

# 6 RETINA IDENTIFICATION

Robert “Buzz” Hill<sup>1</sup>  
Portland, OR  
buzzhill@rain.com

**Abstract** Retina based identification is perceived as the most secure method of authenticating an identity. This chapter traces the basis of retina based identification and overviews evolution of retina based identification technology. It presents details of the innovations involved in overcoming the challenges related to imaging retina and user interface. The retinal information used for distinguishing individuals and a processing method for extracting an invariant representation of such information from an image of retina are also discussed. The issues involved in verifying and identifying an individual identity are presented. The chapter describes performance of retina based identification and the source of inaccuracies thereof. The limitations of the retina based technology are enumerated. Finally, the chapter attempts to speculate on the future of the technology and potential applications.

**Keywords:** Fundus, choroid, fundus camera, astigmatism, ergonomics, infrared imaging, fixation.

## 1. Introduction

Identification of a given person is often an essential part of transactions on a network. While this is the goal, the fact is we often are left with substitutes for true personal identification in such transactions such as something the person knows (password) or has (a card, key, etc.). Retinal identification (RI) is an automatic method that provides true identification of the person by acquiring an internal body image, the retina/choroid of a willing person who must cooperate in a way that would be difficult to counterfeit.

RI has found application in very high security environments (nuclear research and weapons sites, communications control facilities and a very large transaction-

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<sup>1</sup> The author of this chapter is the original RI inventor and the founder of EyeDentify, Inc. (1976). Although, he no longer owns stock or otherwise has an interest in EyeDentify, he has, at various times since 1987, served as its consultant.

processing center). The installed base is a testament to the confidence in its accuracy and invulnerability. Its small user base and lack of penetration into high-volume price-sensitive applications is indicative of its historically high price and its unfriendly perception.

## 2. Retina/Choroid as Human Descriptor

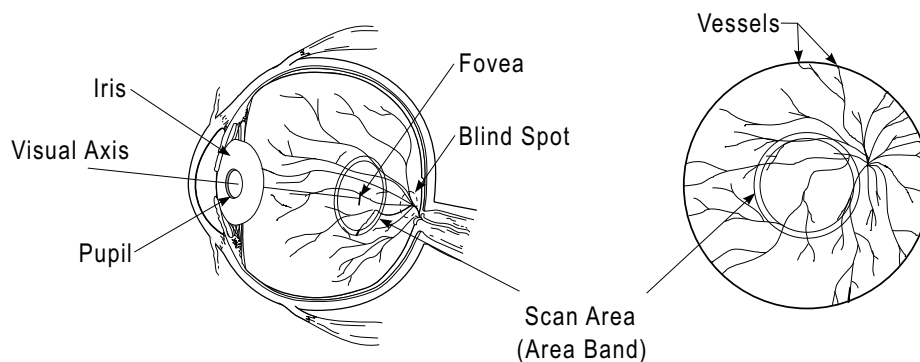
Awareness of the uniqueness of the retinal vascular pattern dates back to 1935 when two ophthalmologists, Drs. Carleton Simon and Isodore Goldstein, while studying eye disease, made a startling discovery: every eye has its own totally unique pattern of blood vessels. They subsequently published a paper on the use of retinal photographs for identifying people based on blood vessel patterns [7].

Later in the 1950's, their conclusions were supported by Dr. Paul Tower in the course of his study of identical twins [8]. He noted that, of any two persons, identical twins would be the most likely to have similar retinal vascular patterns. However, Tower's study showed that of all the factors compared between twins, retinal vascular patterns showed the least similarity.

The eye shares the same stable environment as the brain and among physical features unique to individuals, none is more stable than the retinal vascular pattern.

Because of its internal location, the retina/choroid is protected from variations caused by exposure to the external environment (as in the case of fingerprints, palmprints etc.).

Referring to Figure 6.1, the retina is to the eye as film is to camera. Both detect incident light in the form of an image that is focused by a lens. The amount of light reaching the retina (or film) is a function of the iris (f-stop). The retina is located on the back inside of the eyeball. Blood reaches the retina through vessels that come from the optic nerve. Just behind the retina is a matting of vessels called the choroidal vasculature.



**Figure 6.1** Eye and scan circle (area band).

The products of EyeDentify, Inc. have always used infrared light to illuminate the retina as will be discussed later. The retina is essentially transparent to this wavelength of light. The mat of vessels of the choroid just behind the retina reflect

most of the useful information used to identify individuals, so the term “retinal identification” is a bit of a misnomer but nevertheless useful because the term is familiar. RI in this chapter will be used interchangeably to mean retina/choroid identification. This area of the eye is also referred to by medical doctors as the eye fundus.

It might seem that corrective error changes (such as becoming more near-sighted over time) might change the image of this very stable structure. In fact, the low resolution required to acquire adequate identification information masks any effect the focus errors might have. The RI products of EyeDentify, Inc. take advantage of this fact. No focusing of the RI system optics is necessary reducing cost and making the unit easier to use.

The operational rule-of-thumb for the circular scan RI systems described here is as follows: If the person to be identified can see well enough to drive with at least one eye, it is highly likely that he/she can use RI successfully.

Children as young as four years of age have been taught how to use RI. Once learned, RI is simple to use for the vast majority of the human population.

### **3. Background**

The concept of a simple device for identifying individuals with RI was conceived in 1975. A practical implementation of this concept did not emerge for several years. The author formed a corporation, EyeDentify, Inc. in 1976 and a full time effort began to research and develop RI. In the late 1970s several different brands of ophthalmic instruments called fundus cameras were modified in an attempt to obtain live images of the retina suitable for personal identification [9,10]. Using then available fundus cameras for the optics portion of RI had at least three major disadvantages:

1. Critical alignment was necessary requiring either extraordinary expertise or the assistance of an operator.
2. A bright illumination light was necessary.
3. They were too complex and therefore too expensive.

The early RI experiments used visible light to illuminate the retina. This proved undesirable since the amount of light required for a sufficient signal-to-noise ratio was often uncomfortable to the user. An experiment was tried using near infrared as the illuminating source. This wavelength is invisible to the human eye and eliminates the bright illuminating light that can be annoying to the subject and cause his/her pupils to constrict (lowering the detected light). Inexpensive light sources and detectors existed for the near IR providing a cost saving advantage as well.

The first practical working prototype of RI was built in 1981. An RI camera using an infrared light was connected to a general-purpose desktop computer for analyzing the reflected light waveforms. Several forms of feature- extraction algorithms were evaluated. Simple correlation proved to be a superior matching technique however.

Four years of refinement led to the first production RI system built by EyeDentify, Inc. (then of Portland, OR). It was called the EyeDentification System 7.5 and performed three basic functions:

1. Enrollment - where a person's reference eye signature is built and a PIN number and text (such as the person's name) is associated with it.
2. Verification - a person previously enrolled claims an identity by entering a PIN number. The RI scans the ID subject's eye and compares it with the reference eye signature associated with the entered PIN. If a match occurs, access is allowed.
3. Recognition - RI scans the ID subject's eye and "looks-up" the correct, if any, reference eye signature. If a match occurs, access is allowed.

System 7.5 performed a circular scan of the retina, reducing the circular fundus image composed of 256 twelve bit logarithmic samples into a reference signature for each eye of 40 bytes. The contrast pattern was coded in the frequency domain. An additional 32 bytes per eye of time-domain information was added to speed up the Recognition mode.

### *Patents*

State-of-the-art RI is covered by at least nine active U.S. patents. The RI implementation described here is covered by at least four major U.S. patents dating back to 1978 [2,3,4,5]. The patent with broad first claim to the method of RI [2] expired in 1995 and is thought to have discouraged others from developing RI technology. Now that the method of identifying individuals by their retinal patterns is no longer protected (as opposed to the apparatus to identify), we may see more interest by others in developing RI technology that is not protected by the active patents whose claims are less general than the expired patent. EyeDentify, Inc. either owns or has exclusive license to the three aforementioned patents that have not, as yet, expired. These patents deal with the alignment/fixation and user interface subsystems of the RI technology.

## **4. Technology**

The three major subsystems of the RI technology are:

**Imaging, signal acquisition, and signal processing:** An RI Camera that translates a circular scan of the retina/choroid into a digital waveform.

**Matching:** A computer that verifies or recognizes the acquired eye pattern with a stored template.

**Representation:** The eye (retina) signature reference templates with the corresponding identification information; storage issues.

Sections 6, 7, 8, 9, and 10 describe in more detail the entire RI system. Section 5 discusses representation issues.

## 5. Eye Signature (Reference Template)

The representation of retina is derived from a retina scan composed of an annular region of retina, scan circle (Figure 6.1). The spot size (width of annular band) and scan circle size are chosen to return sufficient light and contrast detail in the worst case (very small eye pupil) to support the performance specification of the RI.

Two major representations for the RI eye signature have emerged. The original representation consisted of 40 bytes of contrast information encoded as real and imaginary coordinates in the frequency domain and was generated with the fast fourier transform.

The second representation, while slightly larger at 48 bytes, leaves the contrast data in the time domain. The primary advantage of the time domain representation of the eye signature is computing efficiency resulting in lower computer cost and/or higher processing speed.

Taking the ratio of the brightness at any point to the average regional brightness removes artifacts that are due to non-uniformity of the beam at the point where it enters the eye. This also normalizes the identifying signal for varying pupil sizes that greatly influence the total light returned to the detector.

The fully processed digital eye signature can be described as a normalized contrast waveform of the entire scan circle. Average RMS contrast averages approximately 1.5 to 4% of the total light detected. The contrast maximum is the brightest reflection from the scan circle and the contrast minimum is the darkest reflection from the scan circle. The waveform is normalized so that the maximum or the minimum is at the 4 bit limit (either +7 or -8, respectively) to fully utilize digital dynamic range.

The simplest form of the RI reference eye signature is an array of 96 four-bit contrast numbers for each of 96 equally spaced scan circle positions for a time-domain pattern of 48 bytes per eye. An optional 49th byte carries the AC RMS value of the waveform to be used for equalizing the RMS values of the acquired and reference waveforms in the correlation (match) routine.

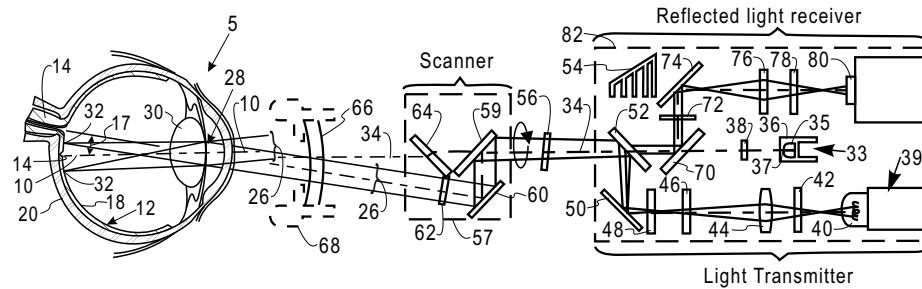
## 6. RI Camera

Most of us, at one time or another, have gone to an optometrist or ophthalmologist to have our eyes examined. As part of the exam, the doctor uses an instrument called a retinoscope. The RI camera accomplishes the same thing as a retinoscope. Its light source is projected onto the subject's retina and (the doctor in case of the retinoscope) detects the return light. The light coming from the retinoscope is in a collimated beam so that the eye lens focuses it to a spot on the retina.

The retina reflects some of the light back towards the eye lens, which once again collimates the light. This light leaves the eye at the same angle that it enters the eye, a process called retro-reflection. The light reflected from the retina is observed by the examining doctor who holds the instrument to his own eye. In the case of RI, a light detector replaces the examining doctor's eye.

If the doctor were to examine the eye from a number of points 10 degrees off the visual axis of the patient's eye, it would simulate the action of the fovea centered RI scan we will discuss here.

### Old Camera



**Figure 6.2** Old camera.

The first products of EyeDentify used a camera disclosed in detail in US Patent #4620318 [4] (Figure 6.2). This design used a rotating mirror assembly to generate the scan circle on the retina. Hot mirrors (reflecting infra red while transmitting visible light) are used to combine the Scanner optical path and the align/fixate target optical path. What follows is a description of the operation of the relevant portions of the camera described in the patent as they relate to the EyeDentification System 7.5.

A fixation target (33) allows the RI subject to properly focus his/her eye (5) and align its visual axis (10) with an optical axis (34) of the scanner. Fixation target (33) includes a visible light emitting diode (35) positioned in a mounting structure (36) having a pinhole (37). LED (35) illuminates the fixation reticle (38).

US Patent#4923297 [1] describes an improved fixation targeting system that replaced the system described above in production 7.5's. This patent describes the 7.5 fixation target system as a quasi-reticle that generates enhanced multiple ghost reflections of a single pinhole. It is a simple plate of glass with a partially silvered mirror on one surface and an opaque mirror surface with a pinhole on the other illuminated by a light emitting diode.

Alignment is a critical requirement of RI and this so-called "ghosticle" alignment/fixation system accomplishes its function elegantly. It is simple and intuitive - just line up the dots - and both alignment and fixation are assured. Yet it is inexpensive and easier to align in production than previous RI alignment/fixation systems.

Once alignment and fixation are accomplished the scan can be initiated either manually by pressing a button or automatically when the RI is placed in the Auto-Acquire mode (a feature introduced in the model 8.5 product).

An IR source (39) provides a beam of IR radiation for scanning fundus (12) of eye (5). IR source (39) includes an infrared light emitting diode (the drawing shows a tungsten bulb (40) as the light source) that produces light that passes through a spatial filter (42) and is refracted by a lens (44). An IR filter (46) (not used in the IR LED version) passes only the IR wavelength portion of the beam, which then passes through a pinhole (48). The beam is then reflected by a mirror (50) onto a beam splitter (52) that is mounted to coincide with the fixation target optical axis (34).

The scanner directs the beam into the fixated eye from an angle of 10 degrees offset from the optical axis. The scanner includes a rotatable housing (57) and scanner

optics that rotate with the housing as indicated by a circular arrow (58). As the scanner rotates, the 10 degree offset beam rotates about the optical axis.

The scanner optics include a hot mirror (59) (one that reflects IR radiation while passing visible light), located in the path of the source beam and the fixation beam. The visible wavelength fixation beam is passed through hot mirror (59), while the IR source beam is reflected away from the housing (57) at a point spaced apart from optical axis (34) and is oriented to direct the IR beam through an IR filter (62) and into the eye (5) as housing (57) rotates. Hot mirror (59) causes a displacement of the fixation beam so an offset plate (64) is positioned to compensate for the displacement.

When housing (57) rotates, the IR beam is directed into the eye (5) in an annular scanning pattern centered on the fovea as represented by circular locus of points (32). Light reflected from fundus (12) of the eye (5) varies in intensity depending on the structures encountered by the scan. The reflected light is re-collimated by the lens (30) of the eye (5) directed out pupil (28), back through objective lens (66) and IR filter (62), and reflected off scanner mirror (60) and hot mirror (59). The reflected beam is then focused by objective lens (56) on to beam splitter (52) which passes a portion of the reflected scanning beam to a hot mirror (70) that reflects the beam through a spatial filter (72). The beam is next reflected by a mirror (74), refracted by a lens (76) and passed through another spatial filter (78) to a detector (80).

### *New Camera*

Current RI camera technology is based on an active US Patent [5]. It is a much simpler design that also takes advantage of the concentric nature of the RI's fixation and scanning to reduce labor intensive alignment of camera parts and the part count.

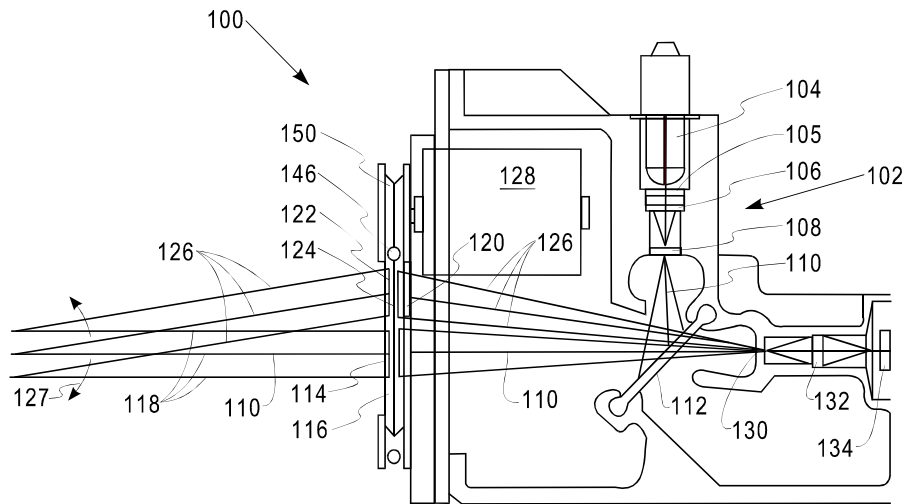
The current RI camera is shown schematically in Figure 6.3. It includes a rotating scanner disk (116) that integrates a multi-focal Fresnel fixation lens (114), a Fresnel optical scanner (122,124) and an angular position encoder (140) into a unitary, inherently aligned, compression-molded scanner disk. An RI subject views through the multi-focal Fresnel lens, an image of a pinhole (108) illuminated by a krypton bulb (104). The multi-focal lens is centered on the disk and creates a multiple in- and out-of-focus images (180 182, 184, 186) of the pinhole image. By setting the focal distances of these images along a range that includes corrective errors of from -7 diopters (very near sighted) to +3 diopters (very far sighted), at least one of the pinhole images will be in relatively sharp focus for virtually everyone in the RI subject population. The images will appear concentric when the RI subject is properly aligned with the scanner disk and associated optics.

Once aligned, the subject initiates scanning which causes the scanner disk to rotate. The Fresnel optical scanner receives IR light from the krypton bulb light source and creates an IR scanning beam (126). IR light reflected by the eye fundus (12) of the RI subject returns via a reciprocal path, by way of a beam splitter (112) and into a detector (134) to generate eye waveform data. Rotational position information from the encoder instructs the signal acquisition system when to sample the detector's output.

The key feature of this new RI camera design is that it integrates and inherently aligns multiple optical elements greatly reducing both the material and labor costs of

the original RI camera. Overall costs of the camera yields to manufacturing economies of scale much more so than with the original RI camera.

Both camera types share the same subsystem functions:



**Figure 6.3** New camera.

### **Target - Align & Fixate**

To insure that the circular scan of the RI is centered on the fovea and that the subject is in the scanner beam throughout the scan, an alignment/ fixation target is presented to the ID subject. One form of this target is an optical system that presents say four simple reticles at focal distances of -7, -3, 0 and +3 diopters. For virtually all of the ID population, at least one of the reticles will be in focus regardless of corrective error (near-sightedness through far-sightedness). When the ID subject “focuses” (fixates) on the target, the RI is angularly aligned to subject's eye, centering the RI's scan circle on the eye fundus. When he/she aligns two or more of the reticle patterns nulling their parallax, the RI illumination beam is centered on the eye pupil. Translation along the optical (Z) axis is not critical and is achieved by providing a rest for some part of the face (forehead, eye socket, etc.). Rotation about the Z-axis caused by head tilt is addressed by the Rotator algorithm, discussed later.

It is important to note that Fixation/Alignment is an absolute requirement for this method of RI to work. It would be prohibitively difficult to identify someone using RI without his or her cooperation in performing this function. Depending on one's perspective, this requirement can be seen as a benefit (usually to the ID subject) or a negative (covert ID). This does, however, prevent RI's use in identifying an individual against his or her will which may make RI appear more acceptable to the ID subject population.



**Transmitter (Light Source)**

The light source is ideally near infrared and is not visible to the identification subject. The illumination spot projected on the retina must be uniform. A suitable diffuser is required to achieve spot uniformity when using a light source that, when projected on the retina/choroid, is not homogenous. This is usually the case with an IR Light Emitting Diode and can also be true of other light sources.

A tungsten lamp is considerably brighter than an IRED and can produce better S/N figures. The disadvantages of such a lamp compared to an IRED is the need for filter, turn-on time and lamp life. Retinal identification systems have been proposed that would use a laser (preferably solid state). The author is not familiar with any commercially available system that uses a laser, however. Further, lasers can be considered dangerous by the RI subject population.

**Receiver**

The light receiver is composed of a silicon photodetector, a high gain pre-amplifier and a sharp cut-off low-pass filter. The filter is necessary to sharply reduce high frequency noise generated by the detector/preamp that is outside of the useable passband which is determined by the spot and scan circle sizes and the scanner speed. With the selected parameters a good choice is an 8th order switched capacitor elliptic filter with a corner frequency of approximately 220 Hz.

**Scanner**

The scanner has to deal with the light noise arising from (i) corneal reflections, (ii) other scattered light sources, and (iii) ambient light. Reflected noise in the RI comes from essentially four sources, the front and back surfaces of the cornea, and the front and back surfaces of crystalline lens. Extensive spatial filtering that is conjugate to the retina and the scan angle reduces the light noise to insignificance.

Corneal reflections of the scanner light source is one of the primary reasons for using a circular rather than a raster scan of the eye fundus. The reflections would render the center pixels of a raster scan of the retina useless unless an annular illumination requiring very critical alignment is used. The scanner consists of the following components comprising the signal acquisition and processing subsystem:

**7. Signal Acquisition Subsystem**

The signal acquisition subsystem consists of the following components:

**Detector/Preamplifier**

The silicon photodetector operating in the photo-ampuric mode receives the light collected from the RI camera. It is converted to a voltage by a low noise op-amp configured as a trans-impedance amplifier. With a carefully selected op-amp, the primary sources of electrical noise are the thermal noise of the feedback resistor and

quantum noise. A second op-amp brings the signal level up to a level sufficient to drive the contrast processor.

#### **A/D Conversion**

The raw unprocessed analog signal derived from the camera photodetector can span at least two orders of magnitude due to the range of pupil sizes encountered in normal operation of the RI. Performing the conversion at this point requires close to 16 bits of resolution to accommodate absolute signal variations, contrast figures and sufficient resolution left to quantize the “contrast” portion of the signal. A more economical scheme is to perform the contrast processing function ahead of the conversion. An 8 bit analog-to-digital converter is all that is required in this case

#### **Contrast Processor**

8. The function of this stage in the signal chain is to reduce the raw camera signal into salient contrast information that has both human descriptor qualities of invariance and discrimination. It can be done in hardware or software and both methods have been used successfully in EyeDentify’s commercial products. The far less expensive modality is hardware because it dramatically reduces the resolution required of the analog /digital converter. The contrast processor removes the redundant or variable content from the acquired scanner waveform while retaining sufficient information to yield a unique eye signature.

### **8. Computing Subsystem**

The computing subsystem could be explained in terms of its hardware and software components.

#### **Hardware**

EyeDentify's System 7.5, the first widely available RI, used a Motorola 68000 microprocessor as both the controller and signal processor. By moving contrast processing to hardware and coding correlation in the time domain in the late 1980s, it was possible to move to a 68HC11 micro-controller to replace most of the functionality of the 68000 based System 7.5. The cost of the computing elements of RI have been and currently are insignificant compared to the opto-mechanical portion of the system.

#### *Software*

The software performs the following two functions: phase correction and matching.

#### **Phase Correction**

Each time the RI subject looks into the RI camera, his or her head may be slightly tilted (rotated) from the position it was before. The rotator algorithm (phase corrector)

shifts the acquired waveform through the equivalent of several degrees of rotation or head tilt. This is done while correlating it with the stationary reference eye signature to find the best match (highest correlation).

### **Matching**

Comparison of the acquired contrast waveform is done with a routine that performs the following steps:

1. Sample rate converts the reference eye signature into an array with the same number of elements as the acquired array.
2. Normalize both arrays to have a RMS value of 1.0.
3. Correlate arrays using the time domain equivalent of Fourier-based correlation.

The quality of match is indicated by the correlation value, where the time shift is zero. It ranges from +1.0, a perfect match, to -1.0, a perfect mismatch. Experience has shown that scores above 0.7 can be considered a match (see Performance discussion below).

## **8. System Operation**

### *Taking an Eye Reading*

Central to every RI transaction is the process wherein the camera scans the RI subject's eye. We present here the detailed user instructions below to give an idea of the user involvement and training needed for retina based identification. The subject is instructed as follows:

If you wear glasses, take them off (does not apply to contacts).

If the system requires PIN (Personal Identification Number), enter it (recognition does not require a PIN).

Position camera at eye level (or eye to camera)

The target consists of a number of softly illuminated dots. Moving the head in relation to the eye lens opening, without tilting or skewing the head centers the target. Do this until all of the dots move one behind the other. The smaller dots will then appear inside the larger dots.

Both eyes should be wide open. Squinting or closing one eye can cause eyelashes to be included in the reading.

Be sure that your eye is about three-quarters of inch from the eye lens.

Press the scan button (or wait for scanner to stop if in the Auto-Acquire mode).

Hold your head steady during the reading.

Although it is important to fixate on the center of the target during the reading, you should not fixate for more than a couple of seconds before pressing the button. Otherwise, the eye may drift.

Various incarnations of RI cameras and systems have different user requirements, but the steps above apply generally to all of them.

### *Alignment/Fixation*

To use RI, it is important for the subject to be aligned with the RI camera and fixated on its target. After peering into the camera, the subject achieves alignment by lining up the dots of the target so they appear as one. At that point fixation is also accomplished since the virtual dot image is then focused on the fovea of the subject's eye (Figure 6.1). This process assures that the subject's eye pupil is within the "acceptance diamond" which is the cross sectional shape of the volume where the entire scan's beam will fill the eye pupil. This volume is essentially like two cones placed together at their bases with their centers along the eye's optical axis (the Z axis). A larger volume means less critical alignment. The volume is a function of the exit/entrance aperture, which is determined by the size of the RI camera's objective lens.

### *Scanning*

Eyeglasses must be removed for the RI camera to work reliably. There are two reasons: 1) Reflections from the lens surface may interfere with the scanner signal, and 2) Distortion of the retina/choroid image may occur if eye glasses are not in the same position on the face from use to use such as when they slide down the ID subject's nose. If an attempt is made to enroll an individual with eyeglasses, it is possible that the eye glass reflection will be enrolled, not the retina/choroid, resulting in a very simple eye signature that might be duplicated.

Contacts do not need to be removed. Certain types of contacts can prove problematical. Lenses can cause improper signatures if any part of the edge of the lens is inside the eye pupil while the eye is being scanned. Generally, the effect of contacts on eye signatures is so slight that it is not necessary to enroll a given eye both with and without them, except possibly in cases of severe or unusual correction (extreme near- or far-sightedness and/or astigmatism).

### *RI at a Distance*

Just as the eye doctor can use a retinoscope at a distance from the patient, a suitably designed RI can be used at a distance from the ID subject. However, the size of the RI must increase proportionate to the scan distance in order to support the RI's scan circle diameter. Working RI systems with an operating distance of 12 inches have been demonstrated in the laboratory. Other considerations in such systems include ambient light conditions and Fixation/Alignment issues. Light shields sizes have to grow in proportion to the operating distance. A long distance universal focus target's requirements change when the operating distance exceeds a certain threshold. Scanner beam size will need to be larger as well.

### *Enrollment*

RI enrollment is the process of acquiring the reference eye signature. Each eye signature is built from several eye readings. The person responsible for enrolling a new RI subject, the enroller guides that person through the following steps:

Instruction on camera use. Enroller instructs the enrollee on correct RI camera use. Enroller usually demonstrates this by scanning his/her own eye and then describes what the Enrollee must do to align the camera. Fixation is automatic when the enrollee achieves alignment.

Several scans until correct fixation/alignment is verified. Out of beam condition (meaning the subject has not achieved alignment) is detected when the raw signal drops off in some part of the waveform. Both manual and automatic modes have proven effective for this purpose. Fixation can only be verified when scans are compared. Correlation scores of a scan with the reference eye signature greater than, say, 0.75 to 0.8 indicate that correct fixation has been achieved.

Several scans averaged. Scans that have a correlation within a certain range (such as 0.75 to 0.8) are added to a waveform average. The impact on correlation scores of variant features such as a choroidal vessel that is substantially tangent to the scan circle is reduced with averaging.

Optional Recognize - verifies whether or not the new enrollment eye signature already exists in the database either because the new enrollee has already enrolled the eye or the database is large enough to include a sufficiently similar eye signature to cause a false accept error in the Recognition mode. This step assures the new enrollment eye signature is unique to the database.

Assignment of linked data (Name, Pin #, etc.).

Store enrollment data.

Automatic RI enrollment techniques have been studied wherein eye scans that do not match any eye signature in the database (using the Recognition algorithm described below) but appear repeatable are given a label indicating such and stored to indicate intrusion attempts. The RI system can alert an administrator when unrecognized but repeatable eye signatures occur by displaying/printing that label.

It is important to note that enrolling is somewhat of an art as well as a science. The enroller, through experience, learns how best to train each new enrollee and to interpret correlation scores during the enrollment process. An enroller should remember several key points. Correlation scores should get progressively better as enrolment progresses. It is important for the enrollee to look away between scans to insure that the averaging process creates a true average of variations in head position. A person's "dominant eye" can be easier to enroll. If one eye is difficult to enroll, try the other.

### *Verify*

Subsequent to enrollment an enrollee can authenticate his/her identity by entering a code (such as a PIN number). An eye scan is taken and compared with the eye signature associated with the PIN number. If the eye scan matched against the eye signature produces a correlation score above the match threshold (typically a correlation score of 0.7), the person scanned is said to be the person enrolled with the given PIN and an appropriate action is taken.

### *Recognize*

A scan is taken and using the recognize algorithm, a match to the entire database above the correlation threshold identifies the person requesting access. Any eye signature recognize algorithm is considerably more compute intensive than verify algorithm. The simplest form of recognize would take the verify time and multiply it by the number of people in the eye signature database. Several multi-level techniques have been developed that reduce the time it takes for the recognition mode on given computing resources. In some cases, execution time has been reduced as much as two orders of magnitude. The down side of the methods tried is that they sometimes eliminated good candidates, producing false reject errors.

Today's fast microprocessors and time domain correlators have nearly eliminated the need for multi-step recognition routines for databases of medium size (hundreds to tens of thousands) and, in the process, have virtually eliminated false reject errors produced by multi-level recognition algorithms.

### *Large Database Recognition*

Recognition is identification where the ID subject does not claim an identity (with a PIN number, card etc.) as part of the process. The acquired scan waveform is compared to an entire database of eye signatures to find the best match.

Currently available parallel processing computers can perform high accuracy RI recognition of databases composed of millions of eye signatures at very low relative cost. Indeed, some RI recognition mode feasibility has been studied on massively parallel processing supercomputers with very promising results. Simply dividing up the database and having each processor correlate the acquired scan with its portion of the database is the simplest method. RI's small signature size, uniqueness and small variance gives it a significant competitive advantage in terms of cost, speed and reliability for large database recognition mode over other biometric ID methods.

### *Counterfeiting the Scan*

A counterfeit eye must have the following characteristics.

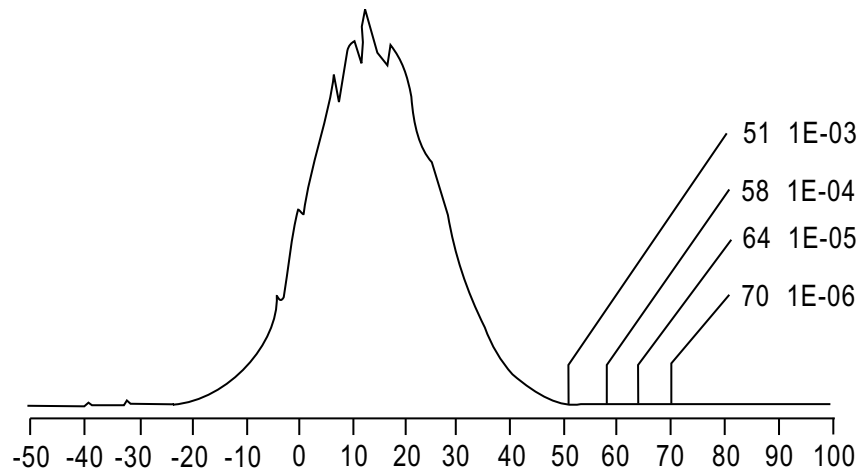
- The same optical system to simulate retina/choroid reflectivity.

- A lens to substantially focus the incoming collimated beam and to re-collimate the reflected beam.

An alignment/fixation system that angularly orients the counterfeit eye about its X and Y axes, translates the counterfeit eye along its X and Y axes, positions the eye at the correct distance from RI camera (translation along Z) and rotates the eye about its Z axis within the tilt range of the Rotation algorithm.

The last item is the most difficult to counterfeit. A well-designed RI provides as little information about the correct alignment/fixation as possible to the would-be counterfeiter. Variable fixation displays could also require a counterfeiter to perform an interpretation of the target in order to correctly interact with the acquisition process. For example, the ID subject could be instructed to remember a random three digit sequence that is displayed in the RI fixation target and to key it in later. This would force the counterfeiting system to see, interpret and output to the RI keypad the three digit sequence.

## 9. Performance



**Figure 6.4** Mismatch distribution in retina based identification.

Many tests of performance of the retina/choroid scanning technology described have taken place, some with databases of several hundred individual eyes. Sandia National Laboratory has tested the products of EyeIdentify and reported no false accepts and a three-attempt false reject error rate of less than 1.0% [11].

### *Mismatch Frequency Distribution*

A frequency distribution of each eye signature compared against all others matches very closely with an ideal gaussian distribution with a mean of 0.144 and a standard deviation of 0.117 as shown in Figure 6.4. The corresponding right tail probability of gaussian distribution with this mean and standard deviation at a threshold score of 0.7 is approximately one in one million.

### *Source of Errors*

The retina/choroid contrast waveform has a low variability when acquired under correct conditions. The conditions under which the variability could increase and cause false reject (Type II) errors are:

- Lack of Fixation or sustained fixation
- Out of scanner beam condition
- Incorrect eye distance to RI camera lens
- Insufficient pupil size
- Obstruction and distortion of the optical path from:
  - dirty camera window
  - contact lens edges
  - subject neglects to remove eyeglasses
- Ambient light interference

Small pupils can cause false rejects. The purpose of the eye pupil is to regulate the amount of light reaching the retina. Bright environments such as those encountered outdoors in the daytime can cause pupils to constrict to a very small size compared to, say, indoor lighting conditions. Because light must pass the eye pupil twice (once entering and once exiting the eye), the return light to the RI camera varies inversely with the fourth power of the pupil diameter. In the worst case (smallest pupil size), resulting retina/choroid signals can be attenuated by as much as four orders of magnitude. The signal can be so low that system noise swamps the acquired eye signature data, lowering correlation scores.

Outdoor environments can also be less conducive to reliable RI performance because of the potential for high ambient light noise entering the camera and interfering with the scanned waveform. Because of the uniqueness of the retina/choroid contrast circle characteristic, false accept (Type I) errors tend to be limited to large database recognition.

## **10. RI Subject Motivation**

An important and enduring observation of the use of RI to enroll and identify several thousand individuals over a period of two decades is the importance of motivation to have the enrollment and identification transactions succeed. Many of these observations can be said, in a general sense, of other biometrics as well.

Enrollment is the subject's first hands-on use of RI. The subject should not fear harm from the RI camera before using it the first time. Learning to align and fixate the RI camera, while a simple process, can be impeded willfully or subconsciously by a suspicious subject. Several scans are necessary and depending on the quality of the



scans, this procedure can take several minutes. Because RI requires cooperation from the subject, sabotage at this stage is very easy. If a subject is difficult to enroll, the subject's motivation can deteriorate as time passes during the enrollment process.

The identification transaction (verify or recognize) is less susceptible to fear based motivational problems simply because if a subject has been successfully enrolled he/she must have overcome considerable fear or reluctance already. But subtle sabotage can be a factor here as well. Deliberate false reject transactions with an accompanying complaint such as “it gives me a headache” can diminish confidence in the system. It is very difficult to ascertain whether subjective comments of this kind are truthful yet the result is the same - RI is less attractive.

Many users have naively assumed that the lack of negative consequences (I can't work here because I can't/won't use RI) is sufficient to gain acceptance of a RI system by the ID subject population. Experience has taught users of RI that a perceived personal benefit (I am better off than people who can't/won't use RI) to the ID subject has a dramatically positive effect on RI enrollment and identification speed and acceptance.

## **11. Limitations**

### *Perceived Health Threat*

While the low light level is harmless to the eye, there is a widely held perception that retinal identification can hurt the retina. This appears to be less true in information access applications since ID subjects are generally less fearful of new technology.

### *Outdoors vs. Indoors*

Small pupils can reduce the Type II (False Reject) performance. Because light must pass the eye pupil twice (once entering and once exiting the eye), the return light can be attenuated by as much as four orders of magnitude when the ID subjects pupils are small. The signal can be so low that quantum and feedback resistor noise swamp the eye signature data lowering correlation scores. Further, outdoor environments are less conducive to reliable RI performance than indoor environments because of ambient light conditions.

### *Ergonomics*

The need to bring the RI device to an eye or the eye to the device makes the RI more difficult to use in some applications than other biometric identification technologies. For instance, it is quite easy for a subject, regardless of his height to reach a hand to a fingerprint or hand geometry. The eye is much less easily manipulated. Bringing the RI camera to the eye seems more practical in “workstation” applications while the opposite is true in physical access control applications.

### *Severe Astigmatism*

Because eyeglasses must be removed in order to use RI systems reliably, people with severe astigmatism may have trouble aligning the dots in the camera's align/fixate target. To these individuals, what appears to them can be quite different than dots. This can result in ambiguous feedback during the alignment step of RI camera use, causing the eye pupil to be outside the "acceptance diamond" for part of the scan. That part of the scan will therefore be invalid.

### *High Sensor Cost*

The camera requirement of RI puts a lower limit on the cost of the system. Manufacturing economies of scale can mitigate this problem, but RI is likely to always be more expensive than some other biometrics such as fingerprint (using chips) or speaker recognition (telephone hand-set as sensor).

## **12. Future**

The inherent simplicity of the RI means that in mass production the cost of the entire unit could come below, say, \$100. This is still considerably more expensive than some competing technologies which have a much cheaper scan component (such as fingerprint chips). The trade off is accuracy. If accuracy is important to the ID application, perhaps the additional cost of RI can be justified.

With the proliferation of e-commerce applications, RI might reach a critical mass. Because of the RI's accuracy and small signature size it fits more naturally with the encryption that is needed for e-commerce security than competing biometric ID technologies. Public key encryption systems are only as secure as their private keys and a high performance biometric identifier like RI is ideal for keeping private keys secret.

## **13. Conclusions**

RI is a highly accurate and secure biometric identification method. The example RI system presented utilizes a small reference data size that makes it attractive in large population networked systems in both verification and recognition modes. RI, currently, is both image and performance based. The performance aspect restricts successful use to those who are motivated to see the ID transaction successful.

RI's weakness are:

- The cost of the signal acquisition hardware

- ID subject's unfounded fear that it is harmful

- Unfriendly access

The future will likely bring the cost of RI down dramatically if a sufficiently large demand is created to achieve manufacturing economies of scale especially as it

applies to the RI camera optics and mechanics. Fear becomes less of an issue as the computer/internet age expands and raises the level of technological awareness and acceptance. Lack of a sufficient level of friendly access may prevent RI from becoming a truly ubiquitous method of identification.

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