

Combining Iris and Periocular Recognition using Light Field Camera

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Abstract—Iris and Periocular biometrics has proved its effectiveness in accurately verifying the subject of interest. Recent improvements in visible spectrum Iris and Periocular verification have further boosted its application to unconstrained scenarios. However existing visible Iris verification systems suffer from low quality samples because of the limited depth-of-field exhibited by the conventional (or existing) Iris capture systems. In this work, we propose a robust Iris and Periocular verification scheme in visible spectrum using Light Field Camera (LFC). Since the light field camera can provide multiple focus images in single capture, we are motivated to investigate its applicability for robust Iris and Periocular verification by exploring its all-in-focus property. Further, the use of all-in-focus property will extend the depth-of-focus and overcome the problem of focus that plays a predominant role in robust Iris and Periocular verification. We first collect a new Iris and Periocular biometric database using both light field and conventional camera by simulating real life scenarios. We then propose a new scheme for feature extraction and classification by exploring the combination of Local Binary Patterns (LBP) and Sparse Reconstruction Classifier (SRC). Extensive experiments are carried out on newly collected database to bring out the merits and demerits on applicability of light field camera for Iris and Periocular verification. Finally, we also present the results on combining the information from Iris and Periocular biometrics using weighted sum rule.

I. INTRODUCTION

Iris recognition has been widely addressed in the field of biometrics by considering its high accuracy in identifying the subject. Iris image can be captured with/without contact and is less sensitive to the environment effects and thus stable over long time. The identification/verification accuracy of the iris recognition solely depends on the quality of the captured iris texture. In general, the Iris textures are captured using near infrared system that allows one to capture even texture from the dark Iris. Recent work has successfully explored the possibility of the Iris recognition in visible spectrum [1] and even at a distance [2]. However, the use of visible spectrum to capture Iris texture will introduce lot of challenges and capturing the texture features for the dark Irises will not be feasible. In spite of this, the use of visible spectrum Iris recognition has received a substantial interest as it allows to acquire Iris at a distance and also allows one to explore as additional biometric characteristic the Periocular region [3].

Among many other challenges in the visible spectrum Iris recognition, the image focus plays a vital role in improving

the accuracy of the overall system. However, the use of conventional (or existing) Iris sensors exhibit the limitations of fixed point of view and focus that is constant during the image acquisition. Thus, better focused images can only be acquired at the time of image acquisition and cannot be easily modified to achieve the best focus or high sharpness from the captured image. This property certainly limits the existing Iris sensors to always ensure the high quality (or best focused) samples to achieve the accurate person verification using Iris in visible spectrum. Further, the oblique shape of the eyeball also poses additional challenges to capture the best focus image as focus of the conventional camera is fixed.

There exist various approaches to address the problem of focus. In [4] [5], extended depth of field is achieved using a wavefront coding at a fixed nature. Here, the wavefront coding technique has been applied on the acquired image to improve the overall sharpness of the image. In [6], the spectral reflection generated by the IR-LED illuminator is used to focus/zoom the lens to achieve the best focus. In [7], auto focus property is explored to automatically align the focus of the camera to capture the best focus image. In [8], the 2D Fourier spectrum is used on the acquired image to select the best focused frame in the video by maximizing the power in both middle and upper frequencies. Recently, a video-based hyper-focal imaging scheme is proposed to capture the Iris in visible spectrum [9]. Here, video frames are captured by varying the focus such that, each video frame is focused differently. Finally, these multiple focus frames are fused to form a single improved focus image.

Thus, from the existing schemes it can be observed that, most of the them [4] [5] [6] [8] [7] are proposed for the near infrared sensor. Further, these schemes are more concentrated in extending the depth of focus that will result in a low dynamic range and low SNR images. Lastly, the use of video frames to generate the multiple focus images demands accurate varying of the focus during acquisition that results in very high computation power.

In this work, we make an attempt to address the problem of focus which is very crucial for the accurate Iris recognition by employing the light-field (or plenoptic) camera [10] [11]. The light field camera (LFC) captures the image by sampling the 4D light field on its sensor in a single photographic exposure by inserting a micro-lens array [10] or a pin-hole array [12] or masks [13] between the sensor and the main lens. Thus, the presence of the micro lens (or array of pin-holes or masks) allows one to measure not just the total amount of light intensity deposited on the sensor, but, also records the direction

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of each ray from incoming light. Finally, by re-sorting the measured rays of light to where they would have terminated one can obtain a number of sharp images focused at different depth [10]. Thus, the light-field camera exhibits interesting features as compared to a conventional camera (existing Iris sensors), such as (1) generating images at different focus (or depth) in one shot, (2) it is not required to move the lens to set the focus on the object in a scene, (3) portable and hand-held; and (4) real-time exposure. Thus by employing the light-field camera, one can obtain a set of images that can be used to perform (1) refocus (2) all-in-focus image (3) depth estimation (4) synthetic aperture. These features of the light-field camera motivate us to investigate its capabilities for biometric applications especially for Iris and Periocular verification.

The main objective of this paper is to explore the strengths of light field camera to address the problem of focus in the Iris capture process. In addition, we also explore the feasibility of Periocular biometrics [3] using light field camera. Since Periocular biometrics involve in verifying the subject based on the eye and its surrounding skin texture. The availability of the best focus image is expected to improve the overall accuracy of the person verification. To this extent, we employed the first available consumer light-field camera developed and marketed by Lytro [14]. We then collect a new light field camera dataset consisting of 84 Irises corresponding to 42 subjects. In order to present the comprehensive comparison with the conventional camera, we also collect the database using SONY DSC S750 digital camera. Thus, for each subject we have collected both light field as well as conventional visible spectrum Iris/Periocular biometric samples. At the outset, following are the main contributions of this paper: (1) New Iris and Periocular dataset is acquired using light field camera by considering the real-life scenario. This is the first and unique database which has been collected so far. (2) Exploring the all-in-focus property of the light filed camera to obtain the best focus image. (3) New scheme for person verification by combining Local binary patterns (LBP) [15] with Sparse Reconstruction Classifier (SRC) [16]. (4) Exploring the fusion of Iris and Periocular biometrics. This will also allow one to evaluate the effectiveness of light field camera for Periocular biometrics. (5) Extensive experiments and comparison of the proposed LBP-SRC based verification scheme with well-known state-of-the-art schemes [17][18][19][20][21][8] on both light field and conventional iris camera database.

The rest of the paper is organized as follows: Section II presents the data collection protocols, Section III discuss the proposed Iris and Periocular based multimodal system, Section IV presents experimental results and Section V draws the conclusion.

II. LIGHT-FIELD IRIS DATABASE CONSTRUCTION

The whole database is captured using both light field (Lytro) and conventional (Sony DSC S750) camera. For each subject, we capture 5 samples corresponding to left and right eye. Thus, each subject will have 10 samples in total. Each sample is captured at a varying distance of 10-15 inches from the subject face in an uncontrolled lighting environment. Each subject is asked to sit on a chair close to which two cameras are mounted on a separate tripod to capture the images with

similar view and pose. The database collection is carried out at our Laboratory over a period of 25 days. The whole database consists of 42 subjects with both left and right iris resulting in a total of 84 unique iris patterns. The captured database has a large number of light eyes (about 90%), amber eyes (about 7%) and brown eyes (about 3%).

The Lytro light field camera employed in this work, has a resolution of 11 Mega rays with a working spatial resolution of 1080×1080 pixels, while the conventional camera is of 7 Mega pixels with a working resolution of 2304×3072 . The conventional camera is set in an auto focus mode. Thus, the collected database has 420 samples for each camera from 84 unique Iris patterns corresponding to 42 subjects.

A. Light field imaging and all-in-focus property

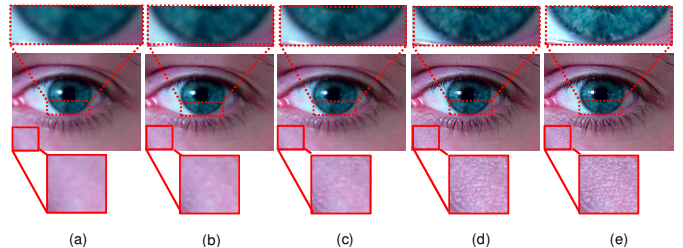


Fig. 1. Multi-focus image obtained using LFC (a) Focus Image 1 (b) Focus Image 2 (c) Focus Image 3 (d) Focus Image 4 (e) All-in-focus Image

Each sample acquired using LFC will result in a raw file that consists of set of images that are focused at different depths in the scene. These multi-focus images will have only one particular region (or area) in focus. In addition to these multi-focus image, the raw file also host meta information that provides the information about the region that are in focus in each of these multi-focus image. We then use this meta information to select the best focus region from each of these multi-focus image to obtain the all-in-focus image. Figure 1 (a)-(d) shows the multi-focus images obtained in one shot using Lytro LFC and Figure 1 (e) shows the all-in-focus image. The obtained all-in-focus image shows the rich features of Iris textures when compared to multi-focus images. Figure 2 shows the sample images acquired using both conventional and Lytro LFC for the same subject. Here also one can acknowledge for the improved visible quality of the LFC imaging.

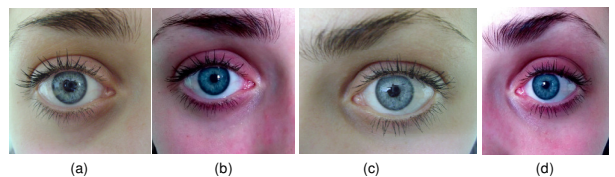


Fig. 2. Example of captured Iris samples; (a) & (c) Conventional Camera, (b) & (d) All-in-Focus light field image

III. THE PROPOSED SCHEME

Figure 3 shows the block diagram of the proposed scheme. The core idea of the proposed scheme is to explore both Iris and Periocular biometrics captured with Lytro LFC. The proposed framework can be considered in three functional blocks, namely: (1) Iris verification (2) Periocular verification (3) Comparison score level fusion

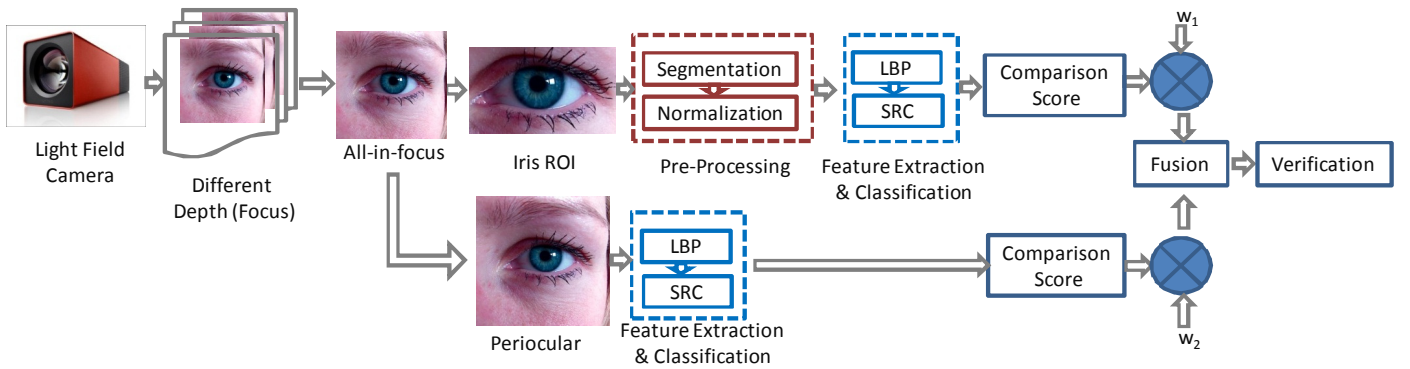


Fig. 3. The Proposed scheme for person verification using Iris and Periocular with light field camera

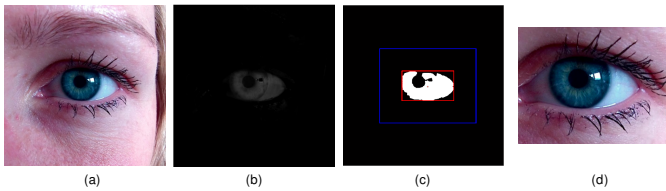


Fig. 4. Illustration of ROI extraction (best viewed in color)

A. Iris verification

After constructing the all-in-focus image (see section II-A), we proceed further to perform the Iris verification that can be explained in the following steps:

1) *ROI extraction*: The first step involves in extracting the Region of Interest (ROI) consisting only eye region. In this work, we propose a simple yet accurate eye region extraction scheme that is illustrated in the Figure 4. The first step involves in converting the RGB image into YC_bC_r and then we obtain the difference between C_b and C_r so that information about the sclera region can be accurately determined (see Figure 4 (b)). We then carry out the morphological operations to weed out small spurious noise and then we determine the centroid to construct the bounding box by locating the outer edge of the obtained sclera region (see Figure 4 (c) (red line)). Since this procedure will allow us to determine only the sclera part, we further extend the bounding box in both horizontal and vertical direction by 100 pixels (see Figure 4 (c) (blue line)) to complete ROI that corresponds to the eye region (see Figure 4 (d)).

2) *Segmentation and Normalization*: In this work, we carry out the Iris segmentation and normalization by employing OSIRIS V 4.1 and more details of this process can be found in [22]. Figure 5 illustrates the qualitative results of the employed segmentation and normalization schemes. Here, one can observe the superior quality of the normalized image obtained with light field camera as compared to that of conventional camera. These qualitative results further justify the effectiveness of the light field imaging for accurate Iris verification by overcoming the problem of focus. Improper segmented Iris are visually determined and manually rectified to improve the performance of the overall system.

3) *Feature extraction and classification*: In this work, we explore a new scheme of feature extraction and classification

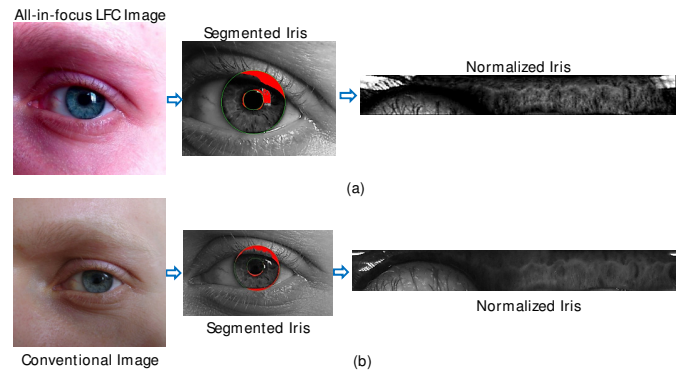


Fig. 5. Segmentation and normalization on (a) LFC (b) Conventional image

based on Local Binary Patterns (LBP) [15] and Sparse Representation Classification (SRC) [16]. Even though, the LBP and SRC are widely explored individually for near infrared iris recognition, the combination of these two approaches are not yet explored especially for the visible spectrum iris verification. Since the LBP algorithm is well known to capture the accurate texture information it appears as an elegant choice to accurately represent the Iris texture features in the visible spectrum. The LBP operates by thresholding the differences of the center value and the neighborhood in a 3×3 grid neighborhood for one pixel. Output value for a pixel is regarded as an 8-bit binary number representing the pixel. The descriptor of the given image is constructed by the histogram of these binary numbers in the whole image [15]. We have employed the LBP operator with a radius of 2. This value is selected based on experimental trials.

In order to accurately classify the texture features, we employ the SRC by considering its exciting results in classifying the biometric features [16]. In this work, we carry out L1 - minimization via SPGL1 solver based on spectral gradient projection [16]. We then obtain the comparison scores that directly correspond to the residual errors obtained using SRC.

B. Periocular verification

Given the all-in-focus image obtained using a light-field camera, the first step in the Periocular verification pipeline is to extract the ROI. In this work, we carry out the manual ROI extraction such that, the extracted Periocular ROI contains small region of skin texture around eye including eyebrows.

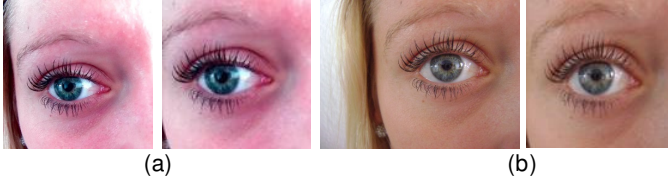


Fig. 6. Extracted ROI on (a) Light field camera (b) Conventional camera

Figure 6 shows the Periocular ROI extracted for both light field and conventional camera. In the next step, we carry out the feature extraction and classification by employing LBP-SRC combination as discussed in the section III-A3. Since the performance of the Periocular verification depends on the accurate texture extraction from the skin region around eye, the choice of LBP-SRC appears to be more appropriate and robust.

C. Combining Iris and Periocular

In this work, we combine the information from Iris and Periocular by fusing the comparison scores of these two individual modalities using the weighted sum rule [23]. Let CS_{Ir} and CS_{Pe} corresponds to the comparison scores of Iris and Periocular modality, then, weighted sum fusion can be expressed as follows [23]:

$$Fusion = W_1 \times CS_{Ir} + W_2 \times CS_{Pe} \quad (1)$$

Where, W_1 and W_2 represent the computed weights corresponding to Iris and Periocular modality respectively. In this work, the weights are computed according to the accuracy of the individual modalities as mentioned in [23].

IV. EXPERIMENTS AND RESULTS

In this section, we present and discuss the quantitative results of the proposed scheme on our newly collected Iris dataset using both Light field and conventional camera. The experiments are carried out on 84 different Iris images with 5 samples each acquired in one session from 42 subjects. Since each Iris has 5 different samples, we propose an evaluation protocol by partitioning four samples as the reference and remaining 1 sample as a probe. This reference and probe partition is repeated for m times ($m = 10$) using leave-one-out crossvalidation. Thus, the experiments are carried out on all 10 different partitions and results are presented by taking the mean of all 10 different trials. Finally, results presented in this paper are reported in terms of Equal Error Rate (ERR), which is defined as a point where the False Match Rate (FMR) [24] is equal to the False Non-Match Rate (FNMR)[24]. Thus the lower the values of EER, the better is the performance.

Table I shows the quantitative performance of the proposed light field based Iris and Periocular verification. Here, we present the quantitative performance of the light field camera as compared with the conventional camera and also present the comprehensive comparison of the proposed LBP-SRC based feature extraction and classification scheme with well known state-of-the-art iris verification schemes mentioned in [17][18][19][20][21][8]. Thus, from the Table I, following facts can be observed: (1) The improved performance of light field camera by an amount of 5% as compared to that of

conventional camera. (2) The superior performance of the proposed LBP-SRC based feature extraction and classification scheme with an improved accuracy of $EER = 2\%$ with light field and about $EER = 3\%$ with conventional camera. (3) Further, the fusion of iris and Periocular using weighted sum rule shows the outstanding accuracy with $EER = 0.8\%$ with light field camera and indicating the effectiveness of adopting the same for Iris and Periocular recognition. Thus, from the above experiments, we found that, the adoption of the light-field camera can improve the performance of the Iris/Periocular based biometric system in real-life surveillance scenarios.

Modality	Methods	EER (%)	
		Light-field camera	Conventional Camera
Iris	Rathgeb et al. [20]	22.21	27.38
	Uhl et al. [17]	12.39	18.24
	Ko et al. [18]	6.51	12.55
	Ma et al. [19]	6.27	12.07
	Masek et al. [21]	4.92	12.44
	Daugman [8]	3.61	8.53
	Proposed Scheme	1.20	8.24
Periocular	Proposed Scheme	12.04	16.21
Fusion	Proposed Scheme	0.81	7.45

TABLE I. QUANTITATIVE EVALUATION OF THE PROPOSED SCHEME

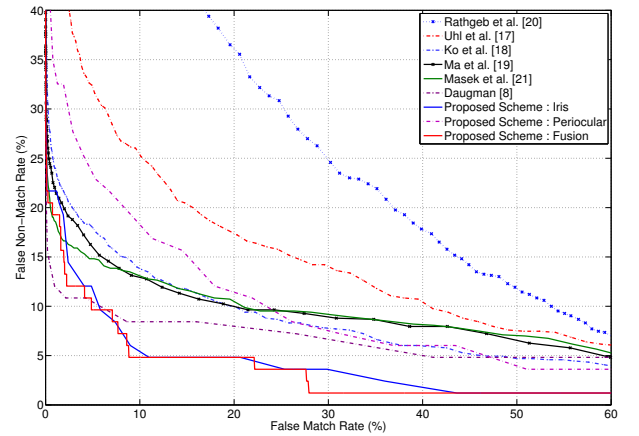


Fig. 7. Verification performance for conventional camera

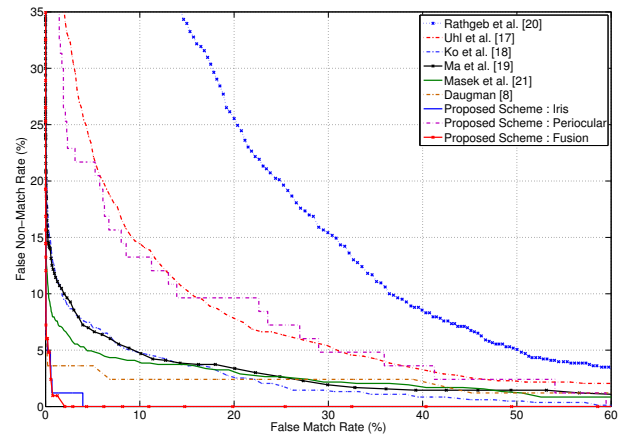


Fig. 8. Verification performance for light field camera

In order to better understand the improved performance of the light field camera over conventional camera, we propose

to measure the focus for each samples acquired using these two cameras. In this work, we employed the focus measure inspired from [25]. Figure 9 illustrates the focus measure on all 420 samples captured using both light field and conventional camera. Here, it can be observed for the high focus values on the samples captured using light field camera and thereby justifying its applicability to build an accurate biometric system.

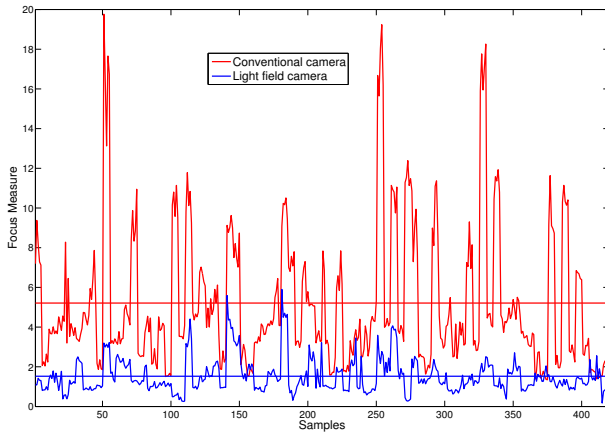


Fig. 9. Focus measure for individual samples

V. CONCLUSION

Our basic idea of this work is to explore the strength of light field camera for the Iris and Periocular based biometric application. To this extent, we employed the Lytro light field camera to successfully address the problem of focus that largely affects the performance of the Iris and Periocular biometric system. We collected a new Iris and Periocular biometric dataset consisting of 420 samples from both left and right eye corresponding to 42 subjects using both light field and conventional camera. Thus, our database has 84 unique iris and Periocular patterns and each of these patterns has 5 samples. We then propose a new scheme for feature extraction and classification using LBP-SRC for accurate person verification. Finally, we combine the information from Iris and Periocular using weighted sum rule to build an accurate multimodal biometric system. Extensive experiments carried out on this dataset indicate the superior performance of the light field camera with an average improvement in EER of 5% as compared to that of conventional camera. Further, experiments carried out reveals the superior performance of the proposed LBP-SRC scheme with the best EER of 1.20%. Finally, outstanding accuracy of 0.81% is achieved by combining the Iris and Periocular biometrics combined using weighted sum rule.

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