Face Anti-spoofing Countermeasure: Efficient 2D Materials Classification Using Polarization Imaging

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***Abstract*— Spoofing is an act to impersonate a valid user of any biometric systems in order to gain access. In a face biometric system, an imposter might use some fake masks that mimic the real user face. Existing countermeasures against spoofing adopt face texture analysis, motion detection and surface reflection analysis. For the purpose of face anti-spoofing analysis, skin structure is a key factor in achieving the target of our study. Skin consists of multiple layers structure which produces multiple reflections: surface and subsurface reflections. In this paper, we proposed a measure to discriminate between a genuine face and a printed paper photo based on physical properties of the materials which contribute to its distinctive reflection values. In order to differentiate the reflections, polarized light (light that vibrates in a single direction) can be used. The Stokes parameters are applied to generate the Stokes images which are then used to produce the final image known as Stokes degree of linear polarization (SDOLP) image. The intensity of the SDOLP image is investigated statistically which has shown promising results in the materials classification, between the skin and the paper mask. Furthermore, comparison between the experimental results from two skin color groups, black and others show that the SDOLP data distribution of black skin is similar to the printed paper photo of the same skin group.**

Keywords—degree of polarization; Stokes parameters; Stokes images; spoofing; material classification; polarization; mask attack; surface reflectance analysis.

I. INTRODUCTION

Nowadays demand on the highly secure identification and personal verification methodologies for biometric authentication system has increased. The demand becomes more apparent as there are various new techniques to spoof the system. Face biometric authentication system is one of the well-known biometric applications, used as a tool to verify or recognize the identity of a person based on the face feature. Among other biometric traits like finger print or iris, face is more easily to be deceived [1].

In some cases, the face biometric system can be spoofed by an impostor with no difficulty. For instance, the impostor can obtain a photo of an authorized person, plays a video, or display a 3D model such as a face mask which mimics a valid individual, in front of the sensor to gain access [2]. This vulnerability of face biometric authentication system has encouraged various studies and preventive measures among biometric community.

Existing face recognition systems that relies on a typical countermeasures against spoofing such as liveness detection and motion analysis, is no longer relevant. Liveness detection which is based on eyes blinking and lips movement has been tricked with perforated mask in the eyes and mouth. While for motion based counter spoofing, it has been challenged with recorded video playback in front of the camera. Therefore it has become necessary to keep on looking for a better approach to overcome spoofing attacks. Since face masks are made of various types of materials, characteristics of these types of materials can provide important information.

Reflectance based analysis is an alternative method to counter spoofing attack. The reflectance data could contribute as a prime discriminative detail. Since skin produces more than one surface reflection, polarized light can be used to separate between the reflections. In spite of some ongoing efforts to counter mask attacks, there is still no in depth study by the biometric community about skin multi reflections characteristic which has emerged as a new protection approaches. Therefore in this paper, we present a reflectance based materials classification method using polarized light.

Initially, we captured images at four polarization angles to obtained Stokes images. Then we produced the Stokes degree of linear polarization (SDOLP) images of the real traits and their printed photos. Following these, we analyzed the images by using descriptive statistics such as mean, standard deviation and kurtosis of their image histogram parameters. In addition to the image histogram analysis, the effect of the skin colour is also evaluated.

The paper is organized as follows. Section 2 includes related work on the countermeasure of the spoofing attacks. In Section 3, the theory of polarization and its interaction with multilayer skin structure is discussed. In Section 4, we present our polarization imaging system, and discussion on the Stokes parameters. Section 5 is about experiments and results obtained. Finally, conclusion and future work are provided in Section 6.

II. RELATED WORK

There have been many attempts to counter face spoofing attacks. These existing methods can be generally classified into three categories: texture based, liveness and motion based, and reflectance based analysis. Texture based approaches as in [3] [6] only rely on local binary pattern (LBP) to analyze the micro-texture patterns of both real face and fake face images. The approach is then used for further exploration amongst 3D facial mask compared to a planar printing mask [4]. Two other methods were then used for further verification on the effectiveness of LBP in detecting mask face [5]. One is warping parameters (WP) and the other is local binary pattern depth (LBP-depth). LBP shows a more convincing result than others.

The countermeasure based on reflectance information has attracted more researcher attention [7]-[9]. In [7], the authors proposed a reflectance based analysis on the texture images from a 2D+3D face mask. This proposed method has been proved to have better features information compared to texture analysis for the purpose of mask detection.

Another study presents a multispectral reflectance using multispectral lighting to discriminate between a real face, a photo face and variety of face masks made of plastic, silica gel, paper, plaster and sponge [8]. As a result, two discriminative light wavelengths (850 and 1450 nm) have been chosen. However, the masks used are not mimic any real person.

Similarly in [9], two discriminative wavelengths (685 and 850 nm) are selected after examining the albedo curves of the forehead region of facial skin and mask materials. The reflectance method shows a greater reflectance contrast with only a single 2D image compared to photometric stereo method which requires many 2D images. In this study, however, the analyses are done directly on the materials without the existing of any mask.

During the past 20 years, polarized light has been used to classify materials. A similar series of experiments are proposed, which claim that polarized reflection can be used to distinguish between metal and dielectrics objects [10], [11]. A polarization-based method for discriminating between parallel and perpendicular components of lights is proposed in both, based upon Fresnel reflectance theory, claiming that metal and non-metal is distinguishable. In a follow-up study [12], the Fresnel polarization reflectance model has been expressed in three terms of the parameters: I_{max}, I_{min} and the phase of the transmitted radiance. These can be used to obtain object features and enable the separation of diffuse and specular reflection components.

Later [13] presented a real-time CMOS image sensor to differentiate between metal and dielectric surfaces, claiming that polarization of the reflected component varies with the conductivity of the metallic surface. The Fresnel reflection coefficients and the degree of polarization are shown to measure the variations of reflection.

Since that, a considerable amount of literature has been published on polarized reflection [14], [15]. In [14], a polarization imaging device is demonstrated to measure the Stokes components of the trans-illuminant light, to distinguish between breast tissue in health or with cancer. One study by [15], the polarized reflection is examined to classify among transparent and opaque objects. The Stokes degree of polarization and polarization Fresnel ratio are presented.

Recently, a study by [16] has proposed a similar approach as in this paper. Polarized light has been used as trials to differentiate between a genuine face, LCD screen and paper mask. They have shown the difference of the polarization images between the real face, LCD and paper mask. However, the images have not been analysed either statistically or by any parameters and algorithm.

Thus, in this paper we present an approach by using the Stokes parameters to study on the polarized reflection of normal light source as trial to discriminate between human genuine face and paper photo. The study is carried out statistically for a small sample size without using any classifier.

III. THEORY

A. Polarization

There are multiple ways to obtain polarized light: through absorption; reflection; refraction; and scattering. In this paper, the polarized light is generated by using linear polarizer. Theoretically, when light ray strikes on a material surface, part of the incident ray is reflected and the other part is absorbed into the material. The reflected light is known as specular reflection. The transmitted light through the surface into the material structure and goes through multiple internal absorption and scattering before re-emerged through the material-air surface into the air. This second reflection is called subsurface or diffuse reflection. The maximum and minimum light intensities transmitted through the polarizer are known as I_{max} and I_{min} which would be equal to I_0^0 and I_{90}^0 respectively, for a 0^0 polarizer [12].

To study on the polarized reflection of the real face and the paper photo, the Stokes parameters are used. Since each material has its own reflection properties, the reflections between the real face and the paper photo should also be different. By using the Stokes parameters, which are the metrics used to represent the states of polarization, the reflection differences between the two materials are analysed.

B. The Interaction of Polarized Light with the Skin

Skin consists of various layers structure. Some analysts have listed three layers structure of human skin which are epidermis, dermis and fat layer [17], [18]. The first layer is called epidermis which is the outermost layer of the skin. It contains particles called melanin which act as absorption and scattering agents [19]. Dermis is a thick layer underneath the epidermis layer which contains ingredients such as hemoglobin. The third layer is the deepest layer made of fat and connective tissue, known as subcutaneous tissue. Fig. 2 illustrates the skin layers structure which has been previously depicted by [20].

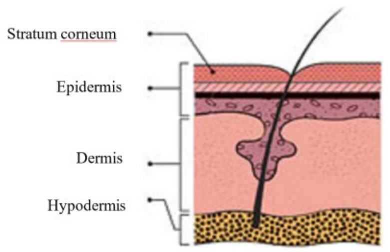


Fig. 2. The structure of the skin layers [20]

Polarized light vibrates mostly in one direction and can be produced through natural process or by placing a polarizer in front of the light. When polarized light falls on the skin surface, the interaction between the light and the stratum corneum, which is a thin layer on the top of the epidermis, is similar as interaction of light and a plate of glass [21].

When a beam of light reaches the skin surface, it will either be reflected by the epidermis surface or refracted and transmitted into the skin. As shown Fig. 3, the incident light wave is reflected by the outermost skin layer in the same direction as the direction of the polarized light beam. Nevertheless, the light component that is not reflected enters the skin through the epidermis and dermis layers.

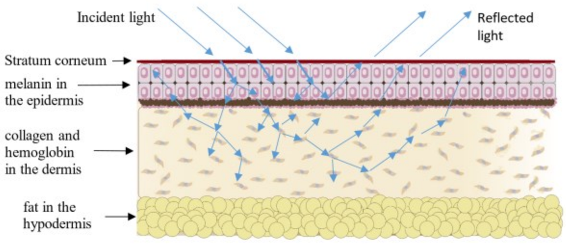


Fig. 3. The types of reflections from the skin surface.

As illustrated in Fig. 3, there are two components of reflected light. One that has the same direction as the incident light known as surface reflection while the other component is randomly polarized after being scattered and absorbed by the particles within the skin layers. This second component is called subsurface reflection.

In this study, printed paper mask of each individual is used as the attacks. The difference of the degree of polarization between the real face and the paper mask is investigated. A device called polarizer, which is a thin coated sheet, is placed in front of the light source to produce polarized light. By adjusting the polarizer angle, the image of both skin and paper mask can be captured either with the surface or subsurface reflection. Therefore, a polarization imaging system is required.

IV. Method

A. *The Polarization Imaging Systems*

Fig. 4 illustrates the polarization imaging system used in this experiment. As can be seen in Fig. 4, two light sources are mounted in line to the camera lens and illuminated the subject at an angle of incidence, θ of 45^0 [21]. The light sources used are two 220V table lights. A linear polarizer, P_1 together with an adjustable polarizer's angle is mounted in front of the camera lens. While the other two static linear polarizers, P_2 and P_3 was each placed in front of each light source. The distance between the camera lens and the subject is 100cm.

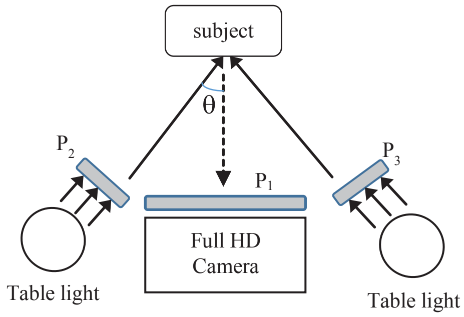


Fig. 4. Measurement setup

B. *Stokes Parameters and Degree of Linear Polarization*

The Stokes parameters are often used to represent the polarization of light. According to [13], these parameters are grouped into a column matrix called Stokes vector, as in

$$S = \begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{bmatrix} = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} \tag{1}$$

The Stokes parameters represent intensity (I), degree of polarization (Q), plane of polarization (U), and ellipticity (V). Since only linear polarized light is applied in our experiment, the V component is omitted as the circular and elliptical polarizations do not occur. The Stokes parameters are denoted as I, Q and U throughout this paper. These parameters are obtained as follows:

$$\begin{aligned} I &= I_0 + I_{90} \\ Q &= I_0 - I_{90} \\ U &= I_{135} - I_{45} \end{aligned} \tag{2}$$

The angles of P_1 are adjusted four times to 0^0, 45^0, 90^0 and 135^0. Initially, these angles have been determined by placing P_1 on top of P_2 or P_3. P_1 was rotated until it turns dark which indicates the cross polarization. At this point, the P_1 angle is set to 90^0. By rotating P_1 to a perpendicular angle to 90^0, clear light transmission can be seen. This angle has been denoted as 0^0. The 45^0 and 135^0 angles were then labelled in between 0^0 and 90^0 and by adding 45^0 to the 90^0 angle, respectively. At each angle, the images of the subjects are captured and labeled as I_0, I_{45}, I_{90} and I_{135}, respectively. Then the images I, Q and U are generated using (2). Next, the Stokes degree of linear polarization (SDOLP) images are defined by

[1] Polarizer angles are referred to the angle of the polarizer P_1 which is mounted in front of the camera lens.

$$\text{SDOLP} = \sqrt{\frac{Q^2 + U^2}{I}} \tag{3}$$

V. Experiments and Results

A. Image Dataset

To the best of our knowledge, a polarized spoofing image database is not yet available. In order to validate the effectiveness of the proposed method, a set of polarized images is captured by using the measurement setup as shown in Fig. 4. Thirty subjects are randomly selected that consist of 11 females and 19 males which are then divided into different skin colour groups: Caucasian, Black and Asian. Table I presents the number of subjects for each skin group available in this self-collected dataset.

TABLE I: The Subjects Classification in the Dataset

Caucasian		Black		Asian	
Male	Female	Male	Female	Male	Female
4	1	3	1	12	9

Images of each subject are captured at four polarizer angles[1]: 0^0, 45^0, 90^0 and 135^0, three frames of images at each angle. In addition, an image of each subject under normal visible light is also captured which is then printed to be used as a paper mask. After recording all the genuine faces, the printed paper masks are placed in front of the camera lens one at a time. The similar processes as capturing the real faces are repeated. All the recorded images for both materials are saved as RGB images. There are 360 RGB images for the genuine face and 360 RGB images for the paper photo.

These images might suffer from the image misalignment between the three frames as they were captured at four different polarization angles within the time slots. To overcome this problem, the three images for each angle are registered and aligned by using a feature-based registration algorithm. After the alignment process, an average image is generated by adding the three aligned images and averaged them. Image averaging could help in reducing any noise occurs. The total number of the aligned images for both materials is 240 gray images. Fig. 5 presents the averaged images of one subject and the paper photo at four polarization angles.

B. The Stokes Degree of Linear Polarization Image (SDOLP)

To generate the SDOLP image, the Stokes components which are I, Q and U must first be produced by using (2). As can be seen in Fig. 6, the Stokes components have been generated thus presented as images. The SDOLP images of the genuine skin and the paper mask are shown in the top and the bottom row, respectively.

Fig. 5. The top row shows the averaged images of the genuine face at four polarization angles. While the bottom row displays the images of the paper mask. From left to right: 0^0, 45^0, 90^0 and 135^0.

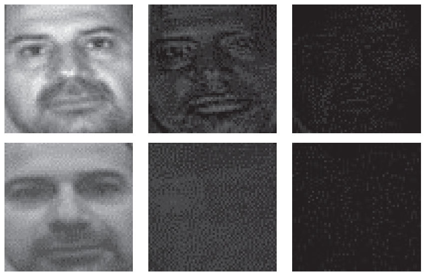


Fig. 6. The Stokes components, from left to right: I, Q, U, of the genuine face (top row) and the paper mask images (bottom row).

(a) (b) (c) (d)

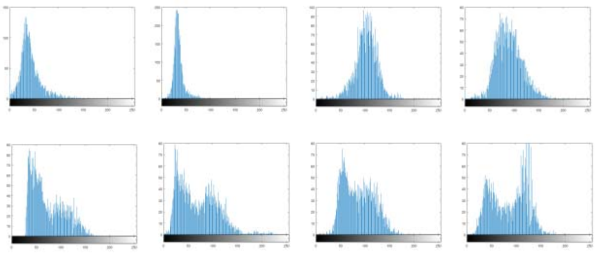
Fig. 7. The Stokes Degree of Linear Polarization (SDOLP) images of four subjects of multi skin colours. The top row shows the real faces while the second row displays the paper masks of the same persons.

After obtaining the Stokes components, the SDOLP images are generated by using (3). Fig. 7 presents the SDOLP images of four genuine subjects and their SDOLP paper mask images. From left to right: Asian, Caucasian, and two Blacks. As can be seen in Fig. 7, the black skin SDOLP images are brighter than the others. Apart from that, the paper mask SDOLP images look more radiant than the real face SDOLP images.

Hence, statistics analysis is carried out to further investigate differences between the materials reflectance. The next section presents the statistics evaluation and results.

C. Materials Classification using Mean, Standard Deviation and Kurtosis

The data distribution of the SDOLP images is studied statistically by using mean, standard deviation and kurtosis. First, histogram of each image which provides a pictorial description of the distribution is plotted and illustrated in Fig. 8. The top row indicates the real face histograms and the second row shows the histograms of the paper masks. As a coarse comparison, the genuine face SDOLP images usually present single modal histograms with small data dispersion, while the paper mask SDOLP images are generally classified as bimodal histograms with wide data distributions. As can be seen in Fig. 8, the Asian and Caucasian skin have a sharp peak histograms compared to the Black skins. In contrast, all the paper masks histograms illustrate bimodal shapes. To verify the differences, statistical comparison is discussed in turn.

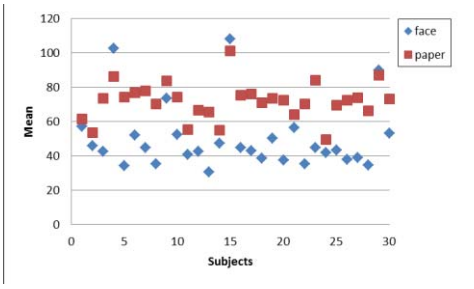


(a) (b) (c) (d)

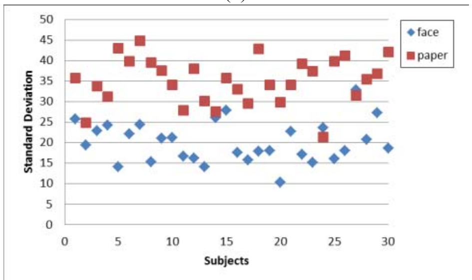
Fig. 8. The comparison of the histograms between the genuine faces (top row) and the paper masks (bottom row).

In statistics, there are four moments that can be used to quantitatively measure a set of data. Generally, mean of a sample is named as the first moment, standard deviation, skewness and kurtosis as the second, the third and the fourth moments, respectively. In this paper, only mean, standard deviation and kurtosis of the data are used as the measurement parameters. Fig. 9 visualized these measures for all the SDOLP images between the data of the real faces and the paper masks. From the data in Fig. 9, it can be seen that the kurtosis values for the paper masks are very low than the genuine faces. Similarly, the standard deviation shows the values that can be differentiated between the two materials although there are few mixed values. The mean values for the real and fake faces seen slightly mixed, but there is still a visible classification pattern.

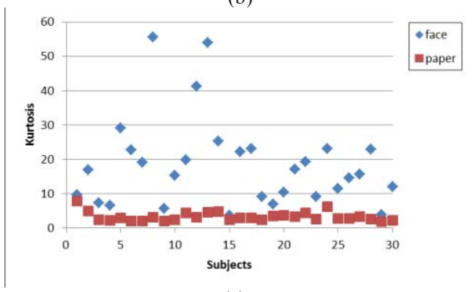
Comparing the three statistical results, a value is then assigned as a threshold in order to classify both materials. Table II presents the threshold assigned for all three measurement parameters. To distinguish between the real face and the paper mask, each score as illustrated in Fig. 9 is compared with the threshold value in Table II. The image is classified as a real face if the mean and the standard deviation are <= the corresponding thresholds while kurtosis is >= its threshold value. Otherwise, the image is recognized as the paper mask attack.



(a)



(b)



(c)

Fig. 9. The pixel intensity data distribution of the SDOLP images. (a) Mean of the images (b) Standard deviation (c) Kurtosis.

TABLE II: THE THRESHOLD OF THE MEAN, THE STANDARD DEVIATION AND THE KURTOSIS

	The Parameters		
	Mean	***Standard Deviation***	***Kurtosis***
Threshold	60.0	25.0	6.0

The results obtained are summarized as True Positive Rate (TPR) and False Positive Rate (FPR) as shown in Fig. 10. From the graph in Fig. 10, it can be seen that by far the True Positive Rate (TPR) shows a promising result for both the genuine faces and the paper masks. With the low FPR (mean = 13.33%, standard deviation<10%, kurtosis<10%), these statistical measures seen practical and significant as a method of materials classification. The most striking aspect to emerge from the data is that the FPR values for the mean are contributed by the black skin group. These can be seen in Fig. 9 where some of the real faces are in the opposite threshold area. Noted that they are the Black skin faces. FPR values for the standard deviation and the kurtosis are very small thus indicate significant classification rates.

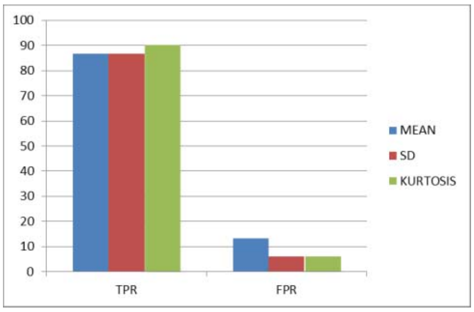


Fig. 10. The TPR and FPR calculated from the mean, standard deviation and kurtosis results.

VI. CONCLUSSION AND FUTURE WORK

This paper argues that polarized light can provides promising materials classification results. The SDOLP images of both the real face and the paper mask are produced based on the Stokes parameters: I, Q and U. All the SDOLP images are then analyzed statistically and the results of the mean, standard deviation and kurtosis of both materials (face and paper) are compared. The True Positive Rate (TPR) and the False Positive Rate (FPR) are calculated and presented. Comparing the results between the TPR and FPR, the SDOLP images provide significant distinguishable values between the genuine human face and the paper mask. The proposed method is robust for a small sample size without having to go through a classifier for validation.

It is somewhat surprising that the face of the black skin subjects could not be differentiate from their printed paper masks statistically although the histograms show significant shape difference. There are several possible explanations for this result. The black skin consists of high amount of melanin in the epidermis skin layer compared to other skin colours. Melanin is a strong scattering agent and since the black skin consists more melanin, this will result in more light is reflected to the air-skin surface [16].

This is an important issue for future research. In our future investigations, we will do further studies in determining other parameters need to be undertaken particularly to differentiate between the black skin and its printed paper mask. A larger dataset could be applied for validation. In addition, a further study on 3D facial mask is therefore suggested.

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