Detection of Fingerprint Pattern and Refractive Index of Deposited Sebum by Using Total Internal Reflection

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Abstract The conventional and well-established technique of fingerprint recording is to record the intensity distribution of the fingerprint through total internal reflection (TIR). The present work proposes a polarization-based non-interferometric technique based on total internal reflection for a quantitative assessment of the refractive index of the sebum associated with the fingerprint as well as its unique pattern. Although the conventional technique of TIR is employed, two polarization-shifted intensity data frames are recorded and combined to arrive at the desired result. It is expected that this additional information may yield a new dimension to forensic science.

Keywords Total internal reflection · Phase difference · Fingerprint · Refractive index

1 Introduction

Analysis of fingerprints has been extensively used for the past few decades in different fields, especially in crime investigation. Fingerprints are also used in biometrics for identity verification [1, 2]. Although different types of patterns and ridges are seen on a fingerprint, it is the presence of minutiae, which are abrupt changes in the ridges that are vitally important to fingerprint detection [3, 4]. Minutiae detection is solely based on the quality of the fingerprint image [5]. Analysis of fingerprints is essentially a pattern recognition system based on acquiring data from an individual. A set of features are extracted from the acquired data [6, 7]. This paper proposes a simple polarization-based setup for high-resolution detection of not only the fingerprint patterns and its analysis but also a quantitative evaluation of the refractive index associated with the sebum, through a simple two-frame algorithm. The sebum that oozes out from the pores is a mixture of water, potassium, urea, lactate, amino acids and bicarbonate, and an over-abundance of one of these constituents is reflected in

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G. R. Kadambi et al. (eds.), *Emerging Trends in Photonics, Signal Processing and Communication Engineering*, Lecture Notes in Electrical Engineering 649,
https://doi.org/10.1007/978-981-15-3477-5_3

the evaluated refractive index of the sebum islands, which in some cases may be indicative of the pathological condition of the individual as well. In this paper four different sets of fingerprint are taken from two different people and hence refractive index of sebum is evaluated. Accordingly, different sets of fingerprints are recoded, analyzed and reported in this work.

2 Theoretical Background

If a light beam is totally internally reflected at the interface of two different dielectric medium of refractive indices n_1 and n_2, ($n_1 > n_2$), as shown in Fig. 1, then phase φ_s and φ_p for transverse electric (s-polarized) and transverse magnetic (p-polarized) polarized light can be expressed as [8]:

$$\phi_p = -2\tan^{-1}\frac{n_1\sqrt{n_1^2\sin^2\theta_1 - n_2^2}}{n_2^2\cos\theta_1}$$
$$\phi_s = -2\tan^{-1}\frac{\sqrt{n_1^2\sin^2\theta_1 - n_2^2}}{n_1\cos\theta_1} \quad (1)$$

The phase difference φ_{diff} between p and s components may be expressed as:

$$\varphi_{\text{diff}} = \varphi_p - \varphi_s = 2\tan^{-1}\left(-\frac{\cos\theta_1\sqrt{n_1^2\sin^2\theta_1 - n_2^2}}{n_1\sin^2\theta_1}\right) \quad (2)$$

The variation in this evaluated phase difference with refractive index n_2 is shown in Fig. 2. This serves as the calibration curve for evaluating n_2 from φ_{diff}.

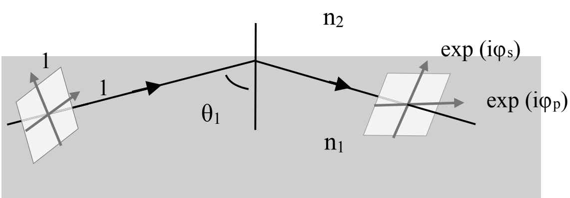

Fig. 1 For a ray of light with normalized s and p amplitude components incident on interface of denser and rarer medium at an angle θ_1 greater than the critical angle, the phases introduced in these components after total internal reflection ray are φ_s and φ_p, respectively

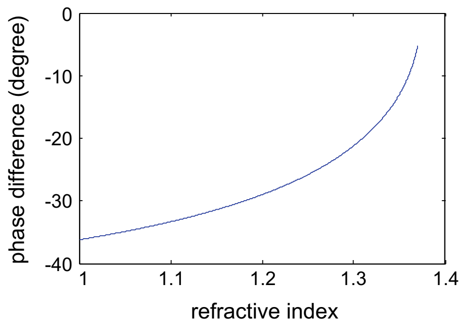

Fig. 2 Calibration curve: Variation in phase difference with respect to change of refractive index of rarer medium for $\theta_1 = 64.8°$ and $n_1 = 1.518$

3 Experimental Setup

Figure 3 presents the proposed experimental setup. An isosceles prism with apex angle 120° is chosen to ensure that light is total internally reflected from the detection surface. The fingerprint is taken on the prism surface. Circular polarizer (CP) and linear polarizer (LP1) combination is so oriented that the light from the LED source (S) entering the prism is linearly polarized at 45°. This ensures that both the s and p polarized states are present in equal magnitude in the input beam. Two intensity data frames are recorded on a CCD with the transmission axis of the output polarizer (LP2) oriented along 45° and 135° so that the s and the p components are added in-phase and out-of-phase, respectively. The phase of the fingerprint may hence be evaluated as [9]:

$$\phi_{\text{diff}} = \cos^{-1}\left(\frac{I_{45^\circ} - I_{135^\circ}}{I_{45^\circ} + I_{135^\circ}}\right) \tag{3}$$

where

$$\begin{aligned} I_{45^\circ} &= 0.5r^2\left|e^{i\phi_s} + e^{i\phi_p}\right|^2 = r^2(1 + \cos\phi_{\text{diff}}) \\ I_{135^\circ} &= 0.5r^2\left|e^{i\phi_s} - e^{i\phi_p}\right|^2 = r^2(1 - \cos\phi_{\text{diff}}) \end{aligned} \tag{4}$$

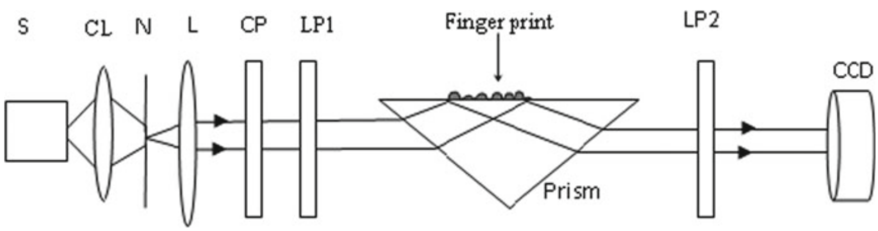

Fig. 3 Schematic diagram of the experimental in-line setup Source = LED, CL = Condenser lens, N = pin hole, L = Lens, CP = Circular polarizer, LP1 = linear polarizer with 45° angle, LP2 = Linear polarizer, CCD = Charge coupled device

4 Results and Discussion

Figure 4 shows the evaluated results of a sample fingerprint. The recorded frames I_{45} and I_{135} are shown in Fig. 4a and b, respectively. Figure 4c presents the 3D phase difference ϕ_{diff} profile, and Fig. 4(d) presents the variation in 2D phase difference along a particular cross-section. This is repeated for three more samples as shown in Figs. 5, 6 and 7. A summary of the fingerprint pattern in the different samples taken from two different persons, as well as the average refractive index of the sebum islands, is presented in Table 1.

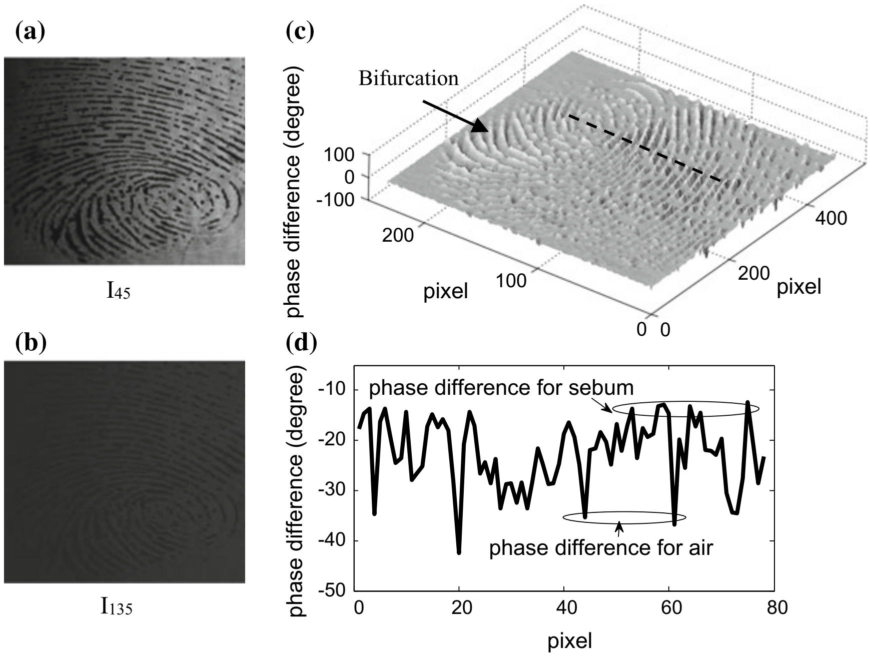

Fig. 4 **a** and **b** Represent intensity data frames for I_{45}° and I_{135}°. **c** and **d** Represent 3D and 2D phase profile for fingerprint

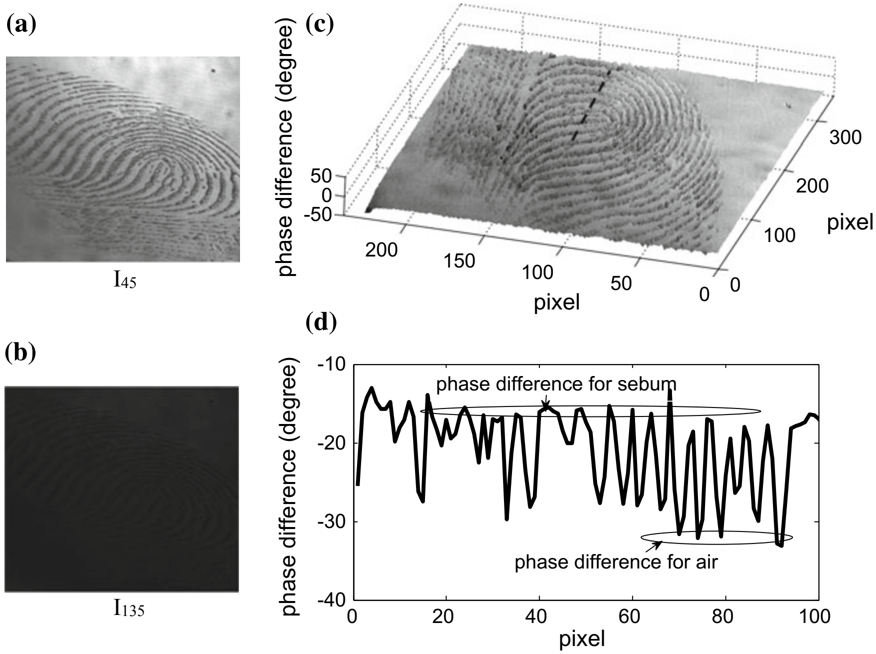

Fig. 5 **a** and **b** Represent intensity data frames for $I_{45}°$ and $I_{135}°$. **c** and **d** Represent 3D and 2D phase profile for fingerprint

5 Conclusion

It has been shown that from the optical phase of the sebum islands left by the fingerprint impression, the refractive index of the sebum can be evaluated. This is expected to add a new dimension to forensic science since the pathological condition of the person may as well have a bearing on the evaluated refractive index.

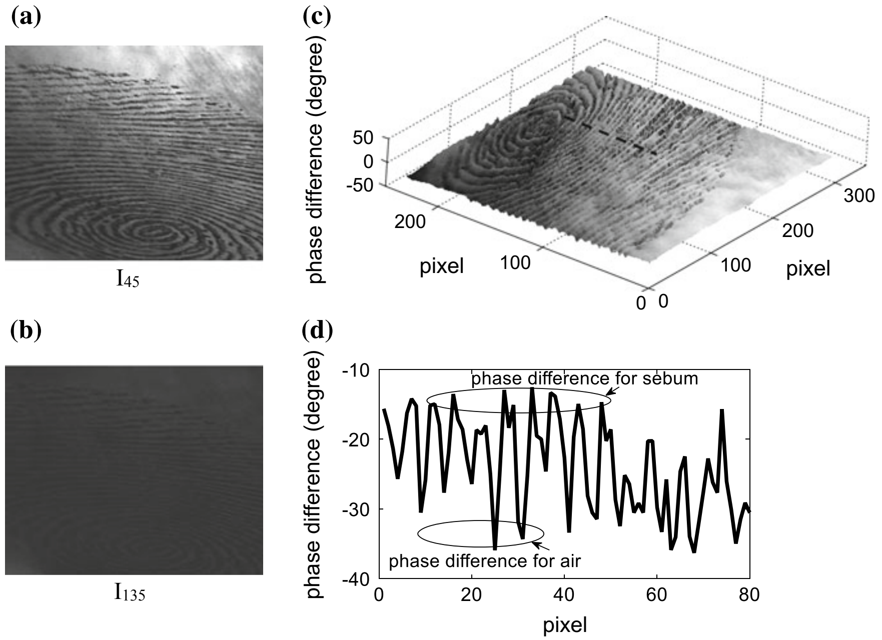

Fig. 6 **a** and **b** Represent intensity data frames for $I_{45}°$ and $I_{135}°$. **c** and **d** Represent 3D and 2D phase profile for fingerprint

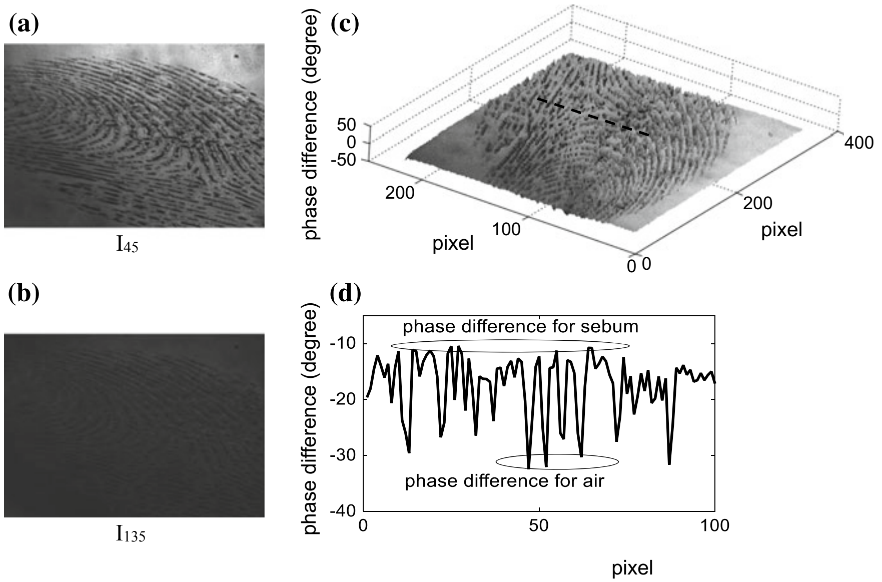

Fig. 7 **a** and **b** Represent intensity data frames for $I_{45}°$ and $I_{135}°$. **c** and **d** Represent 3D and 2D phase profile for fingerprint

Table 1 Comparison of refractive indices of deposited sebum and fingerprint patterns between two different persons taking as a sample

	Set number	Fingerprint types	Phase associated with fingerprint (degree)	Refractive index
Person-1	Figure 4	Whorl pattern	−14.57°	1.344
	Figure 5	Loop pattern	−14.78°	1.342
Person-2	Figure 6	Whorl pattern	−12.86°	1.350
	Figure 7	Arch pattern	−12.36°	1.352

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