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Proof-of-Concept and Evaluation of a Dual Function Visible/NIR Camera for Iris Authentication in Smartphones

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Abstract — *As a robust method of person authentication, iris biometrics is making its way in to consumer devices such as smartphones. Current iris image acquisition devices typically work under controlled environment and constrained acquisition conditions. In this paper, the adaption of iris biometrics for unconstrained, hand-held devices such as smartphones is investigated. A prototype device is presented with full system description. This device is equipped with a single image sensor with both visible and NIR sensing capabilities. The device is analysed in terms of its optical properties and iris imaging capabilities. Preliminary results indicate that there are challenges to achieve a reliable recognition performance from the images captured using this device. Current system acquires images with marginal optical quality and spatial resolution in an unconstrained acquisition scenario for iris recognition. Nevertheless, the analyses presented in this paper indicate a similar camera module with improved optics and sensor could combine iris biometrics with conventional front camera functions such as video call and the capture of selfie images¹.*

Index Terms — **iris camera, consumer biometrics, iris recognition.**

I. INTRODUCTION

Smartphones are everywhere nowadays and by 2016 it is expected that up to 2 billion people will own a personal smartphone [1]. Such a widespread use of smartphones attracts the attention of researchers and engineers in providing reliable assessment of the smartphone user's identity. Some authors have even suggested that smartphones might eventually become mandatory for person authentication [2]. Now, as

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sensitive personal information, financial transactions and user-generated contents are generated and transmitted in increasing volumes via these devices, the importance of smartphone user authentication grows. Biometrics can be used for this purpose and face and fingerprint biometrics are already available in some of today's consumer devices.

As it is generally considered a nearly ideal biometric, iris recognition can provide the security demanded by next generation smartphones. However smartphone based iris biometrics have yet to be demonstrated due to the constrained nature of current iris acquisition techniques and the inability of current smartphone cameras to acquire high quality iris images in the near infrared (NIR) spectrum. The use of NIR is necessary to ensure wide applicability across the population – different coloured iris exhibit different spectral sensitivities and only light coloured iris can be acquired with sufficient iris pattern details at conventional visible wavelengths [3].

A detailed analysis and various design considerations for an iris acquisition system for smartphones were presented by Corcoran, Bigioi and Thavalengal [4]. These authors explain that while the visible wavelength camera systems on today's devices can achieve sufficiently high quality determination of an iris region to facilitate accurate segmentation, the final acquisition should be performed using NIR wavelengths. One potential working solution described in this paper is a dual-camera visible and NIR imaging system. However this solution has associated increased costs and the additional complexity of integrating a dual imaging system into the device.

The work presented in this article takes advantage of the recent availability of dual visible/NIR CMOS sensors [6],[7] to provide an alternative design that combine both visible and NIR imaging into a single optical and sensor system. Although these sensors have not yet seen significant adoption they can also provide benefits in low-lighting conditions where NIR illumination enhancement does not impact on the human visual system. NIR image data can also serve to enhance the quality of visible images, thus justifying the additional costs associated with such hybrid sensors.

II. DUAL FUNCTION RGB-NIR CAMERA FOR SMARTPHONES

For smartphones, a typical use case could be user authentication while holding the device at a comfortable arm's

length. A single user-facing camera to capture both visible (such as video call, selfie imaging) and NIR (iris) image data is considered to be ideal in terms of cost and usability. This paper presents such an RGB-NIR dual function prototype camera and carries out a feasibility study of iris recognition through the use of such a device.

In this section, various important components of the prototype device are described.

A. Sensor

Single sensor digital cameras use colour filter array (CFA) to sample different spectral components. In this kind of arrangement, only one colour is sampled at each pixel location. The most commonly used CFA is a Bayer pattern [5], which is shown in Figure 1(a). Also, these standard RGB cameras are equipped with IR filters to block the IR light in order to improve the image quality.

US 8446470 B2 presented a combined RGB and IR imaging sensor [6]. This sensor replaces a green pixel with an IR pixel in the normal colour filter array. The color filter array of such a sensor is shown in Figure 1 (b).

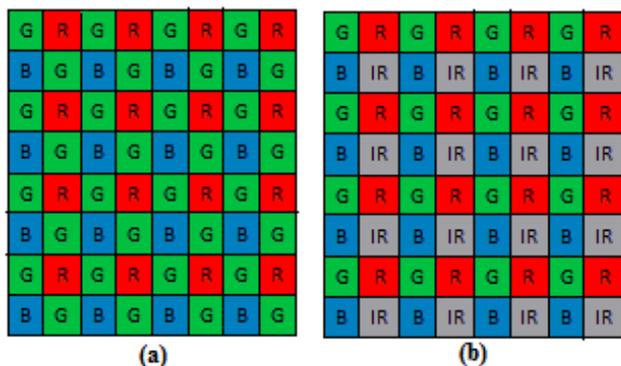


Fig. 1. Colour filter arrays - (a) Bayer CFA, (b) CFA presented in US 8446470B2.

This sensor was primarily aimed to use in an imaging system for vehicles to obtain a more accurate true color representation of the pixels and to limit infra-red color wash out [6]. Such a sensor could be used in developing a hybrid front facing dual purpose camera for smart phones as explained in [4].

RGB-NIR single sensors aimed to be used in cellular phones and other digital still cameras are currently available [7]. Such a sensor could be used to build a dual-purpose RGB-NIR hybrid camera that will be able to carry out both general front-camera operations and iris recognition.

B. Filters

Like any other commercial camera, the spectral sensitivities of red, green, and blue pixels in this camera without the hot-mirror will have a peak around 850nm [8]. The NIR pixels will also have a similar peak value around 850nm. Unlike standard smartphone cameras, a simple IR filter cannot be used in this device as it will block all the IR light. Two of the possible

solutions in this case are - (i) the complete removal of the IR filter or (ii) the use of a dual-band pass filter which is tuned for both the RGB and IR wavelengths.

The first option, with no IR filter, would be the optimal solution for iris recognition, as the IR sensor elements would capture information from a wide range of IR wavelengths. The issue in the case is that the proposed sensor should also be capable to reproduce good quality RGB images if it is to be used as a user-facing camera. With the rise of the self-portrait, or 'selfie' these cameras have become a key feature of modern smartphones, requiring an ability to acquire high-quality personal portrait image. Thus if IR light is not prevented from entering the R, G and B sensing elements of the sensor, the quality of the image would be significantly altered. For this reason, the second option was chosen for our proof-of-concept implementation.

The dual band-pass filter used in the proposed system design follows the filter response characteristics illustrated in Fig. 2. This filter will not only pass all the RGB information as in any other standard camera, but also passes a narrow range of wavelengths around 850nm. This second passband is provided to facilitate iris recognition.

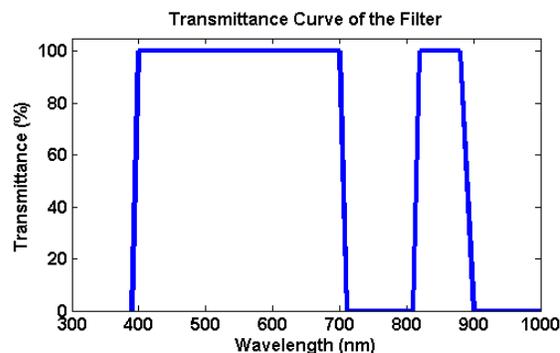


Fig. 2. Transmittance Curve of the filter.

The red, green and blue pixels will typically have similar NIR response as the IR-only pixels. Hence, there is a possibility of NIR washout of the RGB image, particularly if supplemental NIR lighting is employed, or there are high levels of ambient NIR – e.g. in bright sunlight. This effect can be corrected by using an appropriate colour correction algorithm such as a weighted subtraction of IR pixel intensity from red, green and blue pixels in a 2×2 sub pixel array [6].

C. Illumination

Two near infra-red LEDs of wavelength 850nm and half intensity angle 60° are used on each side of the camera as the active illuminator in the proposed system. The choice of these specific illuminators is mainly based on the transmittance characteristics of the filter used on the sensor as well as the general practice in iris recognition.

The LEDs are placed in such a way that it illuminates both eyes of the user and the specular reflections are confined inside the pupil area for our typical operating range of 15-25 cm from the camera. A typical NIR eye image captured using

this prototype device is shown in Fig. 3. Also, the prototype device is shown in Fig. 4, Fig. 5 and Fig. 6. The parameters of the system designed are summarized in TABLE I.

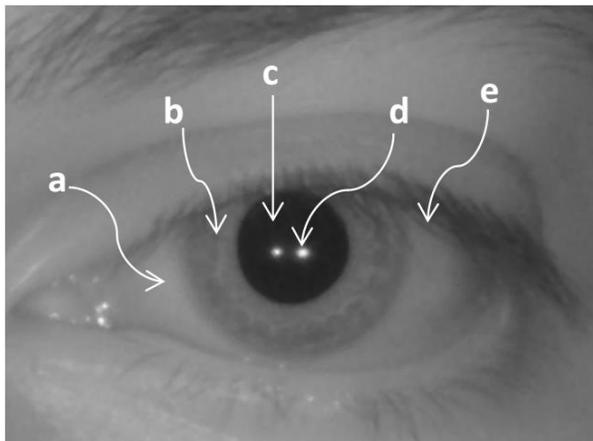


Fig. 3. A typical eye image captured using the prototype device. a- sclera, b- iris, c- pupil, d-specular reflection and e- eyelashes.

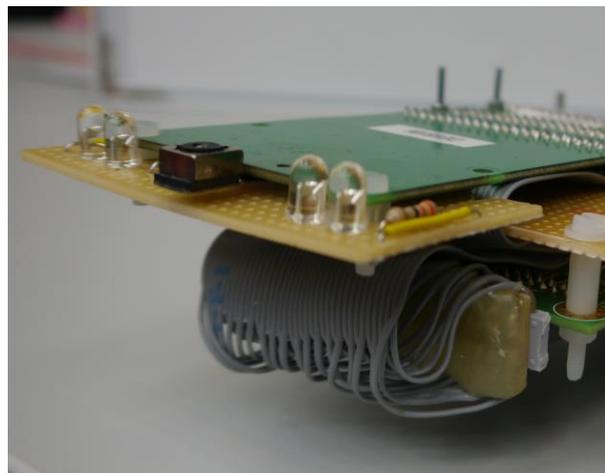


Fig. 5. Prototype device – Close up view of the optics.

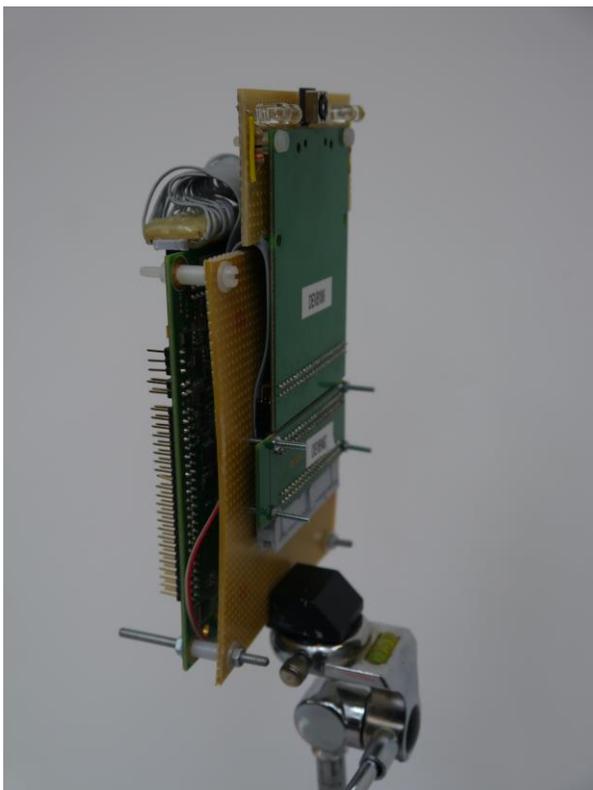


Fig. 4. Prototype device – side view. Smartphone form factor optics can be observed.

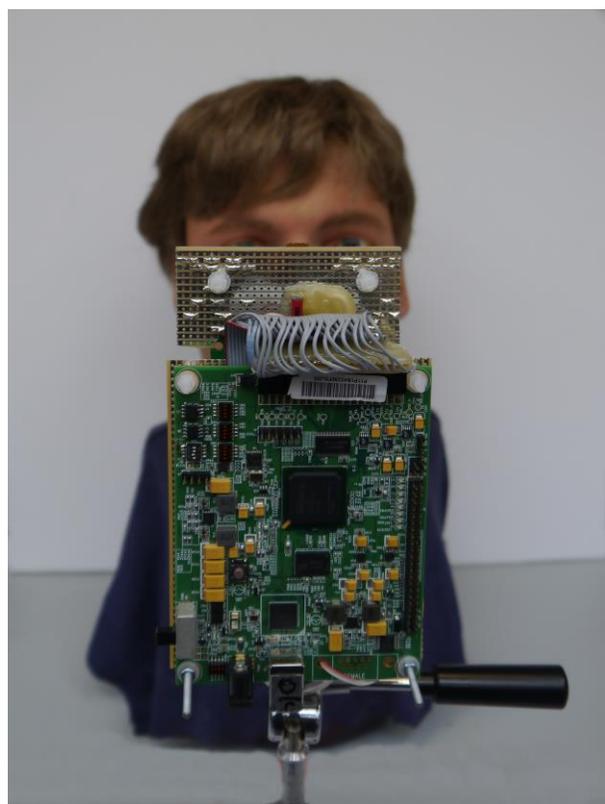


Fig. 6. Prototype device-rear side. This image represents a typical iris image capture scenario

From Fig. 5, a close up view of the optics of the prototype device can be observed. The camera is of current smartphone form factor and can easily be embedded in today's thin smartphones. Surface mount LEDs which comply with the international safety standards are used in this prototype device [14], [15].

III. SYSTEM DATAFLOW

The captured data goes through several processing stages before it is sent to the iris recognition module and the RGB image signal processor (ISP). These processing stages are shown in Fig. 7.

TABLE I
CAMERA SPECIFICATIONS

Parameter	Value
Sensor Size	1/3 inch
Aspect Ratio	16:9
Sensor resolution ($w \times l$)	2688 × 1520
Pixel size	2 μm × 2 μm
Focal length (f)	3.99 mm
F number (F)	2.2
Active Illumination (λ)	850nm

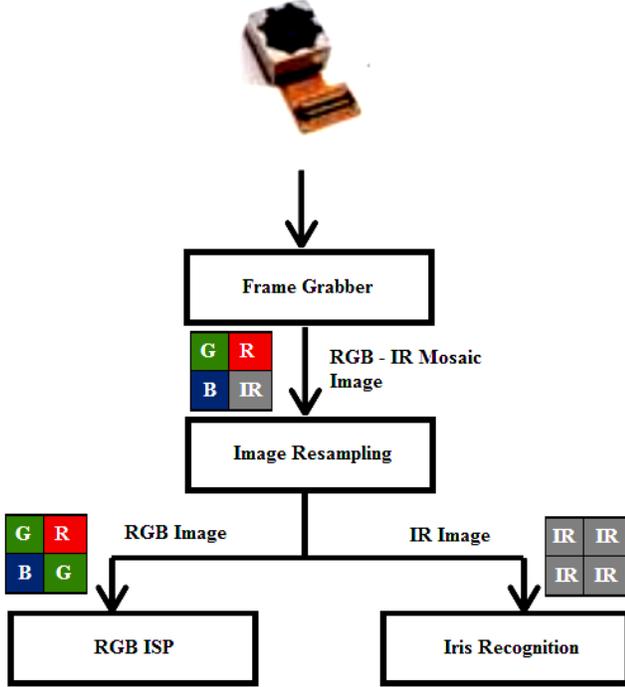


Fig. 7. System overview.

The images obtained by the frame grabber are sent to the image resampling module. This module separates RGB and NIR channels and sends them to their respective processing modules as requested by the application. These processing stages are described briefly in the following subsections.

A. Frame Grabber

The first stage of the data flow is the frame grabber. This stage is responsible for tracking face and eye regions and acquiring the image when triggered by an application. A real-time face tracking technique is used for this purpose [9]. The frame grabber will capture the mosaic pattern (as the one shown in Fig. 1(b) at a resolution of 2688×1520). This mosaic pattern is then transferred to the image resampling module.

B. Image Resampling Module

During this stage, RGB and IR data is separated. The missing G pixel values are restored by analyzing the 2×2 neighborhood to obtain the standard Bayer pattern (as the one shown in Fig. 1(a)). This Bayer pattern is transferred to the RGB ISP for further processing.

In the case of IR information processing, such as iris recognition, the eye region is cropped from the mosaic pattern. IR pixels in these cropped regions are enhanced and super-resolved using a proprietary algorithm. This enhanced iris image is then passed to the iris recognition module.

C. RGB ISP

RGB ISP is responsible for demosaicing the RGB Bayer pattern and enhancing the RGB image such as red-eye removal, face beautification etc.

D. Iris Recognition Module

Iris recognition module processes the input eye image and authenticates the user by analyzing his iris pattern. Iris and pupil are detected from the input IR eye image. The iris is segmented and the segmented iris image is encoded based on a specific encoding scheme. This encoded feature vector is then matched to the feature vectors stored in the database to authenticate the user.

IV. OPTICAL ANALYSIS OF THE PROTOTYPE DEVICE

This section analyzes the suitability of the prototype device presented in the previous section for iris recognition. The important camera parameters are shown in TABLE I. Considering a typical iris acquisition scenario using smartphones with a stand-off distance $d = 200\text{mm}$ and assuming a circle of confusion $c = 2\mu\text{m}$, the far point (S) and near point (R) in which the image is in focus are given by [10],

$$[S, R] = \frac{d \times f^2}{f^2 \pm Fcd}, \quad (1)$$

which gives,

$$S = 211.70\text{mm}, R = 189.52\text{mm}.$$

Hence, the Depth of Field (DoF) is,

$$DoF = S - R = 22.18\text{mm}, \quad (2)$$

At 200mm stand-off distance, this camera will have a magnification factor M ,

$$M = \frac{f}{d - f}, \quad (3)$$

$$= \frac{3.99}{200 - 3.99} = 0.0204.$$

That is, this camera will magnify the iris by 0.0204 on to its sensor. Also, vertical field of view (FoV_v) and horizontal field of view (FoV_h) can be calculated as below [10],

$$FoV_h = 2 \arctan\left(\frac{w}{2f}\right) \quad (4)$$

$$= 2 \arctan\left(\frac{2688 \times 2\mu\text{m}}{2 \times 3.99\text{mm}}\right) \approx 68^\circ$$

Similarly, a vertical field of view of 42° can be obtained.

A. Equivalent Pixel Dimensions and Optical Resolution

Hence, at 200 mm standoff distance, this camera will be able to capture a horizontal distance,

$$d_h = 2 \tan\left(\frac{FoV_h}{2}\right) \times d \approx 270\text{mm} \quad (5)$$

Similarly, the vertical distance captured is $d_v = 154\text{mm}$.

That is, at 200mm, this camera can provide a capture box of $270\text{mm} \times 150\text{mm}$ and a depth of field of 22.18mm. Considering a maximum inter-pupillary distance of 78mm [11], this capture box will be sufficient to obtain both eyes

simultaneously. Further, assuming an iris of size 11mm [12], a magnification of 0.0204 (as shown in (3)) will result in an iris image of 224 μ m diameter on the sensor. The sensor has a pixel size of 2 μ m, so assuming a fill factor of 100% the iris will have 112 pixels diameter on the sensor.

But, due to the nature of the particular CFA used here, IR values are sampled at alternate locations on the sensor. Hence, the number of true IR pixels across iris will be reduced by a factor of two. That is, in this set up, iris will have 56 true, non-upsampled pixels across the diameter.

Within the depth of field, the iris will have pixel range of 53 to 59 pixels on sensor. This is less than the marginal quality of iris image as outlined in ISO/IEC 19794-6 and NIST Mobile ID best practice [13]–[15], but may be acceptable as per the studies shown in [16], [4].

However, valid NIR information would also be available from the RGB pixels (as the color filters do not block light at 850nm and the global cut off IR filter will have to have a pass band around 850nm to allow the IR pixels to function), which could be used to obtain complimentary information which may help in iris recognition.

The practical system modulation transfer function (MTF) at 20cm standoff distance of this device was measured using the Imatest tool [17]. For MTF calculation, NIR images captured with an illumination of 850nm were used. The MTF plot is shown in Fig. 8.

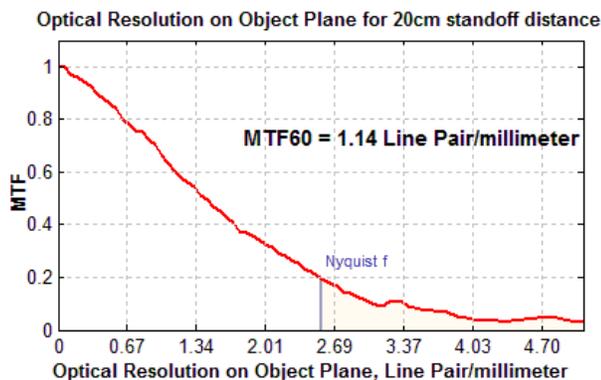


Fig. 8. Modulation Transfer Function of the prototype system.

From Fig. 8, it can be observed that, at 60% system modulation, this set up provides an optical resolution of 1.14 line pairs/millimeter on the object plane. This value is less than the ‘marginal’ quality of 2 line pairs/ millimeter defined by ISO/IEC 19794-6 standard [13].

V. DATA ACQUISITION AND IRIS RECOGNITION

In order to experimentally evaluate feasibility of iris recognition on the images captured by the prototype device, a database of iris images were gathered. The database consists of images from 16 subjects acquired at two different distances 15cm and 20cm from the device. Active illumination of 850 nm was used for image capture. Ambient illumination was not constrained while images were acquired. Some example images of the dataset are shown in Fig. 9 and Fig. 10.

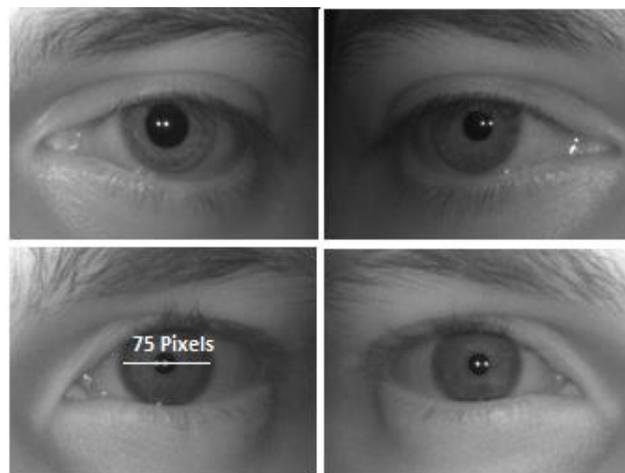


Fig. 9. Examples of iris images captured using the prototype device at 15cm standoff distance. The number of pixels across iris is also marked.

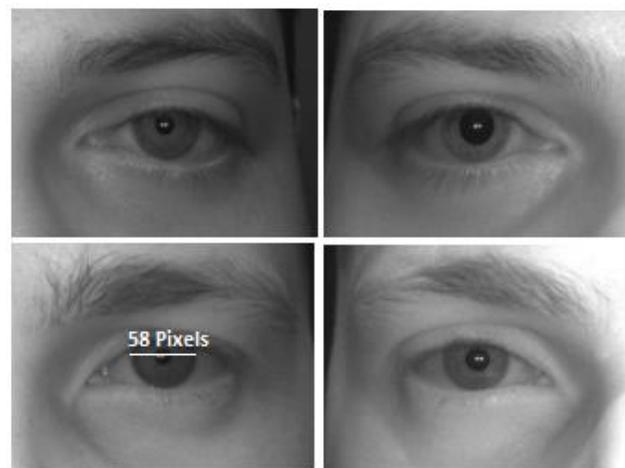


Fig. 10. Examples of iris images captured using the prototype device at 20cm standoff distance. The number of pixels across iris is also marked.

A total of 200 images were captured. Images captured at 15cm standoff distance has an average of 75 true non-upsampled pixels across iris diameter and images captured at 20cm has an average of 58 true non-upsampled pixels across iris diameter. Iris recognition was carried out using a commercial iris recognition algorithm. The receiver operating characteristic (ROC) curves are computed for both 15cm and 20cm standoff distances, which is shown in Fig. 11.

From Fig. 11, it can be noted that images captured at a standoff distance of 15cm outperform the images captured at 20cm. This may be due to the fact that the former set of images has better optical resolution and more number of pixels across iris diameter, and hence more information on the iris region. The score distribution curves of these two set of experiments are shown in Fig. 12.

From the score distribution curves, it can be observed that intra class comparisons of 15cm standoff distance is less overlapped with that of the 20cm standoff distance case. This could be the reason for the poor performance of 20cm standoff distance case. A closer examination on these overlapping cases revealed that the majority of these cases were due to the wrong

segmentation of iris and pupil. Also, the main cause for bad segmentation is the poor image quality such as the low contrast between iris-pupil and iris-sclera, poor image sharpness etc. Images with improved quality may reduce this overlap between intra class and inter class comparisons and thus enhance the performance of the iris recognition system.

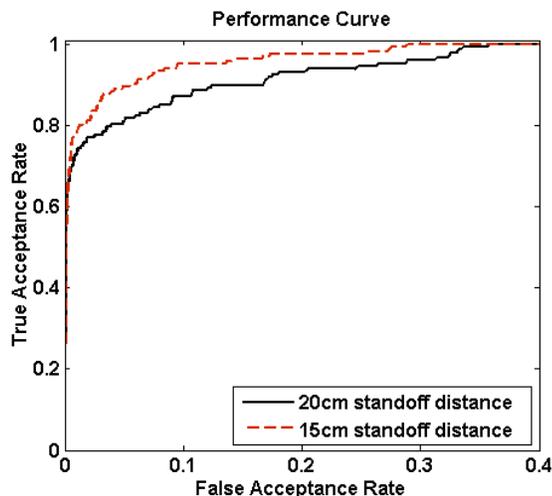


Fig. 11. ROC curves for 15cm and 20cm standoff distances.

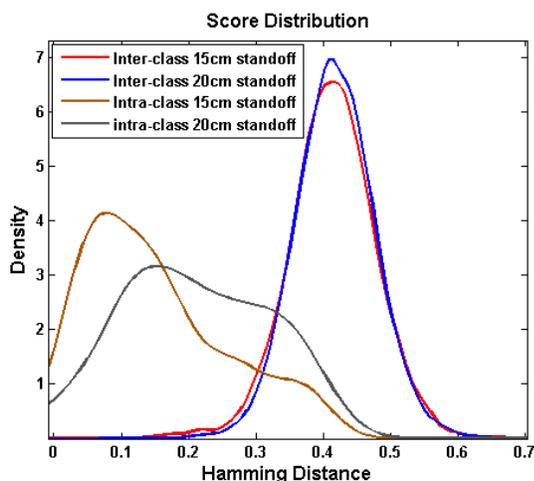


Fig. 12. Score distribution for 15cm and 20cm standoff distances

VI. DISCUSSIONS AND CONCLUSIONS

In this work, a first practical solution for iris acquisition on smartphones is outlined. This takes advantage of the latest visible/NIR image sensors integrated into a user-facing front camera module with additional NIR illumination source. This module combines the functionality of a conventional front-camera, including selfie imaging and video call capabilities, with the potential for iris authentication.

This work demonstrates that there are significant practical challenges in implementing such a system. Corcoran, Bigioi and Thavalengal [4] have shown that the high pixel resolution requirements of international standards [13,15] are not essential and that the discriminating power of iris patterns can be achieved with pixel resolutions down to approximately 60

pixels across the iris diameter. While such resolutions can be achieved at standoff distance of 20cm and a slightly improved at 15cm, the optical properties of the system are marginal. This is reflected in the experimental analysis and the ROC curves provided.

Improved performance could be achieved in several ways. Firstly, the lens and optical design used in the proof-of-concept is not optimized for a dual visible/NIR acquisition – different wavelengths having different focal lengths. An optimized optical element would improve the acquisition quality and the discriminating capabilities of the authentication. Note that additional magnification power is not desirable as this would impact on the use of the visible images for selfie-capture and video calling. However an improved optical design might use a narrower field-of-view for the NIR wavelengths, effectively providing magnification of the eye-regions.

A second improvement would be to increase the pixel density of the iris NIR image. Using a higher density sensor is not possible as a minimum pixel size of $2\mu\text{m}$ is required at NIR wavelengths as per the diffraction limit calculations [4]. And the 5 mm thickness of modern smartphones constrains the use of a larger sensor area. One approach is to develop an enhanced de-mosaicking approach that might enable some of the visible pixel data to improve extrapolation of NIR values between the current NIR pixels. However, it is to be noted that this is not a trivial undertaking. Even today, improvements to the classic Bayer pattern de-mosaicking are still being proposed nearly 40 years after the original patent was filed on this technique [5].

In summary a proof-of-concept of a dual-function user-facing camera has been demonstrated and the iris acquisition capabilities of the system have been tested at 15 cm and 20 cm distances. The pixel resolution of iris regions is marginal and depends on good quality acquisition for acceptable authentication rates. For practical realization of such a dual-mode solution, it would be desirable to improve both the optical design and achieve a higher pixel resolution.

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