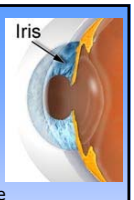
Iris Recognition

Biometrics
CSE 190-a
Lecture 18

Iris

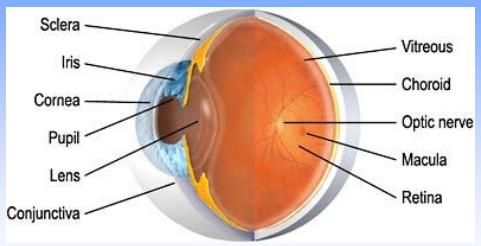


The colored part of the eye is called the iris. It controls light levels inside the eye similar to the aperture on a camera. The round opening in the center of the iris is called the pupil. The iris is embedded with tiny muscles that dilate (widen) and constrict (narrow) the pupil size. The sphincter muscle lies around the very edge of the pupil. In bright light, the sphincter contracts, causing the pupil to constrict. The dilator muscle runs radially through the iris, like spokes on a wheel. This muscle dilates the eye in dim lighting. The iris is flat and divides the front of the eye (anterior chamber) from the back of the eye (posterior chamber). Its color comes from microscopic pigment cells called melanin.

The color, texture, and patterns of each person's iris are as unique as a fingerprint.

http://www.stlukeseye.com/anatomy/Iris.asp

Anatomy of the eye



Structure of Eye and location of Iris

http://www.maculacenter.com/eyeanatomy.htm

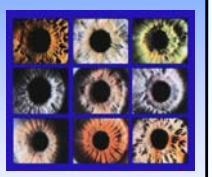
Iris

© IEEE Computer 2000

- Iris is the annular region of the eye responsible for controlling and directing light to the retina. It is bounded by the pupil and the sclera (white of the eye); iris is small (11 mm)
- Visual texture of the iris stabilizes during the first two years of life and carries distinctive information useful for identification
- Each iris is unique; even irises of identical twins are different

Advantages of Iris for Recognition

- Believed to be stable over a person's lifetime
- Pattern is epigenetic (not genetically determined)
- Internal organ, highly protected and rarely damaged or changed
- Iris patterns possess a high degree of randomness
- Imaging procedure is non-invasive
- Template size is small
- Image encoding and matching process is fast



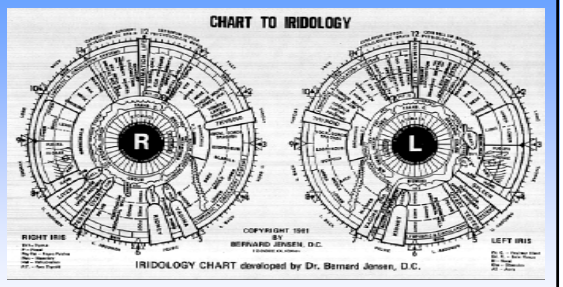
Stability of Iris Pattern

The iris begins to form in the third month of gestation, and the trabecular network creating its pattern are largely complete by the eighth month.

Pigment accretion can continue into the first postnatal years. Iris color is determined mainly by the density of melanin pigment. Blue irises result from an absence of pigment.

"The available clinical evidence indicates that the trabecular pattern itself is stable throughout the lifespan."

Iridology



"Throughout the ages, the eyes have been known as the windows to the soul, and modern behavioral research is proving this adage to be true. If you look closely at the iris of the eye, you will notice small, dark dots, light streaks or rounded openings in the fibers. These characteristics provide the key to unlocking the mysteries of the personality" (Rayid International).

Iridology

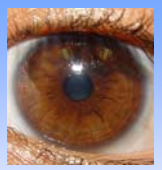
- There is a popular belief in systematic changes in the iris pattern, reflecting the state of health of each of the organs in the body, one's mood or personality, and revealing one's future.
- Iridology resembles palm-reading and is popular in parts of Romania and in California (According to Daugman).

"All scientific tests dismiss iridology as a medical fraud"

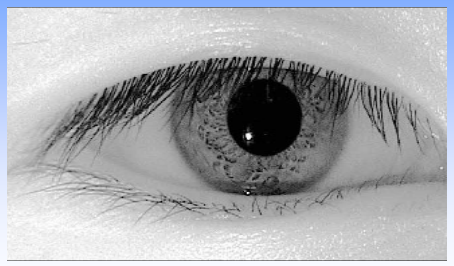
– Berggren, L. (1985), "Iridology: A critical review", *Acta Ophthalmologica*, 63(1): 1-8

Iris under different lighting

- Visible Light
  - Layers visible
  - Less texture information
  - Melanin absorbs visible light
- Infrared Light
  - Melanin reflects most infrared light
  - More texture is visible
  - Preferred for iris recognition systems



Infrared Iris Image



In infrared light, even dark brown eyes show rich iris texture

Iris Capturing Devices

- Different Cameras available:
  - Hand held
  - Wall mounted

http://www.panasonic.com/business/visionsystems/biometrics.asp
http://www.oki.com/jp/FSC/iris/en/irisgt_h.html
http://www.igiris.com/products/index.html

Deployment of Iris Recognition

- The largest deployment of iris recognition systems is in the United Arab Emirates (17 air, land, and sea ports).
- 3.8 billion comparisons are conducted each day; average time per match is only a fraction of a second.

Frequent Flyers (belonging to EU) are enrolled in the "Privium" program at Schiphol Airport (NL), enabling them to enter The Netherlands without presenting their passports .

- German Chancellor *Gerhard Schroeder* tests the iris recognition system used for automated passport control at Frankfurt's international airport, Europe's largest, in August 2004.
- Up to 100 passengers use the service each day to bypass lengthy lines at regular security checkpoints.

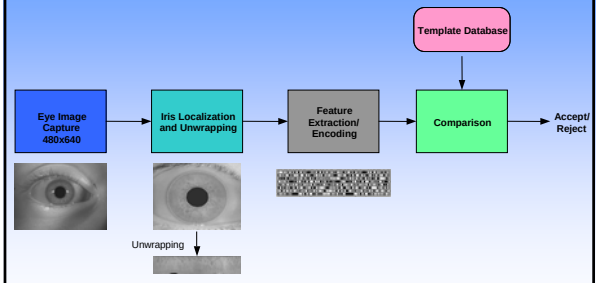
Condominium residents in Tokyo gain entry to the building using iris patterns, and the elevator is automatically called and programmed to bring them to their residential floor.

The United Nations High Commission for Refugees administers cash grants to refugees returning to Afghanistan from surrounding countries after the fall of the Taleban, using iris patterns in lieu of any other forms of identification. More than 350,000 persons have so far been processed by this program using iris recognition.

Iris Representation Schemes

- Daugman
  - Gabor Demodulation (PAMI 1993)
- Lim, Lee, Byeon, Kim
  - Wavelet Features (ETRIJ 2001)
- Bae, Noh, Kim
  - Independent Component Analysis (AVBPA 2003)
- Ma, Tan, Wang, Zhang
  - Key local variations (IEEE TIP 2004)

Daugman's Approach



- *J. Daugman, "Statistical Richness of Visual Phase Information: Update on Recognizing Persons by Iris Patterns", International Journal of Computer Vision, 2001.*
- *J. Daugman, "Biometric Personal Identification System Based On Iris Analysis", US Patent 5291560, 1994*

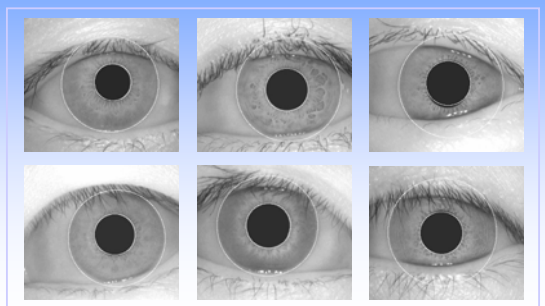
Iris Localization - Curvilinear Boundaries

- Iris is localized using an integro-differential operator:

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

- $G_\sigma(r)$ is a smoothing function such as a Gaussian of scale σ
- $I(x,y)$ is the raw input image, and the operator searches for the maximum in the blurred partial derivative of the image with respect to an increasing radius r and center co-ordinates (x_0,y_0)
- The operator essentially is a circular edge detector and returns a "spike" when a candidate circle shares the pupil (iris) center coordinates and radius.

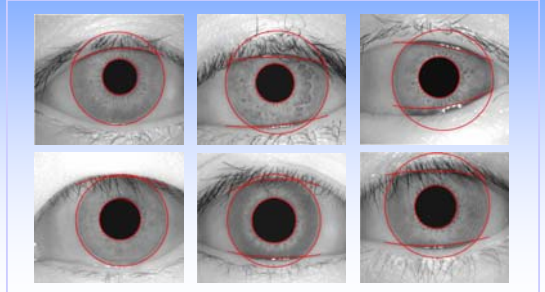
Detected Curvilinear Boundaries



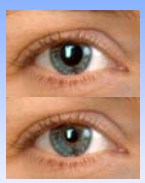
Iris Localization - Eyelid Boundaries

- An approach similar to detecting curvilinear edges is used to localize both the upper and lower eyelid boundaries
- The path of contour integration in equation (1) is changed from circular to arcuate, with spline parameters fitted by standard statistical estimation methods to describe optimally the available evidence for each eyelid boundary

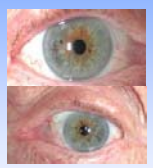
Detected Eyelid Boundaries



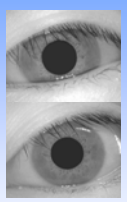
Intra-class Variations



Pupil Dilation (lighting changes)



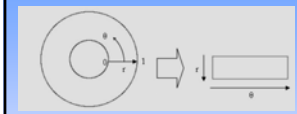
Inconsistent Iris Size (distance from the camera)



Eye Rotation (head tilt)

Establishing Coordinate System

Daugman's Rubber Sheet Model



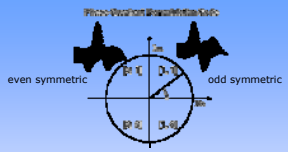
Centers of iris and pupil coincide

Centers of iris and pupil do not coincide

The model remaps each point within the iris region to a pair of polar coordinates (r,θ) where r is in the interval [0,1] and θ is angle in [0,2π]

- The model compensates **pupil dilation** and **size inconsistencies** by producing a size- and translation-invariant representation in the polar coordinate system
- The model does not compensate for **rotational inconsistencies**, which is accounted for during matching by shifting the iris templates in the θ direction until two iris templates are aligned

Iris Feature Encoding



Gabor filtering in polar coordinate system

$$G(r,\theta) = e^{i\omega(\theta-\theta_0)} e^{-(r-r_0)^2/\alpha^2} e^{-i(\theta-\theta_0)^2/\beta^2}$$

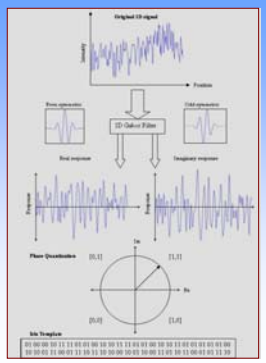
- (r,θ) specify position in the image, (α,β) specify the effective width and length and ω is the frequency of the filter

Demodulation and phase quantization

$$g_{\{\mathrm{Re,Im}\}} = \mathrm{sgn}_{\{\mathrm{Re,Im}\}} \iint_{\rho\phi} I(\rho,\phi) e^{i\omega(\theta_0-\phi)} e^{-(r_0-\rho)^2/\alpha^2} e^{-(\theta_0-\phi)^2/\beta^2} \rho d\rho d\phi$$

- $I(\rho,\phi)$ is the raw iris image in polar coordinate system, and $g_{\{\mathrm{Re,Im}\}}$ is a complex valued bit corresponding to the sign of the real and imaginary parts of filter responses

A 1D illustration of the encoding process



A total of 2,048 bits, i.e. 256 bytes of information is extracted from the whole iris image

** John Daugman's personal website: http://www.cl.cam.ac.uk/users/jgd1000/*

Example of Iris Coding

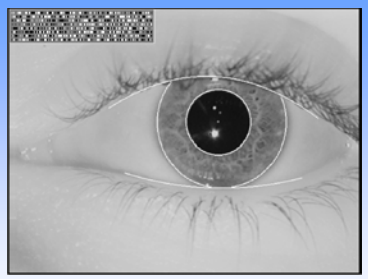
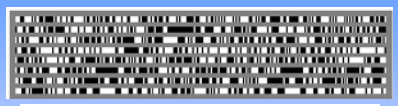
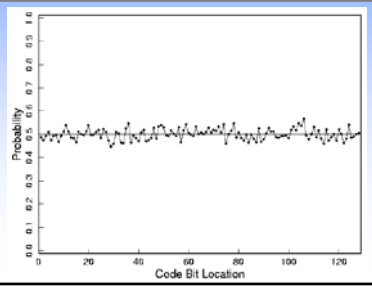


Image size is 64 x 256 bytes and the iris code is 8 x 32 bytes; Gabor filter size is 8 x 8

J.Daugman, "Statistical Richness of Visual Phase Information: Update on Recognizing Persons by Iris Patterns", International Journal of Computer Vision, 2001.

Independence of bits across IrisCodes





Iris Code Matching

- The comparison is done by computing the Hamming distance between two 256-byte iris codes
- The Hamming Distance between an iris code A and another code B is given by:

$$HD = \frac{1}{N}\sum_{j=1}^{N} A_j \otimes B_j$$

XOR

where N=2,048 (256 x 8) if there is no occlusion of the iris. Otherwise, only valid iris regions are used for computing the Hamming distance

* Daugman, J. "High confidence visual recognition of persons by a test of statistical independence." *IEEE Trans. on PAMI*, 1993

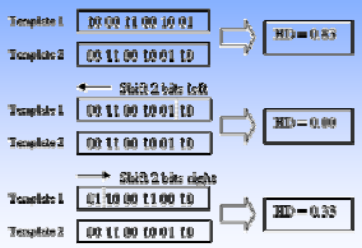
Hamming distance

- Hamming distance: given two patterns *X* and *Y*, the sum of disagreeing bits (sum of the exclusive-OR between) divided by *N*, the total number of bits in the pattern

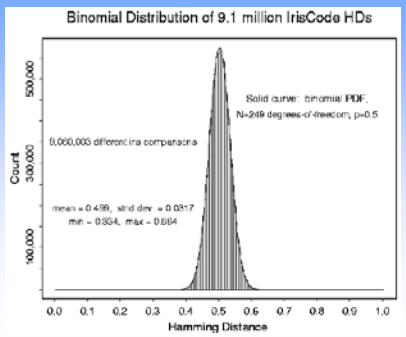
$$HD = \frac{1}{N}\sum_{j=1}^{N} X_j \otimes Y_j$$

- If two patterns are derived from the same iris, the Hamming distance between them will be close to 0.0 due to high correlation
- In order to account for rotational inconsistencies, one template is shifted left and right bit-wise and a number of Hamming distance values are calculated from successive shifts.
- The smallest Hamming distance is selected as it corresponds to the best match between two templates.

An illustration of iris matching by code shifting

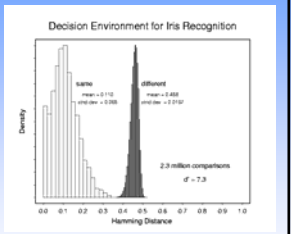


Distribution of Hamming Distances among Unrelated IrisCodes



Matching Score Distribution

- The genuine and impostor Hamming distance distributions for about 2.3M comparisons
- There is hardly any overlap and hence one can choose a threshold such that there is very small probability of error
- This experiment shows that iris indeed is a very good biometric that can achieve very high performance



Matching Distance Distributions

J. Daugman (1993) "High confidence visual recognition of persons by a test of statistical independence." *IEEE Trans. PAMI*, vol. 15(11), pp. 1148-1161.

Tests of the Daugman Iris Recognition Algorithms

Testing Organisation	*Number of Cross-Comparisons*	*False Matches*
Sandia Labs[1], USA (1996)	19,701	0
British Telecom Labs[2], UK (1997)	222,743	0
Sensar Corp.[3], USA (2000)	499,500	0
Joh.Enschede[4], NL (2000)	19,900	0
EyeTicket[5], USA (2001)	300,000	0
National Physical Lab[6], UK (2001)	2.73 million	0
J. Daugman[7], UK (2003)	9.1 million	0
Iridian Technologies[8], USA (2003)	984 million	0

http://www.cl.cam.ac.uk/users/jgd1000/

Limitations of Iris

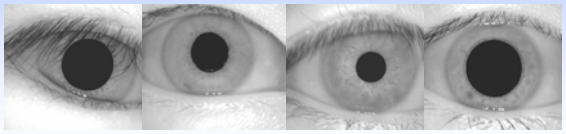
- Capturing an iris image involves cooperation from the user; user must stand at a predetermined distance and position in front of the camera
- Cost of high performance iris systems is relatively high

http://news.bbc.co.uk/1/hi/uk/1816221.stm

http://www.oki.com/en/press/2002/z02011e.html

Limitations of Iris

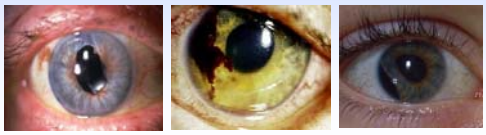
- Iris images may be of poor quality resulting in failures to enroll
- In a recent test by MPs, up to 7% iris scans could still fail, due to anomalies such as watery eyes, long eyelashes or hard contact lenses.



Occlusion (eyelids/eyelashes) Defocus Motion blurred Large pupil

Limitations of Iris

- Iris can change over time (e.g., as a result of eye disease), leading to false rejects.
  - more than 200,000 cataract operations are performed each year in UK
  - about 60,000 people in UK have Nystagmus (tremor of the eyes)
  - about 1,000 people in UK have Anaridia (no iris)
- Blind people may fail the test

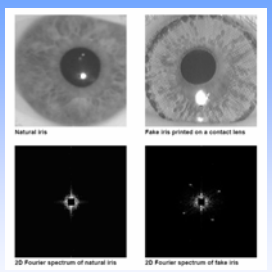


cataract surgery hyphaema (blood clot) iridodialysis

Anti-Spoofing Liveness Detection

Contact lens or photograph of a person's iris pattern can be used to spoof some iris recognition systems

Live VS. Printed Iris

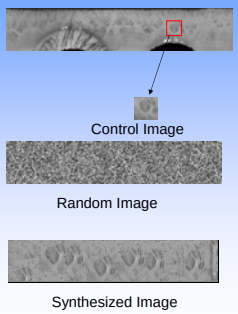


The dot matrix printing process generates four points of spurious energy in the Fourier plane, corresponding to the directions and periodicities of coherence in the printing dot matrix, whereas a natural iris does not have these spurious coherences.

Synthetic Iris Images using Markov Random Fields

- Texture synthesis approach used
- Input primitives include multiple samples of partial real iris images
- Synthesis – Primitives blended randomly to modify an independent random field (IRF) iteratively
- Result – Iris like image!

Iris Synthesis



- Control
  - Iris Image
- Input
  - Random Noise Image
- Output

Makthal and Ross, "Synthesizing Iris Images using Markov Random Fields", EUSIPCO 2005 (Submitted)

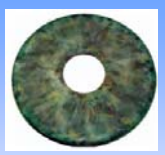
Multi-layer Synthetic Iris - Lefohn

- Generate a 3D model for iris
- Overlay many semi-transparent layers over the base layer
- Computer graphics methods used to render these layers onto the 3D surface
  - Different lighting and shadow effects used
  - Multiple layer texture generated

Lefohn et. al. "An oculanist's approach to human iris synthesis", IEEE Computer Graphics and Applications, Dec 2003

Synthesized Images

(a) Base Layer

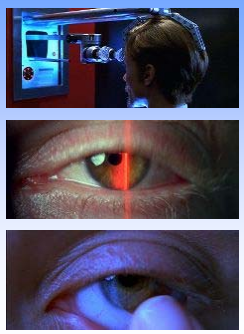


(b) 10 layers superimposed

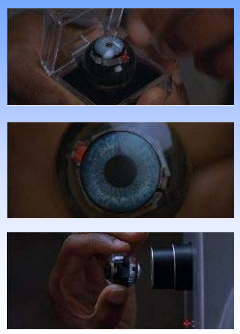
(c) Synthetic Iris images

Lefohn et. al. "An oculanist's approach to human iris synthesis", IEEE Computer Graphics and Applications, Dec 2003

Is iris recognition worth the trust in the future?



Charlie's Angels (2000)



Dracula 2000 (2000)

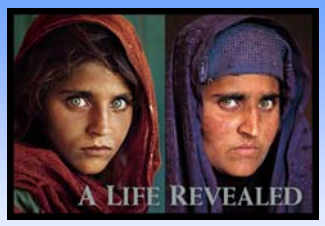
Liveness Detection

- Photonic and spectrographic countermeasures
  - spectrographic properties of tissue, fat, and blood
  - spectrographic properties of melanin pigment
  - coaxial retinal back-reflection ("red eye" effect)
  - 4 Purkinje reflections from corneal and lens surfaces
- Behavioral countermeasures
  - involuntary: autonomic nervous system
    - hippus (pupillary unrest)
    - pupillary light reflex (brainstem control)
  - voluntary: conscious control, challenge responses
    - eye movements on command
    - eyelid blinks on command

United Arab Emirates (UAE) Border Control

- Passengers arriving at all 17 air, land, and sea ports of entry into UAE today must look into an iris camera
- About 7,000 persons each day take this test; 2,557,000 so far
- Each person is compared against a central 'Watch List' of 505, 000 expelled foreigners' IrisCodes
- Each such exhaustive search of IrisCodes takes about 1 s
- 7,000 x 505,000 IrisCodes = 3.5 billion iris comparisons per day
- Approximately 300 billion iris comparisons performed in this program to date
- 17,927 matches to the 'Watch List' of expellees have been found
- UAE Ministry of Interior says no matches have been disputed; all confirmed ultimately with other records. False Match Rate = 0.

National Geographic, 1984 and 2002



Sharbat Gula, first photographed in 1984 aged 12 in a refugee camp in Pakistan by National Geographic photographer Steve McCurry, was traced 18 years later to a remote part of Afghanistan where she was again photographed by McCurry. Appeared in national Geographic

http://magma.nationalgeographic.com/ngm/afghangirl/

- Sharbat Gula, first photographed in 1984 aged 12 in a refugee camp in Pakistan by National Geographic (NG) photographer Steve McCurry, and traced 18 years later to a remote part of Afghanistan where she was again photographed by McCurry.
- NG turned to the inventor of automatic iris recognition, John Daugman at the University of Cambridge.
- The numbers Daugman got left no question in his mind that the haunted eyes of the young Afghan refugee and the eyes of the adult Sharbat Gula belong to the same person

John Daugman, a professor of computer science at the University of Cambridge, used his biometric technique to show that the haunted eyes of the young Afghan refugee and the eyes of the adult Sharbat Gula belong to the same person.