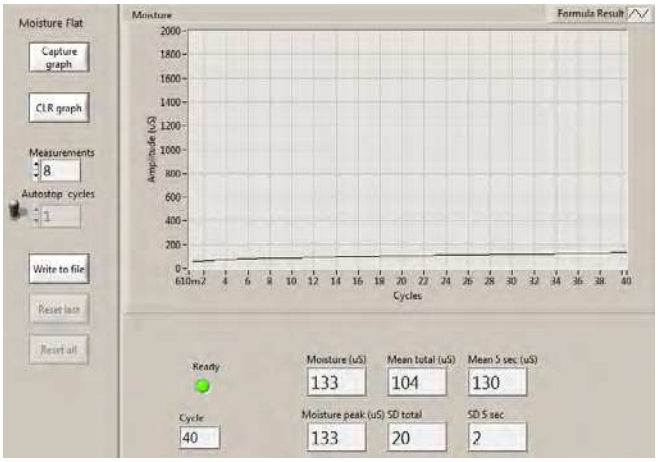


Fig. 4. Occlusion during continuous skin moisture measurement.

4. Optical fiber NIR spectroscopy technique (1100-2000nm)

Near Infrared (NIR) spectroscopy technique are capable of providing information on constituent's concentration. NIR spectroscopy was first developed in the 1980s by Norris *et al*. in analysis of agricultural products (Williams and Norris, 2001). Measuring oxygen saturation of hemoglobin is one of the most successful NIR spectroscopy applications in the field of biomedical engineering. There are also large interests of NIR application in non-invasive blood glucose measurement even though most of them are not clinically reliable until today (Arimoto *et al*, 2005). NIR region are the most prominent for water absorption bands. It allows direct moisture measurement at a certain range of wavelength. This is due to overtones and combinations of the fundamental vibrations that are active in the NIR range and taking place from hydrogen covalent bonds (Suh *et al*, 2005). Water spectrum dominating NIR spectra with overtone bands of the O-H bonds with peak absorption at 760 nm, 970 nm (due to the second overtone of the O-H stretching band), 1190nm (the combination of the first overtone of the O-H stretching and the O-H bending band), 1450 nm first overtone of the OH-stretching band and a combination band), and 1940 nm (combination of the O-H stretching band and the O-H bending band) (Luck, 1974, Nicolai *et al*. 2007).

Spectroscopic measurements are directly related to water content and can be represented by a classical Beer's Law relationship through the absorption of the hydroxyl moieties. The basic working relationship of the light attenuation can be stated by the exponential law of absorption. The differential absorption can be expressed as:

$$dI = - \alpha I_o \, dx \tag{2}$$

Where α is the absorption coefficient and is a measure of the rate of loss of light from the direct beam due to the dissolved and suspended substance within the water and the water itself. It is an inherent optical property. Upon integration from 0 to x, gives the exponential law of absorption:

$$I = I_o e^{-\alpha x} \tag{3}$$

0 is the starting point of the light passage through the absorbing medium. X is the length of the medium or the distance of light travel through the medium. I_o is the light intensity at point 0. Since the medium is a solution, the concentration, c is included. The absorbance of a sample is proportional to both concentration and the path length that light travels (Martin, 1993). Therefore, the equation becomes:

$$I = I_o e^{-\alpha xc} \tag{4}$$

However, based on the above mentioned, the attenuation of the light is not entirely due to the absorption of light energy, but to some extent, it is also as the result of light scattered to the other side by the particles of the solution (Jenkins and White, 1976). Therefore, the equation can be rewritten as:

$$I = I_o e^{-[\alpha a + \alpha s]xc} \tag{5}$$

One of the advantages of the usage of optical techniques for water content measurement is its flexibility. Non-occlusive measurements can be made using NIR technique since it is not necessarily for the interface of probe light to be made in contact with the skin surface. Moreover, a single measurement point technique can be expanded to a two-dimensional area by using an image sensor with a series of spectral filters (Arimoto *et al*, 2005). Eun-Jung Suh (2005) concluded the following advantages that NIR spectroscopy has for biomedical applications:

i. it is a non-invasive and non-destructive analytical technique.
ii. One can use fiber optics for *in vivo* measurements.
iii. It is possible to monitor not only the surface of biological tissues but also their insides because NIR light penetrate into the tissues.

An *in vitro* spectroscopic experiment using porcine skin has been reported by Walling and Dabney (1989). Study on the differences of the absorption spectra between free and bound water has been conducted by Martin (1995). Martin has successfully showed that the absorption spectra can distinguish four types of water in skin. Those are water associated with the lipid phase within the stratum corneum, bulk water below the stratum corneum, secondary water of hydration on stratum corneum keratin and primary water of hydration on stratum corneum keratin. Also in the work, Martin (1995) has experimentally obtained profiles of the measurement depth in diffuse reflectance spectroscopy. Attas *et al* (2002) have conducted an experiment using near infrared spectroscopic imaging with wavelength between 960nm and 1700nm for in-vivo skin hydration measurements. The system is the combination between a near infrared camera with a liquid-crystal tunable filter (LCTF) to acquire spectral images at multiple narrow wavelength bands. The proposed system produces two-dimensional skin hydration mapping system. This technique enables the reading of absorption distribution over the skin surface. The use of mid-infrared range of wavelength in attenuated total reflectance (ATR) spectroscopy is also an efficient technique to assess skin water content. The penetration depth of mid-infrared signal is much shallower than the NIR diffuse reflectance. This is because the ATR measurement utilizes evanescent wave that localizes on the surface of the ATR crystal (Arimoto et al, 2005). Good correlation between NIR absorbance and water content has been showed empirically through *in vitro* and *in vivo* technique. This is an additional advantage of NIR analysis over other measurements.

Suh *et al* (2005) have conducted an experiment to evaluate water content in stratum corneum using a FT-NIR spectrometer with a fiber-optics probe. This technique is considered rapid

and non-destructive. This serve as an advantage over other conventional NIR instruments with integrating sphere or moving grating that are hard to move and handle for practical use. The use of optical fiber probe is valuably being used for clinical diagnostics. The correlation between skin water contents and the NIR values have been investigated by using the conventional capacitance method as the reference. In order to find a robust model for skin moisture measurement, they have used three regions of NIR wavelengths which are 1130-1830nm, 1200-1670nm and 1380-1600nm. The calibration results of their experiment are shown in Table 2. The results presented also include NIR spectral treatment through first and second derivatives techniques. The first derivative will removes the baseline or offset produced by the scattering effects. On the other hand, the second derivative eliminates the gradient of the spectrum (Owen, 1995; Dabakk *et al*, 1999).

Spectral Range (nm)	Spectral Treatment	No. Factors	SEC (%)	SEP (%)
1130-1830	None	7	3.82	3.98
	1D	2	5.52	6.17
	2D	2	4.65	7.21
1200-1670	None	6	4.35	4.90
	1D	3	5.06	7.35
	2D	3	4.56	9.20
1380-1600	None	2	7.43	6.53
	1D	1	6.95	7.50
	2D	3	4.90	9.63

Table 2. Calibration results for water content measurement using FT-NIR conducted by (Suh *et al*, 2005).

In the near infrared application on skin conducted by Suh *et al* (2005), water molecules show two clear absorption bands at 1450 nm and 1940 nm. The peaks absorbances are sufficiently high and can easily be identified in the spectrum of the human skin. The absorption band around 970nm is considered weak, produces higher light scattering effect which is mainly due to short wavelength and there is too much penetration into the inner skin that make it not valuable for the measurement of water content in the stratum corneum. Starting from 1100nm, the NIR detector is changed from silicon to a lead sulphide (PbS) detector. The development of a calibration model is suggested at the spectral range above 1150nm.

Woo *et al* (2001) have presented a comparative evaluation between the performances of conventional scanning-type spectrometer using NIRSystems model 6500 (Foss NIRSystems Inc., Silver Spring, MD) and portable NIR system, a newly integrated system equipped with an optical fiber using microchip technology. The fiber-optic probe used with the portable NIR system has a total of nine reflectance fiber-optic bundles. Eight surrounding bundles are used for illuminating the sample while one at the center of the bundle for receiving the light reflected from the sample. A 0.3-mm gap was maintained between the fiber terminal and the skin surface in order to receive the light reflected light effectively and to avoid contacting the skin surface directly. This is done by using a holder that could strongly support the fiber-optic bundle to obtain a stable spectrum. They identified in the experiment that the calibration results efficiency were fairly similar between both spectrometers. The calibration results for water content measurement using portable NIR system is shown in

Table 3. It is also identified that better calibration result was acquired when second derivative spectra is applied on the 1150-1650nm wavelength range, with SEC value of 5.1% and SEP value of 5.6% (Woo *et al*, 2001).

Spectral Range (nm)	Spectral Treatment	No. Factors	SEC (%)	SEP (%)
1150-1650	None	13	4.5	4.9
1150-1650	1D	9	4.7	5.0
1150-1650	2D	8	4.7	5.3
1350-1500	None	8	6.6	6.7
1350-1500	1D	11	5.9	6.9
1350-1500	2D	10	6.3	7.4

Table 3. Calibration results for water content measurement using Portable NIR System conducted by Woo *et al* (2001).

5. Optical fiber NIR analysis at 970nm

5.1 NIR reflectance spectroscopy

The range of NIR signal between 1100nm to 2500nm is commonly being suggested for biochemistry application, typically for quantitative analysis. Nonetheless, lower NIR region in between 700nm to 1100nm have also been used widely in physical analysis as well as in analytical chemistry. For instance, International Organization for Standardization, ISO 7027 (1990) has suggested LED with peak wavelength at 860nm to be used as illuminating radiation in water turbidity measurement. In fruits quality analysis, range of NIR wavelength in between 700-1100nm has widely been applied for the measurement of soluble solids content and acidity (Nicolai *et al*, 2007). This section presents an overview on spectroscopy skin analysis using lower range of NIR wavelength and the focus will be given particularly for wavelength at 970nm.

The NIR spectral representation for different parts of body may be different due to the variation of skin thickness and surface roughness that will define the magnitude of diffuse and specular reflectance. To understand this further, spectroscopic implementation can be conducted on a person by collecting spectral signature from different part the person body. The spectroscopic instrumentations used for the measurement in this example are from Ocean Optics (Dunedin, Florida, USA) as demonstrated in Figure 5. The value of reflectance was measured using Spectrometer (650-1100nm). Other custom setup prior to the measurement includes integration time = 10ms, spectra averaged = 30 and boxcar smoothing = 1. Light source used was HL-2000 tungsten halogen lamp with spectral emission between 360nm to 2000nm and colour temperature of 2960K. The reflectance spectrum of the halogen lamp was calibrated using WS-1-SL, a white diffuse reflectance standard with above 99% reflectivity from 400-1500nm and above 96% reflectivity from 250-2000 nm. Reflectance probe used in this measurement is R600-7-SR-125F, a standard reflectance/backscattering probe with 6 illumination fibers around 1 read fiber. Each fiber has a core diameter of 600μm.

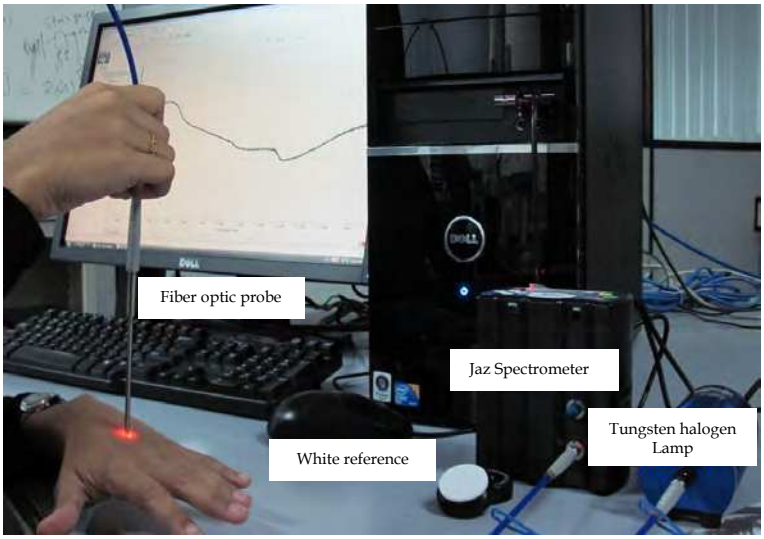


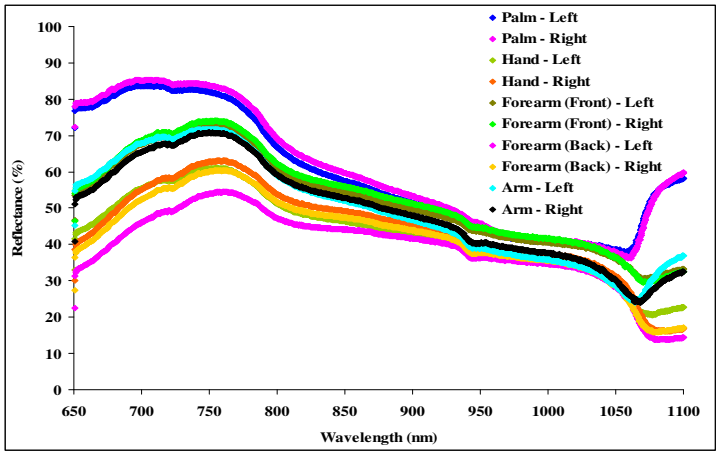
Fig. 5. Spectroscopy experimental setup.

Figure 6 (a) shows the NIR spectra of a person right upper limb and Figure 6 (b) shows the spectra of a person face. The patterns of spectra for every parts of the upper limb appear to be the same except at wavelength above 1050nm where the reflectance increases in its intensity for palms, front forearms and arms. While the reflectance of hands and back forearms drop further beyond 1050nm.

From the measurement of reflectance spectra shown in Figure 6 (a) and (b), it is identified that the reflectance intensity varies naturally according to different body parts. The high reflectance variation may greatly hide the absorbance magnitude that comes from moisture content of the skin. Therefore, it is important to localise the calibration equation of the skin moisture measurement based on body part, unless if the optical fiber probe is designed in such away that the penetration depth is only within the stratum corneum.

5.2 Skin optical simulation through ASAP - RSM

ASAP (Advanced Systems Analysis Program) is an optical engineering software developed by Breault Research Organization, Inc. that can be used to simulate optical system with 4 major steps in its application; build the system, create sources, trace the rays and perform analysis. RSM (Realistic Skin Modelling) provides interactive scripts for modelling light propagation, absorption and scattering in skin. RSM accurately replicates the absorption and scattering properties of human skin. The absorption and scatter characteristics of each layer of tissue are calculated separately. This is done by taking into consideration the different chromophore concentrations in each layer such as melanin, hemoglobin, water, bilirubin and beta carotene. RSM can function with the range of source wavelength between 250nm and 1000nm (Breault Research Organization, Inc, 2008).



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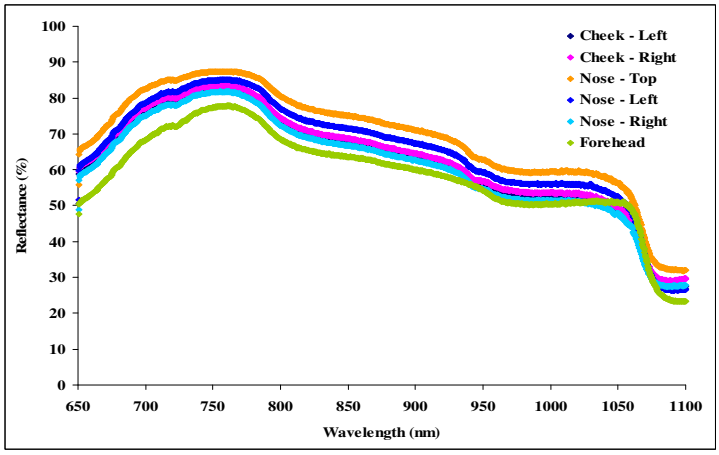

(b)

Fig. 6. NIR spectra from a person (a) upper limb (b) face.

ASAP-RSM software can be used to address the issue related to low absorptivity, high scattering and deep penetration of NIR wavelength at 970nm. Figure 7 shows the results of simulation when a circular beam with 1000000 rays are illuminated perpendicularly onto a skin surface with variation in the amount of water content in the stratum corneum with 15µm of thickness. The relative volume absorption of NIR radiation increases with higher amount of water content in the stratum corneum. The peak responsivity is identified at 970nm, indicated by the graph steepest gradient produced if compared to other neighbouring wavelengths of 950nm, 960nm, 980nm and 990nm. Figure 8 shows the image of the magnitude of volume absorbance at 970nm, taken at 10µm depth from the skin surface.

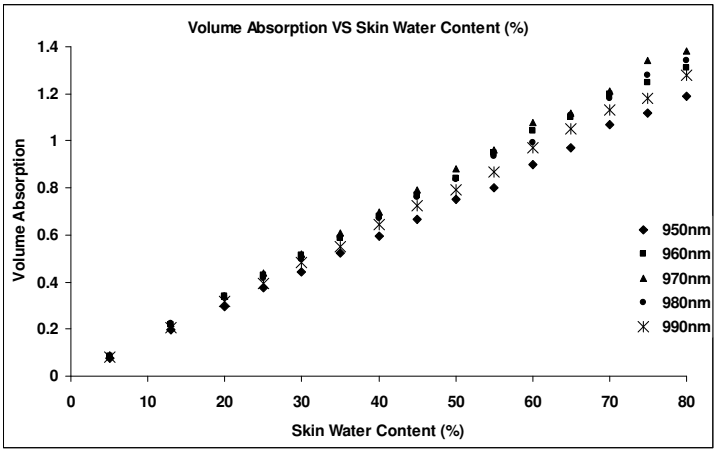

Fig. 7. Relationship between relative volume absorption and water content in stratum corneum for 5 different near infrared wavelengths.

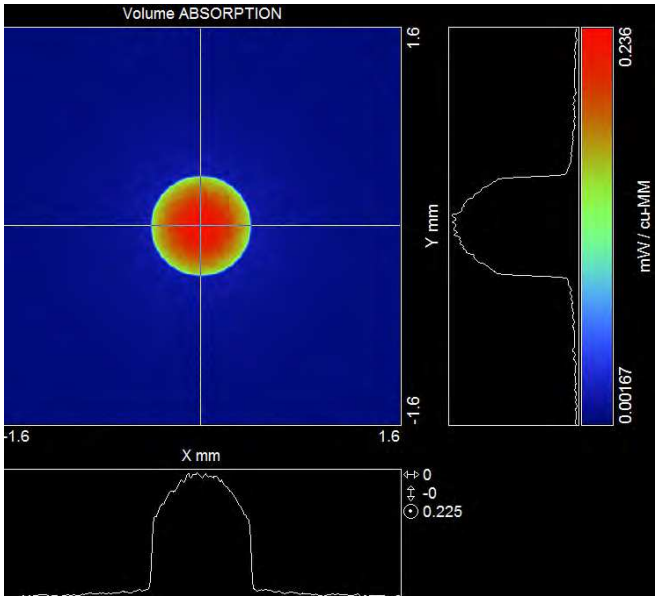

Fig. 8. Volume absorbance at 970nm, taken at 10μm depth from the skin surface.

Figure 9 shows in details the peak absorbance of water content for wavelength from 700nm to 1000nm. As has been proven by Figure 7, 970nm produces the peak absorbance for water content in stratum corneum. Wavelength at 760nm has a very weak peak absorbance for water content and can be seen slightly when compared with wavelength 700nm and 800nm.

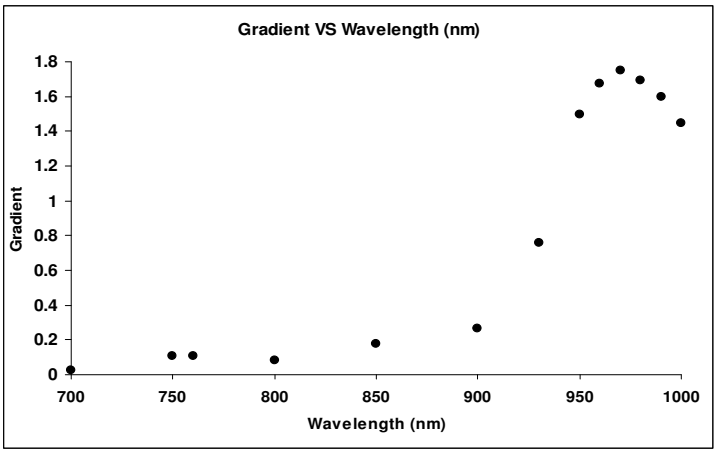

Fig. 9. Relationship between gradient (responsivity) and wavelength.

As has been stated by Suh *et al* (2005), the absorptivity of moisture at 970nm is very low while the scattering volume is high. Due to small thickness of stratum corneum, it is difficult to directly quantify its moisture content using a typical fiber probe configuration. Table 4 shows the absorption coefficient, μ_a (mm^{-1}) for 6 different percentages of moisture content in stratum corneum. In the simulation through RSM as shown in the example within this chapter, the scattering coefficient, μ_s for stratum corneum is $8.8794mm^{-1}$ and anisotropy factor (g), the average directional cosine of the scattered light is kept constant at 0.9, indicating that the tissue is highly forward scattering.

Moisture content (%)	5	10	15	20	25	30
Absorption Coefficient, μ_a (mm^{-1})	0.00226	0.00453	0.00679	0.00906	0.01132	0.01359

Table 4. Moisture absorption coefficient.

The typical implementation of spectroscopy analysis is fundamentally based on detection of broad spectrum from ultraviolet to near infrared. This can be done by illuminating the sample with light source with broad spectral wavelength. The resultant spectrum will then be detected by spectrometer that consist of grating, to disperse the incoming signal into its respective wavelength and optically allowing it to fall on a single or two photodiode array, depending on the effective range of wavelength that the instrument is required to interpret. Fiber optic probe is commonly being used as light transferring medium between the light source and spectrometer. As has been discussed in the earlier section of this chapter, for a single spectroscopy application such as for the measurement of skin moisture content, only a single wavelength that usually response the best. To apply a large range of non-contributed wavelength for a simple spectroscopy measurement has unnecessarily increased the cost of operation. A single wavelength sensitivity spectroscopy system that making use of LED with a narrow wavelength with peak emission that corresponds the best with the composition of interest and photodiode with spectral responsivity matches the LED spectral emission will significantly lowering the cost of operation and directly suit the application.

Figure 10 illustrates the conceptual design of optical fiber sensor for skin moisture measurement using ASAP-RSM. The reflectance fiber probe is arranged in bifurcated configuration with each cable having a diameter of 1mm. The LED is 5mm type and illuminates its radiation from a cubical die.

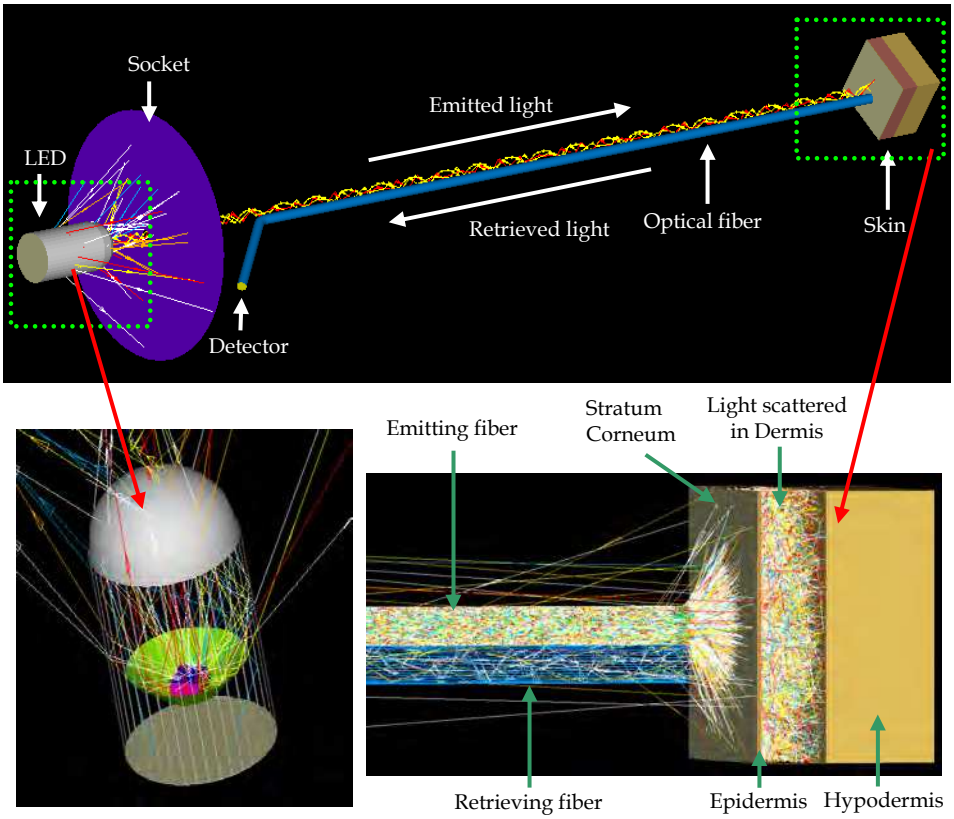

Fig. 10. Conceptual design of optical fiber sensor for skin moisture measurement.

In the application of ASAP-RSM, to obtain good results for analysis, highest possible number of rays traced during simulation is desirable. This will require a powerful computer with high processing speed and memory capacity. With smaller number of rays to be traced in the optical system, the small value of absorbance will drown within high intensity of light scattering, thus, no meaningful results can be generated. An optical model has been developed with one retrieving fibers allocated in the middle of two emitting fibers. All fibers used are having core diameter of 1mm. Light source (wavelength=970nm) with emitting diameter of 1mm and 45^{o} angle of emission has been directed through both emitting fibers with 3 millions total number of rays. The probe is placed right on top of the skin surface. The thickness of stratum corneum is set to 40μm. Using the existing optical parameters for all skin layers, no valuable results can be generated. When the absorption coefficients of water content are increased 100 times, then some useful results can be observed. This is

presented in Figure 11 where fluctuation of intensity still occur despite a good correlation is achieved with low root mean square error (RMSE) of 2.63%.

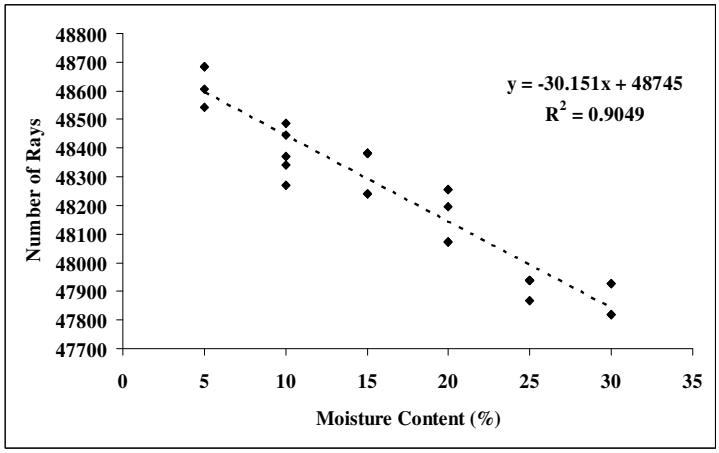

Fig. 11. Number of rays VS moisture content (absorption coefficient X100).

This simulation analysis has presented an early overview on possible application of 970nm in skin moisture measurement. The real challenge is to be able to produce an optical fiber probe that can minimize the high scattering effect from the radiation and ensuring very minimal amount of light penetrating deeper into the skin, beyond the stratum corneum. To put this implementation into being will enable the development of low cost optical fiber NIR sensor for skin moisture measurement.

6. Conclusion

This chapter has presented multiple experimental designs that are commercially available in the market such as impedance based design, within the clinical trial such as long NIR wavelength (1100-2500nm) and those that has possible venture into implementation such as lower range of NIR wavelength (970nm). The main aim of this continuous research is to be able to produce an optical fiber instrument that can minimise or to some extend eliminate any setback in the conventional implementation. Optical fiber NIR sensor has always be a promising technology as quantitative instrumentation for analytical science.

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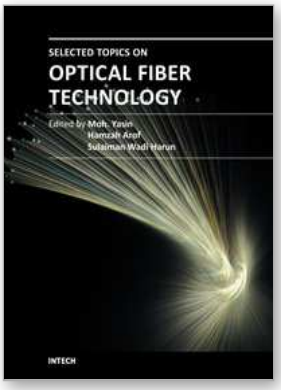

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This book presents a comprehensive account of the recent advances and research in optical fiber technology. It covers a broad spectrum of topics in special areas of optical fiber technology. The book highlights the development of fiber lasers, optical fiber applications in medical, imaging, spectroscopy and measurement, new optical fibers and sensors. This is an essential reference for researchers working in optical fiber researches and for industrial users who need to be aware of current developments in fiber lasers, sensors and other optical fiber applications.

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