

BIOMETRICS

IRIS RECOGNITION: THE PATH FORWARD

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Iris recognition systems have made tremendous inroads over the past decade, but work remains to improve their accuracy in environments characterized by unfavorable lighting, large stand-off distances, and moving subjects.

B iometrics is the science of establishing human identity by using physical or behavioral traits such as face, fingerprints, palm prints, iris, hand geometry, and voice. Iris recognition systems, in particular, are gaining interest because the iris's rich texture offers a strong biometric cue for recognizing individuals.¹

Located just behind the cornea and in front of the lens, the iris uses the dilator and sphincter muscles that govern pupil size to control the amount of light that enters the eye. Near-infrared (NIR) images of the iris's anterior surface exhibit complex patterns that computer systems can use to recognize individuals. Because NIR lighting can penetrate the iris's surface, it can reveal the intricate texture details that are present even in dark-colored irides. The iris's textural complexity and its variation across eyes have

led scientists to postulate that the iris is unique across individuals. Further, the iris is the only internal organ readily visible from the outside. Thus, unlike fingerprints or palm prints, environmental effects cannot easily alter its pattern. The "What Makes the Iris Unique?" sidebar hints at iris recognition's potential.

An iris recognition system uses pattern matching to compare two iris images and generate a match score that reflects their degree of similarity or dissimilarity. Iris recognition systems are already in operation worldwide, including an expellee tracking system in the United Arab Emirates, a welfare distribution program for Afghan refugees in Pakistan, a border-control immigration system at Schiphol Airport in the Netherlands, and a frequent traveler program for preapproved low-risk travelers crossing the US-Canadian border.

To further the advances made in iris recognition over the past decade, researchers must solve issues such as capturing eye images of sufficient quality in less than ideal conditions and accurately localizing the iris's spatial extent in poor-quality images. However, the promise of iris recognition—borne out by the complexity of the patterns and their assumed stability—is compelling motivation to solve these problems and facilitate a broader use of iris recognition systems.

IRIS ANATOMY

The iris dilates and constricts the pupil to regulate the amount of light that enters the eye and impinges on the retina. It consists of the anterior stroma and the posterior epithelial layers, the former being the focus of all automated iris recognition systems. As Figure 1 shows, the anterior surface is separated into the *pupillary zone* and the *ciliary zone*, which are divided by the *collarette*, an irregular jagged line where the sphincter and dilator muscles overlap. The two zones typically have different textural details.

As the pupil dilates and contracts, *crypts*—pit-like oval structures in the zone around the collarette—permit fluids to quickly enter and exit the iris. A series of radial streaks, caused by bands of connective tissue enclosing the crypts, straighten when the pupil contracts and become wavy when the pupil dilates. Concentric lines near the outer ciliary zone become deeper as the pupil dilates, causing the iris to fold. These *contraction furrows* are easily discernible in dark irides.

The *limbus* and *pupillary boundaries* define the iris's spatial extent and, in 2D images of the eye, help delineate it from other ocular structures, such as the eyelashes, eyelids, sclera, and pupil. The rich textural details embedded on the iris's anterior surface provide a strong biometric cue for human recognition.

ELEMENTS OF A RECOGNITION SYSTEM

As Figure 2 shows, most iris recognition systems consist of five basic modules leading to a decision:

- The *acquisition* module obtains a 2D image of the eye using a monochromatic CCD camera sensitive to the NIR light spectrum.
- The *segmentation* module localizes the iris's spatial extent in the eye image by isolating it from other structures in its vicinity, such as the sclera, pupil, eyelids, and eyelashes.
- The *normalization* module invokes a geometric normalization scheme to transform the segmented iris image from cartesian coordinates to polar coordinates.
- The *encoding* module uses a feature-extraction routine to produce a binary code.
- The *matching* module determines how closely the produced code matches the encoded features stored in the database.

Acquisition

Most iris recognition systems require the participating individual to place his or her eye about six inches from a camera. An external NIR light source, often colocated with the acquisition system, illuminates the iris. The acquisition module captures a series of ocular images; uses a scheme

→ WHAT MAKES THE IRIS UNIQUE?

According to the biometric literature, the iris's structural texture is substantially diverse across the population. Even the irides of monozygotic twins exhibit structural differences, suggesting that random events impact the tissue's morphogenesis.¹ Large-scale testing has confirmed the potential to identify individuals from a large database of iris patterns. Recent experiments conducted on a database of 632,500 iris images—316,250 persons spanning 152 nationalities—suggest the possibility of a decision policy that could yield a zero false-match rate.²

However, this rate is predicated on the quality of the iris image, which must be strictly monitored to ensure reasonable textural clarity. Tests that the National Institute of Standards and Technology conducted in 2006 involving a broad range of image quality suggest that the false-nonmatch rate of the best-performing iris recognition algorithms can vary between 1.1 to 1.4 percent at a false match rate of 0.1 percent.³

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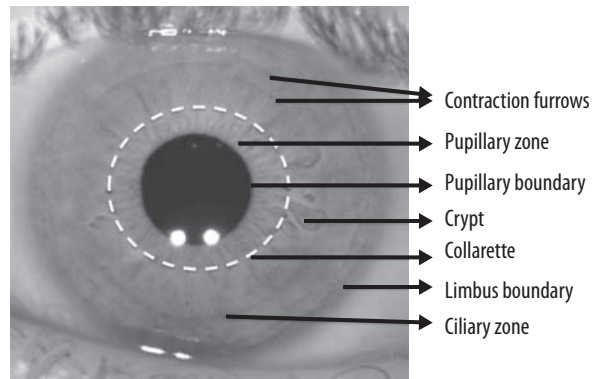


Figure 1. The anterior portion of an iris imaged in the near-infrared spectrum. The anterior has complex textural patterns that provide a strong biometric cue.

to evaluate image quality; and selects one image with sufficient iris information, which then undergoes additional processing.

Segmentation

The segmentation module detects the pupillary and limbus boundaries and identifies the regions where the eyelids and eyelashes interrupt the limbus boundary's contour. The integro-differential operator is the traditional detection mechanism, although more recent work has promoted the use of active contours to account for nonconic

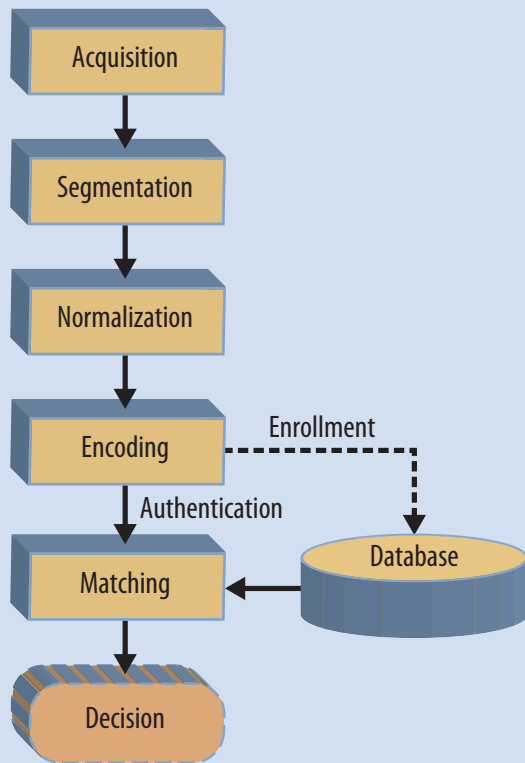


Figure 2. Block diagram of an iris recognition system. During enrollment, the system places encoded features into a database. During authentication, the system compares the presented iris against the database code to verify a claimed identity or identify an individual.

boundary attributes.^{2,3} An integro-differential operator is defined as

$$\max(r, x_0, y_0) \left| G_\sigma(r) * \frac{\partial}{\partial r} \oint_{r, x_0, y_0} \frac{I(x, y)}{2\pi r} ds \right|$$

where $I(x, y)$ is the image intensity at pixel location (x, y) , r is the radius of the pupil or iris, (x_0, y_0) is its center, and $G_\sigma(r)$ is the Gaussian smoothing function with scale σ . Thus, the integro-differential operator searches for a circular boundary with radius r and center (x_0, y_0) that exhibits a maximum change in radial pixel intensity across its boundary.

Iris segmentation is a critical component of any iris detection system because inaccuracies in localizing the iris can severely degrade the system's matching accuracy and undermine the system's usefulness.

Normalization

Once the segmentation module has estimated the iris's boundary, the normalization module uses a rubber-sheet model to transform the iris texture from cartesian to polar coordinates. The process, often called *iris unwrapping*,

yields a rectangular entity that is used for subsequent processing. Normalization has three advantages:

- It accounts for variations in pupil size due to changes in external illumination that might influence iris size.
- It ensures that the irides of different individuals are mapped onto a common image domain in spite of the variations in pupil size across subjects.
- It enables iris registration during the matching stage through a simple translation operation that can account for in-plane eye and head rotations.

Associated with each unwrapped iris is a binary mask that separates iris pixels (labeled with a "1") from pixels that correspond to the eyelids and eyelashes (labeled with a "0") identified during segmentation. After normalization, photometric transformations enhance the unwrapped iris's textural structure.

Encoding

Although a recognition system can use the unwrapped iris directly to compare two irides (using correlation filters, for example), most systems first use a feature extraction routine to encode the iris's textural content. Encoding algorithms generally perform a multiresolution analysis of the iris by applying wavelet filters and examining the ensuing response. In a commonly used encoding mechanism, 2D Gabor wavelets are first used to extract the local phasor information of the iris texture. The mechanism then encodes each phasor response using two bits of information, resulting in an *IrisCode*. Figure 3 shows an *IrisCode* example.

Matching

The matching module generates a match score by comparing the feature sets of two iris images. One technique for comparing two *IrisCodes* is to use the Hamming distance, which is the number of corresponding bits that differ between the two *IrisCodes*. The binary mask computed in the normalization module ensures that the technique compares only bits corresponding to valid iris pixels. The two *IrisCodes* must be aligned before computing the Hamming distance through a registration procedure. While a simple translation operation could suffice in most cases, more sophisticated schemes can account for the elastic changes in iris texture.⁴

Researchers have also designed other types of encoding and matching schemes, based on discrete cosine transforms,⁵ ordinal features,⁶ and scale-invariant feature transforms.⁷

MULTISPECTRAL RECOGNITION

A multispectral image contains information across multiple wavelengths, or *spectral channels*, of the electromagnetic spectrum. Multispectral imaging is used in

applications ranging from remote geospatial sensing and night-vision systems to ancient document analysis and medical imagery. It is also a tool in the biometric analysis of face, fingerprints, and palm prints. More recent work has explored its use in iris recognition, motivated by the idea that iridal composition is biologically diverse, so different ranges of the electromagnetic spectrum might better capture certain physical characteristics of the epigenetic iris pattern.

In one effort to explore multispectral recognition, researchers showed how visible spectral iris images—red, green, blue (RGB) images in the 400-nm to 650-nm range—fused with NIR images at the match-score level can improve recognition accuracy.⁸ Because various anatomical structures are embedded on the iris's stroma, a differential reflectance of these structures can result in a rich set of features for matching. The researchers also found that the nature of iris information presented in different spectral channels varies according to eye color. Figures 4, 5, and 6 show the intensity of iridal reflection across four spectral channels for dark brown, light brown, and blue eyes.

The use of multispectral information has the potential to improve the segmentation and enhancement processes in iris recognition. It could also aid in detecting moles and freckles on the iris's surface—information that iris recognition systems could incorporate in the matching module. Current research is exploring the possibility of processing the iris information available in high-resolution color images of the face. Researchers are also investigating the use of iris images obtained at longer wavelengths (950 to 1,700 nm, for example) in scenarios that regularly use multiple sensors with diverse characteristics, such as military applications.

RESEARCH CHALLENGES

The tremendous progress in iris recognition systems has resulted in several challenges and new opportunities, which have been the focus of recent research efforts.

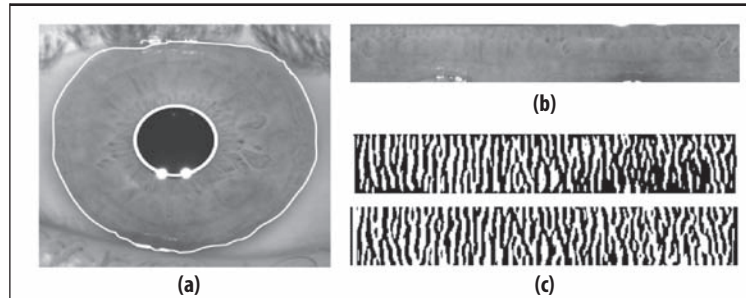


Figure 3. Sample outputs of (a) iris segmentation, (b) normalization, and (c) encoding. Normalization unwraps and enhances the iris image, while encoding extracts textural features and encodes them as a 2D binary code. Because the encoding of each pixel in the normalized iris uses two bits of information, there are two binary codes—one for each bit.

Localizing the iris

The iris is a moving object with a small surface area, residing within an eyeball that can move independently of the iris. The eyeball in turn is within the head—another moving object. The formidable challenge, therefore, is to reliably locate the eyeball and localize the iris's position in



Figure 4. Multispectral imaging of a dark brown iris. The iris exhibits high iridal reflectance in the NIR channel. The reflectance decreases significantly in the other channels.

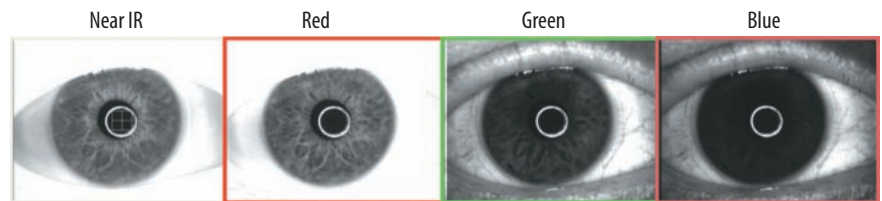


Figure 5. Multispectral imaging of a light brown or green iris. The iris exhibits high iridal reflectance in the NIR and red channels. Reflectance decreases significantly in the other channels.

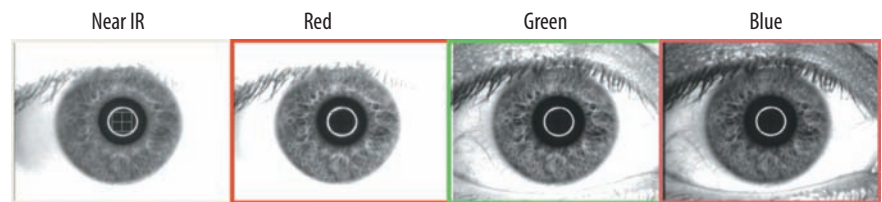



Figure 6. Multispectral imaging of a blue iris. The iridal reflection is comparable across all four channels.

images obtained at a distance from unconstrained human subjects. Because acquisition modules typically image the iris in the NIR spectrum, appropriate invisible lighting is required to illuminate the iris before acquiring the image. These factors confound the system's ability to operate successfully when the subject is more than a few meters away from the camera.

Recent efforts have successfully designed and developed iris-on-the-move and iris-at-a-distance recognition systems.⁹ Other efforts are investigating technologies such as wavefront-coded imaging to increase the camera's depth of field.¹⁰



The formidable challenge is to reliably locate the eyeball and localize the iris's position in images obtained at a distance from unconstrained human subjects.

Processing nonideal irides

Nonideal irides can result from motion blur, camera diffusion, transmission noise, out-of-focus imaging, occlusion from eyelids and eyelashes, head rotation, off-axis gaze or camera angle, specular reflection, poor contrast, and natural luminosity—factors that can lead to a higher false-nonmatch rate. Robust image-restoration schemes are needed to enhance the quality of such iris images before the system processes them. Recent research has attempted to deal with the problem of off-axis iris images by designing suitable calibration and geometric correction models.¹¹

Quantifying individuality

A common assumption is that the textural relief of an iris is unique because of its random morphogenesis, and large-scale empirical evaluations have confirmed this notion across the population. By exploiting this perceived uniqueness, researchers have been able to integrate the iris biometric into a cryptographic framework, allowing the system to extract a repeatable binary string from multiple samples of the same iris.¹² However, no effective theoretical models exist for quantifying the iris's individuality. Although researchers have used match-score distributions and IrisCode statistics to infer the iris biometric's degrees of freedom, no one has yet directly used the iris's biological underpinnings to ascertain its individuality. This interesting problem has implications for using iris recognition in a court of law in accordance with *Daubert's* admissibility criteria and Federal Rules of Evidence.


Combining ocular features

By combining the iris with other ocular features such as conjunctival vasculature, researchers might be able to de-

velop robust ocular-based multibiometric systems that can operate in environments characterized by harsh lighting, moving subjects, and large stand-off distances. Explicitly combining ocular features with local facial attributes such as skin texture and facial marks in the periocular region can enhance the performance of face-based biometric systems. Using the iris in a multimodal framework can enhance matching accuracy and improve depth of field by allowing the use of low-resolution iris images.

Ensuring security and privacy

The use of biometric systems in large-scale government and civilian applications has raised concerns about the iris template's security and the retention of its owner's privacy. Security and privacy are of particular concern in centralized databases, which can store millions of iris templates. Privacy-enhancing technology, along with cancelable biometrics, is likely to raise the privacy and security levels of such information. However, more research is required to incorporate these schemes in an operational environment.

Despite its challenges, iris recognition is gaining popularity as a robust and reliable biometric technology. The iris's complex texture and its apparent stability hold tremendous promise for leveraging iris recognition in diverse application scenarios, such as border control, forensic investigations, and cryptosystems. The use of other ocular features and facial attributes along with the iris modality could enable biometric recognition at a distance with good matching accuracy. The future of iris-based recognition looks bright, particularly in military applications that demand the rapid identification of individuals in dynamic environments. 

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