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Analysis of Non-Invasive Fingerprint Thickness Based Authentication Method Utilizing Near Infrared Spectroscopy

Q A Tajul Ariffin[1], N Sulaiman[1]

[1]Faculty of Engineering, IIUM, 53100 Gombak, Selangor, Malaysia.

qamarulaiman@gmail.com, nadzril@iium.edu.my

Abstract. Fingerprints are a popular method of biometric based authentication. However, methods currently in use are susceptible to being bypass through the use of forgeries of the fingerprint pattern. Measuring the epidermal thickness of the fingerprint is a solution to the issue, as there are no current ways for a third-party to precisely replicate the thickness measurements. Near-Infrared Diffused Reflectance (NIR-DR) spectroscopy is the proposed method of measuring fingerprint thickness. Reflectance reading is taken at 5 specific wavelength points to generate a simplified plot for comparison. Thickness measurement is gauged by calculationg change in reflectance percentage between the 800-900nm range. Data gathered showed variation in the reflectance spectra that was unique to each subject. Application for a fingerprint thickness-based authentication method is plausible but require additional research with a larger population sample and looking into the effects of age and skin colour for their effect on epidermal thickness.

1. Introduction

Biometrics have become a popular tool for authentication as security shifts from detecting “what you know” to “what you have” [1]. Fingerprints are the most popular form of biometric authentication method due to its characteristics. The patterns of the fingerprint are formed from the ridges and valleys on the surface of the epidermal layer of the skin. As such, these patterns are unique from person to person, and are able to form specific features, called minutiae, that allows for easier identification and classification. The location of these ridges and valleys are caused by the location of the papillae, peg like bumps, that lie between the epidermal and dermal layer of the skin. The papillae [2] act as a permanent blueprint, ensuring that the fingerprint pattern is the same throughout a person’s life.

Fingerprint authentication methods functions through three stages. The first stage, data acquisition, determines how the system acquires the biometric information from the fingerprint. It’s then followed by feature extraction, where the system detects the unique features of the scanned fingerprint. Lastly, it goes through the matching process where the features of the scanned fingerprint are compared and authenticated against a stored database of other scanned fingerprints. Currently, there are three main methods of data acquisition in use, which are optical, capacitive and ultrasonic, function through some variation of detecting the location of the ridges and valleys on the fingerprint’s surface [3].

However, this is also a major weakness, since fingerprints naturally leave traces of their pattern on things they touch. Furthermore, with the advance in technology, high resolution cameras are now able to see the details of a person’s fingerprint from a single photo. A third party may be able to bypass an authentication system through spoofing [4] [5], where a duplicate of the fingerprint is created and used to “trick” the system into thinking it is being presented with the actual print. Coupled with a person’s fingerprints being permanent, having their pattern exposed puts them at risk in all fingerprint-based authentication systems. Thus, a more secure methods of fingerprint-based authentication are necessary.

This work is aimed at developing a novel method of authentication through the use of Near-Infrared (NIR) spectroscopy to measure the thickness of the epidermal layer as there is no current method for a third party to replicate the thickness of a person’s fingerprint. NIR spectroscopy has been successfully used for *in vivo* estimation of epidermal skin thickness and had detected variations in the epidermal thickness between fingers of different participants [6].

2. Research Methodology

NIR spectroscopy was selected for its viability in the use of thickness-based fingerprint authentication due to its non-invasive method of evaluating skin thickness. The measurement is conducted through the process of near-infrared diffused reflectance (NIR-DR).

In NIR-DR, a beam of light is projected onto an object’s surface. As the photons travel, some will be reflected by the surface, called specular reflection, while some will pass through into the object. While traveling within the object, the photons may be reflected internally as it comes into contact with materials that compose the layer, as seen in **Figure 1**. This process is called diffused reflection. The thickness of the object effects the amount of light that is reflected back to the sensor of the system.

The skin layer is composed of two layers, the epidermis and dermis layer, and an epidermis-dermis barrier exist between them. As photons go past this barrier, it becomes much less likely for the photon to reflect back to the surface, thus reducing overall reflectance.

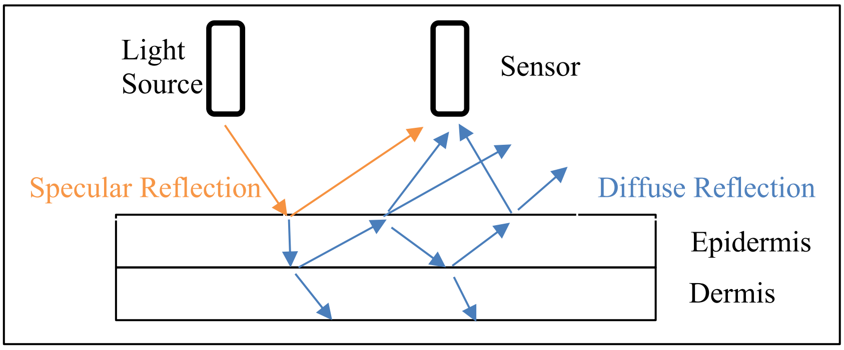

Figure 1: Diagram of how diffuse reflection works. The amount of light that is reflected back to the sensor is reduce as the photons scatter within the epidermis layer.

2.1. Experiment Setup

The experiment setup as show in **Figure 2** utilizes a NIR Spectrometer (Ocean Insight STS-NIR Miniature Spectrometer) and a halogen light source (HL-200). The devices are connected to a reflectance fiber probe (R400-7-VIS/NIR). The reflectance fiber probe is composed of seven fiber optic cables arranged in a circle. The six outer optical fiber are connected to the halogen light source, while the single central optical fiber is connected to the NIR spectrometer [6].

Light generated from the halogen source travels through the six outer-fibers until it comes in contact with the skin of a person’s fingertip. The light is reflected off the skin or is diffused into the epidermal layer. Some of the light is reflected to the central sensing fiber, which is then transmitted to the NIR spectrometer for data processing.

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2.2. Procedure

The experiment would measure the reflectance of each fingertip on both hands. Due to current real-world limitations, only 5 volunteers were able to contribute to the study at this point, giving a total of 50 measurements with no ethical issue. The spectra result of each fingerprint was evaluated along five wavelengths, 680±1 nm, 800±1 nm, 900±1 nm, 960±1 nm and 980±1 nm as these points would generate a simplified plot of the spectra.

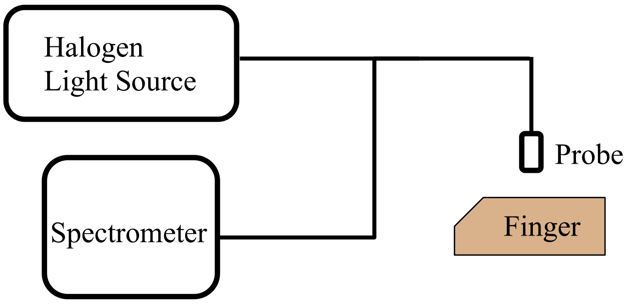

Figure 2: Schematic layout of the experiment

Using the methods stated, spectra scans measuring the reflectance of each finger for each of the 5 volunteers was recorded. The spectra of each person were then compared to the other for that specific finger. As shown in **Figure 3**, a graph of the reflectance reading of the left index finger of each of the 5 subjects, separated by color. The spectra of each fingerprint follow an overall shape, but the actual reflectance value varies from finger to finger. Hence, wavelengths 680nm, 800nm, 900nm, 960nm and 980nm were selected for evaluation as they would best generate a simplified plot that best reflect the shape of the original spectra, as seen in **Figure 4**. Additional comparison is performed on the spectra scan of each fingerprint of a single hand, as seen in **Figure 5**, to observe if epidermal thickness is unique from person to person or from finger to finger.

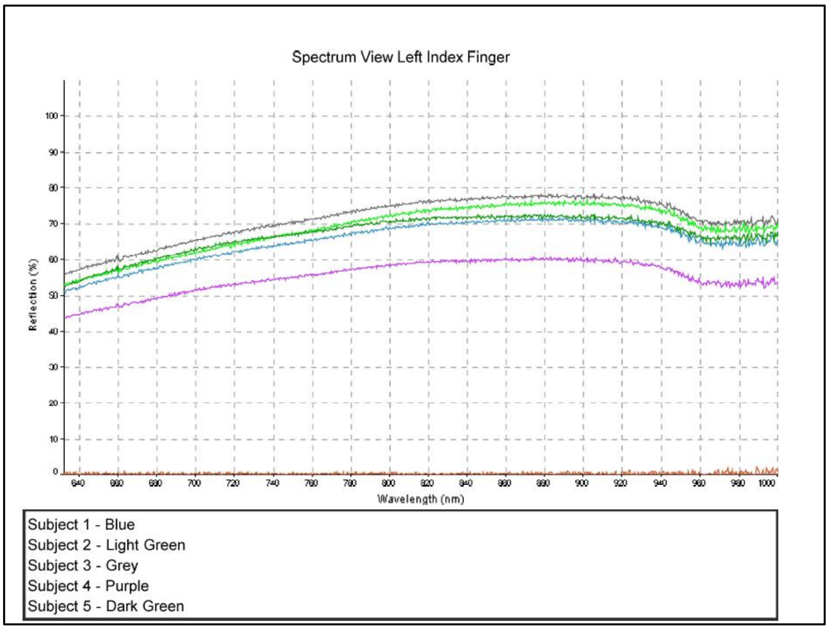

Figure 3: Reflectance spectra comparing the left index finger of 5 subjects obtained through NIR-DR Spectroscopy

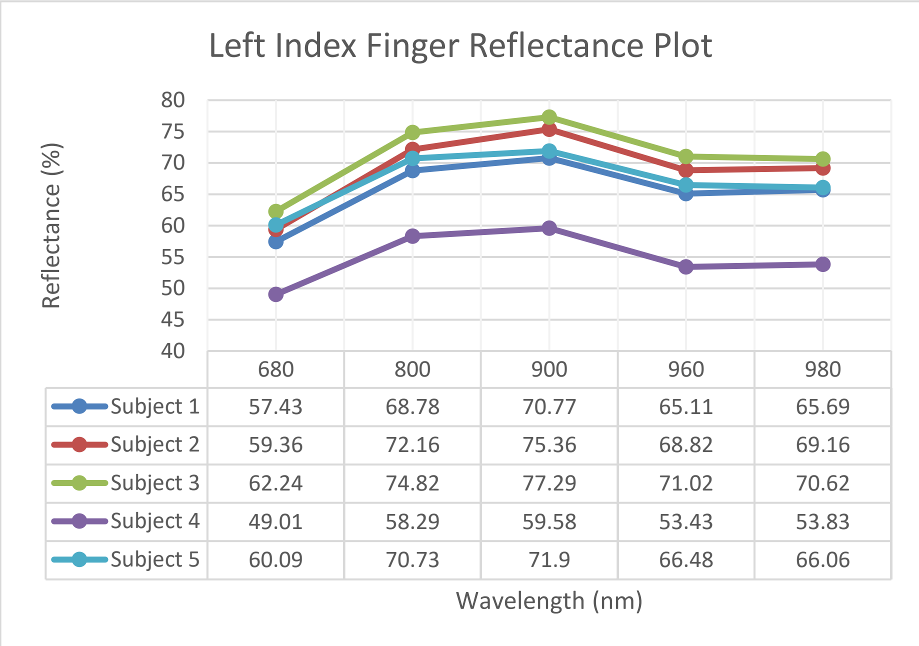

Figure 4: Graph comparing the reflectance value for the left index finger of each participant between 680-980nm.

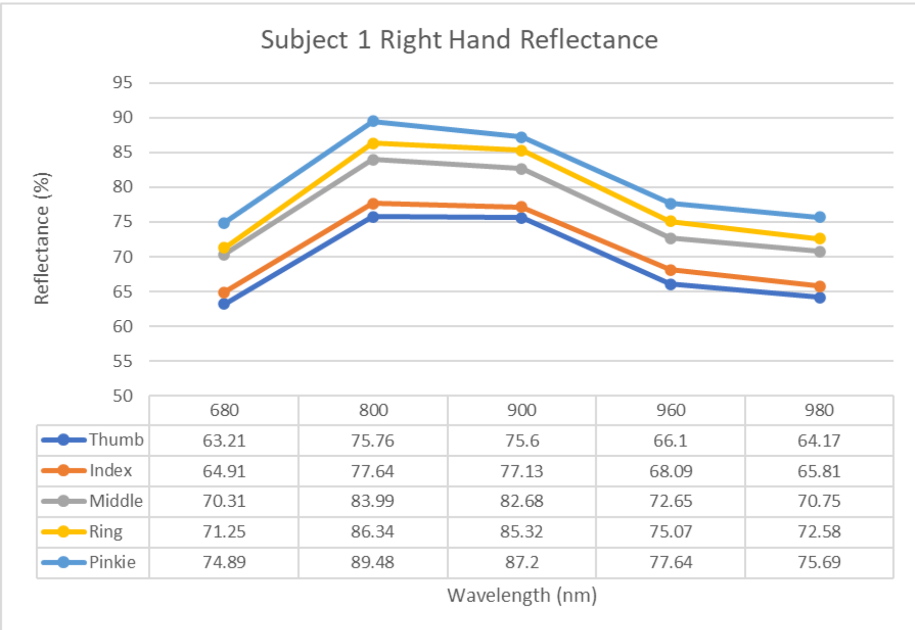

Figure 5: Graph plotting the reflectance percentage of each finger in the right hand of Subject 1.

3. Result and Analysis

The pattern of the reflectance spectra can be explained due to how the photons behave within the skin layer. As the wavelength of the halogen light increased, the photons were able to penetrate deeper into the epidermal layer [7]. As these photons scatter within the epidermis, they may come into contact with the epidermis-dermis boundary, which re-direct the photons towards the surface. However, as the penetration depth increases even more, more photons will pass through the epidermis-dermis layer, which results in a backscatter effect. Photons below the epidermis-dermis boundary that scatter towards said boundary are now re-directed further into the dermis layer instead of towards the surface. This is visible in the spectra, as the reflectance slowly rises with the increase in wavelength and the sharp fall that it occurs after it passes the epidermis-dermis boundary depth [7].

Calculating the slope of the spectra between the ranges 800nm to 900nm, as seen in **Table 1**, is then used to gauge the thickness of the epidermis layer. 800nm is selected to reduce the effect of visible light on to the reflectance value. Thicker epidermis layer allows for more photons to travel above the epidermis-dermis boundary, which in turn results in a higher reflectance value gain. Thinner epidermis layer result in more photons travelling below the epidermis-dermis boundary, which results in a lower reflectance gain. As the wavelength exceeds 900nm, the majority of the photons now exist below the epidermis-dermis boundary, which is thus ignored for gauging the epidermal thickness.

Table 1: Slope comparison of Left Index Fingerprint spectra between 800nm to 900nm

Subject	Slope
1	0.0199
2	0.0320
3	0.0247
4	0.0129
5	0.0117

A factor to consider is the effect of skin color on the reflectance value. Melanin is more absorbent of red light (620nm to 750nm) than NIR light [8], which causes the initial low starting point of each spectra reading. Those with darker skin color will result in an overall lower reflectance spectrum [9].

Age is also known to impact epidermal thickness, resulting in a thinner skin layer [10]. Subject 4 was of significant age in comparison to other subjects and did have a relatively low spectra slope between 800nm to 900nm. However, this value is currently inconclusive as there is no data on the previous epidermal thickness of Subject 4's finger. Furthermore, Subject 5 has an even thinner skin layer but was of a younger age than Subject 4.

While the epidermal thickness varies from person to person, it is also varied between each finger in a person's hand. In **Table 2**, we see that the slope between the 800nm to 900nm are still significantly different from one another, showing that their differences in each finger's epidermal thickness. The thumb was expected to have a thicker epidermal layer [6], which is not the case. This may be due to the epidermis layer being much thinner overall, allowing for shorter wavelengths penetrating deep enough to hit the epidermis-dermis boundary earlier.

Table 2: Slope comparison of Fingerprint spectra of Right Hand between 800nm to 900nm

Finger	Slope
Thumb	-0.0016
Index	-0.0051
Middle	-0.0131
Ring	-0.0102
Pinkie	-0.0228

4. Conclusion
The proposed method was successful in measuring the thickness of the epidermal layer, and detected variations within the reading that were exclusive to each participant. The use of epidermal thickness evaluation is plausible in the application of biometric security.

However, further research with a larger sample population is needed for a more conclusive result. Research observing the extent of external effects, such as skin color and age, on how it may impact the epidermal thickness of a person's fingerprint would also be necessary.

5. Acknowledgement

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