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# Iris Authentication in Handheld Devices – Considerations for Constraint-Free Acquisition

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**Abstract —** *As a near ideal biometric, iris authentication is widely used and mobile acquisition techniques are known. But iris acquisition on handheld imaging devices, such as smartphones, poses multiple, unique challenges. In this paper, a range of factors that affect the quality of iris images are reviewed. Iris size, image quality and acquisition wavelength are found to be key factors. Experimental results are presented confirming the lower limits of iris size for useful authentication performance. The authentication workflow for handheld devices is described. A case study on a current smartphone model is presented, including calculation of the pixel resolution that can be achieved with a visible-only optical system. Based on these analyses, system requirements for unconstrained acquisition in smartphones are discussed. Several design strategies are presented and key research challenges outlined together with potential solutions[1].*

**Index Terms — Iris biometrics, smartphones, consumer biometrics.**

## I. INTRODUCTION

Biometrics when combined with a personal device, such as a smartphone, can offer an interesting and highly effective solution for personal authentication – for an overview and discussion see Corcoran [1]. Fingerprint biometrics is already available on consumer devices. The iris of the human eye has been shown to be a superior biometric and is yet to make its way on to personal devices [2], [3], [4].

Typically, an iris-image is acquired by a dedicated infrared imaging system and the eye is pre-aligned with the acquisition camera. Many systems that acquire iris-images from mobile persons are known, with the “Iris on the Move” system being one of the best known [5]. The system is proposed for airports where iris information is being used increasingly to verify passenger identity, and users are constrained to walk past a multi-camera acquisition point where multiple images are acquired under controlled illumination conditions. This differs from its use on a typical smartphone with a single fixed camera, unconstrained eye positions and limited control of illumination conditions.

A detailed quality analysis of iris based systems from NIST [6] suggests that iris information is generally best obtained by illuminating the eye regions with near-infrared (NIR), which will bring out the main features of the underlying pattern. However other studies have used visible light to determine and identify iris patterns [7]–[9]. There are also studies on non-cooperative iris acquisition, typically obtained at a distance of 3-10 meters using directed NIR illumination sources [9]–[13].

The main contribution of this work is to review and gather together existing interdisciplinary knowledge of iris biometrics to examine the feasibility to implement a practical constraint-free acquisition process on today’s handheld devices. Details of the optical, electronic sensing and digital processing subsystems available in a modern smartphone are considered, as are detailed studies on image quality from the field of biometrics. Previous studies have limited their considerations, or have constrained the acquisition process to improve image quality and resolution. This work will be particularly helpful for embedded systems engineers who may not be familiar with optical and biometric considerations.

Several key challenges are presented and quantified. Practical solutions are then outlined. Thus this work provides a roadmap for future research to tackle these challenges to constraint-free iris acquisition on today’s device.

### *A. Smartphone Imaging and Iris Biometrics*

Iris imaging on smartphones is not currently implemented due to the difficulty of acquiring suitable high quality images in an unconstrained and ill-conditioned environment. There are multiple acquisition challenges:

(i) The iris is a relatively small target located on a wet, curved and reflecting surface;

(ii) Occlusions occur due to eyelids and eye-lashes;

(iii) Specular reflections may block portions of the iris pattern;

(iv) The iris pattern is best viewed with NIR illumination;

(v) Relative motion between eye and the device;

The NIST study on iris quality provides a range of useful information on the required size and resolution of an iris region, in pixels [6]. In addition many different aspects of the acquisition system can affect the quality of the iris pattern that is extracted from the raw image. There are also a number of ISO standards for dedicated iris imaging systems [14], [15]. A brief description of the feasibility and various design considerations for a smartphone-based iris recognition system is given by Corcoran, Bigioi, and Thavalengal [16].

The focus of this work is on the use of the front or user-facing camera of a modern smartphone for iris recognition. As this camera will almost invariably be facing the user during normal use, it provides a convenient means for authentication

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of the current user of the device.

### B. Related Literature

There has been past work on iris recognition using mobile and handheld devices. One of the earliest works shows a cold mirror with IR Pass filter (750nm) attached on a camera-phone with 2048×1536 pixel CCD sensor and 3x optical zoom [17]. Later Cho, Park, and Rhee [18] improved the localization of pupil and iris regions for the same system. The existing Xenon flash was used as an illumination source in this early research. In a follow up work, dual IR illuminators were added to a similarly modified camera-phone [19]. This modified camera system has an operating range of 35-40 cm (with the help of optical zoom) and captures dual eye regions. The user has to align his eyes with the specific area indicated on the cold mirror in order to accurately estimate the eye location. Considering a standard iris of size 11mm, approximately 210 pixels across iris will be present in the images acquired using this set up. A significant portion of this research paper focuses on determining optical and motion blur from the specular reflections in the pupil.

In the context of this work, the approach described by Park *et al* [19] is the closest previous research. However it uses quite large eye regions for iris extraction based on the use of the 3x optical focus to zoom the eye regions. In this regard the acquisition process of Park *et al* [19] is constrained, as the eye pair must be well centered in the region delineated by the cold mirror.

This work envisages an unconstrained and semi-automated eye-region acquisition. Thus, when a user picks up a phone, it automatically tracks their eyes until a 'good' iris region can be acquired. This 'good' iris is passed to a workflow that automatically enables the device and its resources and services once the device user is authenticated. The goals of this paper are to (i) define what is meant by a 'good' iris; (ii) evaluate the feasibility of determining and acquiring a suitable iris candidate on today's handheld devices, and; (iii) outline the acquisition framework, associated workflows and key challenges in successfully implementing iris authentication in the unconstrained use case for a handheld imaging device.

The remainder of this paper is organized as follows. Section II gives background information on relevant iris image quality requirements. Section III outlines iris authentication workflow. Some proof of concept tests are presented in Section IV. Section V presents a recent smartphone case study. Section VI and VII define relevant system requirements for smartphone iris recognition system. The conclusion and possible future work are presented in Section VIII.

## II. Iris Image Quality Requirements

ISO/IEC 19794-6 outlined iris image quality parameters for an iris recognition system [14], [15]. Similarly, the NIST Mobile ID Device-Best Practice Recommendation (MID-BPR) [20] also provides guidelines for capture and use of iris images as a biometric modality in mobile devices. A detailed quality analysis of iris based systems is available from NIST [6]. Based on these studies, the most important iris image parameters to be considered in the design of an iris authentication system for mobile devices are discussed in the following subsections.

### A. Acquisition Wavelength

Existing commercial systems use near infra-red (NIR), in the range 700-900 nm for iris image acquisition [3], [4]. This wavelength range has been chosen because NIR illumination is non-intrusive as well as it helps in revealing the detailed underlying iris pattern even for a heavily pigmented iris. Some studies have used visible light to determine and identify iris patterns [7]–[9]. However only lighter colored iris regions can provide useful patterns in visible light and in fact visible light will degrade the iris patterns in heavily pigmented iris [21].

Studies have been made on the use of different wavelengths for iris image acquisition. Ross, Pasula and Hornak [22] explored the possibility of iris image acquisition beyond 900nm wavelength. Boyce *et al* [23] have discussed the potential of using multispectral information associated with NIR, and visible (RGB) wavelengths of the electromagnetic spectrum to improve segmentation and employ user specific wavelength for iris image acquisition. NIST MID-BPR recommends illumination of the wavelength 700-900nm which is compliant with various standards such as IEC 825-1 and International Standard ISO 60825-1 [20].

### B. Iris Image Size and Quality

The number of pixels across iris diameter can be considered as one of the main criteria affecting iris image quality. This number depends on the iris acquisition device and the standoff distance. ISO/IEC 19794-6 suggests a minimum of 100-149 pixels across iris (8.3 pixels/mm considering the average iris size of 11-13 mm), 60% modulation at 2 line pair/mm in the iris plane as marginal and recommends above 200 pixels across iris (16.7 pixels/mm, 60% modulation at 4 line pair/mm) [15]. Daugman notes that 80-130 pixels across iris is more typical in the field trials [4]. Also, NIST MID-BPR [17] states 140, true non-up sampled pixels across iris diameter as the minimum acceptable. This is broadly in agreement with the NIST study [6] and provides the basis for a standard 2048 bit iris code.

#### 1) NIST IQCE Study Methodology:

However it may be feasible to use lower iris resolution for consumer applications. Some preliminary studies suggest that usable iris patterns with practical discrimination ability can be obtained from iris images of lower pixel resolution [16], [24].

The NIST IQCE evaluation presents the effect of spatial sampling rate on iris recognition performance [6]. To simulate the impairments caused by a low-resolution camera, experiments are carried out by down-sampled iris images using block averaging of different scales. These images are further up-sampled by bi-cubic interpolation to their original size (640×480) since commercial iris comparators cannot process images below the size of 640×480. The original images have approximately 220 pixels across the iris diameter.

The IQCE report states that when effective iris diameter is reduced to 110 pixels across the diameter, false match rate

(FMR) is improved slightly, but false non-match rate (FNMR) is degraded when compared to the performance with the original images. Further reducing number of pixels to 55 across iris diameter, FMR reached back to its baseline value but FNMR was further degraded. When iris diameter was further reduced, both FMR and FNMR were severely degraded. Another study [24] undertaken on a moderately sized database presents very similar results.

### C. Other Image Quality Parameters

Other relevant image quality parameters that affect the iris recognition performance include,

#### 1) Usable Iris Area:

NIST IQCE classifies usable iris area as the quality parameter which has the greatest effect on recognition performance [6]. Usable iris area is the percentage of iris available for matching after masking off the occlusions and specular reflections present in the iris area. Pupil dilation also affects the usable iris area. The occlusions in iris area affect iris segmentation which leads to reduction in performance. ISO/IEC 19794-6 suggests at least 70% of usable iris area to be present in an iris image used for biometric authentication.

#### 2) Iris-Pupil and Iris-Sclera Contrast:

Iris-pupil and iris-sclera contrast plays an important role in proper iris segmentation and hence in the recognition performance. Illumination wavelength, capture device characteristics, eye diseases, shadows etc. can cause poor contrast between iris-pupil and iris-sclera. A capture device which can resolve sufficient contrast between these three regions can positively impact iris segmentation and enhance recognition performance. The ISO/IEC 19794-6 standard requires a minimum of 50 gray level separations between iris and pupil and 70 gray level separations between iris and sclera.

#### 3) Image Sharpness:

Images with low sharpness inflate FNMR and FMR [6]. Defocus and compression can reduce the image sharpness. By ensuring in-focus acquisition of iris images recognition performance can be significantly improved. Focus performance can be improved using auto-focus algorithms optimized for the eye region, and through optical designs that increase depth of field. Different focus assessment techniques presented in the literature can be used to select a well-focused image from a set of acquired images or to provide guidance to assist in acquiring a well-focused image [25]–[27].

#### 4) Gaze Angle:

Off-axis images present a significant challenge to iris recognition technology. According to the NIST IQCE evaluation, gaze angle significantly affects the FNMR. Real-time gaze compensation technique introduced by Daugman [25] or other techniques in literature can be used for this purpose [28], [29]. Schuckers *et al* [29] noted considerable improvement on iris recognition performance when gaze angle was compensated for images which are up to $15^{o}$ off–axis. Also, current gaze estimation techniques can estimate gaze angle with an average $3.5^{o}$ error over a $50^{o}$ range [30].

### D. Image Acquisition System

The key element for acquiring high quality iris images is the imaging system. Early iris acquisition devices were unfriendly and required high levels of user co-operation. These cameras typically provide a chin rest, or head bar to constrain the user during acquisition. A comparatively less constrained iris acquisition device was first presented by Wildes *et al* [31], which uses an array of illuminators, a diffuser, a polarizer, two square edges and a silicon intensified camera. This set up was intended to give a uniform illumination to cover a wider region and to reduce specular reflection. One research direction from the literature has been focused towards designing a compact acquisition device that can provide high quality iris images. An example for such an acquisition device is given by Cambier and Siedlarz [32], which uses a CCD or CMOS camera of focal length 14.2 mm with a 1/3'' monochrome sensor and a cold mirror. Daugman noted that monochrome CCD cameras of resolution 480×640 are typical in commercial iris recognition systems [4]. These devices also assume user co-operation and the size of optics make it impossible to use in today's thin smartphones. A comprehensive review of iris acquisition devices is given by Rakvik *et al* [33].

## III. Iris Authentication Workflow

Most commercial iris acquisition systems place significant constraints on the subject in order to obtain a good quality iris image. To better understand the quality requirements for handheld imaging devices, one should consider the underlying iris authentication process that will likely be implemented on such a device.

The underlying iris authentication process has three primary components, namely: (i) iris acquisition; (ii) iris analysis and matching; and (iii) authentication of the user.

### A. Acquisition Process

If iris authentication is to be a success for mobile handheld devices, it must be implemented in a more flexible manner, ideally being operable in unconstrained conditions and made available as a service that is in practice transparent to the user.

To achieve these goals there are two main requirements. Firstly, it should be possible to carefully track an eye until the iris region is in an ideal state (position, focus) and then trigger an acquisition [34]–[36]. Secondly, when an iris is acquired it is important that the size, image focus, and overall optical quality are adequate. It is mainly this second aspect that is examined in this paper.

### B. Main Iris Analysis Process

While the analysis can be considered as the backbone of any iris authentication process it is also very well studied in the literature. Indeed there is no shortage of techniques and tools available to process and analyze a high quality iris image. A range of these were evaluated, but, for the purpose of this work, techniques developed by Daugman [4] were used.

The iris recognition can be separated into the individual steps of (i) iris segmentation – where iris region is localized, (ii) iris normalization – where the localized iris images were transformed in to a doubly dimensionless polar coordinate system, (iii) pattern enhancement – here the normalized iris images were enhanced and finally (iv) feature or code extraction – which encodes the underlying iris pattern to a feature vector.

### *C. Authentication*

The third part of the workflow is the final authentication based on the results of iris analysis. Of course any biometric system is prone to various attacks that compromise the underlying information. A key challenge for iris authentication to become accepted on smartphones is the robustness of the authentication and the corresponding risk of iris code theft. This field is a research topic in itself and there is much work on cancellable biometrics and associated techniques [37]. One solution is to combine the biometric with a device key, employing zero-knowledge-proof techniques to provide authentication beyond the device [38], [39].

## IV. Proof of Concept Tests

Having outlined the workflow for a handheld iris authentication system, the next consideration is on acquisition quality requirements. In this section, some experiments to confirm the lower thresholds of iris size that provide acceptable results is summarized [16]. This involves repeating experiments carried out by NIST IQCE across three publicly available databases – CASIA v4 interval, MMU 1 and UBIRIS v1 databases.

### *A. Test Databases*

CASIA and MMU databases consist of NIR iris images while UBIRIS contains images captured in visible wavelength. CASIA v4 interval database consists of high quality NIR images collected using a close up iris camera. This database comprises 249 subjects and an overall 2639 images, each image of resolution 320×280 and has approximately 200 pixels across iris [40]. MMU1 iris database consists of 450 iris images from 46 subjects. Iris images are of size 320×240, with an average 110 pixels across iris diameter. These images were captured at a range of 7-25 cm from the subject [41]. UBIRIS v1 database consists of 1877 images collected from 241 subjects. The images are captured at a distance of 20cm from the subject [41]. The images from session 1, in which images are of size 800×600 with an average 370 pixels across iris diameter, are used for these experiments.

### *B. Methodology*

Experiments were carried out according to the NIST evaluation set up. All images in each database were down-sampled to reduce the effective number of pixels across the iris diameter and verification was carried out on these down-sampled images. Note that, following the analysis by Daugman [4], left and right irises of the same person are considered as different classes in these experiments.

### *C. Results and Observations*

Receiver operating characteristic (ROC) curves for each database is shown in Fig 1.

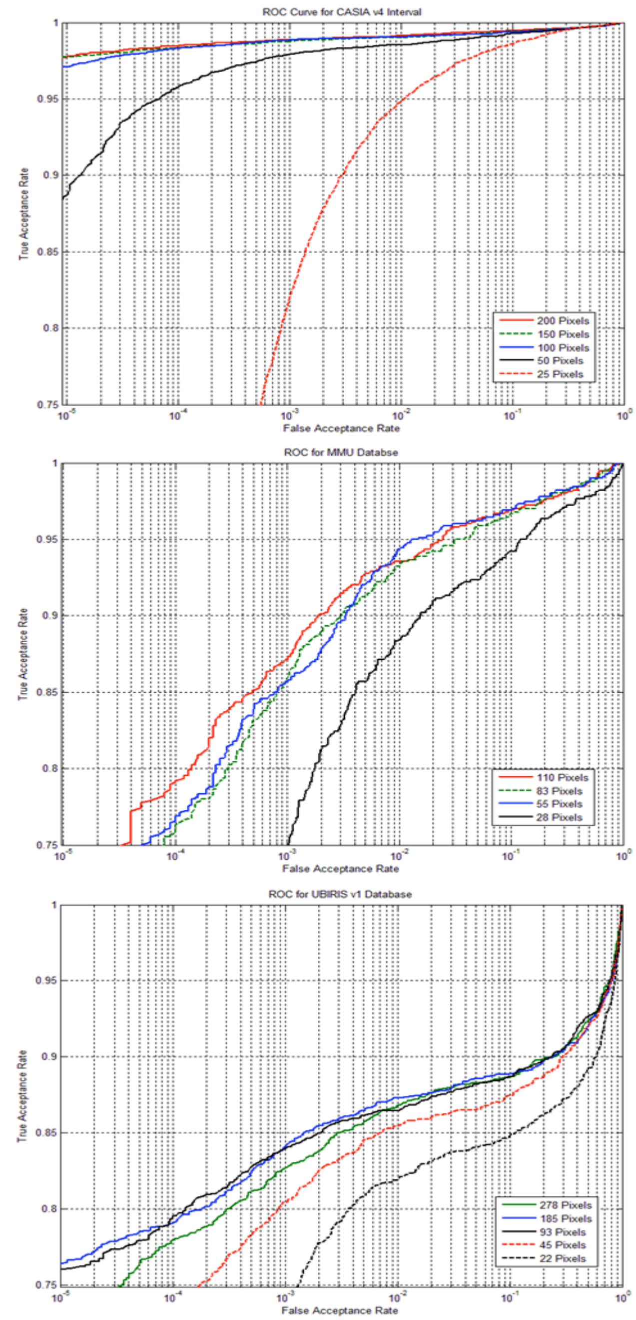


**Fig. 1. ROC Curves for CASIA v4 interval. MMU1 and UBIRIS v1 database for different number of pixels across iris diameter.**

From Fig.1, it can be observed that, the performance curves of images above 50 pixels across the iris diameter (approximately) in all the three databases represent similar performance while the performance curve of images below 50 pixels across the iris diameter shows significant disadvantage as compared to the rest. This suggests that 50-100 pixels across the iris diameter contain sufficient information for iris recognition, which can be approximated as 5 pixels per mm spatial resolution at the iris. A slight deterioration in performance of the images with 278 pixels across iris in UBIRIS database, when the false acceptance rate is less than $10^{-3}$ is also in accordance with NIST observation that irises too big can also cause recognition failure [6]. These results can be summarized in terms of the verification performance as shown in Fig.2.

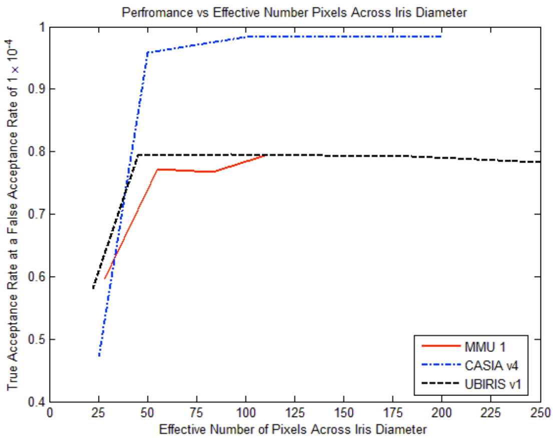


**Fig. 2. Iris recognition performance for different databases as a function of effective number of pixels across iris diameter.**

From Fig.2, it can be observed that there is no significant performance improvement when the effective number of pixels across the iris diameter is increased above 50 pixels. Further, increasing the number of pixels above 100 across iris diameter does not improve recognition performance at all. In a typical smartphone use case this suggests 5 pixels per mm spatial resolution, assuming good image quality. Note that, spatial resolution is also related to optics and sampling along with the pixel count [24]. These results are essentially in agreement with the NIST evaluation [5].

Further, after examining in detail the false rejection cases in the UBIRIS and MMU databases, it was observed that the main cause for false rejection is the failure to correctly segment the iris. A secondary cause is the relatively small usable iris area in some images. In particular occlusions due to eyelids and eyelashes contribute to incorrect segmentation and reduction in the usable iris area. By removing the images in which iris segmentation was not correct, the performance improved from 0.79 to 0.98 at a false acceptance rate of $10^{-4}$ in UBIRIS database for the case of 50 pixels across iris diameter.

Thus it can be concluded that iris images between 50 and 80 pixels in diameter along with commercial grade iris recognition algorithm may provide sufficient discriminating capability. It is also clear that the accurate segmentation of the iris region is critical to achieve a high degree of recognition. Given the unconstrained nature of handheld devices and the variety of environments in which they are used, one key challenge will be to adapt existing acquisition and segmentation techniques to operate in a range of typical use cases for iris biometrics.

## V. Smartphone Case Study

As a case study on the use of existing smartphone cameras for iris image acquisition, one of the state of the art, 2014 model smartphone rear-facing cameras is analyzed. The specification of this camera is shown in Table I.

**TABLE I: CAMERA SPECIFICATIONS**

| Parameter | Value |
|---|---|
| Sensor Size | 1/3 inch |
| Aspect Ratio | 16:9 |
| Sensor resolution ($w \times l$) | 2688×1520 |
| Pixel size | 2µm × 2µm |
| Focal length ($f$) | 3.82 mm |
| F number ($F$) | 2 |

### *A. Optical Analysis*

Considering a typical iris acquisition scenario using smartphones with a stand-off distance $d = 250mm$ and assuming a circle of confusion $c = 2\mu m$, the far point $(S)$ and near point $(R)$ in which the image is in focus are given by [42],

$$\left[S, R\right] = \frac{d \times f^2}{f^2 \pm Fcd}, \tag{1}$$

which gives,

$$S = 268.4mm$$
$$R = 234.0mm$$

Hence, the Depth of Field $(DoF)$ is,

$$DoF = S - R, \tag{2}$$
$$= 34.4mm.$$

At $250mm$ stand-off distance, this camera will have a magnification factor $M$,

$$M = \frac{f}{d - f}, \tag{3}$$

$$= \frac{3.82}{250 - 3.82} = 0.0155.$$

That is, this camera will magnify the iris by 0.0155 on to its sensor. Also, vertical field of view $(FoV_v)$ and horizontal field of view $(FoV_h)$ can be calculated as below [42],

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

$$= 2\arctan\left(\frac{2688 \times 2\mu m}{2 \times 3.82mm}\right) \approx 70^o$$

$$FoV_v = 2\arctan\left(\frac{l}{2f}\right) \tag{5}$$

$$= 2\arctan\left(\frac{1520 \times 2\mu m}{2 \times 3.82mm}\right) \approx 43^o.$$

### *B. Equivalent Pixel Dimensions and Optical Resolution*

Hence, at 250 mm standoff distance, this camera will be able to capture a horizontal distance,

$$d_h = 2\tan\left(\frac{FoV_h}{2}\right) \times d \approx 350mm . \quad (6)$$

Similarly, the vertical distance captured is $d_v = 200mm$. That is, at 250 mm, this camera can provide a capture box of 350 mm × 200 mm and a depth of field of 34.4mm. Considering a maximum inter-pupillary distance of 78mm, this capture box will be sufficient to obtain both eyes simultaneously. Further, assuming an iris of size 11mm [4], a magnification of 0.0155 will result in an iris image of 170 µm diameter on the sensor. The sensor has a pixel size of 2µm, so assuming a fill factor of 100% the iris will have 85 pixels diameter on the sensor. Within the depth of field, the iris will have pixel range of 79 to 91 pixels on sensor. Whilst this is greater than the minimum value of 50 pixels across the iris as estimated above, the effect of Bayer filter on the detector have been ignored, and of course, this commercial camera has only RGB pixels and no NIR channel.

The modulation transfer function (MTF) at 250mm standoff distance of this camera was measured in white light using the Imatest tool [43]. The MTF plot is shown in Fig.3.

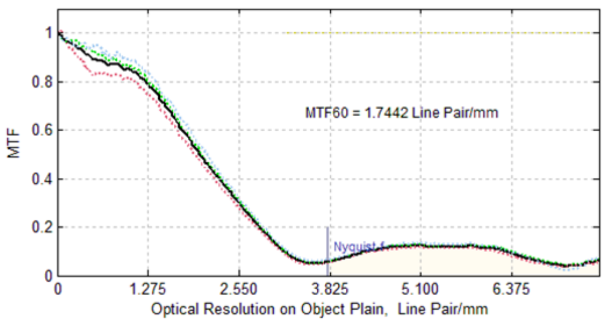


**Fig. 3. MTF plot at a stand-off distance of 250mm.**

From Fig.3, one can note that, at 60% modulation, the optical resolution is 1.7 line pair/mm on the object plane. This optical resolution is below the marginal image quality as suggested by ISO/IEC 19794-6. One reason may be that the lens on the rear-facing camera is optimized for distant objects, not for a 250mm object distance.

### C. *Diffraction Limit Calculation*

The radius of the Airy disk, which defines the lens diffraction limit, can be calculated for visible wavelength $(\lambda = 550nm)$ as:

$$r = 1.22F\lambda = 1.34\mu m . \quad (7)$$

According to Rayleigh criterion, two separate point images can be resolved if they are separated by a distance greater or equal to $r$. At the longer NIR wavelength of 850nm, this radius would be approximately 2.07µm. However it is clear from the MTF that the lens is far from diffraction-limited.

### D. *Considerations for Infrared Imaging*

Here it can be concluded that the example smartphone is marginally capable of acquisition with acceptable optical quality for visible iris image, with the camera to iris distance of 250mm. It can be observed from (7) that at NIR wavelengths the effects of the diffraction limit become noticeable, potentially restricting iris quality if improved lenses are incorporated. At NIR wavelengths, there may be a shift in focus, compared to the visible focus, due to longitudinal chromatic aberration, producing a blurring effect.

## VI. Acquisition System Requirements

In the previous section, it is shown that at least one model of contemporary smartphone is potentially capable of implementing visible iris authentication, although not with high reliability. However visible wavelength authentication is limited to a segment of the population with lightly-colored iris [44], [45]. A practical acquisition needs to employ NIR wavelengths, but could rely on established visible wavelength face and eye tracking techniques to determine suitable iris regions for NIR acquisition and subsequent segmentation.

### A. *Acquisition Process – Wavelength and Illumination*

For optimal iris region acquisition it is recommended to use an NIR illumination and a band pass NIR filter on the acquisition system [4]. In the context of a consumer device this requires redesigning the current imaging system and sensor.

The availability of low cost NIR LED sources is of interest and these are often used in automotive environments, but have not yet been widely adopted in handheld imaging systems. Such NIR sources could be placed alongside or below the main user-facing camera to prevent shadows caused by eyebrows [14]. ISO/IEC 19794-6 recommends an angle of 5 degree between the line extending from the center of the illumination source to the pupil center and the optical axis of the camera in order to avoid a NIR 'red-eye' effect [14]. An advantage of NIR illumination is that a non-visible light source does not annoy the user.

### B. *Acquisition Process - Camera*

A dedicated iris acquisition system is needed to provide a working solution based on the technology available in today's smartphones. Several key design questions that will shape a working reference design are discussed below.

#### 1) *Dual Eye or Single Eye Capture?*

NIST IREX III evaluation shows that false negative identification rate was reduced by a factor of two when both eyes are used for identification as compared to the single eye case [46]. Further, it is shown that dual iris approach is significantly better, particularly when the number of enrolled images is small as is likely for a personal smartphone [47]. NIST Mobile ID Best Practice recommends capturing both irises simultaneously for higher subject acquisition profiles, which will help to achieve higher accuracy and comparison speed [20]. There are some challenges as the dual iris approach may require a dual illumination system. Also it is challenging to ensure that both eyes are equally illuminated in an unconstrained environment.

The most practical approach may be a single-eye acquisition system that can obtain a pair of eyes sequentially, while tracking the individual eye regions. Such an approach could be implemented by requiring the user to execute an eye sweep or side-to-side head movement, or alternatively by employing a directed light source that illuminates each iris region in turn.

#### 2) *One Camera or Two?*

The best use case for iris acquisition on a smartphone is in the video-call mode when the user-facing camera is naturally acquiring a stream of images. However today's user-facing cameras do not have sufficient quality to acquire a useful iris pattern at NIR wavelengths, as they are designed for a wide field-of-view, usually have fewer pixels than the higher quality rear-facing camera and are optimized for visible RGB imaging. A hybrid single-camera design is being investigated but presents some difficult design challenges: (i) a movable NIR optical filter might be needed to support iris acquisition mode, or alternatively a dedicated second NIR detector must be provided; (ii) optical design at visible and NIR wavelengths has to be optimized for two different sets of requirements, but using the same CMOS sensor.

Another solution is presented by Kim *et al* [48], which uses two sensors - one designed for visible light and another designed for NIR radiation is used. A reflection/ penetration filter is used to allow the light in the visible area to pass through and reach the specific visible light sensor and reflects the NIR waves to the iris sensor. The feasibility of this camera for today's ultra-thin smart phones has yet to be examined in detail, but on initial evaluation it too appears infeasible.

The alternative is a dual-imaging system. This increases costs, but has several advantages: (a) the field of view (FoV) of the infrared imaging system can be reduced, increasing pixel resolution and image quality in the iris region; (b) visible and infrared optical designs are independent, so that both can be optimized independently and (c) no movable IR filter is needed. Despite the added costs of a second imaging system the two-camera approach has some compelling advantages.

Irrespective of the choice between a single hybrid imaging system or a dual-imaging system, there are further design considerations such as scanning type, SNR and maximum exposure time [15], [20], [49].

### C. *Face & Eye Tracking, Focus & Exposure*

Modern cameras implement hardware face detectors [50] to track faces and eye-gaze [35], [36]. Tracking data can be used in turn to perform a continuous focus on the face region [51]. Also, face detection can be used to optimize image exposure on handheld devices [52]. Eye tracking also facilitates eye-blink and liveliness detection. A detailed analysis of liveliness detection techniques can be found in the work of Toth [53].

The proximity sensor of the phone or the measure of inter-pupillary distance can be used to precisely calculate the distance of the person from the phone. This enables acquiring images when the eyes are in the depth of field of the camera. Given the extent of established technologies embedded in today's camera modules, acquiring well-focused eye regions in an image should not prove unduly challenging.

## VII. Iris Analysis and Authentication

Most commercial iris recognition system use Daugman's original approach to iris recognition [4]. His work showed that it will take only 0.45 seconds for the whole iris recognition process from assessing the focus, iris localization, occlusion detection and masking, feature extraction to comparison of two feature vectors on a 300MHz RISC processor. This algorithm can be used 'as is' in today's smartphones and the computation power of such devices guarantees fast iris recognition. Recent improvements on segmentation, feature extraction, and other techniques will improve system performance and reliability.

In the proof of concept tests summarized in Section IV, it is shown that segmentation plays a crucial role in recognition performance. State of the art techniques can be used to improve segmentation [25], [54]. Feature extraction can be further improved by using techniques like fragile bit masking, dividing iris region in to different groups and encoding by giving each region different weights [55], [56] or using computationally efficient techniques presented by Savvides *et al* [57].

## VIII. Conclusions And Future Work

In this paper, the feasibility of iris authentication in smartphones using a constraint-free acquisition workflow is explored. Here the main findings are summarized and future research for iris acquisition on handheld devices is outlined.

### A. *Quality Metric-Key Criteria*

The feasibility studies have shown that iris regions larger than 50 pixels in diameter can provide sufficient quality for reliable authentication. In practical unconstrained scenarios it is advisable to aim for a higher resolution in the region of 70-80 pixels. This provides more flexibility in dealing with small aberrations such as slight motion blur and off-center gaze.

Sharpness and contrast measures of the iris region can provide an indication of a well-focused iris and are important for good segmentation results. Eye gaze and eye openness are also critical and the eye regions must be substantially forward-looking to facilitate accurate segmentation. Once these criteria are all satisfied an optimal iris region can be determined for acquisition and subsequent segmentation.

### B. *System Feasibility-Physical Limits*

The analysis in section V suggests that iris regions of the order of 80 pixels can be obtained with the primary smartphone camera. Today's user-facing camera has either smaller pixel size, or fewer pixels, or both. Nevertheless current trends, driven by the popularity of the self-portrait, or selfie, are seeing higher quality cameras in the user-facing role.

Equally important, the acquisition of iris region images is ideally at NIR wavelengths. The discussion on Section V indicates that today's market leading smartphone's primary cameras are on the edge of feasibility for NIR acquisition.

### C. Key Challenges

The earlier discussion leads us to identify several key challenges for iris acquisition systems on smartphones.

*1) Infrared Optical & Sensor Systems:*

The visible wavelength camera systems on today's devices can achieve sufficiently high quality determination of an iris region to facilitate accurate segmentation. However the final acquisition should be performed using NIR wavelengths to be generally applicable across the population. A working solution requires a dual-camera visible and NIR imaging system, with associated increased costs and the complexity of integrating this dual imaging system into the device. However bearing in mind the recent availability of dual visible/NIR CMOS sensors [58], [59] an alternative and a major design challenge, would be to combine both visible and NIR imaging into a single optical and sensor system. Meeting the requirements of both visible and NIR channels in a single optical design would be challenging but the cost savings are significant compared to a dual-camera approach.

*2) Iris Acquisition & Segmentation:*

Modern camera systems have built-in face and eye tracking capabilities. Further, the focus tracking system in many cameras uses the eyes, or central regions of the face to maintain continuous focus. And the same techniques that can track eyes in an image sequence also enable the degree of openness of an eye to be determined. Thus obtaining well-focused and open eye regions is not as challenging as it may at first appear. In an unconstrained acquisition system the real challenge is to determine the eye-gaze and eye-motion from frame to frame. Rapid eye saccades can introduce gaze and motion artifacts that subtly distort the iris pattern and corrupt the authentication process. This represents a second key challenge requiring further study.

*3) Illumination Conditions:*

Previous researchers have commented on problems caused by challenging illumination conditions in full sunlight [17], [19]. This work has not yet investigated this aspect of unconstrained iris acquisition. However from experience with different smartphone models it is to be expected that strong sunlight may pose significant challenges for NIR imaging systems.

*4) Iris Pattern/Template Security:*

If both irises of the person are used then very robust authentication can be achieved. However the real challenge for biometrics in the handheld devices is how templates are stored locally. For example, it is known that an iris pattern can be reverse engineered from the underlying iris code [60]. Thus the security of the device, and its user, rely on keeping the extracted iris code secret. This is a complex problem and lies outside the scope of the present work. It represents another key challenge for a practical iris authentication system for smartphones.

Future research will present practical implementations and testing of several of these approaches.

### D. Concluding Remarks

Biometrics is establishing a presence in consumer electronics markets, in particular through devices such as smartphones. Being a near ideal biometric, iris recognition is very likely to be adopted in these devices in near future. For wider adoption, a constraint free, user friendly iris acquisition is required. The analyses and discussions presented in this paper lay a foundation for the design of more reliable, unconstrained iris recognition system for next generation smartphones.

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