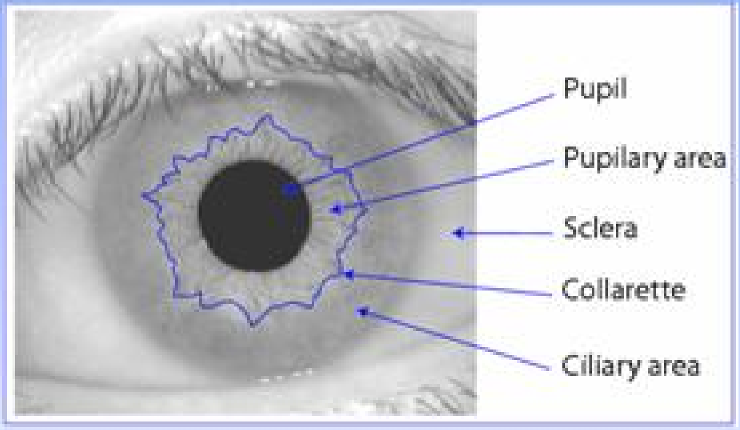
Iris Biometric: Algorithms, Performance & Applications



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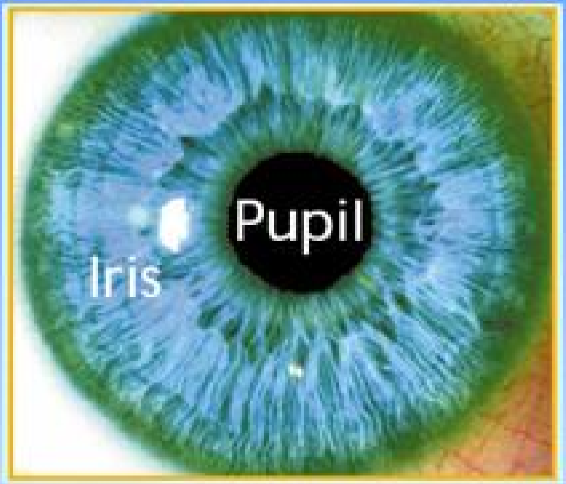
Iris as a Biometric

Iris



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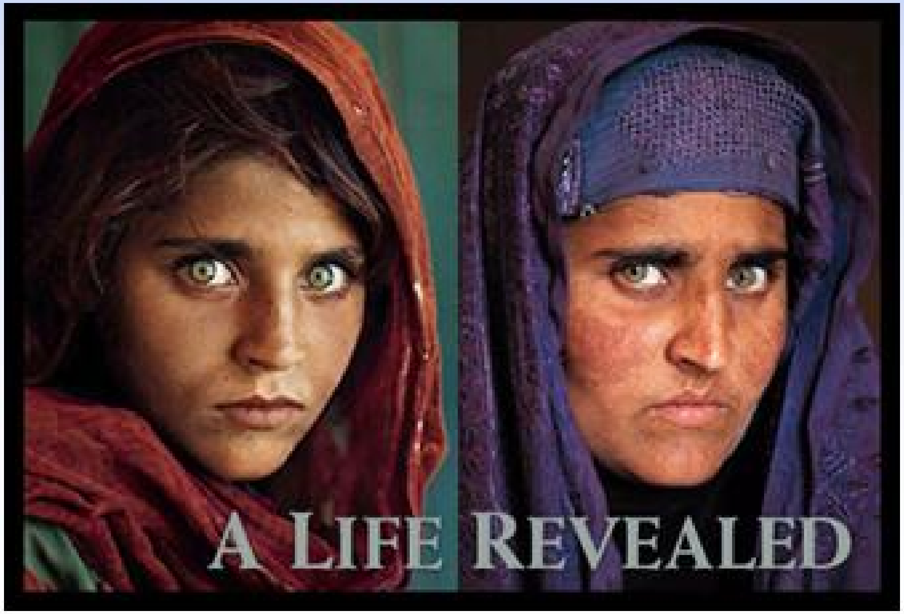
http://www.cl.cam.ac.uk/~jgd1000/SchipholRecognition.jpg

- Iris is the annular region of the eye bounded by the pupil and the sclera (white of the eye)
- 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

- Believed to be stable over a person's lifetime
- Imaging procedure is non-invasive
- Template size is small
- Likelihood of iris getting damaged or changed is rare because it is an internal organ



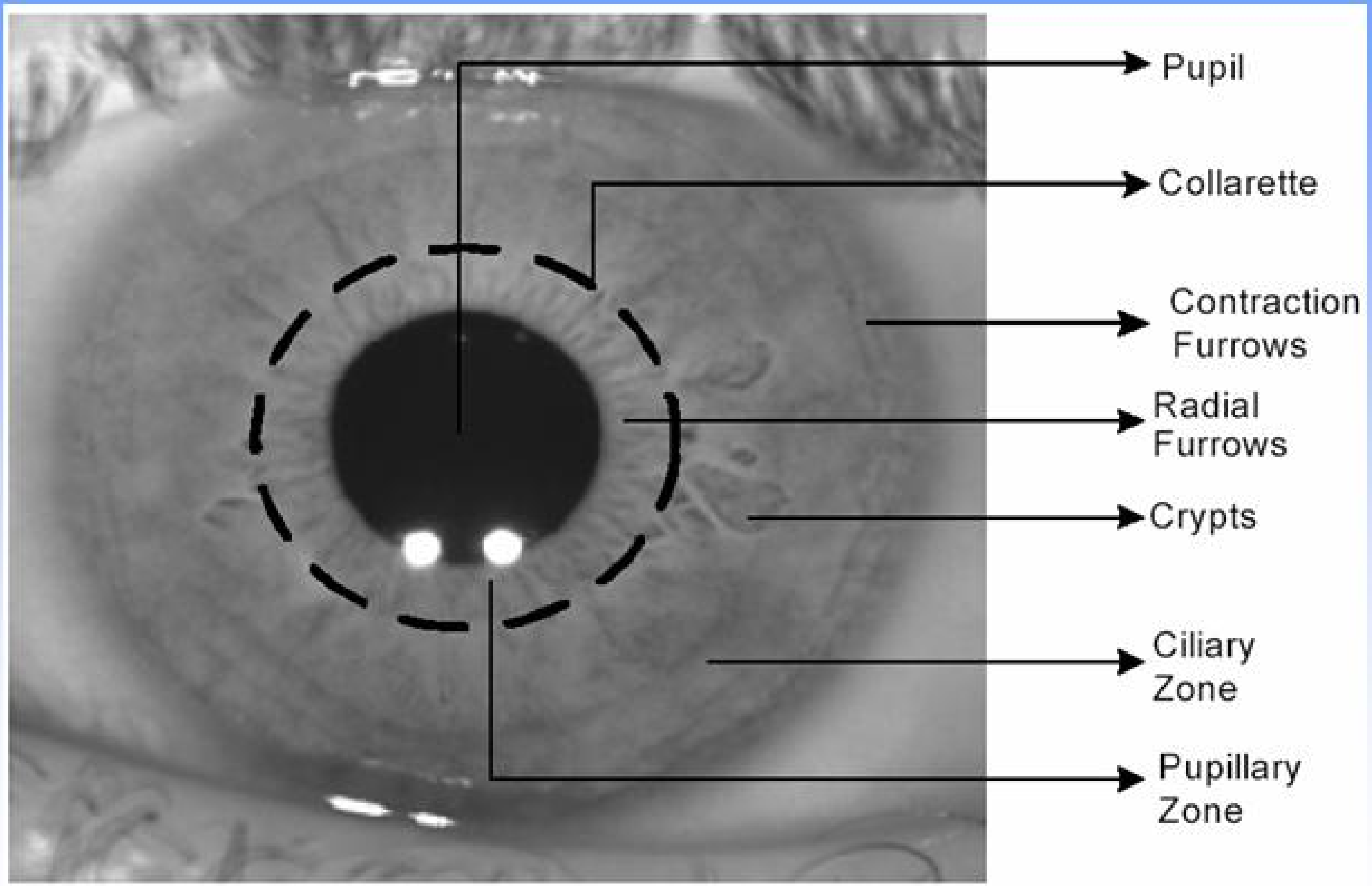
http://magma.nationalgeographic.com/ngm/afghangirl/

Large-scale Identification

- The United Arab Emirates (UAE) Ministry of Interior requires iris recognition tests on foreigners entering UAE from all 17 air, land, and sea ports.
- Via internet links each traveler is compared against each of 544,000 expellees (foreign nationals expelled for various violations), whose IrisCodes were registered in a central database upon expulsion.
- The time required for an exhaustive search through the database is about 1 second.
- On the average day, 7,000 arriving passengers are compared against the entire watch list of 544,000 in the database; this is about 3.8 billion comparisons per day.

http://www.cl.cam.ac.uk/~jgd1000/deployments.html/

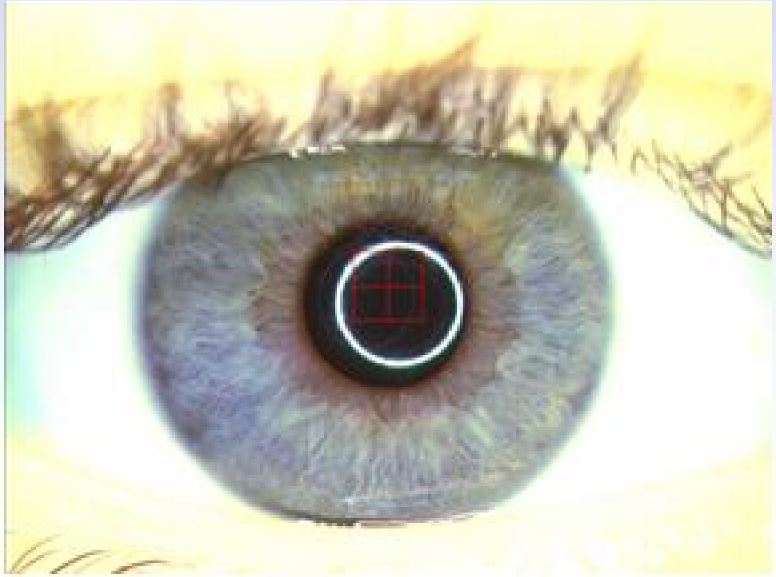
Anatomy of the Iris

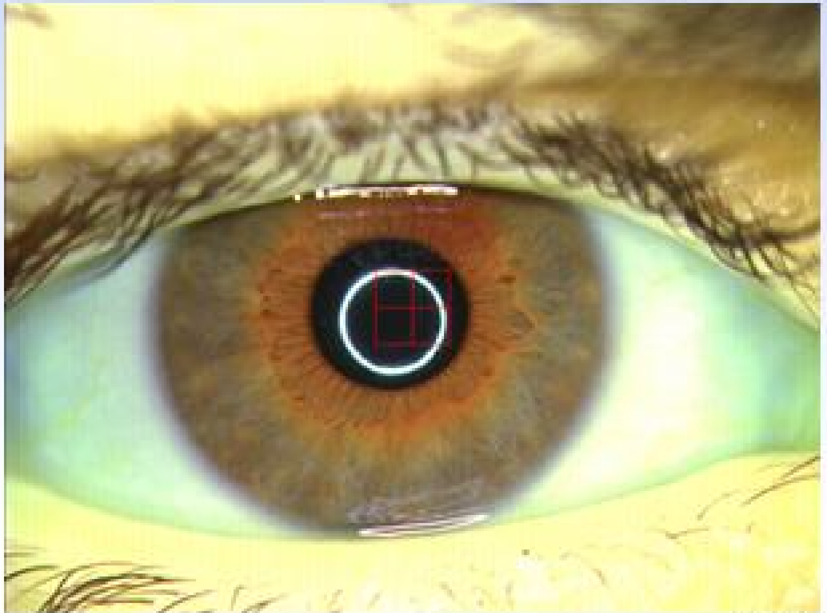


Factors affecting eye color

- Melanin content that is genetically determined
- Cellular density of the stroma
- Darkly pigmented epithelial layer

Light blue	0 dominant alleles
Blue	1 dominant allele
Blue-green	2 dominant alleles
Hazel	3 dominant alleles
Light brown	4 dominant alleles
Brown	5 dominant alleles
Dark brown / black	6 dominant alleles

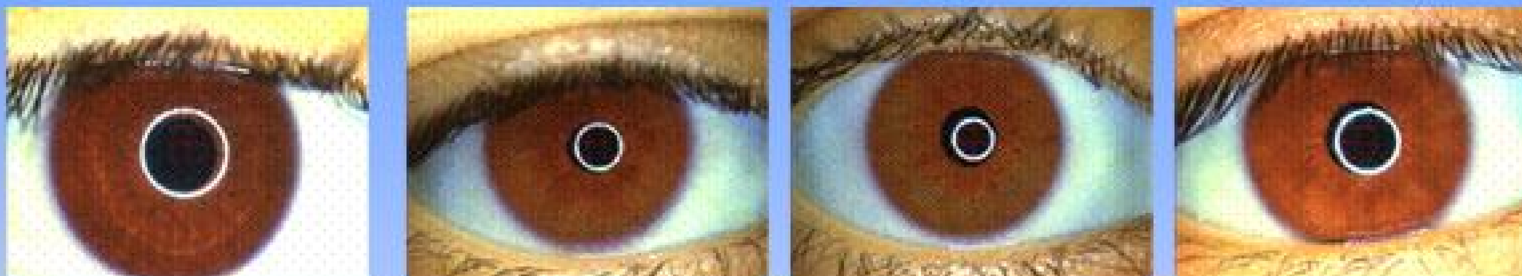




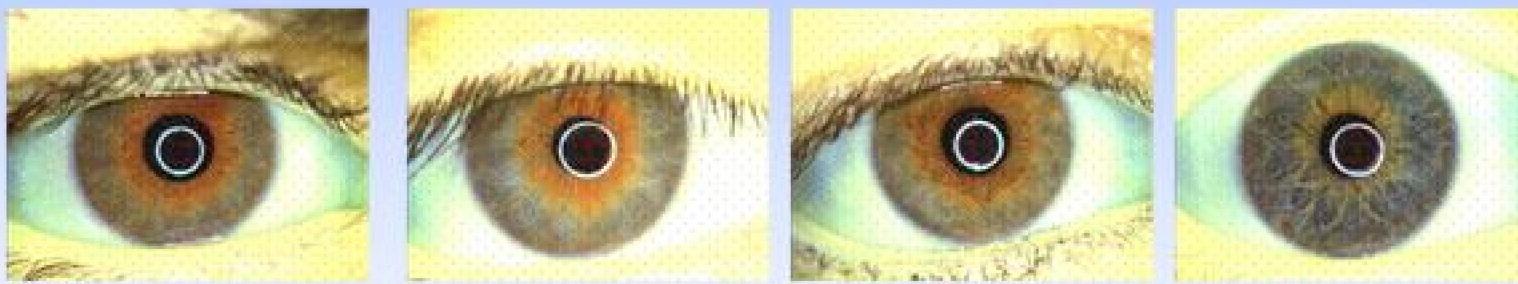
Variations in Eye Color

Image dimension: 1300 x 1040

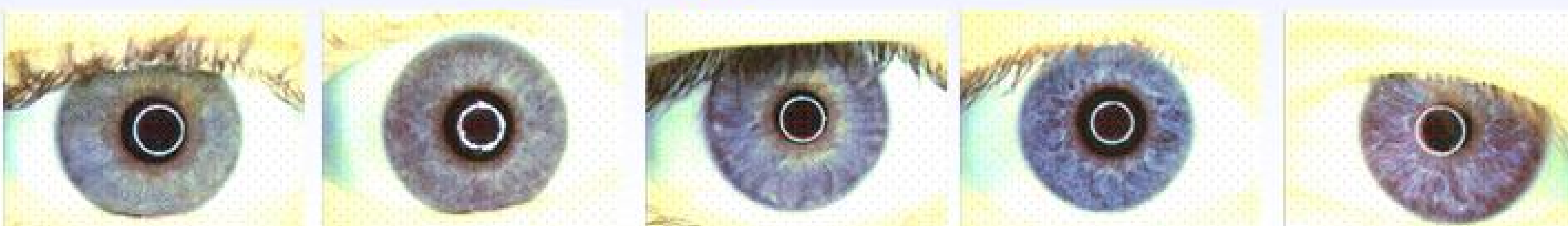
Brown Dark~Light



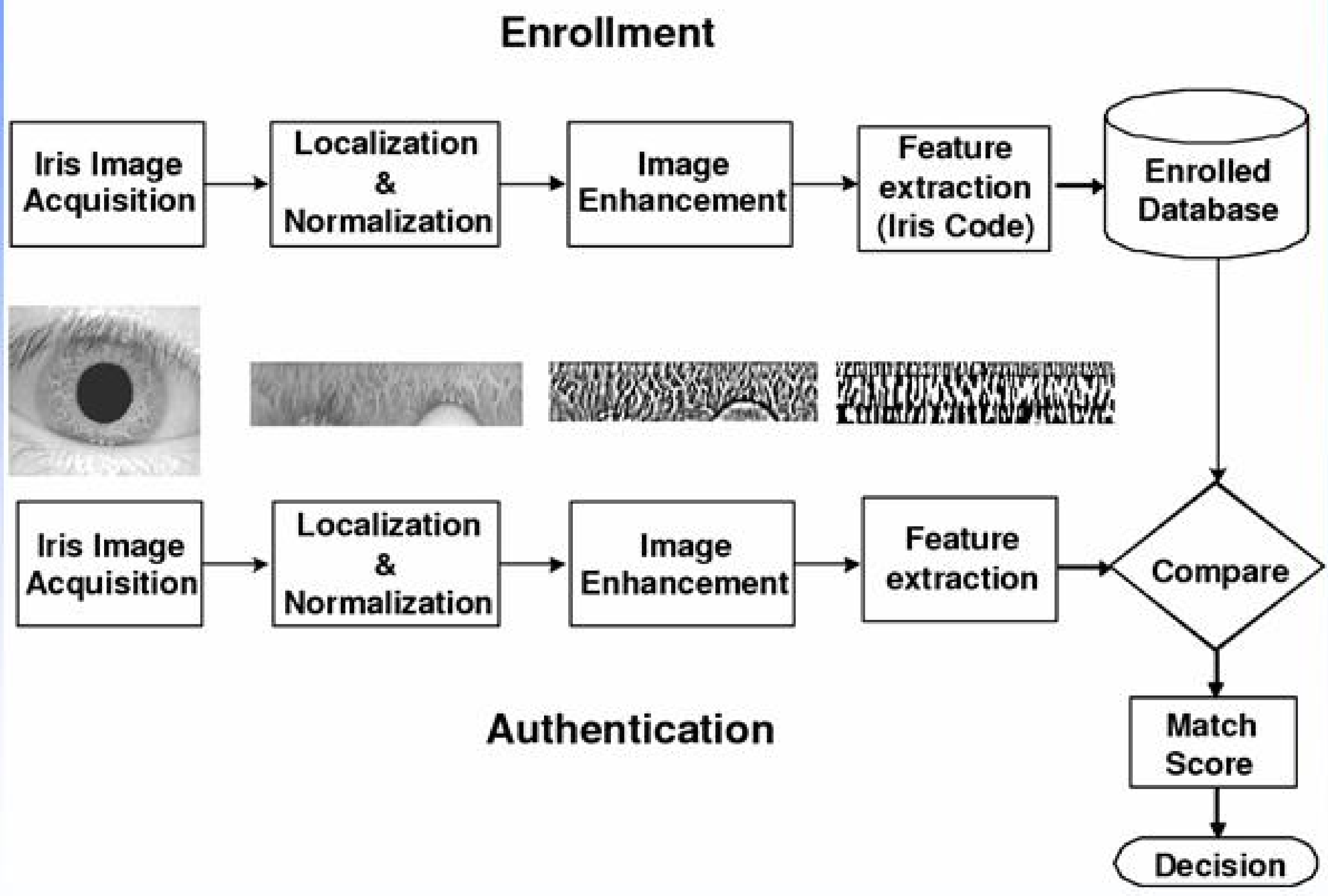
Light/Brown Green



Blue



Iris Processing Steps



Iris Localization

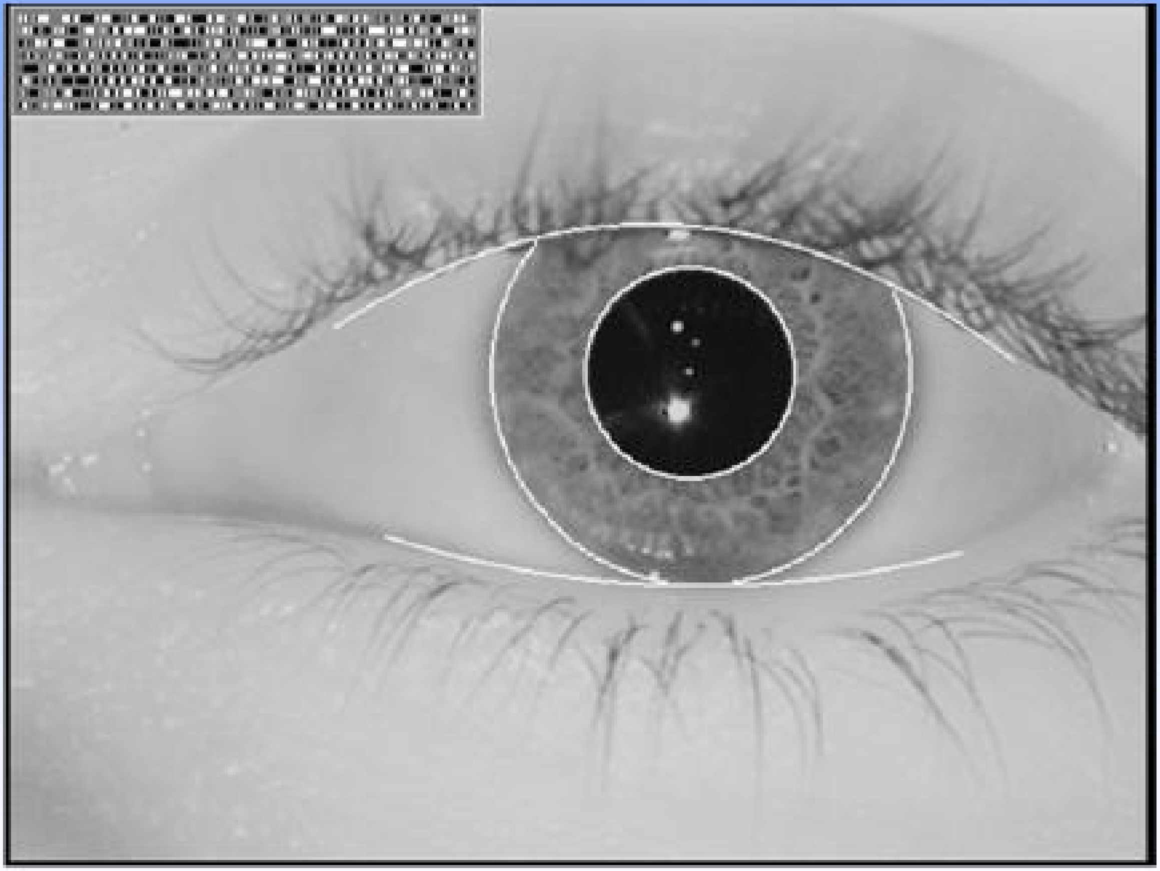
- Iris is localized using an integro-differential operator:

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

  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)

- This operator is very effective because of the almost perfect circular geometry of the pupil and iris

Example of Localization



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

Unwrapping the Iris

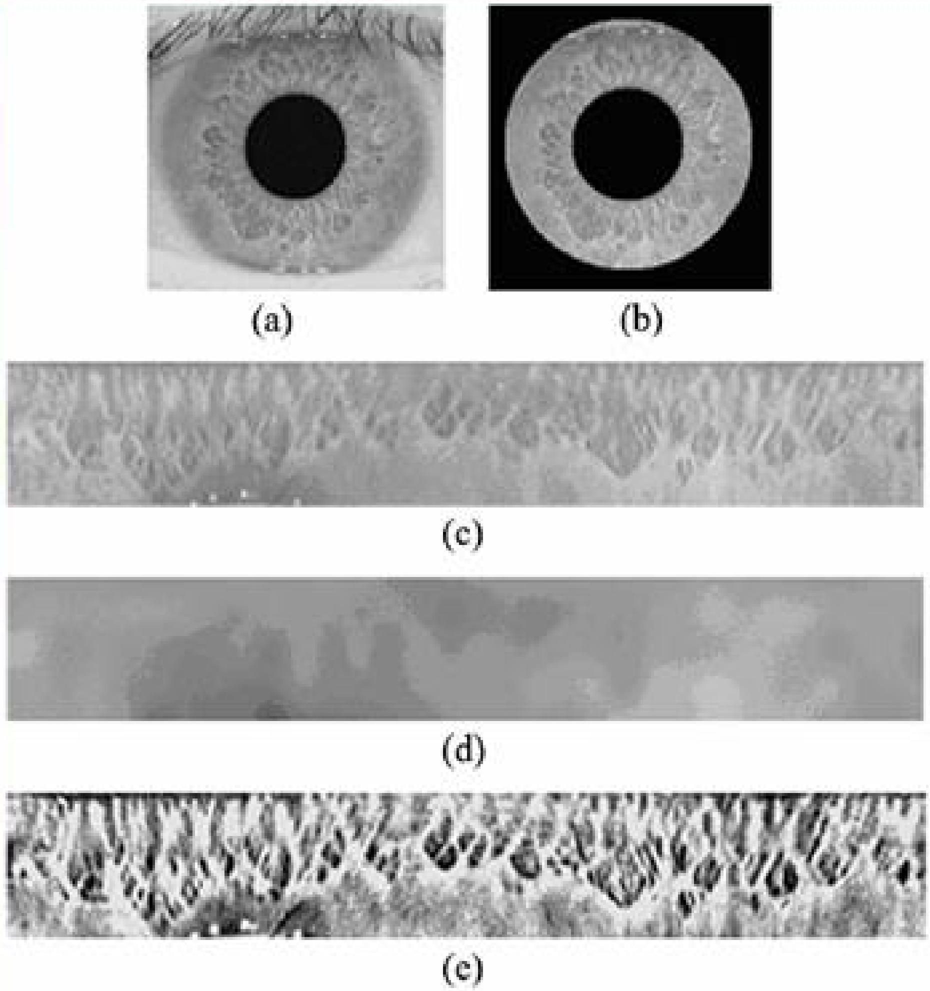


Fig. 3. Iris image preprocessing: (a) original image; (b) localized image; (c) normalized image; (d) estimated local average intensity; and (e) enhanced image.

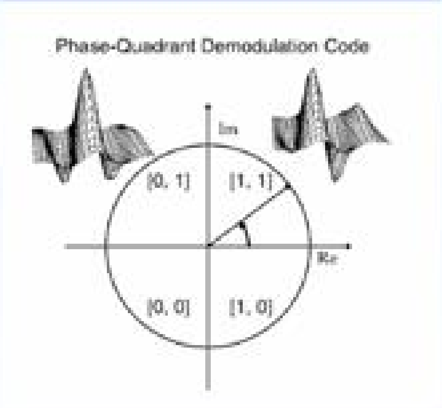
Ma et al., "Efficient iris recognition by characterizing key local variations", IEEE TIP, 2004

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)

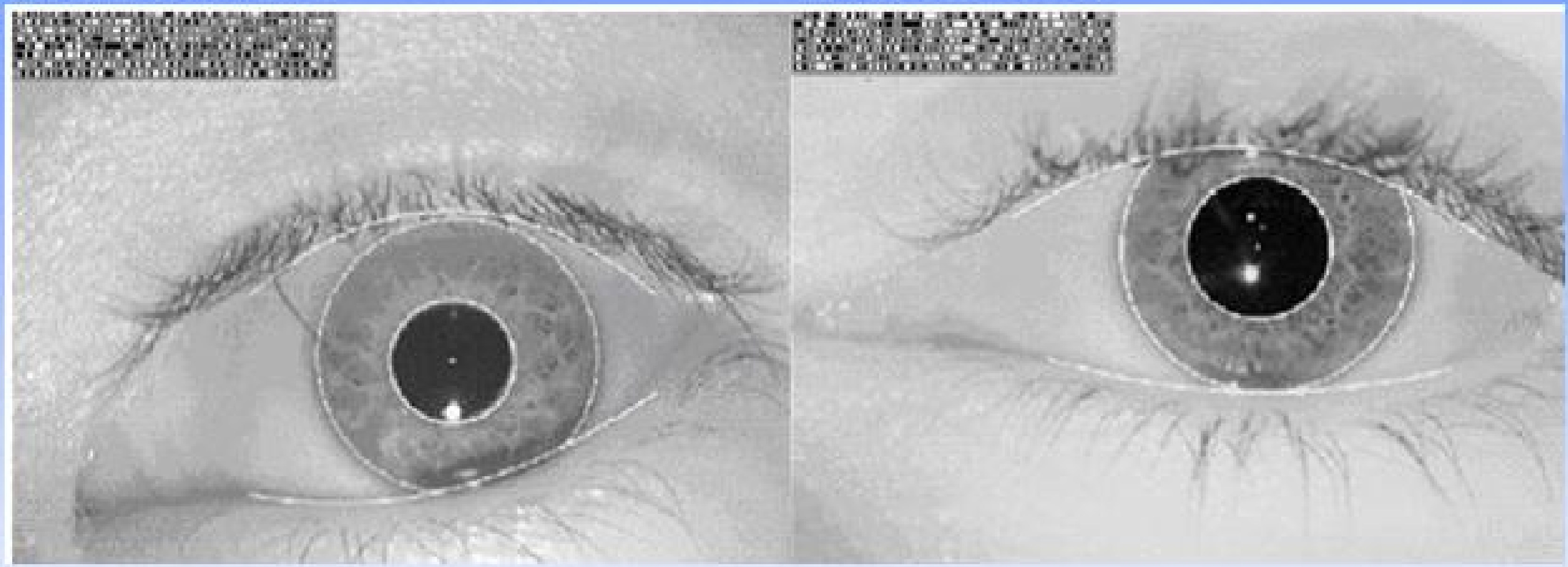
Daugman's Approach

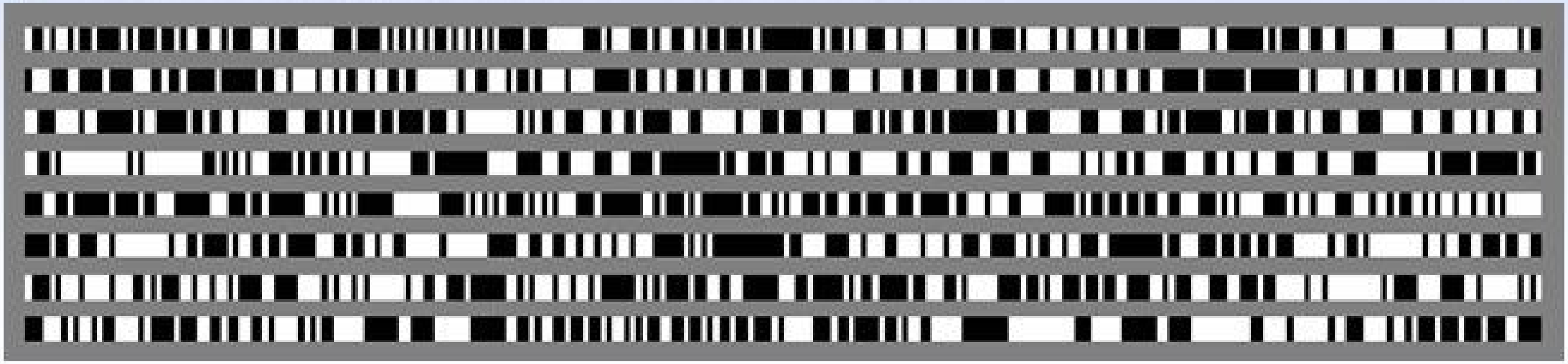
- Exploits randomness in the detailed texture of an iris
- 2D Gabor wavelets are used to encode phase information
- A test of statistical independence is carried out to determine the number of degrees of freedom



- Iris collage obtaibed from http://www.cl.cam.ac.uk/users/jgd1000/iriscollage.jpg
- *J.Daugman, "Statistical Richness of Visual Phase Information: Update on Recognizing Persons by Iris Patterns", International Journal of Computer Vision, 2001.*

Iris Matching using Iriscodes





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

Iris on the Move

- Sarnoff's Iris on the Move can identify 20 people per minute as they walk through a security portal.
- It can capture an iris as far as 10 feet away and within a wider range of view than earlier systems

-http://www.hoyosgroup.com/iom.html

http://www.nta.org/IPAM/IrisOnTheMove05.pdf

Iris Identification System

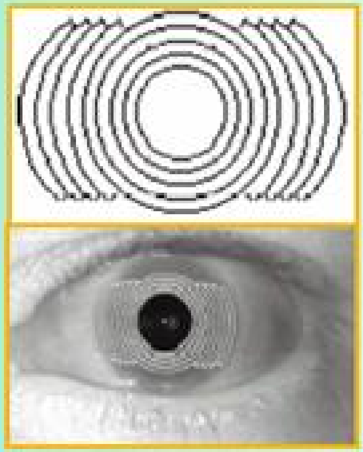
1. A user stands one to three feet from the system, which contains three standard video cameras.

2. Two wide-angle cameras image the user's torso. Using technology developed specifically for this application, the system determines the position of the eyes.

3. A third camera focuses on an eye and captures a single black-and-white digital image. Successful identification can be made through eyeglasses and contact lenses, and at night. If needed, the picture is rotated to compensate for a tilted head.

Michael Negin et al., An Iris Biometric System for Public and Personal Use, IEEE Computer, pp. 70-75, Feb 2000

Iris Identification



4. The system uses a circular grid as a guide to encode the pattern in the iris.

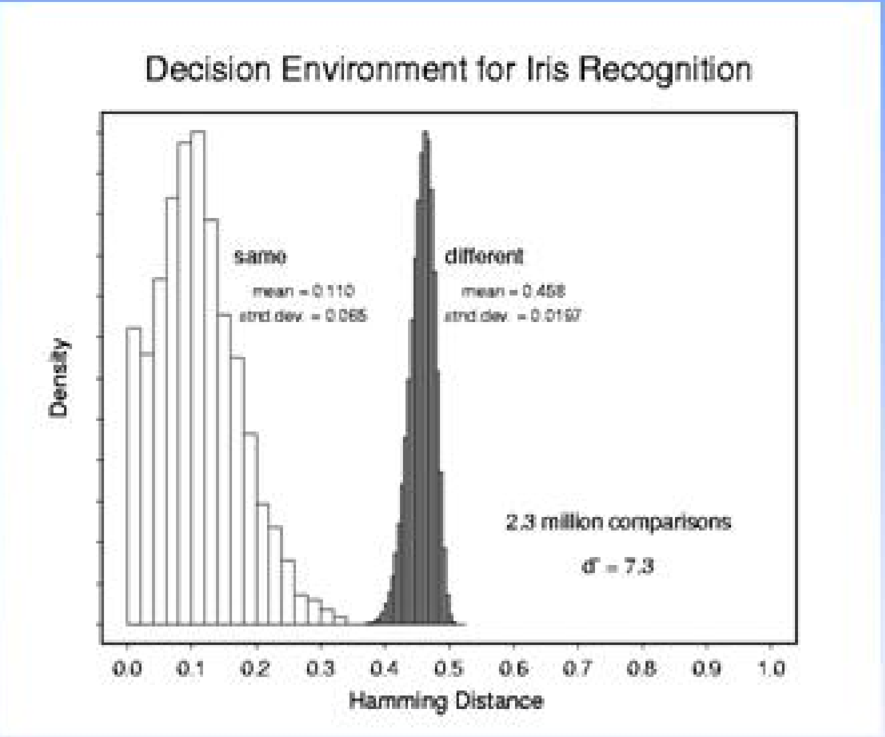
5. The grid is overlaid on the eye's image. The system looks at the patterns of light and dark iris areas and their distribution inside the grid, then generates a 512-byte human bar code for that person. The system will perform properly even if eyelashes or the eyelid obscure part of the grid.

6. The system checks the bar code against the version stored in a computer database. The entire process—from first picture to verification—takes about two seconds.

Michael Negin et al., An Iris Biometric System for Public and Personal Use, IEEE Computer, pp. 70-75, Feb 2000

Matching Score Distribution

- The genuine and impostor Hamming distance distributions for about 2.3M comparisons
- There is very small overlap between the genuine and impostor distributions



Match Score 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.

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

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

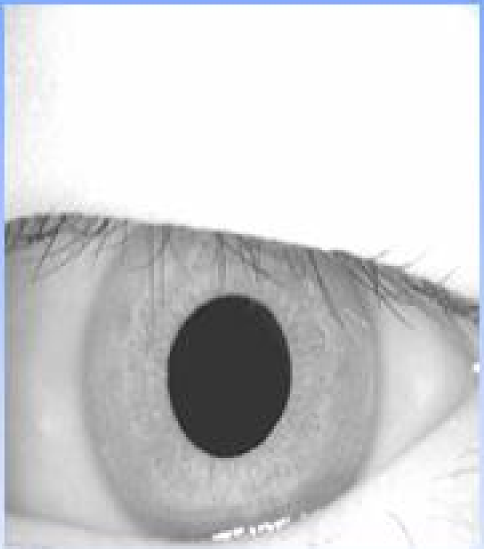
- Iris data of some users may be of poor quality (e.g., iris with large pupil, or off-center images) resulting in a failure to enroll

- The iris can change over time (e.g., as a result of eye disease), leading to false rejects

- Cost of high performance iris systems is relatively high

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

Poor Quality Iris Images



- Drooping eyelids
- Large pupil
- Off-centered iris

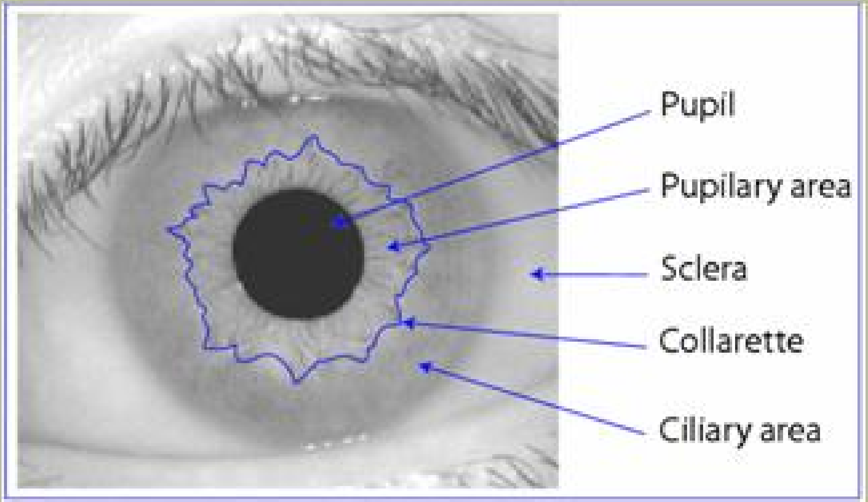
Assessing Quality of Iris Images

Image Quality

- Image quality has one of the **largest** effects on iris recognition performance.
- Trial studies in [1][2][3] showed that poor image quality lead to surprisingly **high FRR** of 11.6%, 7%, and 6%, respectively at 0% FAR.
- Iris texture is highly localized and frequency responses are a good indicators of iris image quality.

[1] H. Wang, D. Melick, etc, "Lessons Learned From Iris Trial," Biometric Consortium Conference, 2002
[2] D. Thomas, "Technical glitches do not bode well for ID cards, experts warn," Computer Weekly, 2004
[3] S. King, H. Harrelson and G. Tran, "Testing Iris and Face Recognition in a Personal Identification Application," Biometric Consortium Conference, 2002

Highly Localized Iris Texture



Texture in the **pupillary** area is more distinct than that in the **ciliary** area. The two are separated by the **collarette** boundary.

- The upper regions are often more occluded compared to lower regions
- The inner regions provide finer texture compared to outer regions
- Sung [4] showed that improvement in the matching performance can be obtained by simply weighting the pupillary (ciliary) area with 1(0)

[4] H. Sung, J. Lim, et al. "Iris Recognition Using Collarette Boundary Localization," Int'l Conf. On Pattern Recognition, Vol. 4, pp. 857-860, 2004

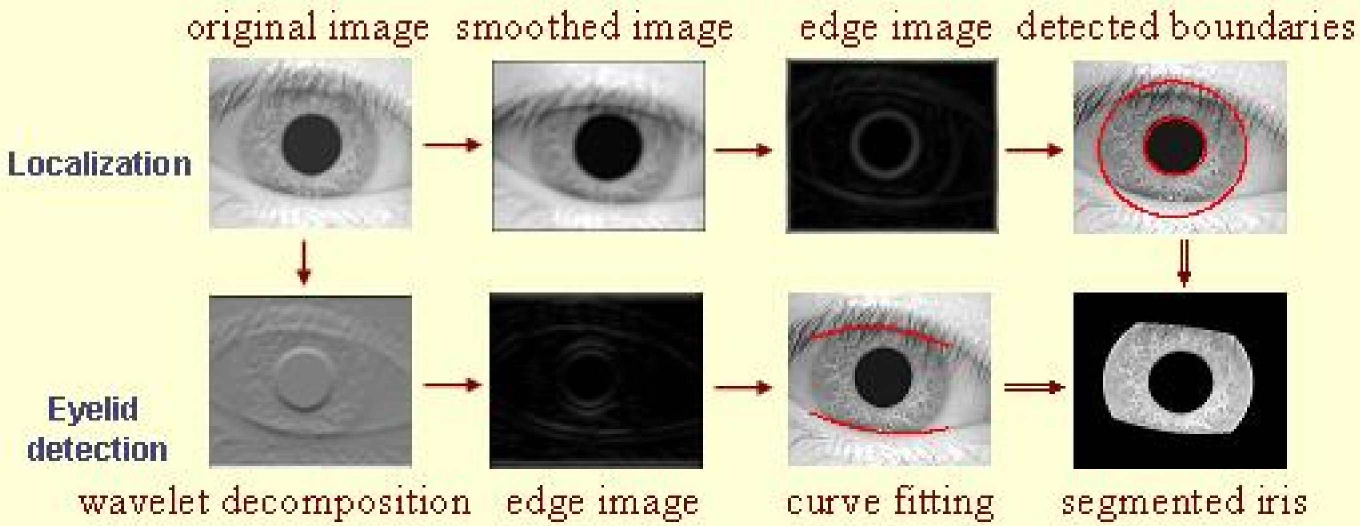
Localized Quality for Iris Images

Objective: Develop **local quality** measures and an overall **quantitative** index for use in iris recognition systems.

Steps involved:

1) Iris segmentation
2) 2-D wavelet Transform on segmented iris
3) Band-wise local quality estimation using wavelet energy
4) Normalization using rubber-sheet model
5) Overall quality index generation

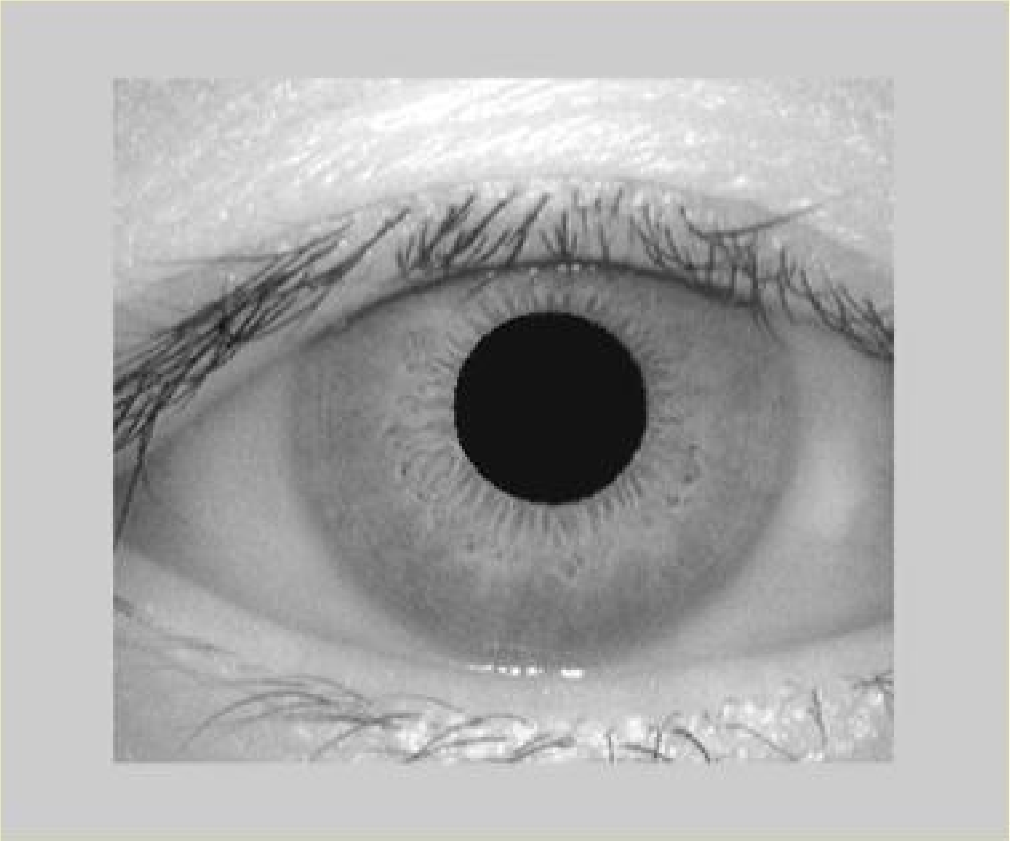
Iris Segmentation



Inner/Outer boundaries Detection	Upper/Lower eyelids Detection	Eyelashes Detection
• Morphological opening • Canny edge detection • Hough transform	• Wavelet decomposition • Canny edge detection • parabolic curve fitting	• Intensity thresholding

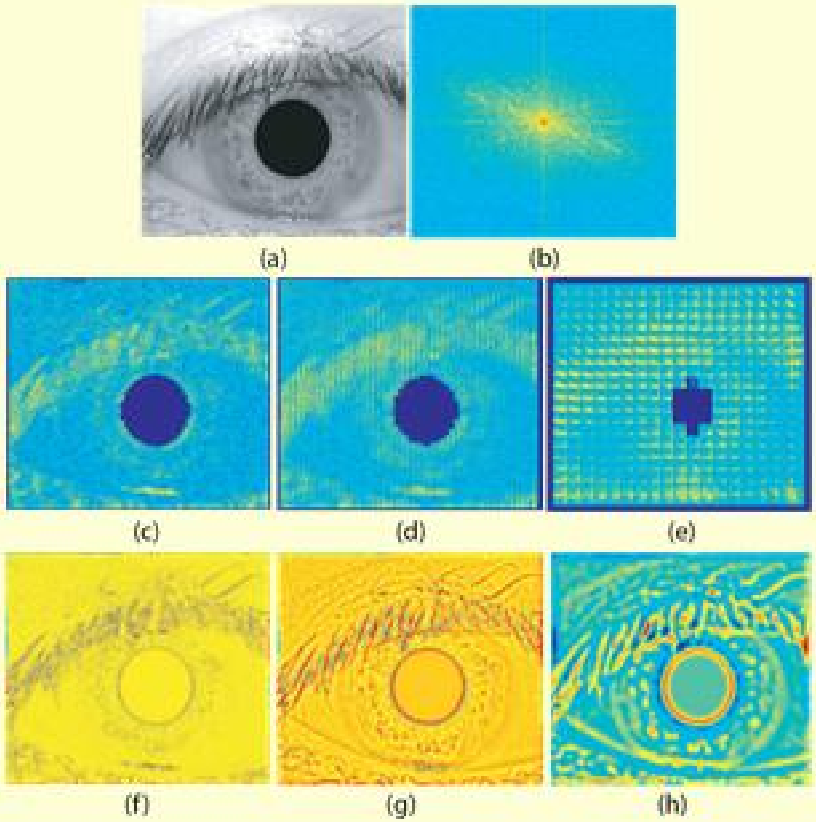
Segmentation Algorithms

Iris Segmentation



Demo

Wavelet Transform vs. Fourier Transform



FT

STFT
window sizes
(2x4, 4x6, 14x16)

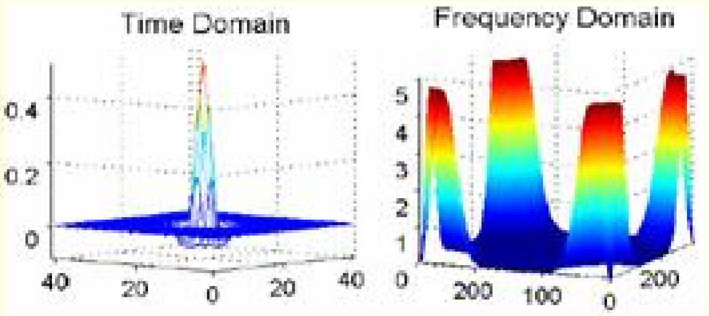
Mexican Hat
WT
scales
(0.5, 1.0, 2.0)

- Fourier Transform (FT) does not localize in space, while Short Time Fourier Transform (STFT) is limited in delivering a fine space-frequency resolution
- Wavelet Transform (WT) has smooth representation in both space and frequency domains

Wavelet-based Iris Local Quality

1. Given a segmented iris image *I(x,y)*, apply 2D continuous Mexican hat wavelets ϕ with three different scales *s* (=0.5, 1.0, 2.0)

$$w(s) = \frac{1}{\sqrt{s}} \iint_{R^2} I(x,y)\phi\left(\frac{x-a}{s}, \frac{y-b}{s}\right)dxdy$$



Mexican hat wavelet ϕ

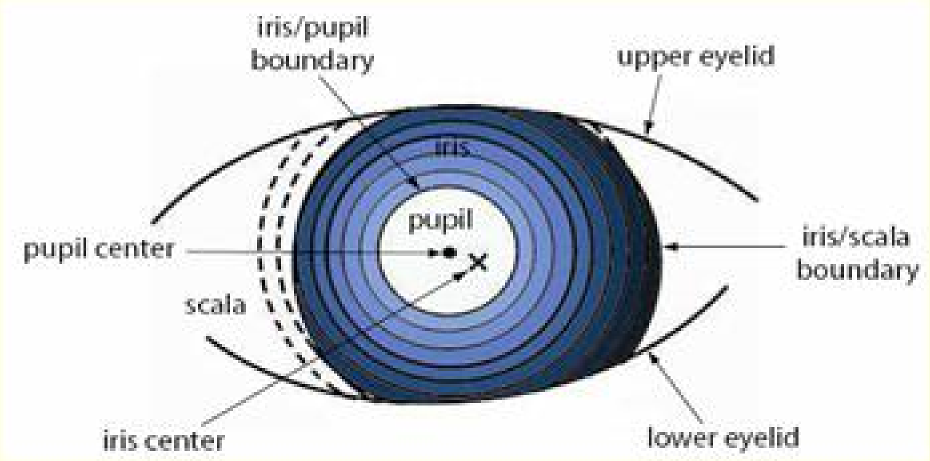
- Multi-scale Mexican hat wavelets act like a set of band pass filters and are suited for extracting features exhibiting sharp variations (e.g., pits and freckles) and non-linearity (e.g., zigzag collarette, furrows).

Wavelet-based Iris Local Quality

2. Group features into bands concentric at the pupil center and define the local quality in the t^{th} band as

$$Q_t = \frac{1}{r_t} \sum_{k=1}^{r_t} (|\, w(s_1) \times w(s_2) \times w(s_3)\,|^2)$$

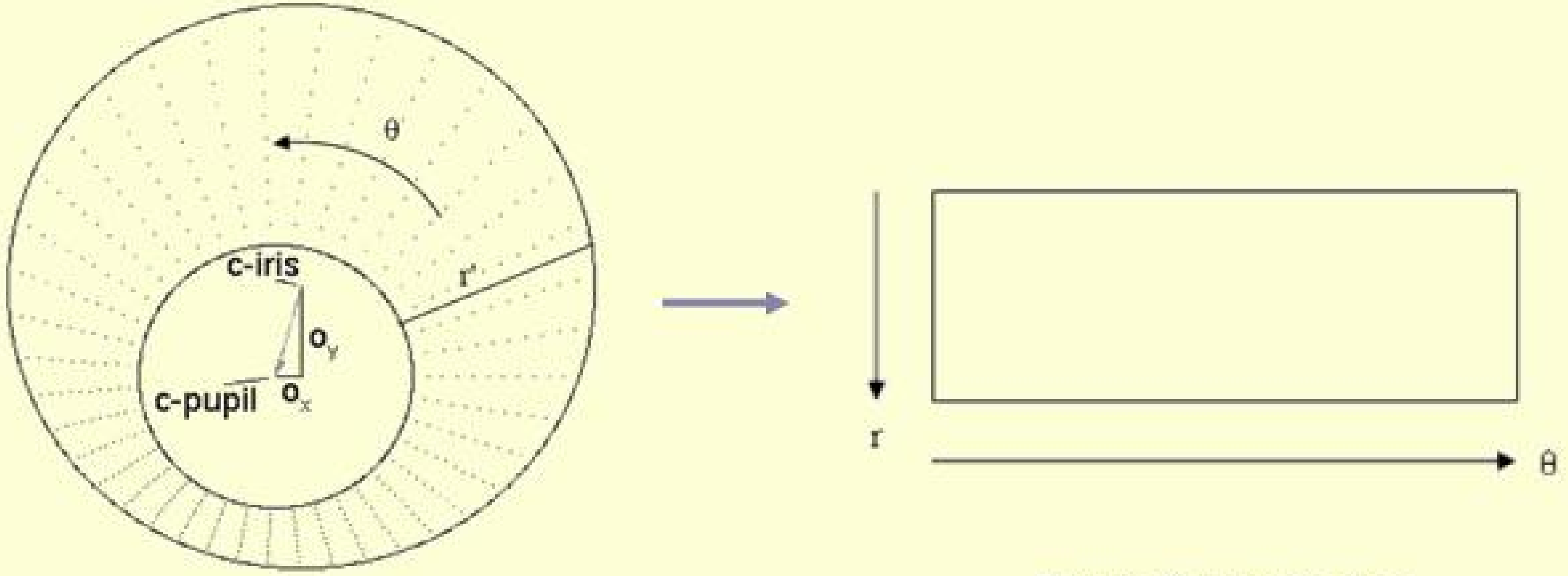
where $w(s_1), w(s_2), w(s_3)$ are the wavelet coefficients of the three scales (0.5, 1.0, 2.0). r_t is the total number of coefficients in the t^{th} band.



Feature Localization

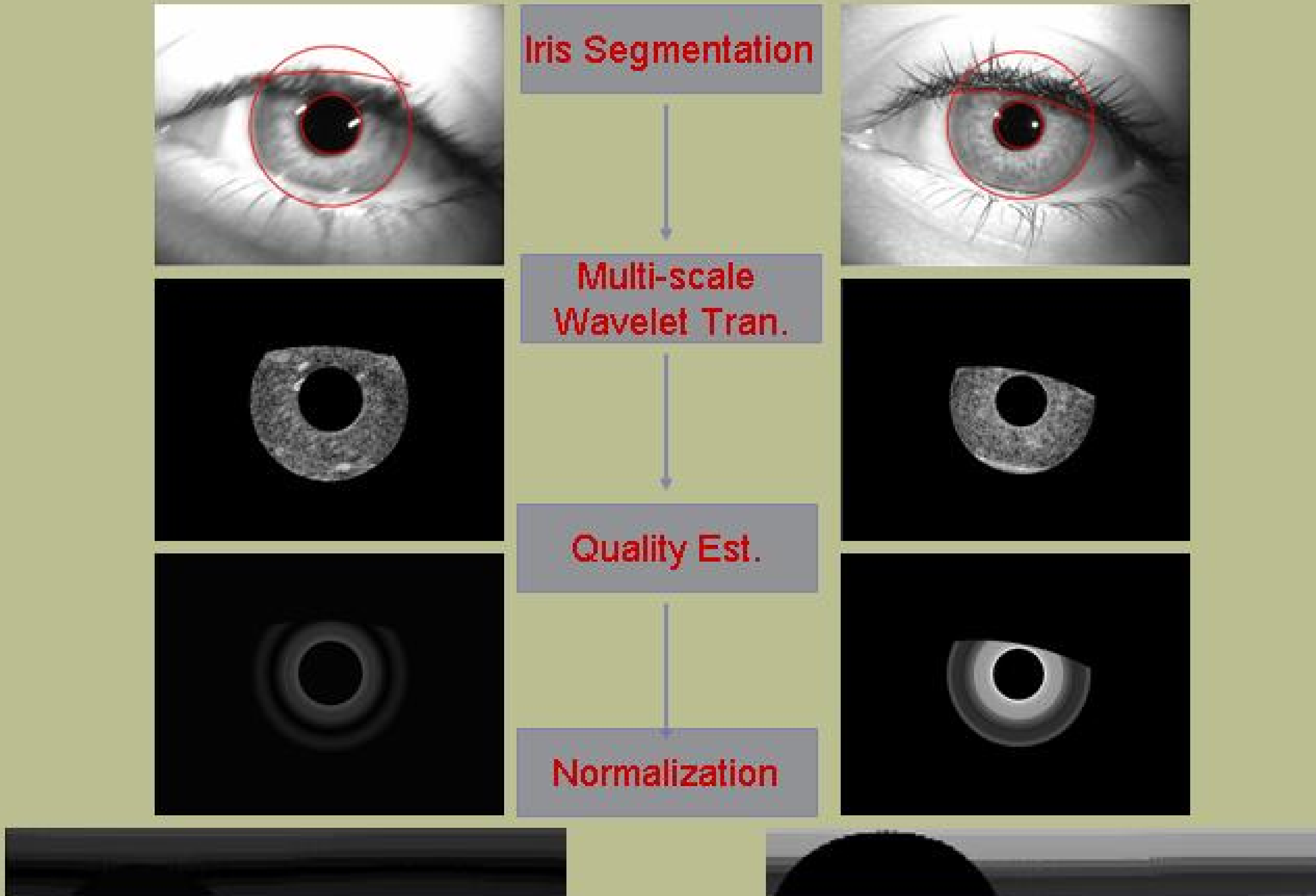
Rubber-sheet model based Normalization

3. Apply Daugman's rubber sheet model (r=48, θ=256) to account for variations of iris size caused by
   1) pupil dilation due to changes in lighting condition
   2) flexible distance from the camera during image acquisition



Cartesian Coordinates

Polar Coordinates


Iris Segmentation
Multi-scale
Wavelet Tran.
Quality Est.
Normalization

Overall Quality Index

4. An overall quality index is defined as a weighted average of the band-wise local quality measure:

$$Q = \frac{1}{T}\sum_{t=1}^{T} m_t \log Q_t,$$

where T is the total number of bands and m_t is the weight for the t^{th} band, given by

$$m_t = \exp\{-\| l_t - l_c \|^2 / 2q^2\},$$

with l_c denoting center of the pupil, and l_t denoting the mean radius of the t^{th} band to l_c.

- m_t is used to give more confidence on inner iris regions since they are more likely to contain fine texture and less occlusion compared to the outer regions.

Experiments

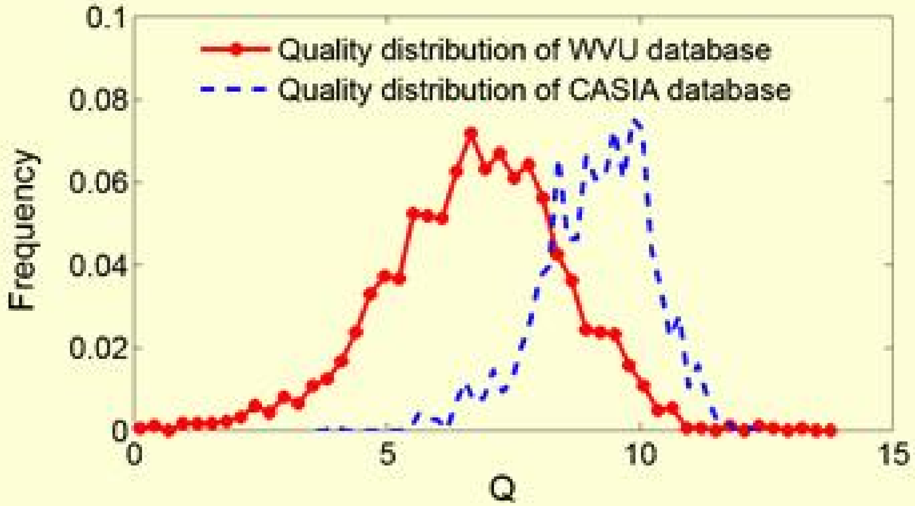
1. **Using overall quality index Q to predict the matching performance:**
   - Partition database into multiple classes with respect to Q. Obtain ROC curves and EER (Equal Error Rate) for each class and compare.
2. **Using local quality measures Q_t to improve the matching performance:**
   - Modify the Hamming distance by employing local quality measures

$$HD = \frac{1}{B}\sum_{i=1}^{B} X_i \otimes Y_i \longrightarrow HD_Q = \frac{1}{B}\frac{\sum_{i=1}^{B}\sqrt{Q_{g(i)}^{X} \times Q_{g(i)}^{Y}}\,(X_i \otimes Y_i)}{\sum_{i=1}^{B}\sqrt{Q_{g(i)}^{X} \times Q_{g(i)}^{Y}}}$$

where X_i and Y_i are the ith bit of the iris code of the template (X) and query (Y) generated using Daughman's matching algorithm, respectively. And g(i) maps the i^{th} bit to its corresponding quality band. The new match distance is weighted by the associated local quality measures $Q_{g(i)}^{X}$ and $Q_{g(i)}^{Y}$.

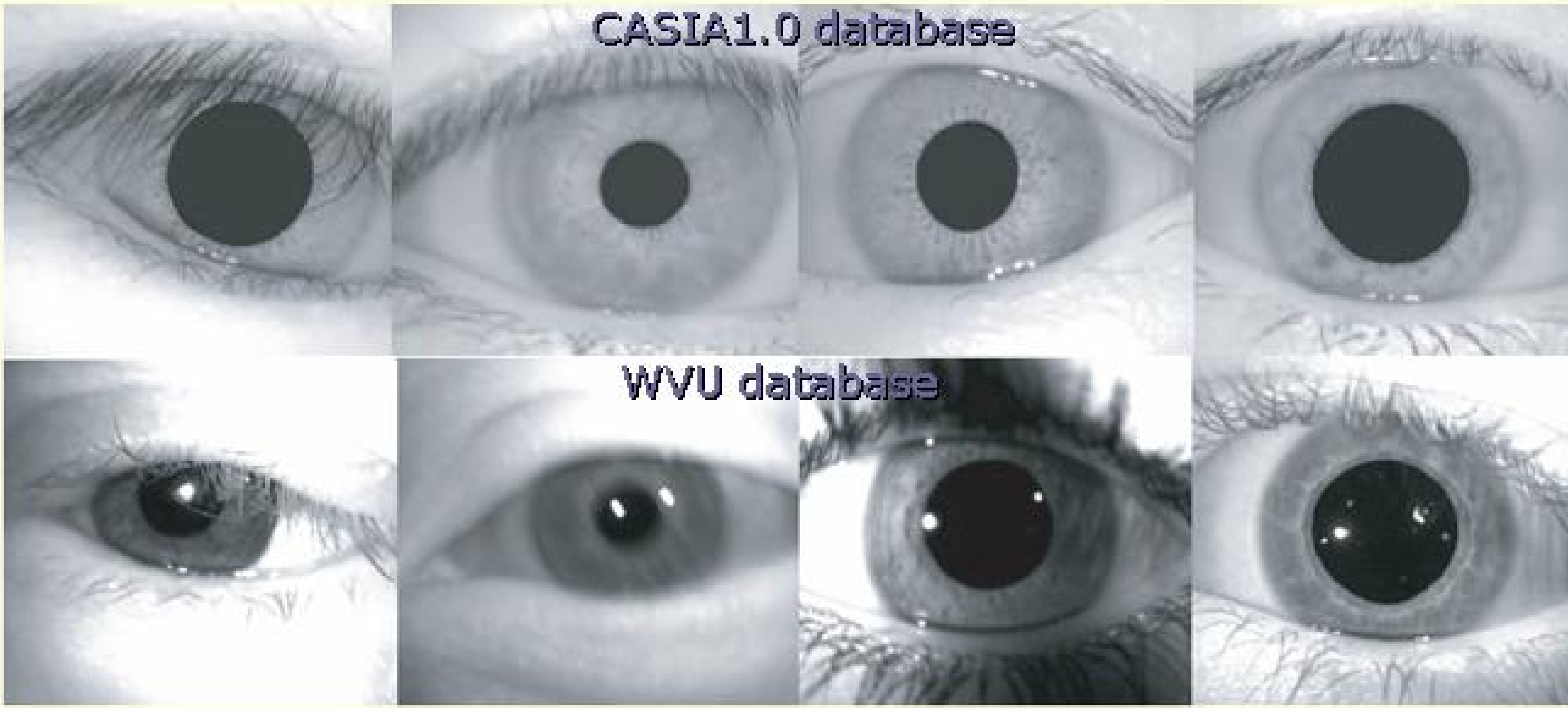
Databases

- **CASIA** database
  - 108 different eyes, 7 images per eye (756 images)
- WVU database
  - 380 different eyes, 3-6 images per eye (1852 images)



The images in the WVU database were heavily affected by lighting conditions and large variance in size of the iris area due to inconsistencies in the distance between the user and the camera during image acquisition.

Examples of Poor Quality Iris Images



occlusion

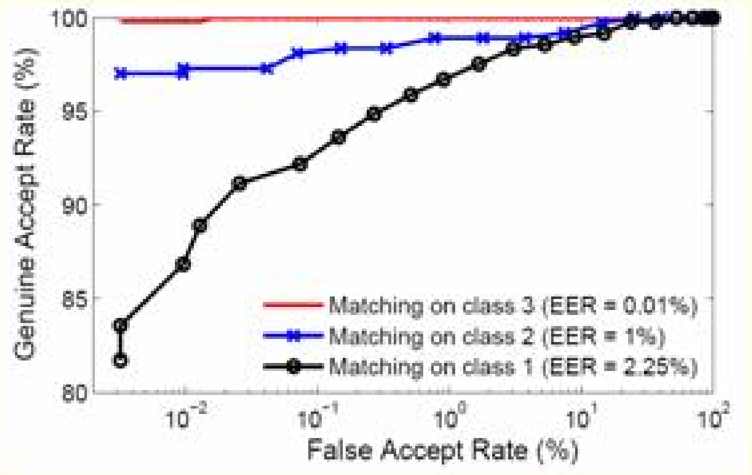
poor focus and eye motion

non-uniform illumination

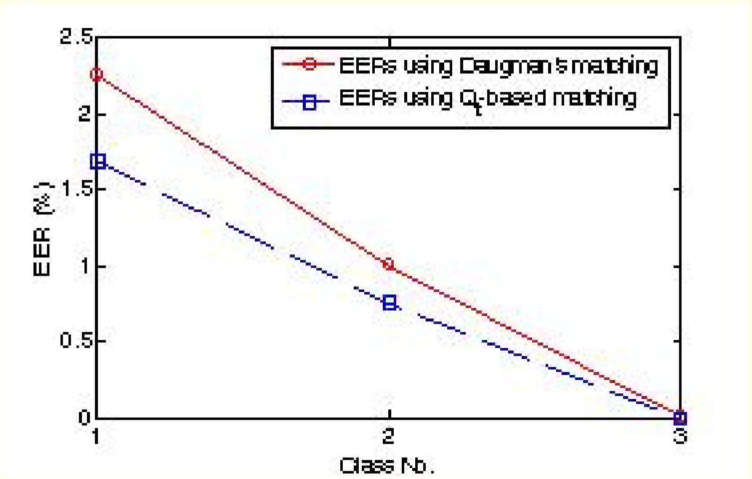
large pupil

Iris images with different texture quality

Performance (CASIA db)

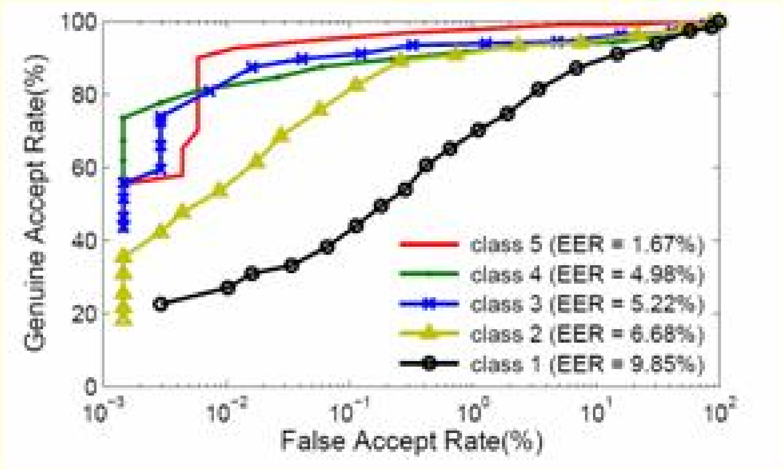


- Experiment 1:
  Partition the database into three classes (poor (1), moderate (2) and good (3)). ROC curves for each class shows the capability of Q to predict the match performance.

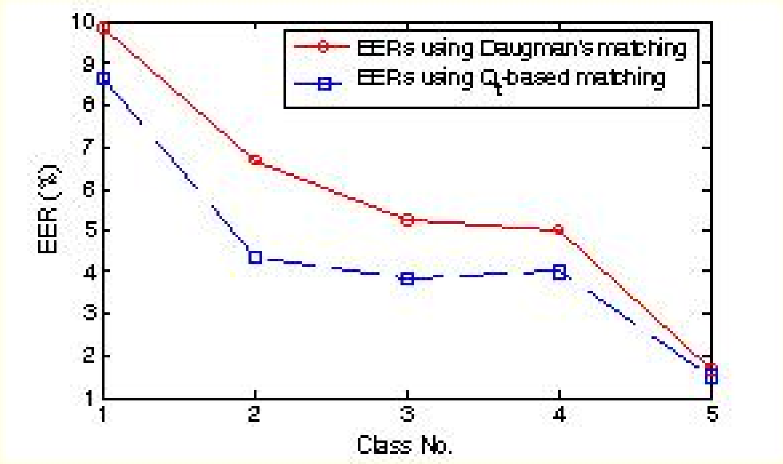


- Experiment 2:
  Weight the Hamming distances between template and query using local quality measures. Higher matching performance (in terms of EERs) is observed for each class, compared to original Daugman's matching algorithm.

Performance (WVU db)



- **Experiment 1:**
  Partition the database into five classes (very poor (1), poor (2), moderate (3), good (4) and good (5)). ROC curves for each class shows the capability of *Q* to predict the match performance.



- **Experiment 2:**
  Weight the Hamming distances between template and query using local quality measures Q_t. Higher matching performance (in terms of EERs) is observed for each class, compared to original Daugman's matching algorithm.

Comments

- Frequency response is a good indicator of image quality. However, highly localized iris features requires the frequency analysis to be localized in both frequency and space.
- We propose an iris local quality measure using multi-scale 2D wavelet transform, considering its localization in both frequency and space. We demonstrate that matching performance can be improved by incorporating local quality into matching distance measure.
- Experimental results have also shown that the overall quality index, Q, can reliably predict matching performance
- We are currently conducting quality-based multi-modal fusion such that user-specific weights can be automatically assigned based on image quality of each modality

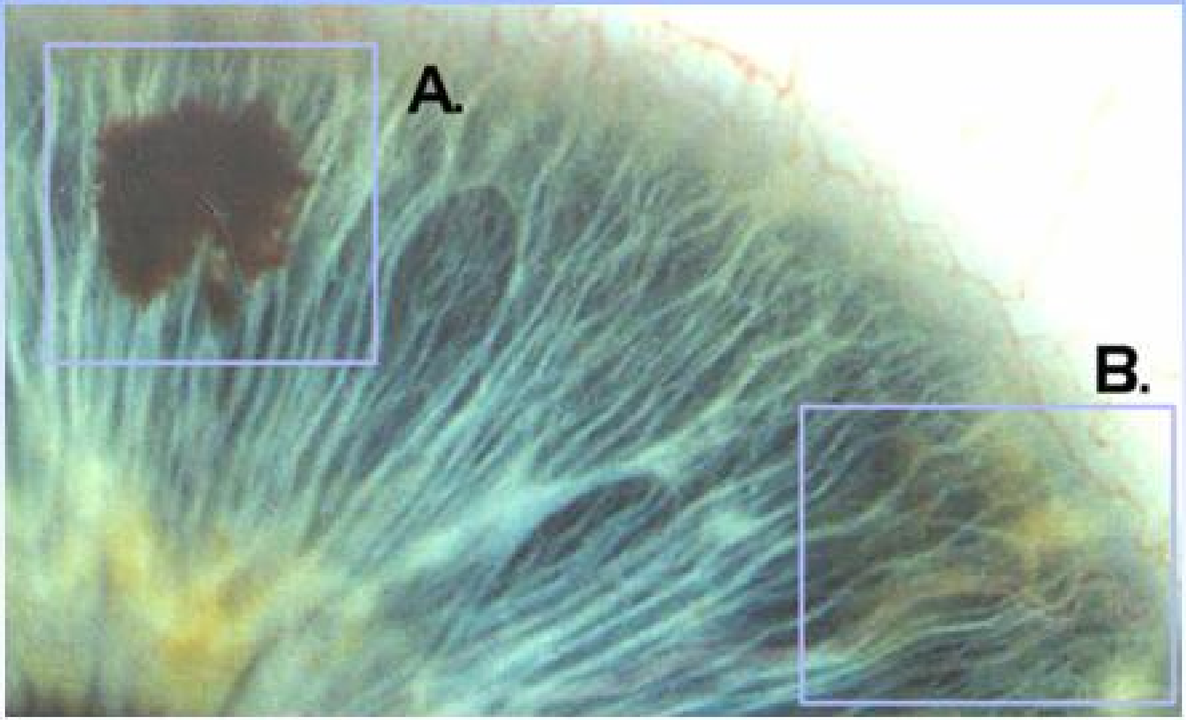
Multispectral Iris Recognition

Why Multispectral?

- Iris typically imaged using near-infrared (NIR) illumination (700 – 900nm)
- The rich and complex iris texture is captured by this arrangement
- What type of information can be acquired at lower wavelengths?
- Will different eye colors reveal different components of the iris depending upon the spectral channel used?

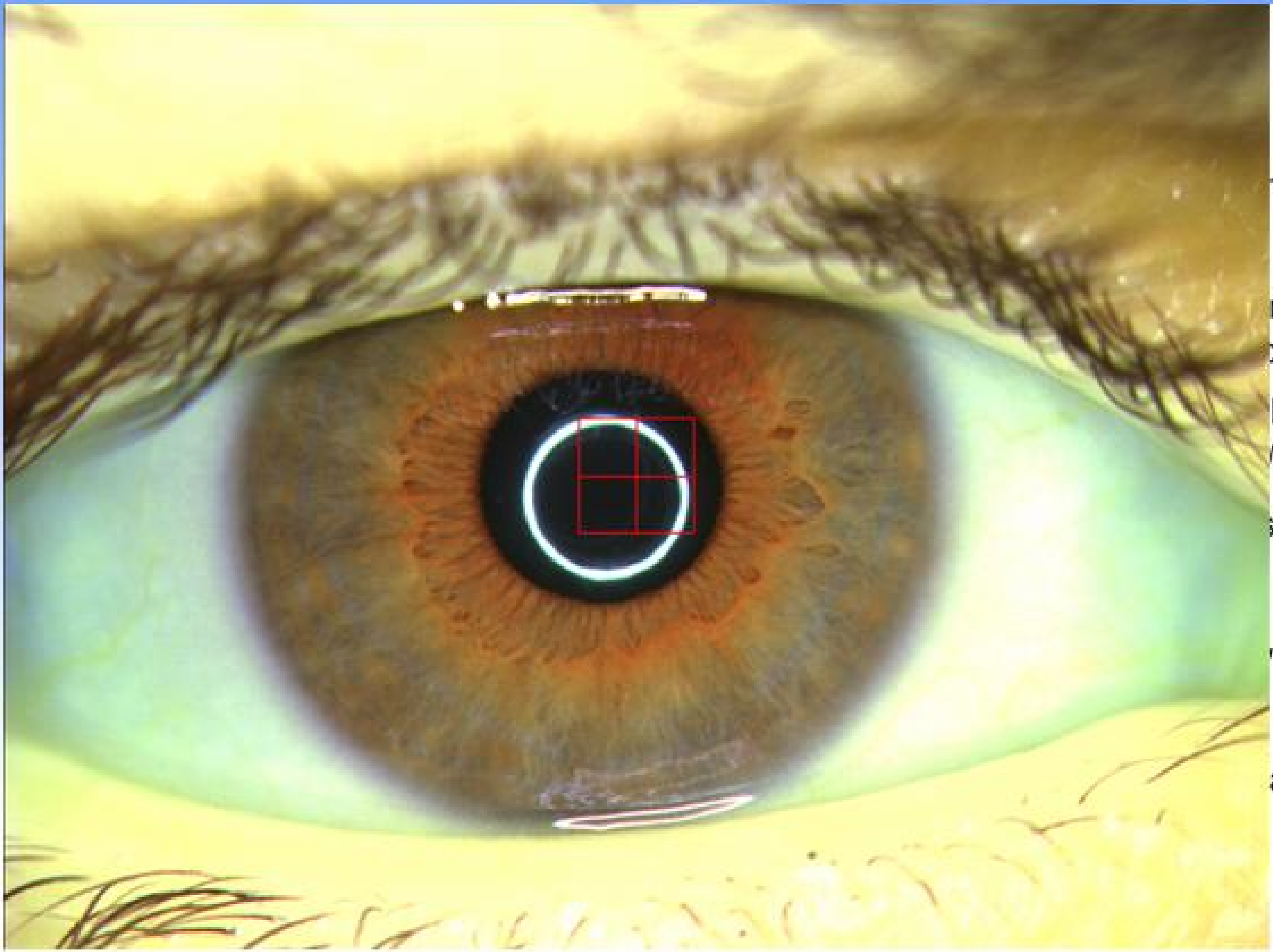
Color texture matching schemes

- Exploit the rich textural information along with distinct landmarks
- Can iris matching be done by forensic experts?



http://www.milesresearch.com/images/A01_le2.jpg

Structure of the iris



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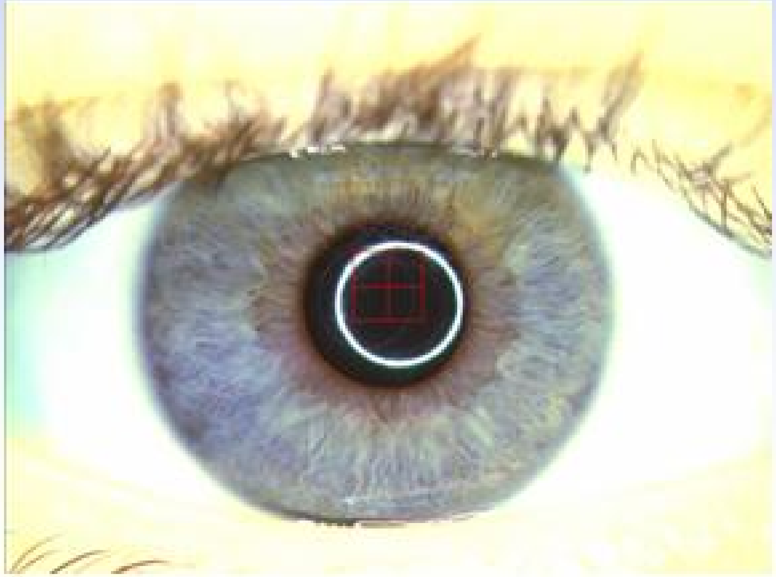
Multispectral Processing

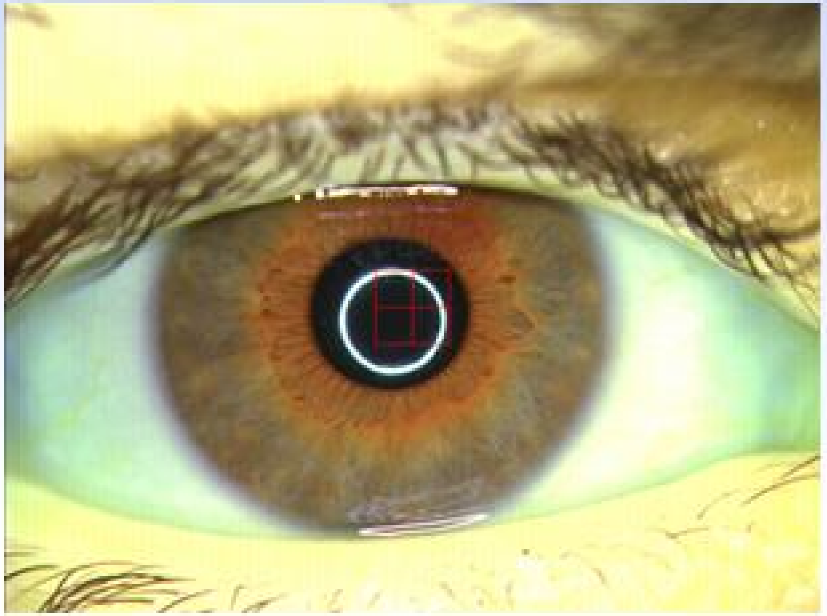
- Acquiring co-registered iris images at multiple wavelength bands: R, G, B, IR
- Data acquisition from subjects having different eye colors
- Iris segmentation:
  - Based on individual spectral channels
  - Based on multiple spectral channels
- Image enhancement technique
- Interoperability between IR and R/G/B images
- Multispectral iris fusion

Factors affecting eye color

- Melanin content that is genetically determined
- Cellular density of the stroma
- Darkly pigmented epithelial layer

Light blue	0 dominant alleles
Blue	1 dominant allele
Blue-green	2 dominant alleles
Hazel	3 dominant alleles
Light brown	4 dominant alleles
Brown	5 dominant alleles
Dark brown / black	6 dominant alleles

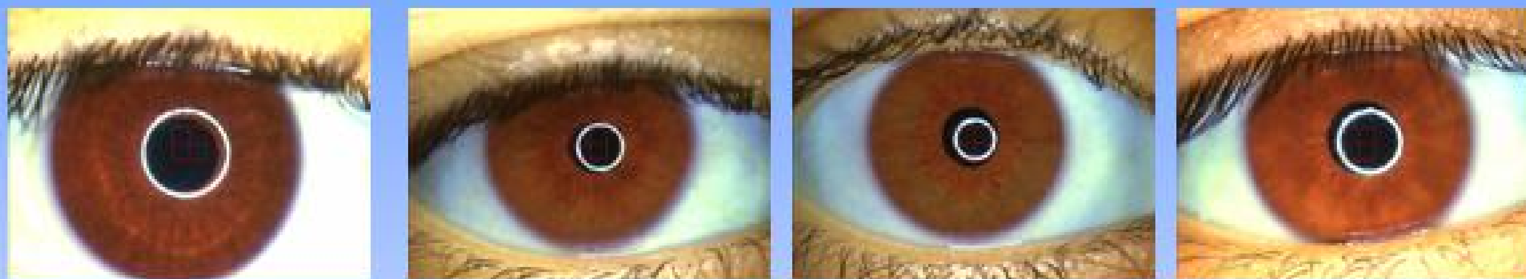




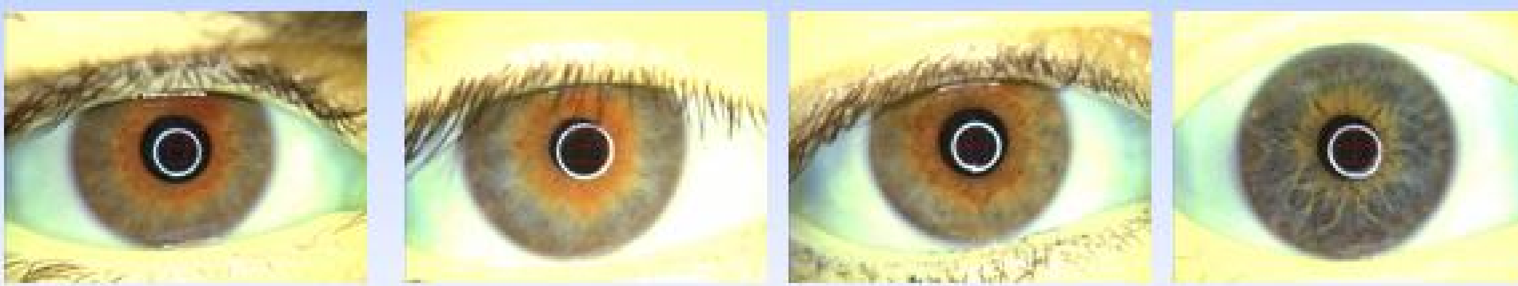
Variations in Eye Color

Image dimension: 1300 x 1040

Brown Dark~Light



Light/Brown Green



Blue

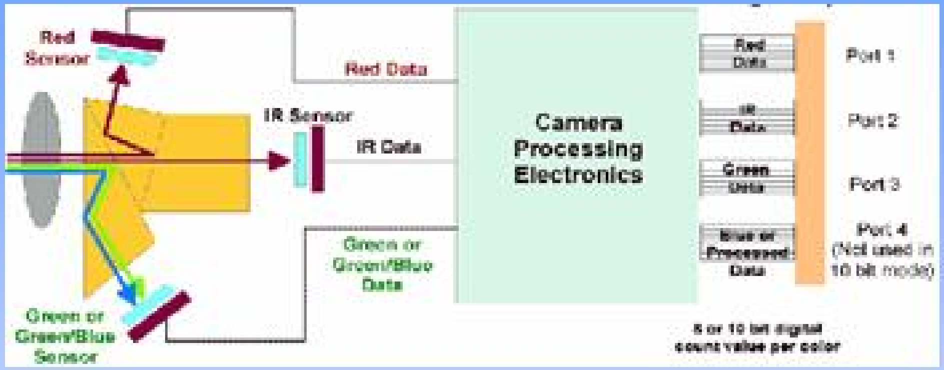
Multispectral acquisition devices

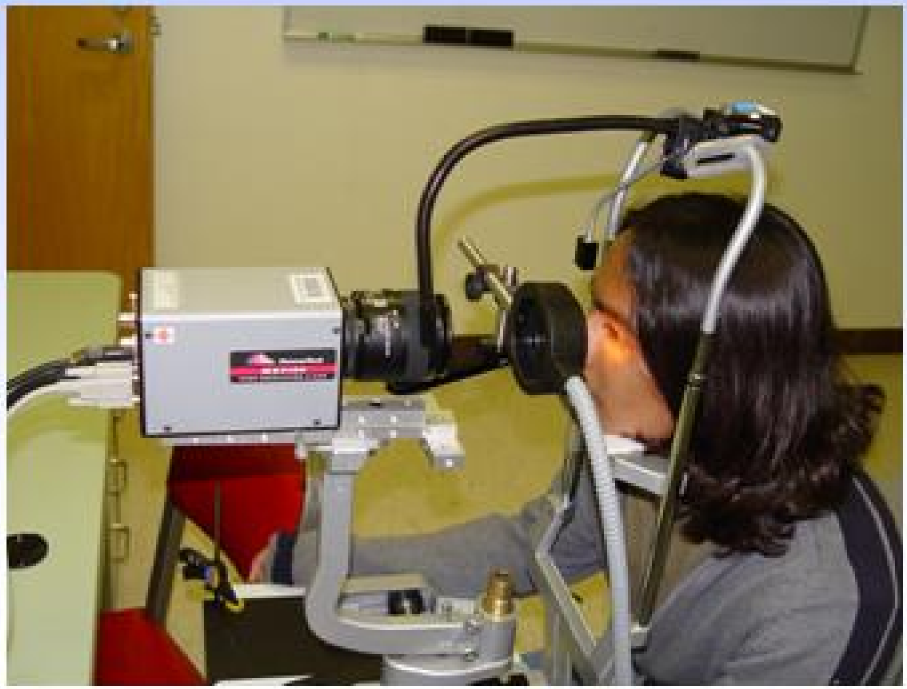
- Multispectral Camera
  - MS3100
    - 3 CCDs
      - NIR/Red/RGB

- Near-IR Camera
  - Hitachi KPF-120
    - 1 CCD
    - NIR

Camera Arrangement

- Camera Setup
  - Slit lamp Mount
  - F-mount Macro Lens





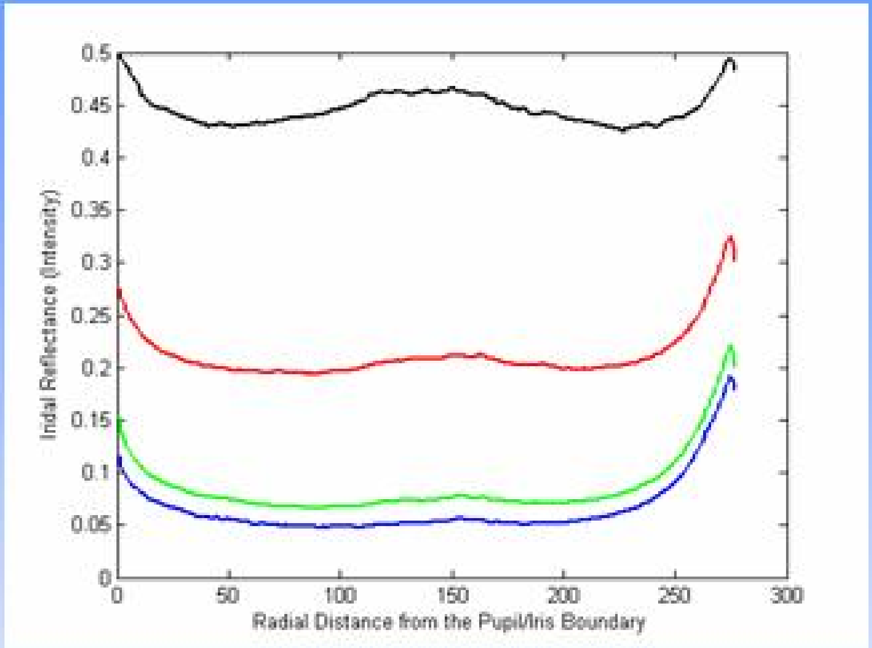
Broadband Light Source

- Light Source
  - Fiber Optic Ring Light
  - Tungsten Krypton Bulb

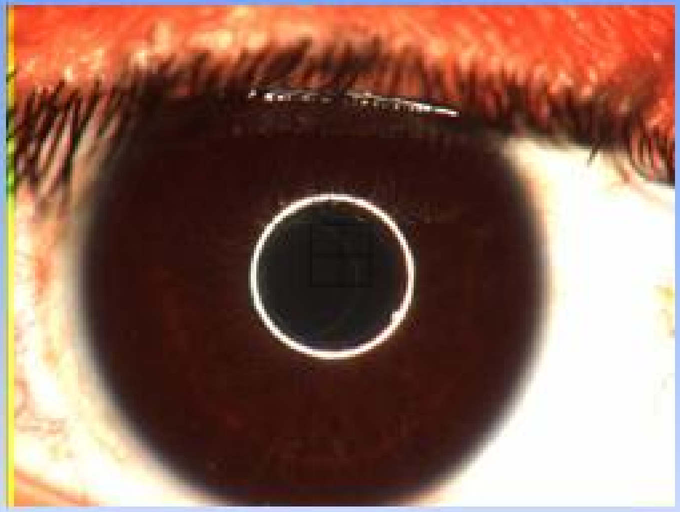
Preliminary Dataset

User 1	Brown (Dark)
User 2	Brown (Dark)
User 3	Brown (Dark)
User 4	Brown (Light)/Green(Hazel)
User 5	Brown (Dark)/Brown(Yellow)
User 6	Brown (Light)/Brown(Gray)
User 7	Brown (Dark)
User 8	Brown (Light)/Brown(Yellow)
User 9	Gray(Blue)/Blue
User 10	Gray(Blue)/Blue
User 11	Brown (Yellow)/Gray(Blue)
User 12	Brown (Light)/Green(Hazel)
User 13	Gray
User 14	Brown (Dark)/Brown(Light)
User 15	Brown (Light)
User 16	Brown (Dark)
User 17	Blue(Gray)
User 18	Brown(Dark)/Brown(Light)
User 19	Brown(Dark)/Brown(Light)
User 20	Brown/Gray(Yellow)
User 21	Brown
User 22	Brown(Light)/Blue(Yellow)
User 23	Brown
User 24	Brown (Dark)

Dark Brown



RGB



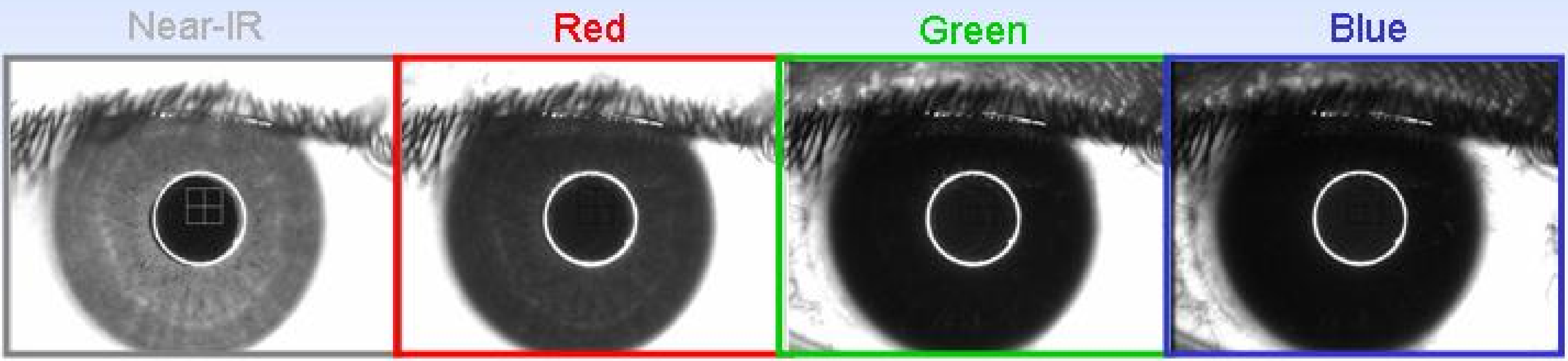
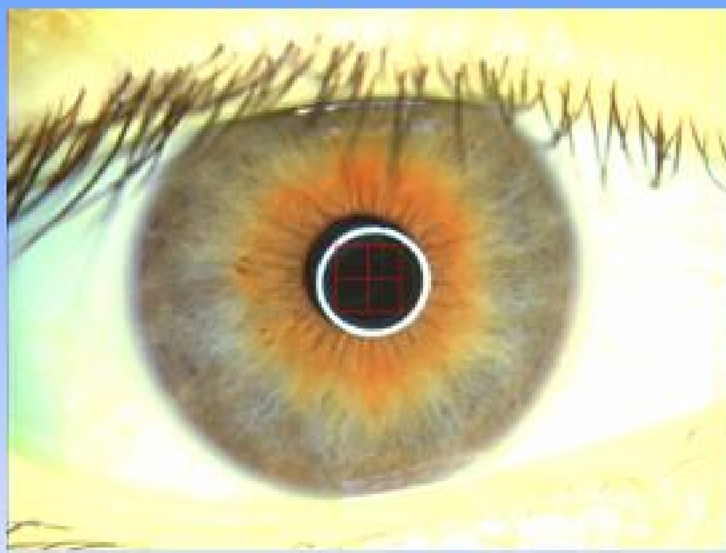


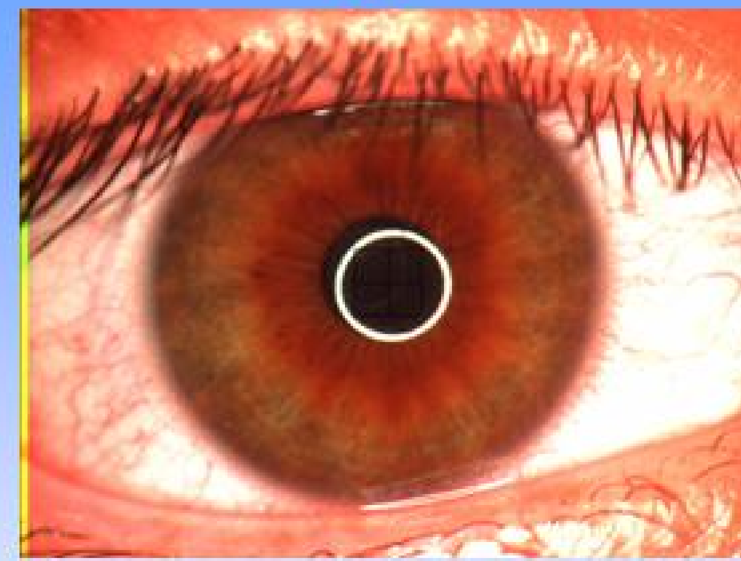
Image dimension: 1300 x 1040

Light Brown

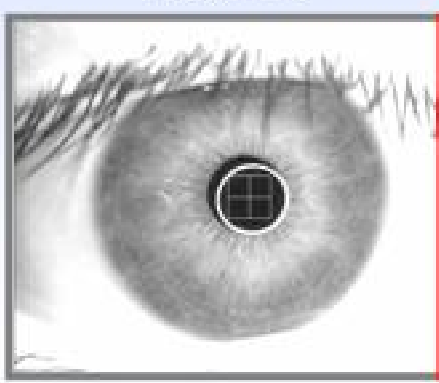
False Color~CIR



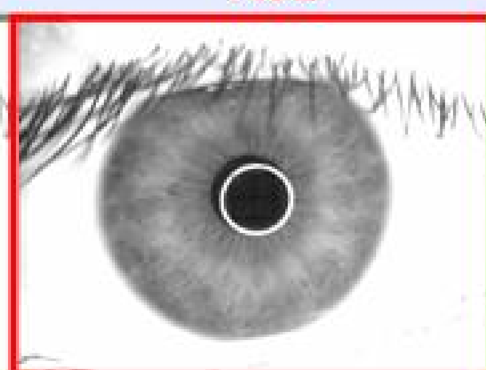
RGB



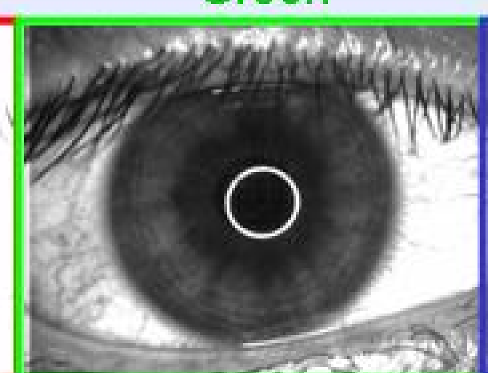
Near-IR



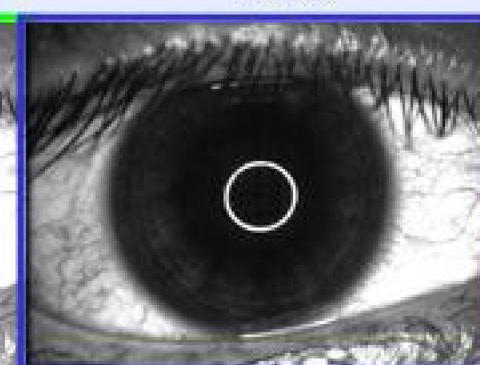
Red



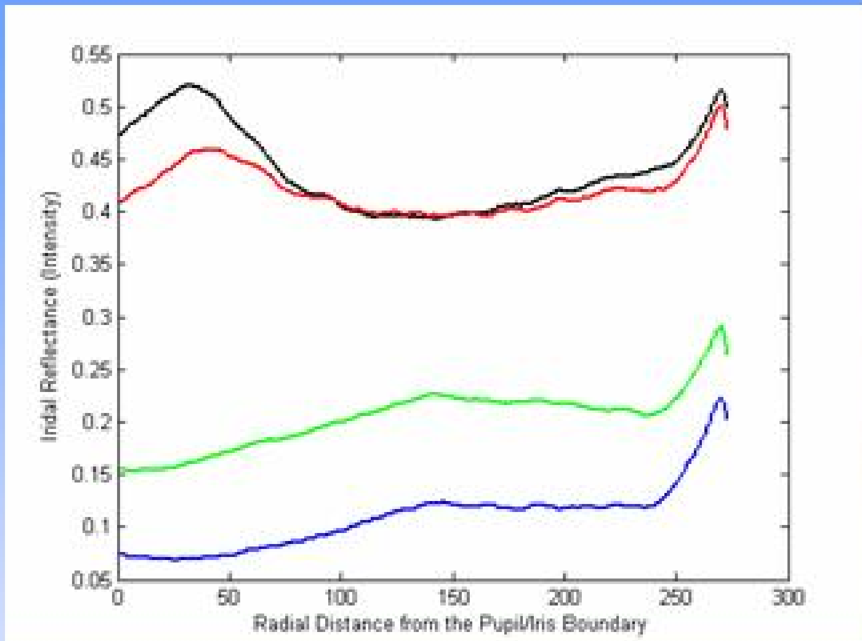
Green



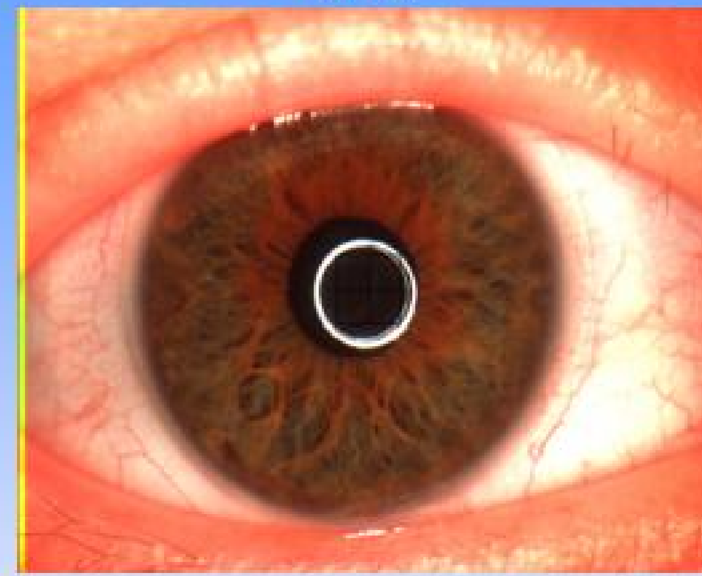
Blue



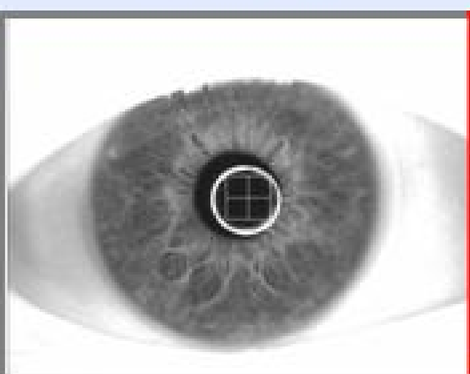
Green



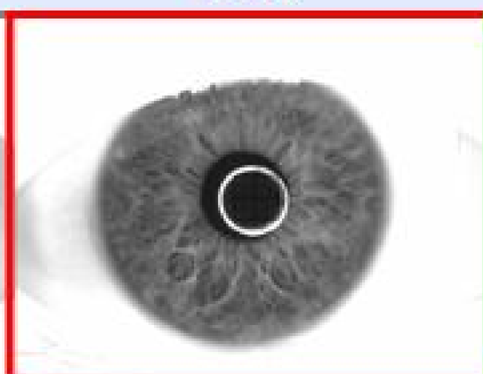
RGB



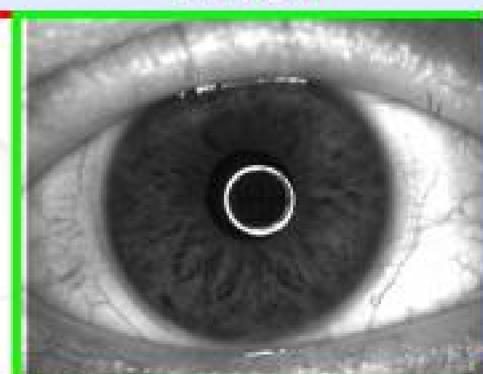
Near-IR



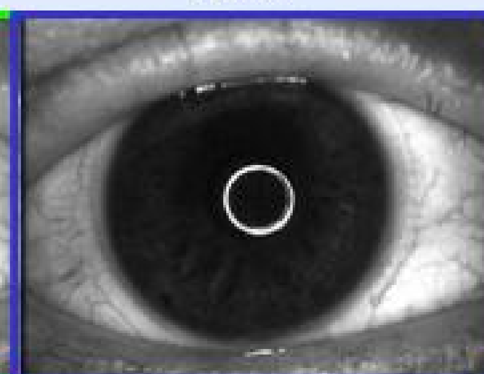
Red



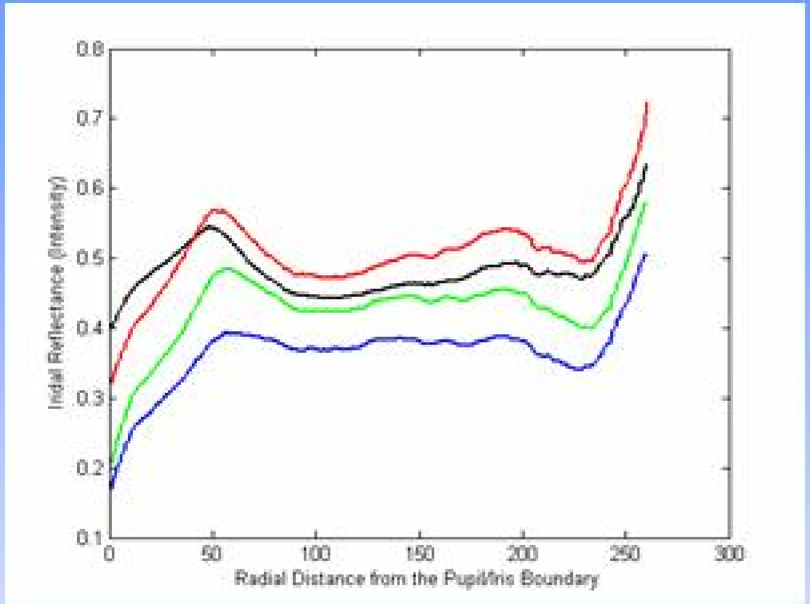
Green



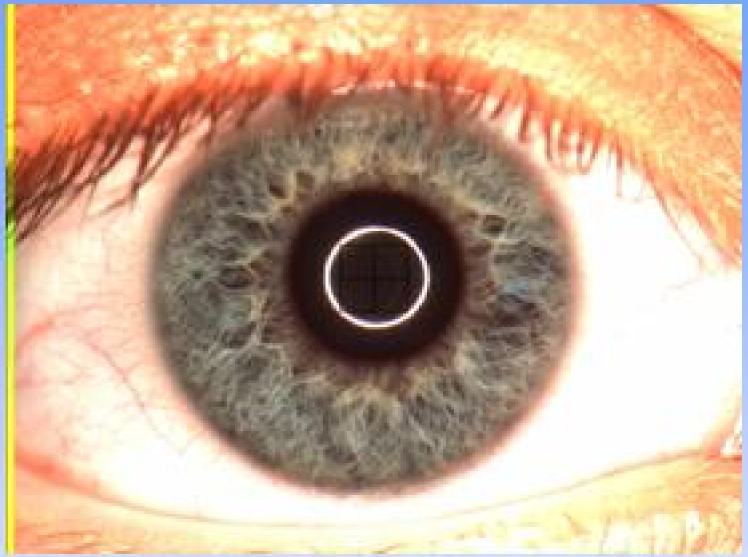
Blue

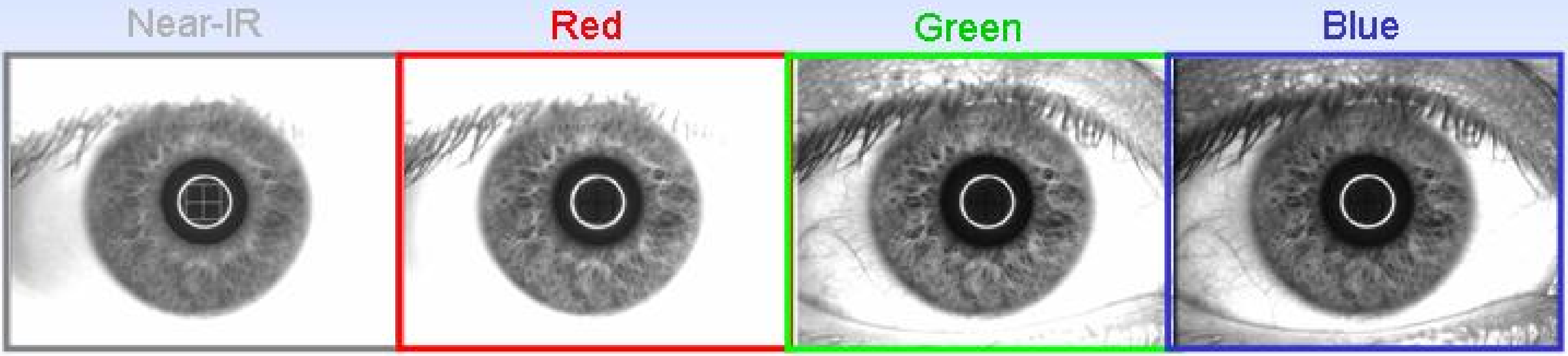


Blue

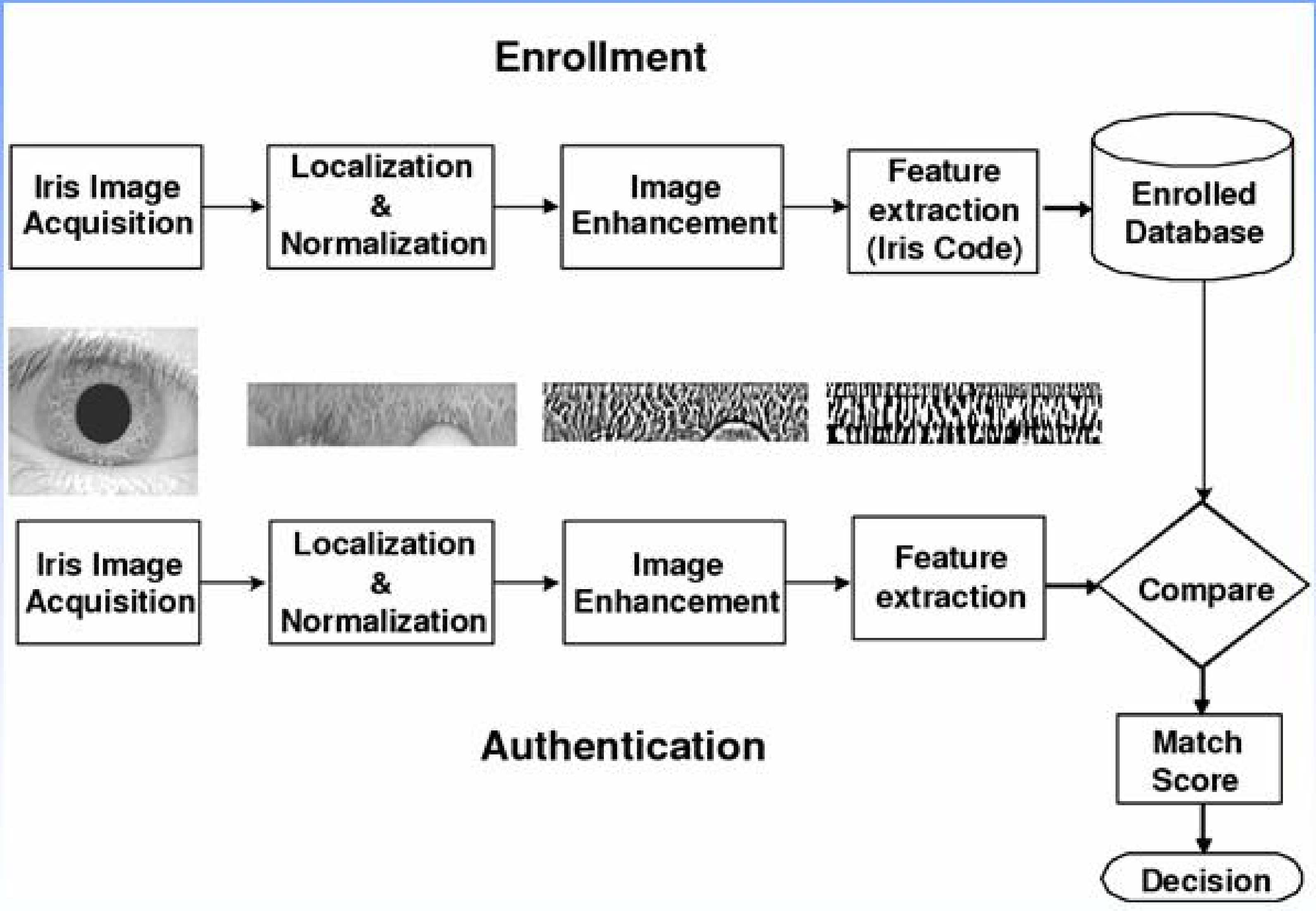

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
250
300
Iridal Reflectance (Intensity)
Radial Distance from the Pupil/Iris Boundary

RGB

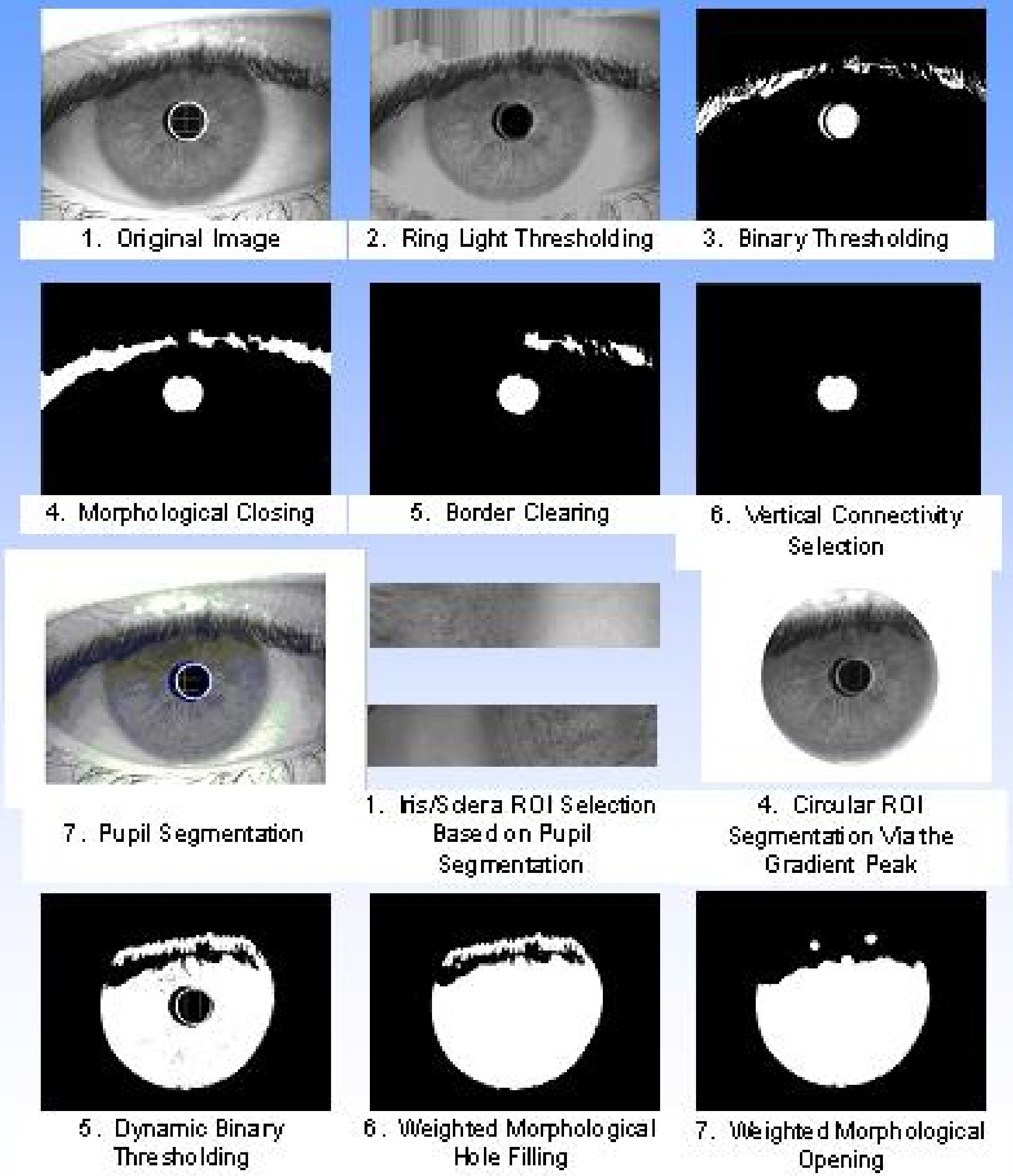



Near-IR
Red
Green
Blue

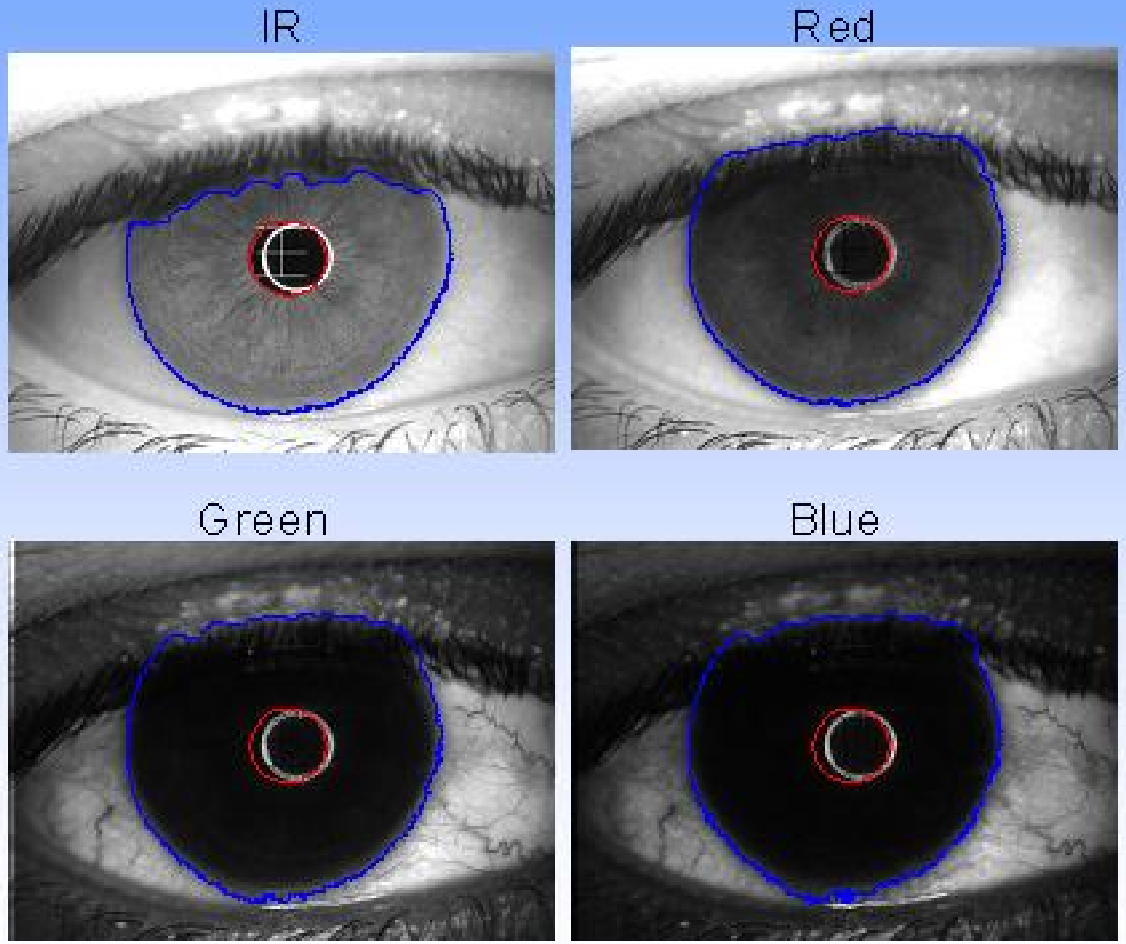
Iris processing steps



Iris segmentation: Salient steps

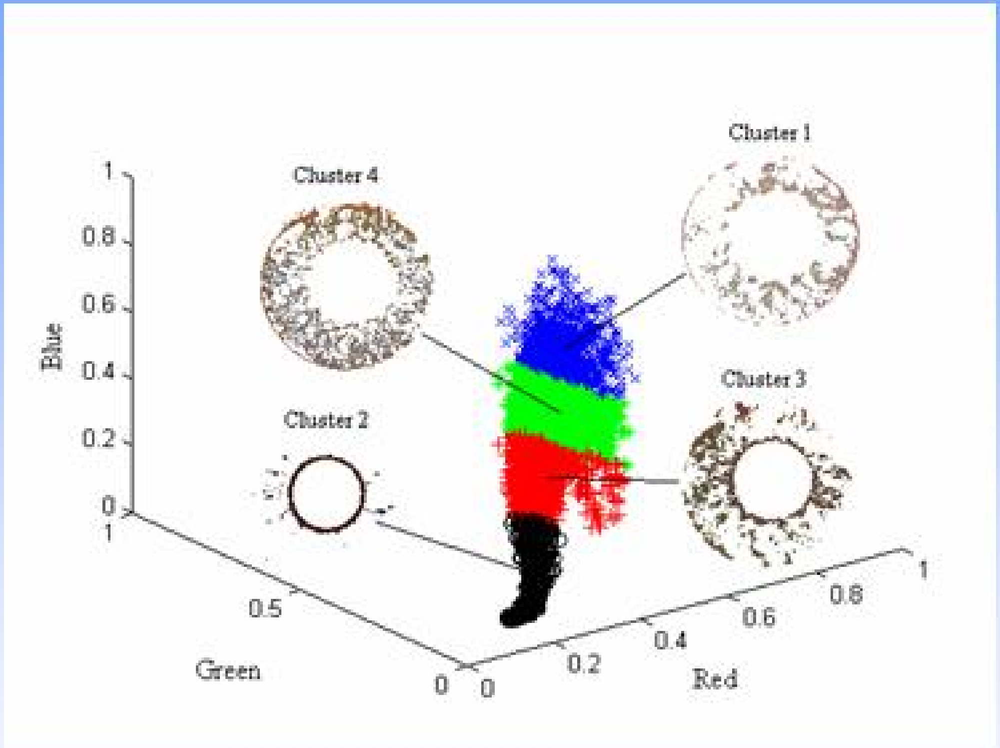


Iris segmentation: Result

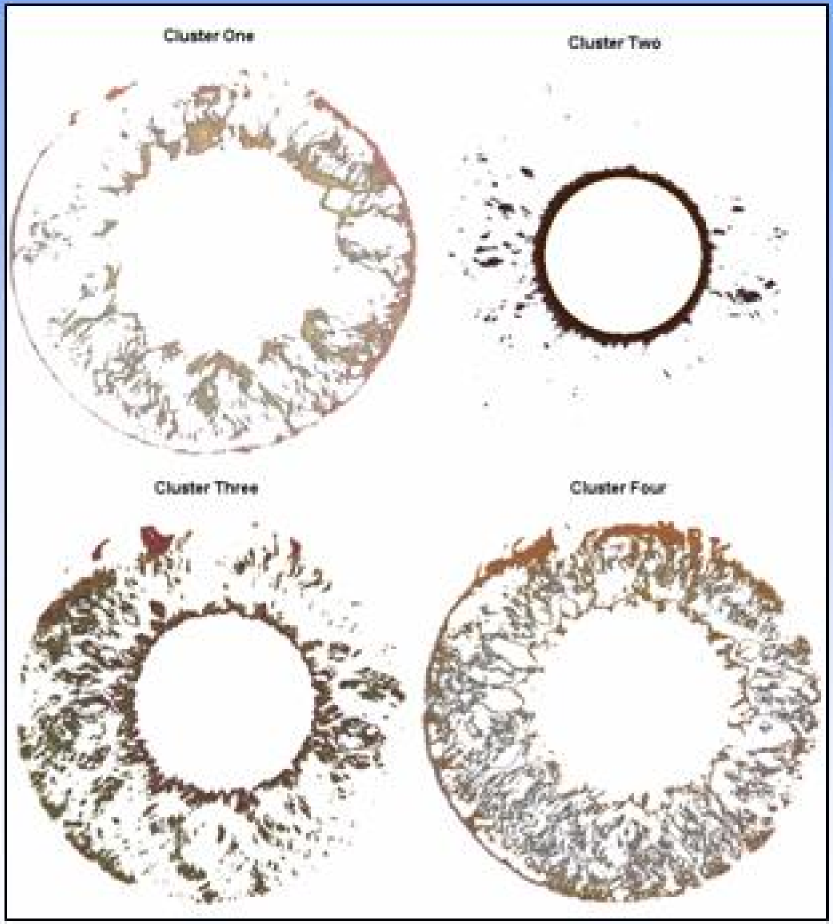


Segmentation using multispectral information

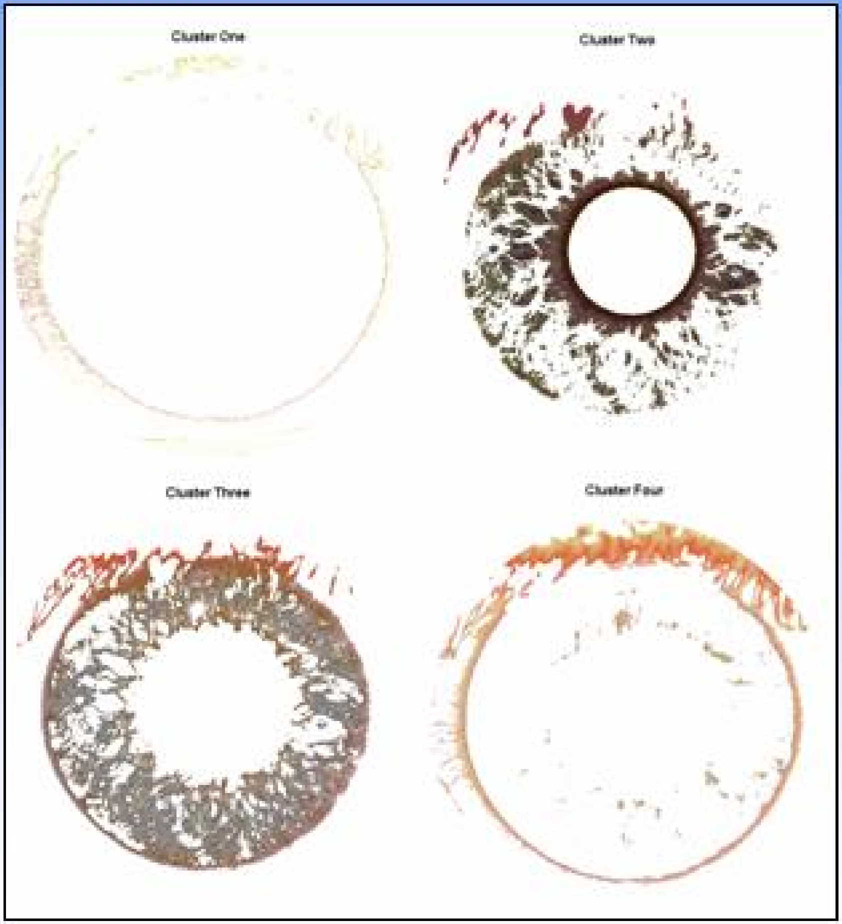
- Clustering iris pixels in color space in order to elicit the salient structures embedded on the iris surface



Clustering in RGB space

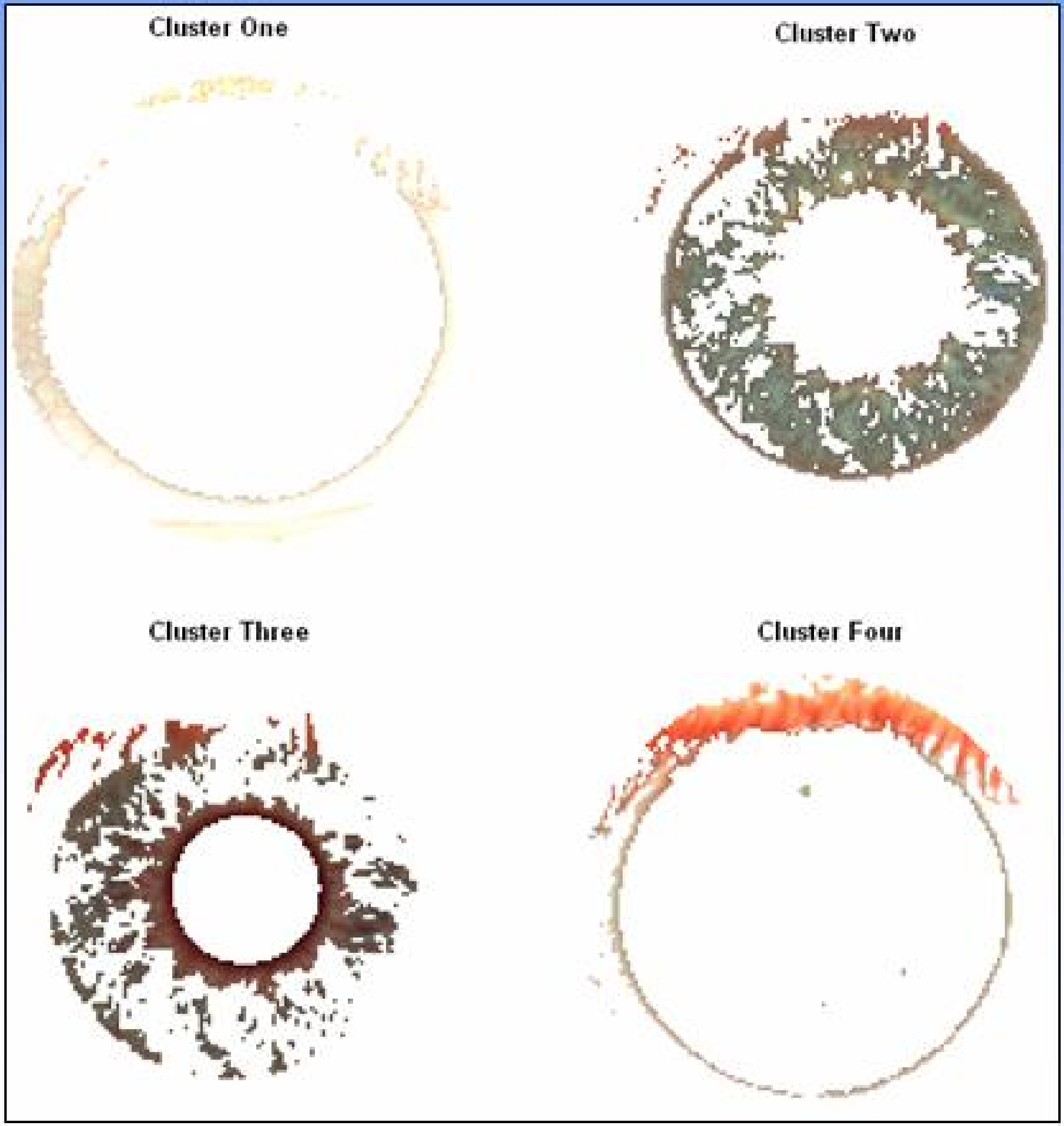


Clustering scheme on an *accurately segmented* iris



Clustering scheme on an *over-segmented* iris

Clustering in IR-R-G-B space



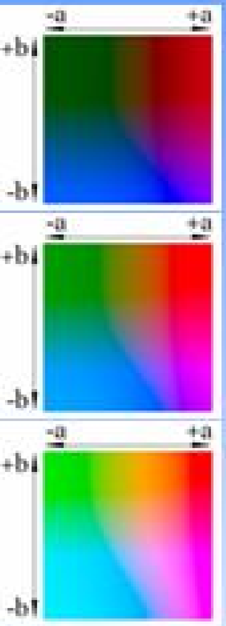
Clustering scheme on an *over-segmented* iris

Clustering in L*a*b* space

Clustering scheme on an *over-segmented* iris

Segmented iris

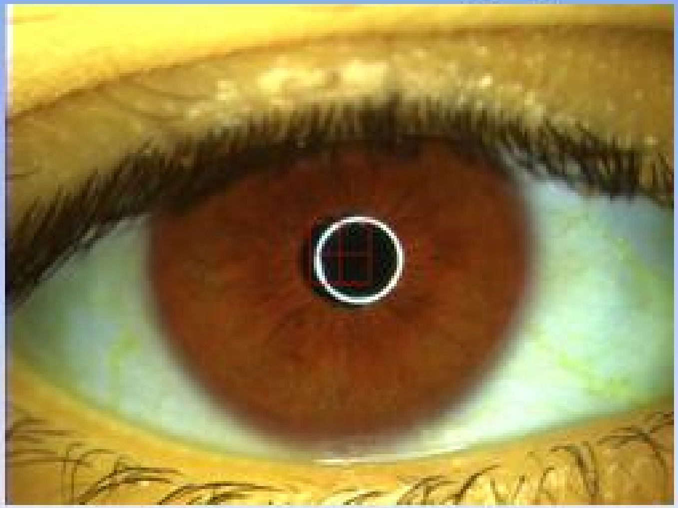
The L*a*b* color space



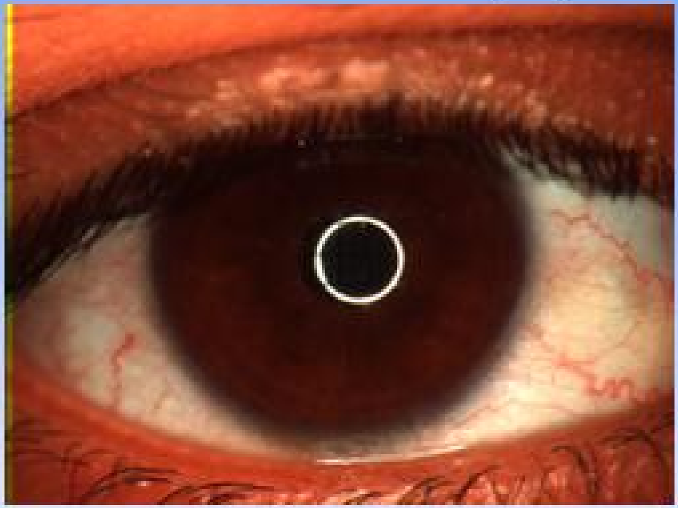
- Transform RGB information into CIE's L*a*b* space
- Perform adaptive histogram equalization in the transformed space
- This enhances the "structures" within the iris

L*a*b* Adaptive Histogram Equalized
Brown Eye

False Color ~ IR,R,G



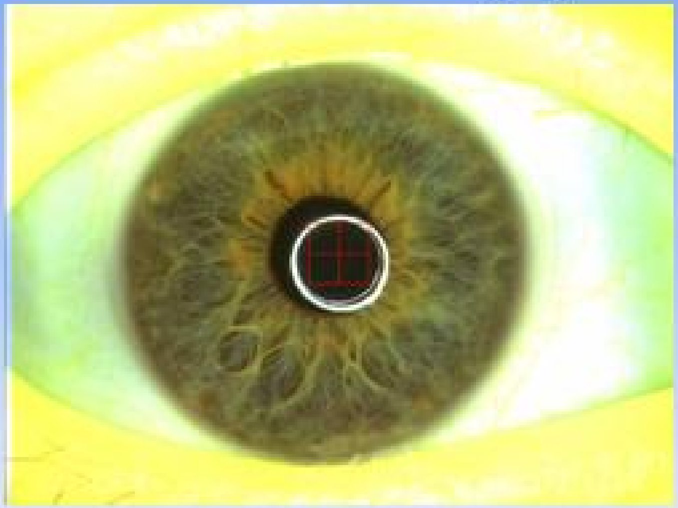
Actual Color ~ R,G,B

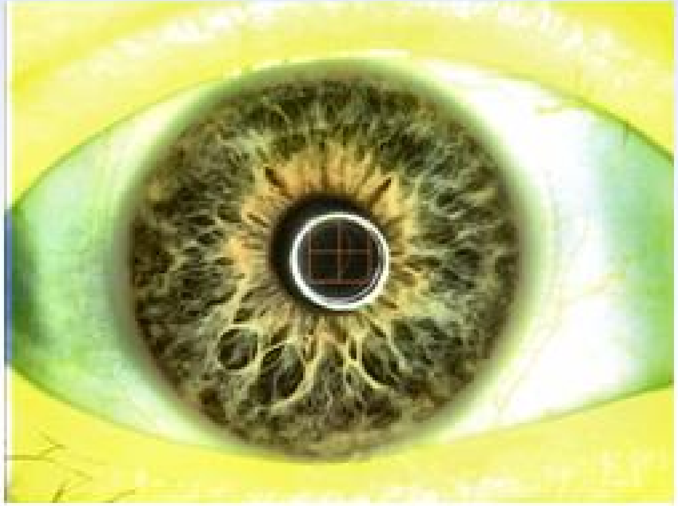


L*a*b* Adaptive Histogram Equalized
Green Eye

False Color ~ IR,R,G

Actual Color ~ R,G,B

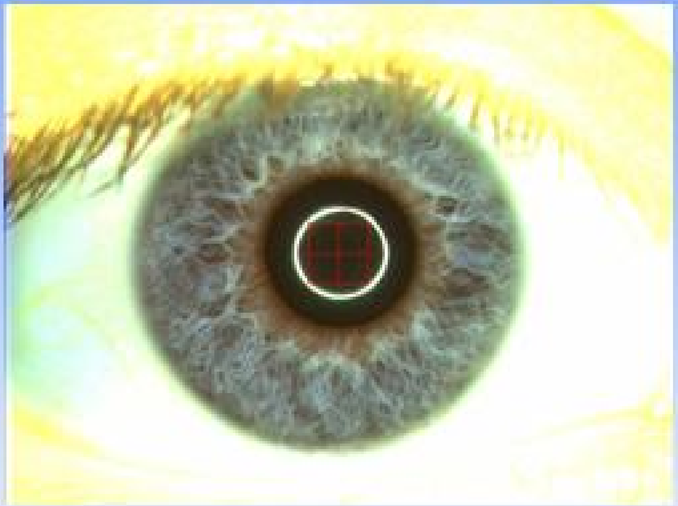


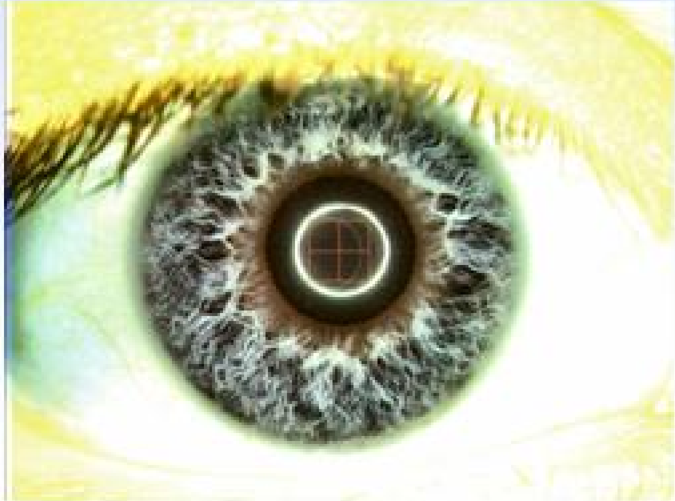


L*a*b* Adaptive Histogram Equalized

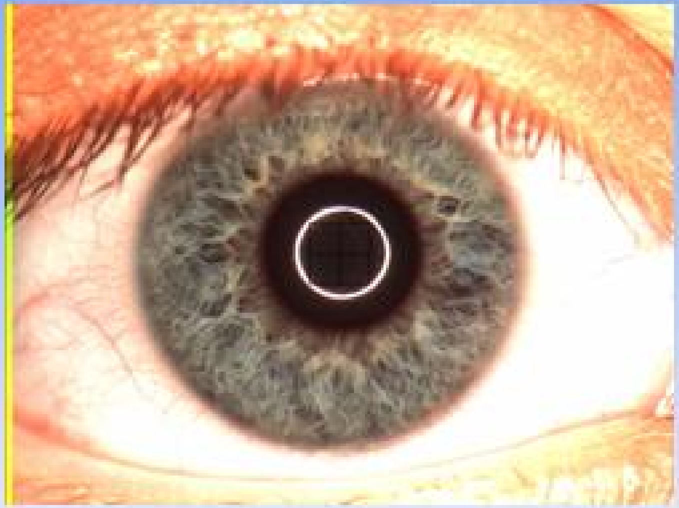
Blue Eye

False Color ~ IR,R,G

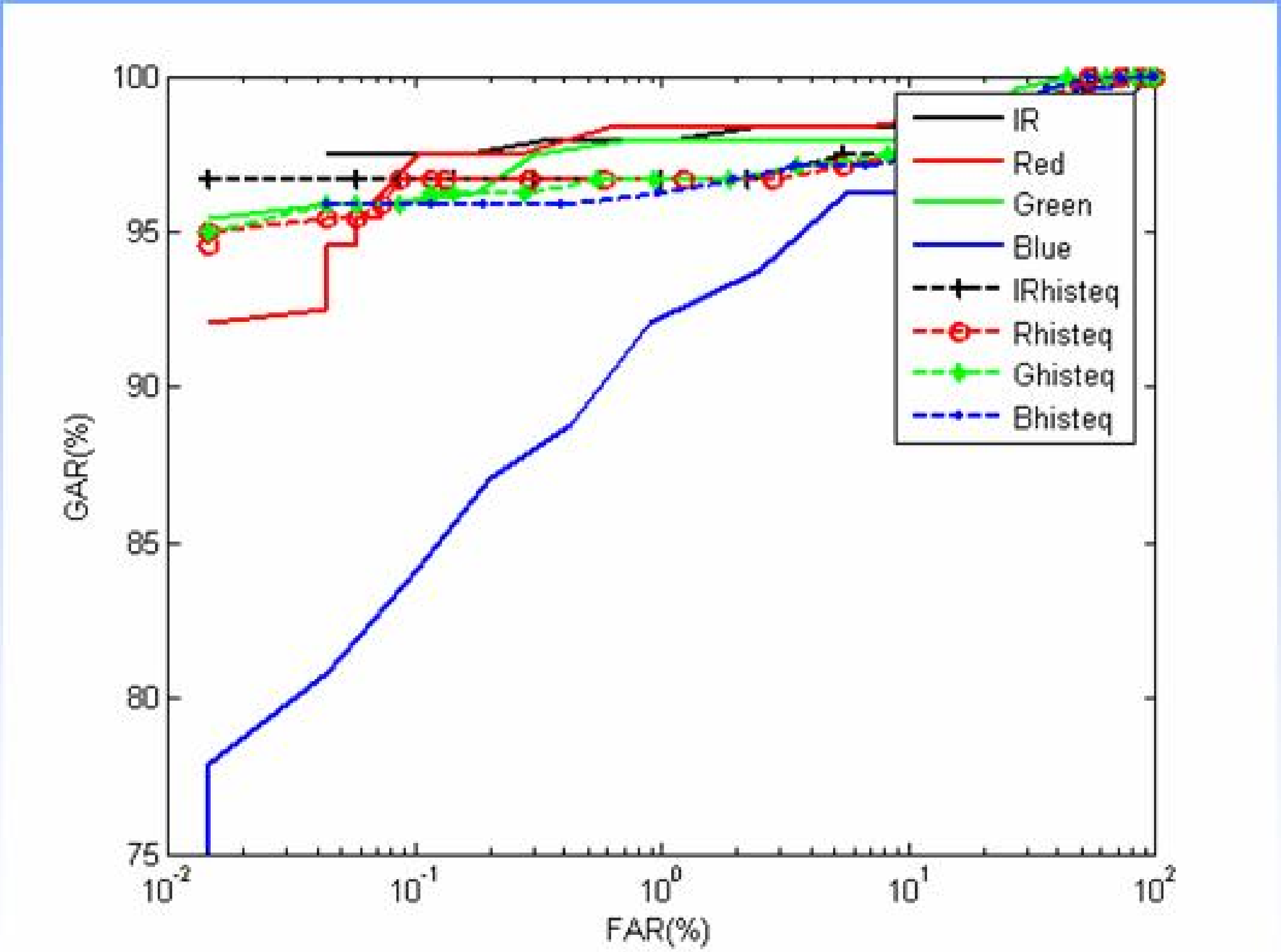




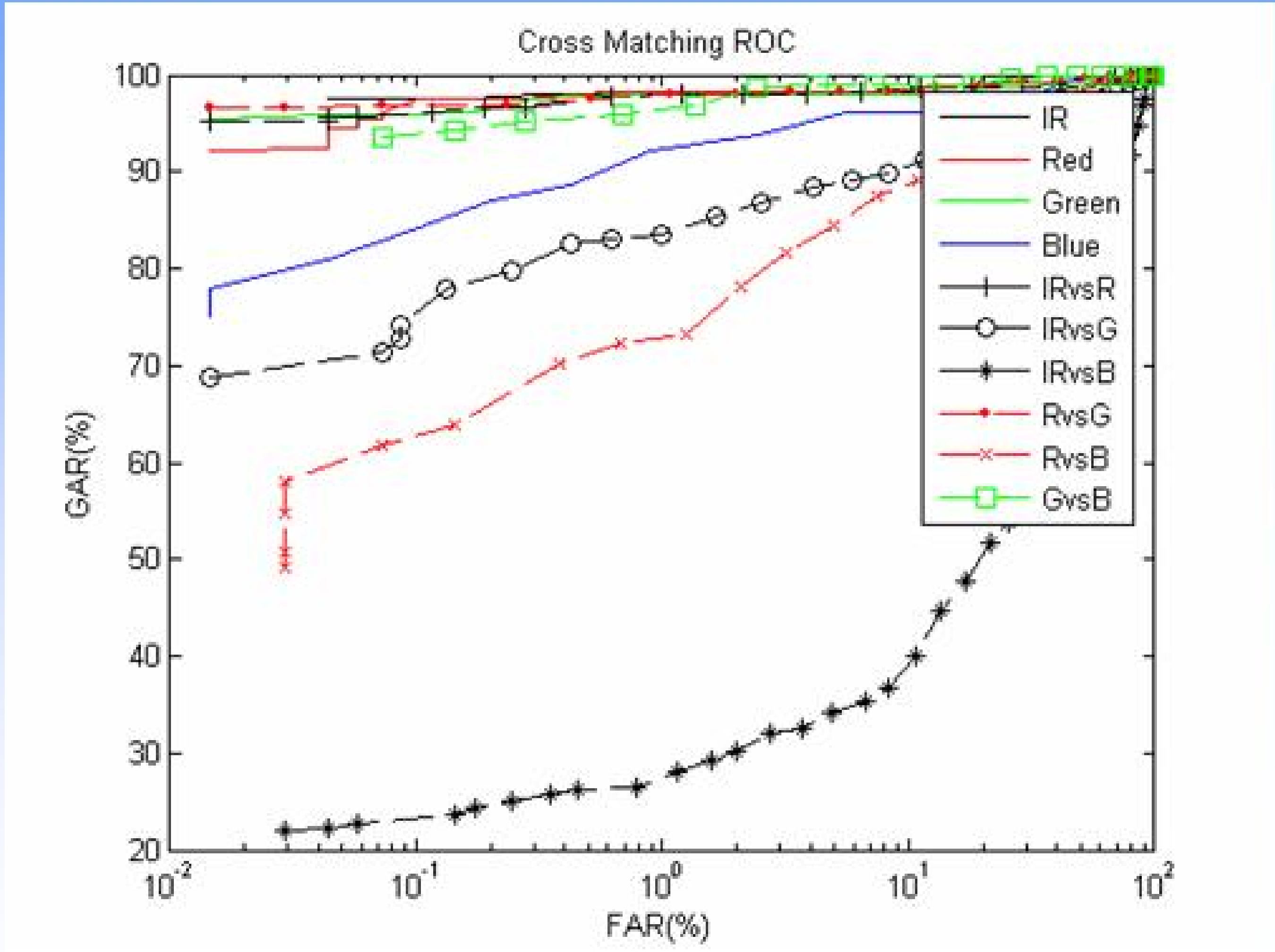
Actual Color ~ R,G,B

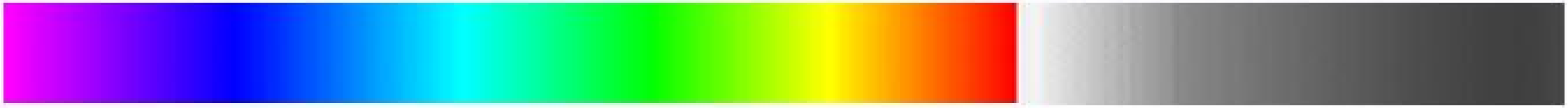


Performance after L*a*b* Adaptive Histogram Equalization

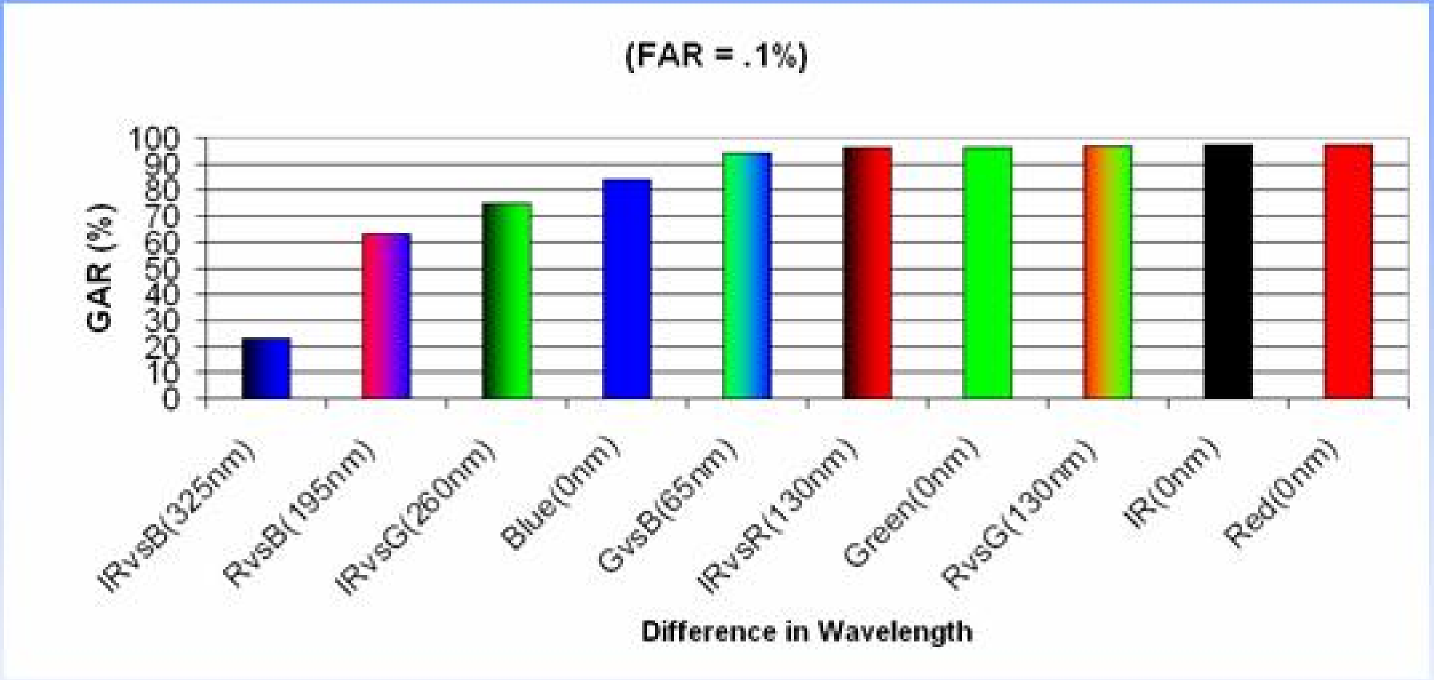


Interoperability between channels

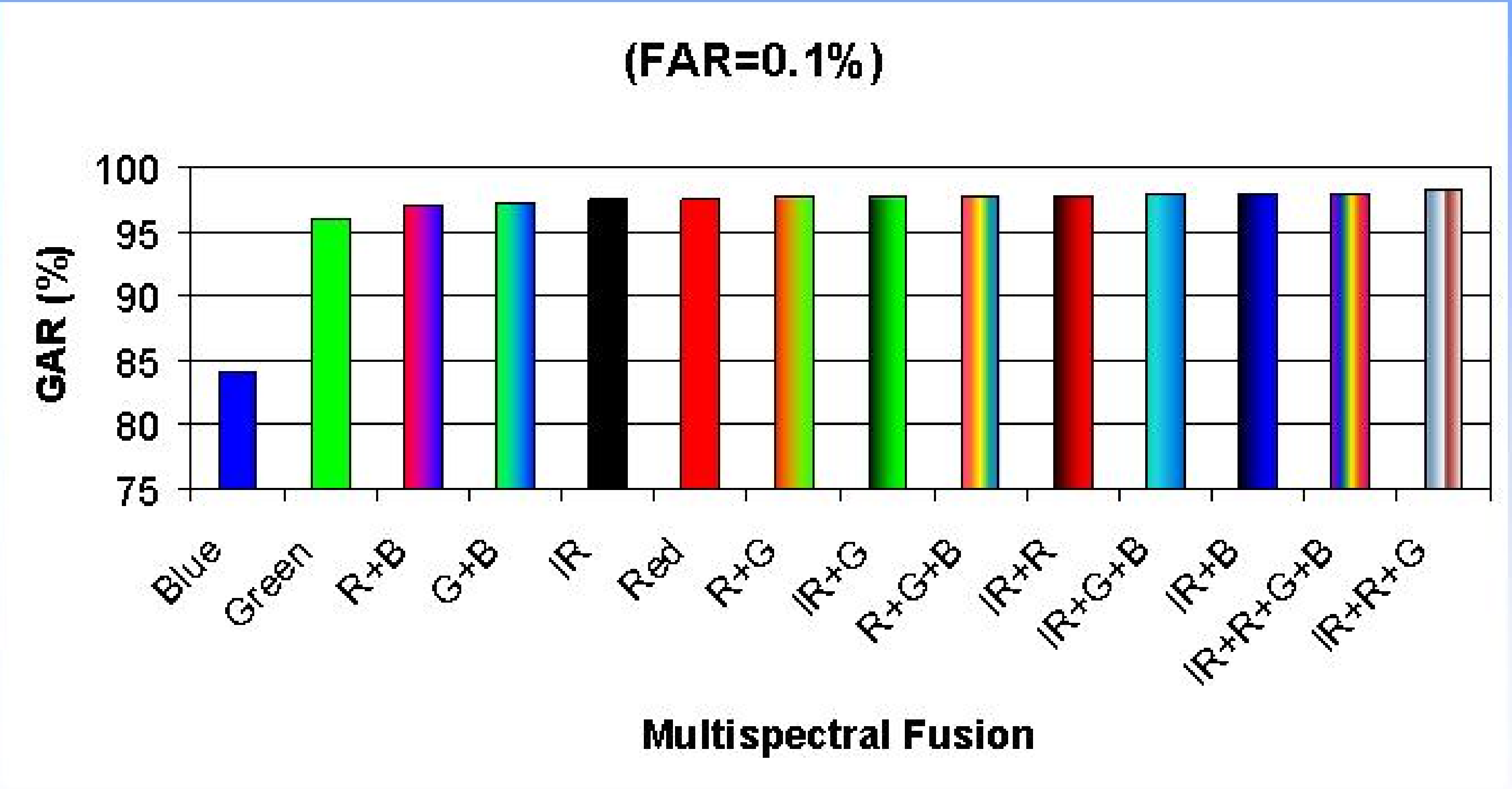




Interoperability at FAR=0.1%



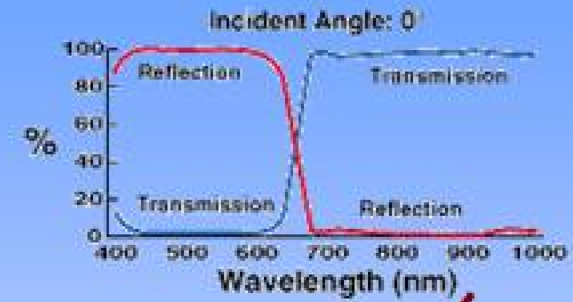
Sum Rule Fusion at FAR=0.1%



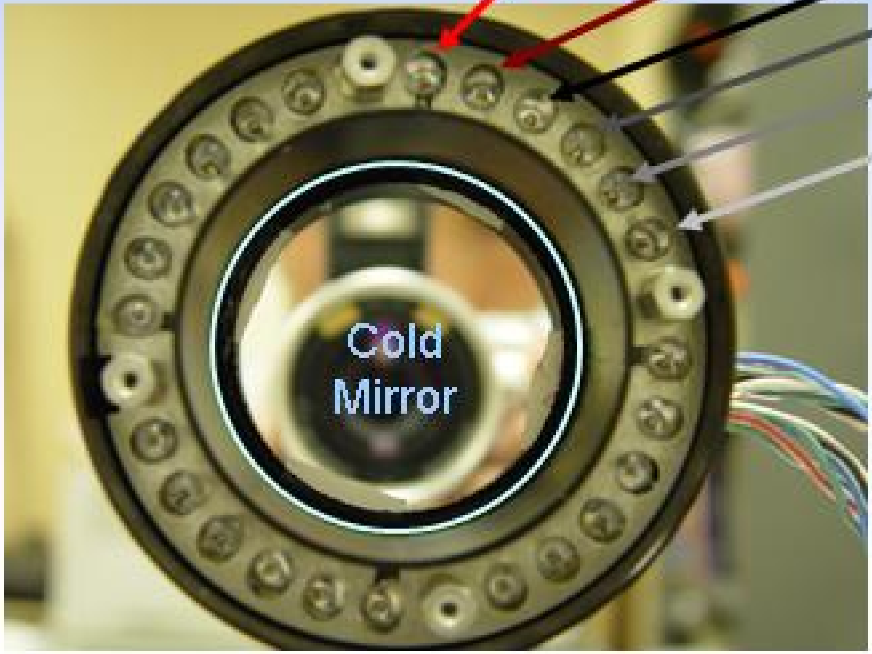
Comments

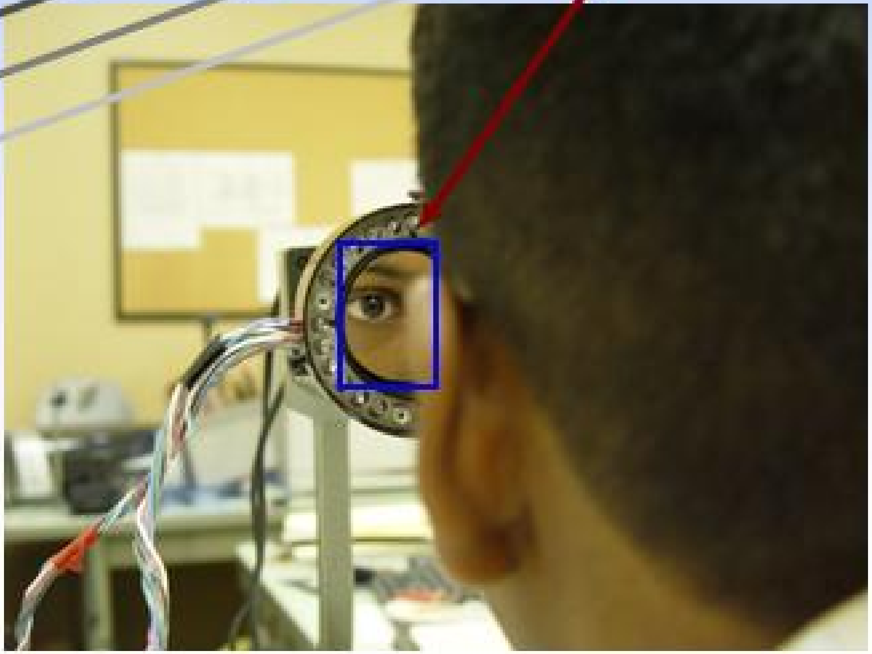
- Method to acquire co-registered iris images at multiple wavelength bands: R, G, B, IR
- Data acquisition from subjects having different eye colors
- Iris segmentation:
  - Based on individual spectral channels
  - Based on multiple spectral channels
- Image enhancement technique
- Interoperability between IR and R/G/B images
- Multispectral iris fusion

Near-IR Arrangement

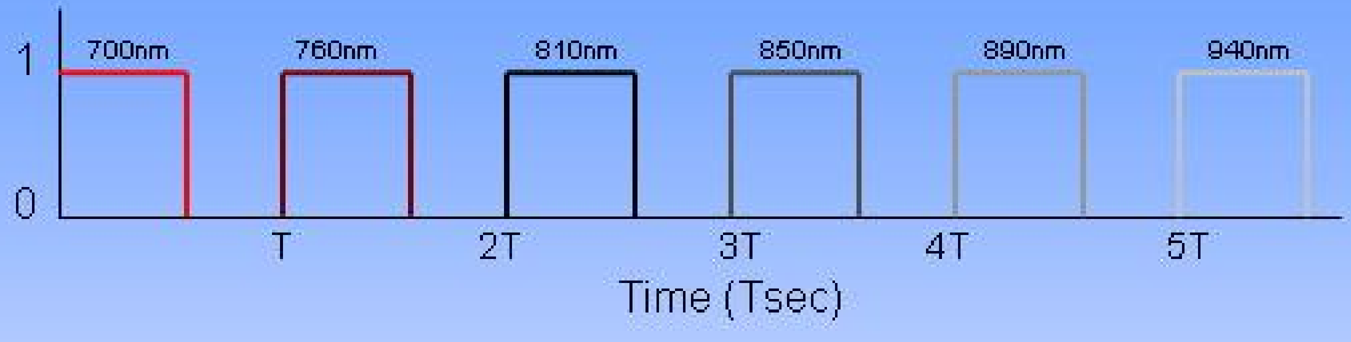


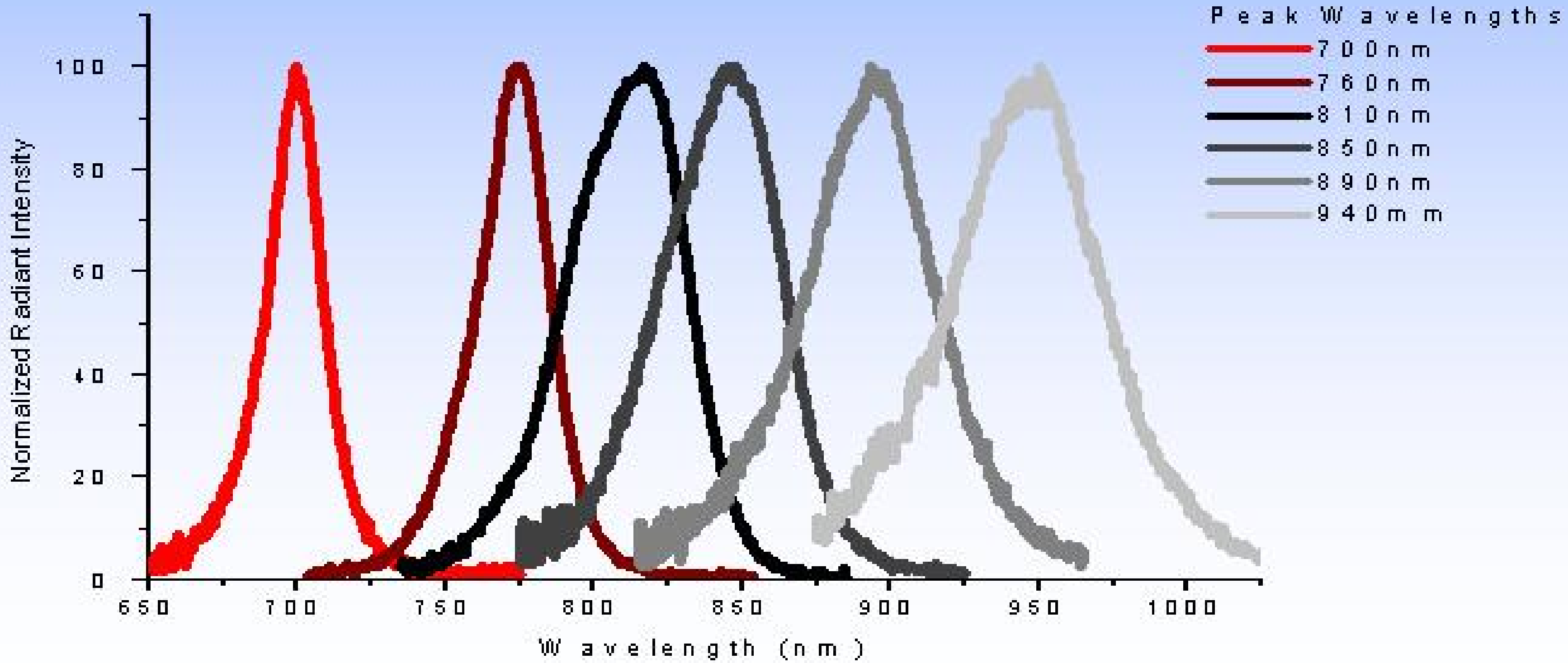
- Cold Mirror Filter
  - Removes Ambient Corneal Reflections
    - Reflects Visible light
    - Transmits IR
- LED Ring Light
  - Sequential~ 700nm, 760nm, 810nm, 850nm, 890nm, 940nm





Near-IR Illumination Spectra

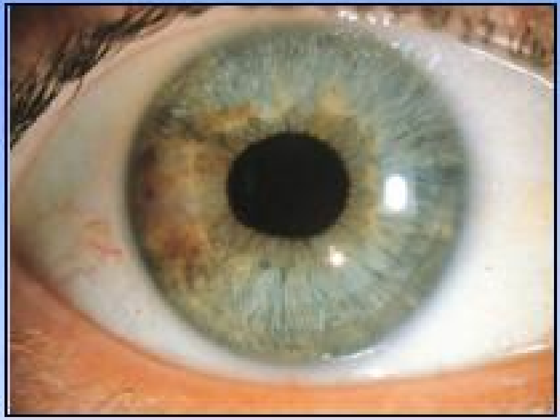


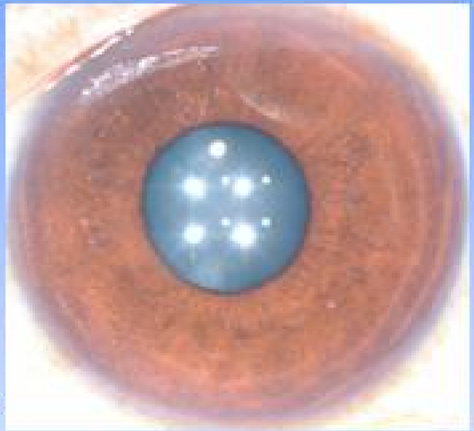


* Spectrum taken with Agilent 86142B Optical Spectrum Analyzer

Eliciting pigmentation information, moles and freckles

- Distinct components of the iris contributing to the 'identity' of the iris
- Moles, freckels, pigmentation levels





http://www.tedmontgomery.com/the_eye/eyephotos/pics/IrisNevus.jpg
http://www.milesresearch.com/images/ExampleIrisPicJGL.jpg

http://www.milesresearch.com/camera/IrisExampleDV2E.jpg

Future Work

- Designing new segmentation routine:
  - combine segmentation results of individual channels
- Exploring alternate color spaces for representing and matching color irises
  - image enhancement
  - high-resolution texture matching
- Studying complementary information available across multiple channels
  - moles, freckles, pigmentation level, etc.
- Facilitating interoperability across multiple channels
- Off-angle iris recognition; iris recognition at a distance