Design of an Iris Imaging Platform

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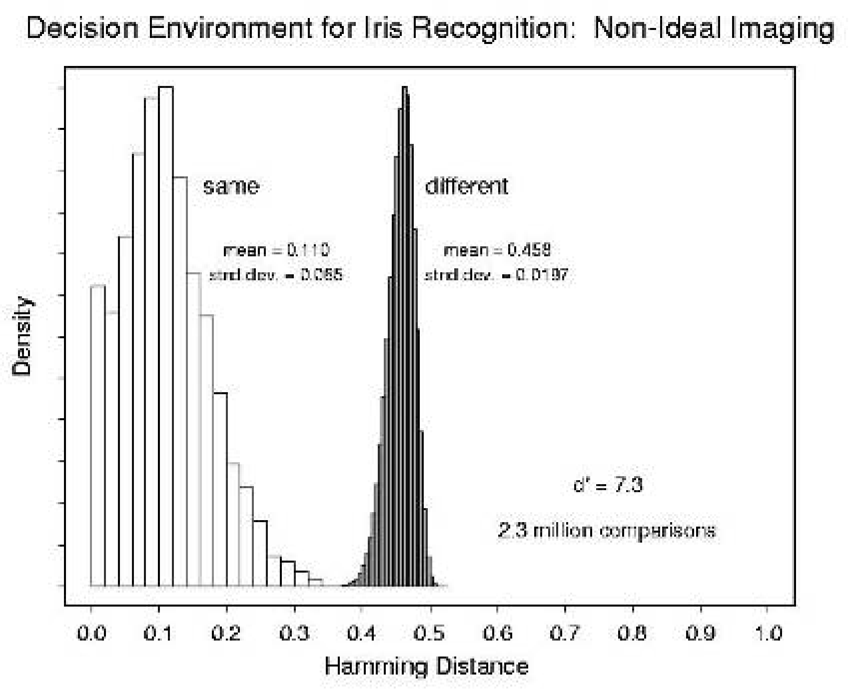
Objectives

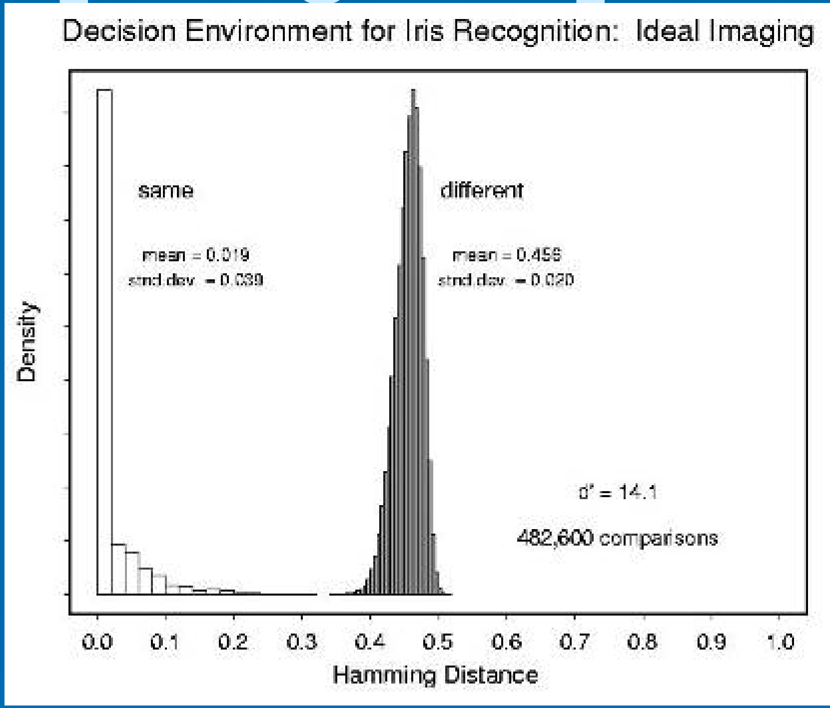
- Show how the imaging platform affects iris recognition accuracy
- Discuss components of the imaging platform
- Present design of NIST platform
- Show images captured by NIST platform.

Differing Error Rate Results

- False Non-match Rate
  - [Daugman] no false non-matches in 7070 comparisons
  - [IBG] one false non-match per 94.339 comparisons
- False Match rate
  - [Daugman] no errors in 9.21 million comparisons
  - [IBG] one false match per 28,902 transactions
- IBG results are at the transaction level, same device, averaged over three devices

Effects of imaging Platform on Distributions [Daugman]





Poor Imaging

Good Imaging

“Genuines” distribution (on left) varies greatly with image quality; affects FNMR

“Imposters” distribution (on right) is largely independent of image quality; affects (FMR)

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Plan

- Image platform affects iris accuracy
- No quantified data that identifies effects of different imaging defects
- NIST imaging platform will produce baseline
  - images of sufficient quality to achieve full accuracy potential of algorithms
  - Imaging defects can be introduced, one at a time to quantify the effects of each
    - Separately
    - In combination

Components of an Iris Imaging Platform

- Digital Image Sensor
- Lens
- Illuminator
- Camera
- Subject interface

Digital Image Sensor

Digital Image Sensor

- Converts image to digital form
- CCD or CMOS
- Sensor must not have IR, Color, or anti-aliasing filters

Digital Image Sensor (cont.)

- Sensor size affects resolution
  - Analogous to advantage of large film size
- Pixel size affects dynamic range
  - Large pixels capture more light, decreasing noise.
  - Pixels smaller than the diffraction limit do not increase resolution
- Defective pixels: inevitable with solid-state sensors
  - always black
  - always white
  - “lazy pixels”, sensitivity differences
  - number and maximum cluster size must be specified
  - Modern cameras compensate for these

Digital Image Sensor (cont. 2)

- Solid state sensors: CCD or CMOS
  - CCDs have been the choice for low noise
  - CMOS sensors are approaching the performance of CCDs
- Number of pixels does not fully define resolution
  - Pixel spacing controls spatial sampling rate
    - Aliasing
    - Nyquist limit
  - Pixel-pixel crosstalk reduces resolution
    - Acts as low pass filter on image
  - Sensor may have built-in filters that make it inappropriate for NIR (Near Infrared) imaging
    - RGB
    - Anti-aliasing (low-pass)
- Sensor spectral sensitivity must extend into the NIR.

Important Digital Image Sensor Specifications

- Dynamic Range
  - = 20 log (Max Output (p-p) / Read Noise (rms))
- Fixed pattern noise (FPN)
  - = Fixed pixel-pixel offset variations
- Photo Response Non-Uniformity (PRNU)
  - = Fixed pixel-pixel gain variations
- Responsivity
  - = Output in digital numbers / light input in nJ/cm^2
- Read Noise
  - = Random rms noise of the digital output
- Noise Equivalent Exposure
  - Read Noise / Responsivity
- Saturation Equivalent Exposure (NEE)
  - = Maximum Output /Responsivity

Lens

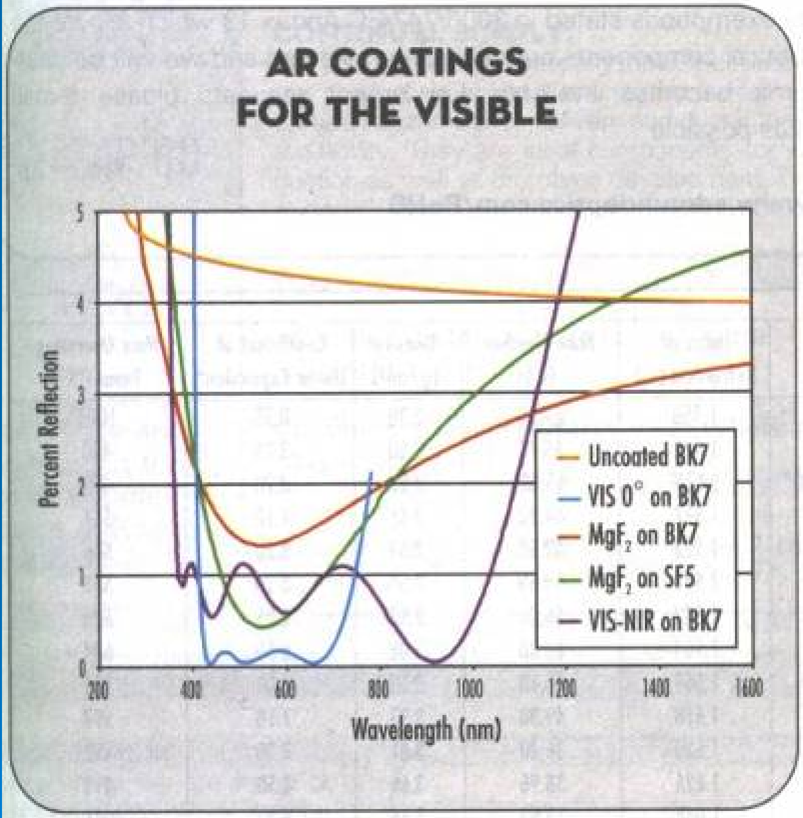
Lens

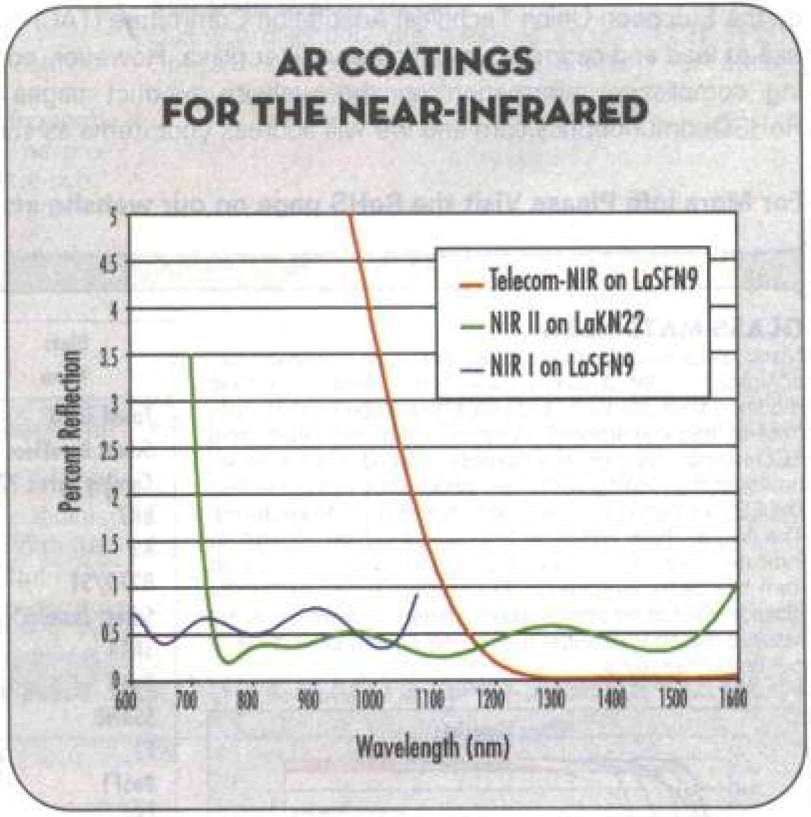
- The lens must project an accurate image of the subject onto the digital sensor.
- NIR digital imaging places special requirements on the lens
  - Design must be optimized for the NIR
  - Coatings must reduce reflections in the NIR
  - Optical design must include sensor cover glass

NIR Lens Requirements

- Lens must be optimized for low aberrations in the NIR
- Lens coatings must be designed for the NIR
  - Lens elements are coated to reduce reflections and avoid light loss of approximately 4.0 – 5.0% at each surface.
    - 10 – 20 surfaces are common
    - NIR optimized coatings will reduce loss to 0.5-1% per surface
  - Lens coatings not optimized for the NIR will cause:
    - light loss
    - internal reflections
    - ghost images
- Broad-band lenses cover both the NIR and visible range
- Lens must be designed for digital sensor use
  - Cover glass on sensor must be included in lens design
  - Small pixel sizes (3-12 microns) increase requirements for lens quality.

AR (Anti-reflective) Coatings





Courtesy of Edmund Optics

Measures of Lens Quality

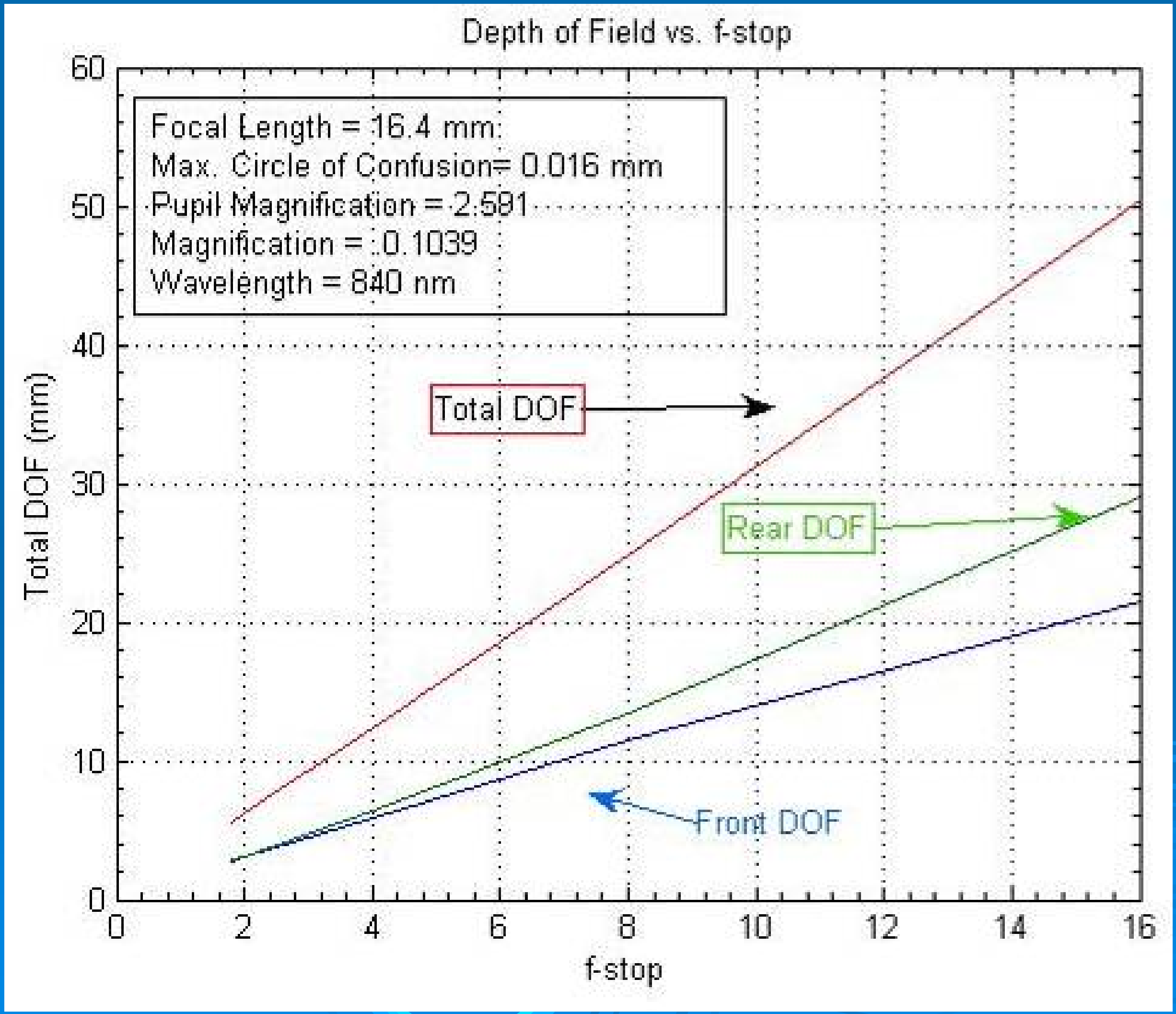
- Image Sharpness
- Distortion level
- Uniformity of light distribution

Image Sharpness

- Lack of sharpness has several causes
  - Focus error
  - Diffraction
  - Lens aberrations
  - Sensor spatial sampling rate
  - Sensor pixel crosstalk
  - Subject motion
- Overall Image sharpness can expressed as **MTF** (Modulation Transfer Function)

Depth of Field Curves

Depth of field is the distance range over which an image is deemed in-focus



DOF Formula
DOF = range over which object is in focus

- DOF =

  $c * N * (1+M/p) / (M^2 * (1 \pm (N * c) / (f * M)))$

  Use + for front DOF, - for rear DOF
- Where:

  c = diameter of largest acceptable circle of confusion

  N = f-number

  M = magnification

  p = pupil magnification

  f = focal length of lens

Diffraction

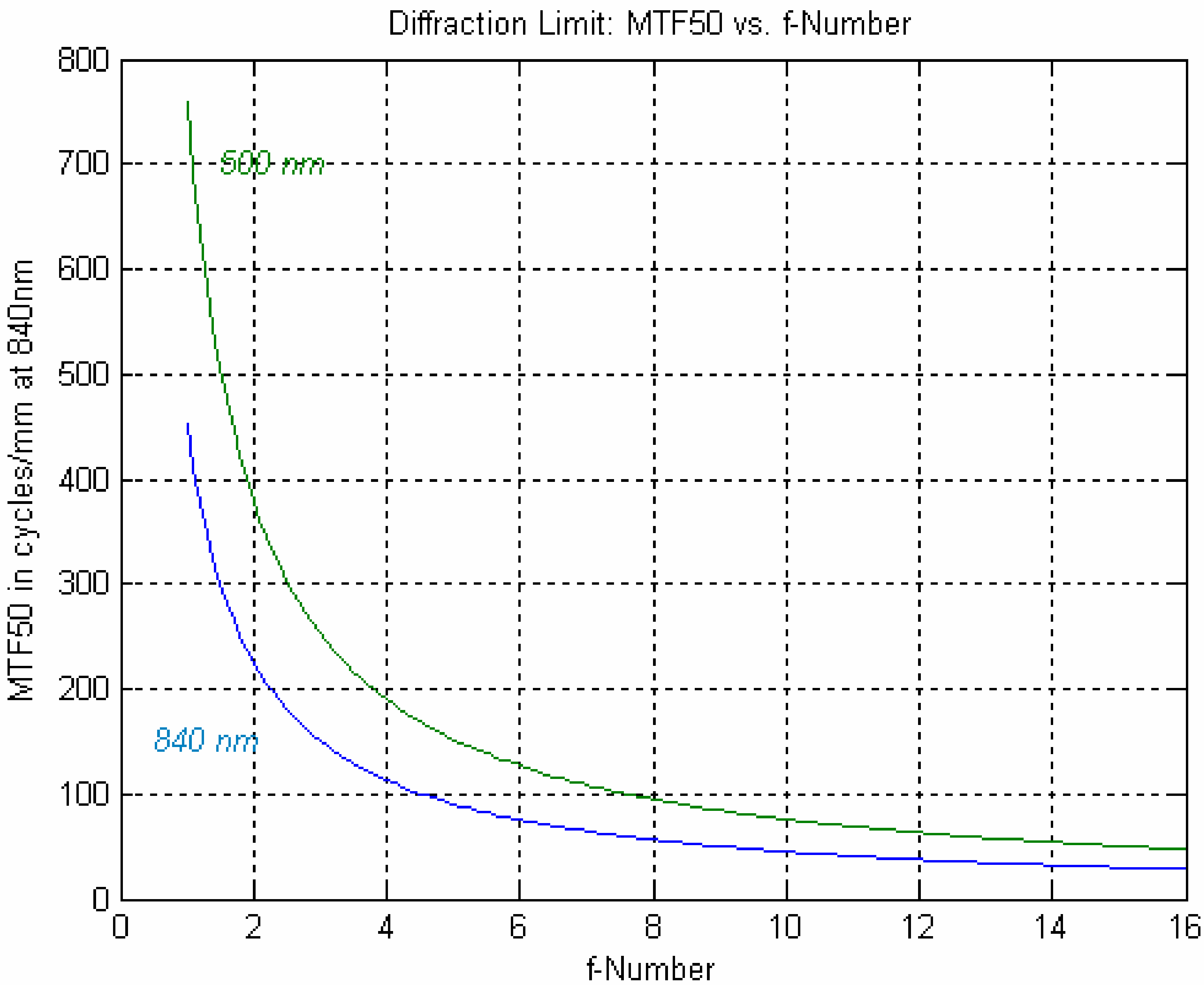
- Diffraction imposes a fundamental physical limit on image sharpness
  - A point source of light passing through an aperture produces a diffraction pattern of alternating light and dark concentric rings.
  - Called an **Airy disk**
- Radius, R, of the Airy disk from peak to first minimum varies directly as the f-number and the wavelength
  - R = 1.22 * wavelength * f-number
  - N.A. is equivalent measure: N.A. = 1 / (2 * f-number)
  - Airy Disk Simulation (Nikon)

Lens Resolution and f-number

- Lenses are usually aberration limited at low f-numbers
- At high f-numbers, lens resolution becomes diffraction limited.
- In the NIR, due to longer wavelength, diffraction results in almost a 40% reduction in resolution relative to visible light.

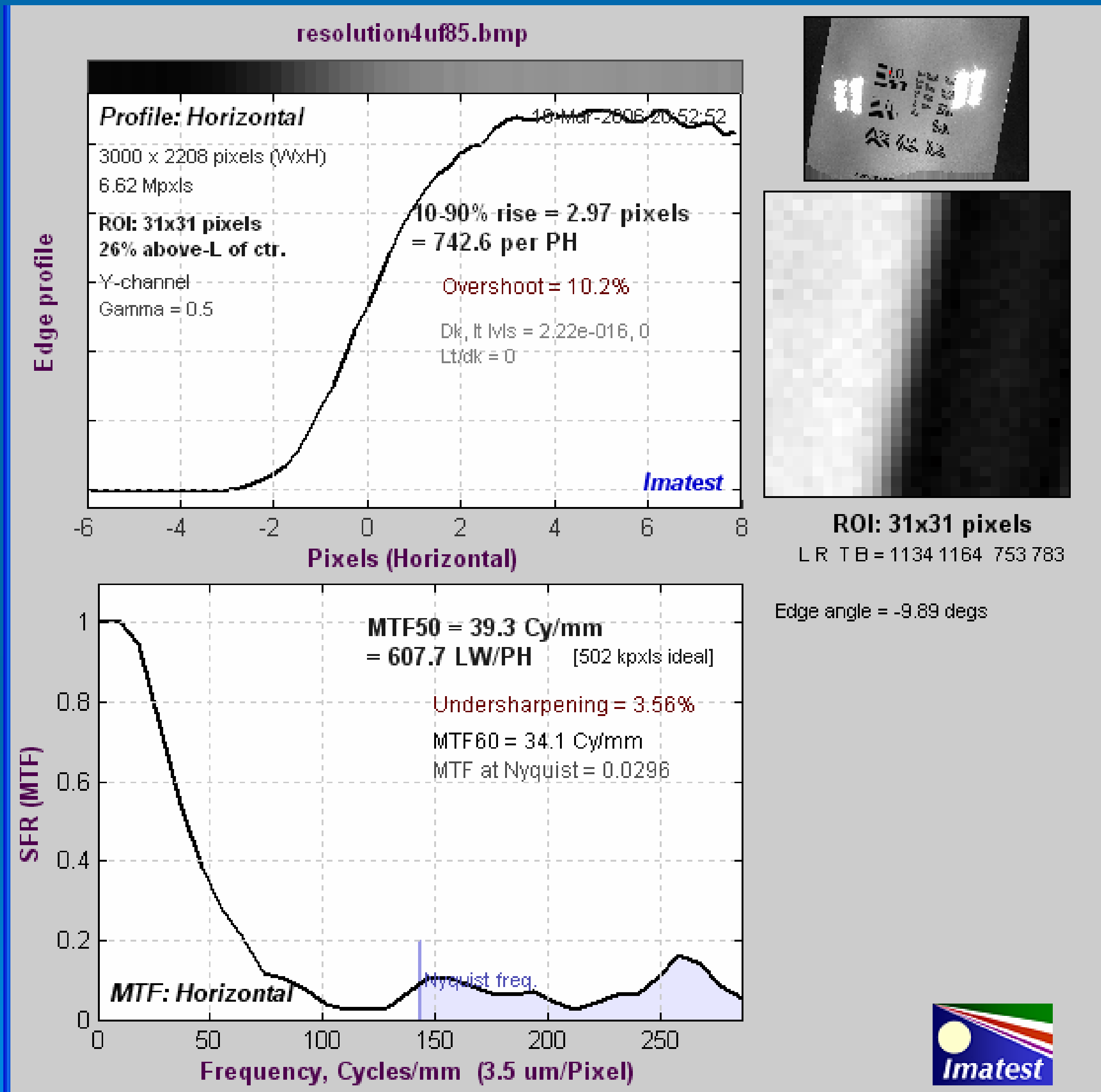
Quantifying Sharpness Using MTF

- Traditional method of measuring MTF is by human observation of a resolution chart image.
  - value is subjective
  - typically yields optimistic MTF at about 2-5% modulation
- MTF can be objectively measured using the slanted-edge method.
  - Requires an image with a sharp, slanted dark/light edge and suitable software [Imatest]
  - ISO 12233:2000 Photography -Electronic still picture cameras – Resolution measurements
- Complete MTF specification must include a **modulation level**, a **wavelength**, and **overshoot limit**. For example:
  - MTF at 60%, 840nm, is 4 line-pairs/mm with edge trace overshoot less than 10%
- MTF50 = lp/mm at 50% modulation
  - 0.38 /(Wavelength * f-Number)



Diffraction Limit: MTF50 vs. f-Number
MTF50 in cycles/mm at 840nm
800
700
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
f-Number
500 nm
840 nm

Sloping Edge Resolution Test



Magnification = 0.0875
FOV = 120mm
Wavelength = 840nm
MTF60 at object = 3 lp/mm

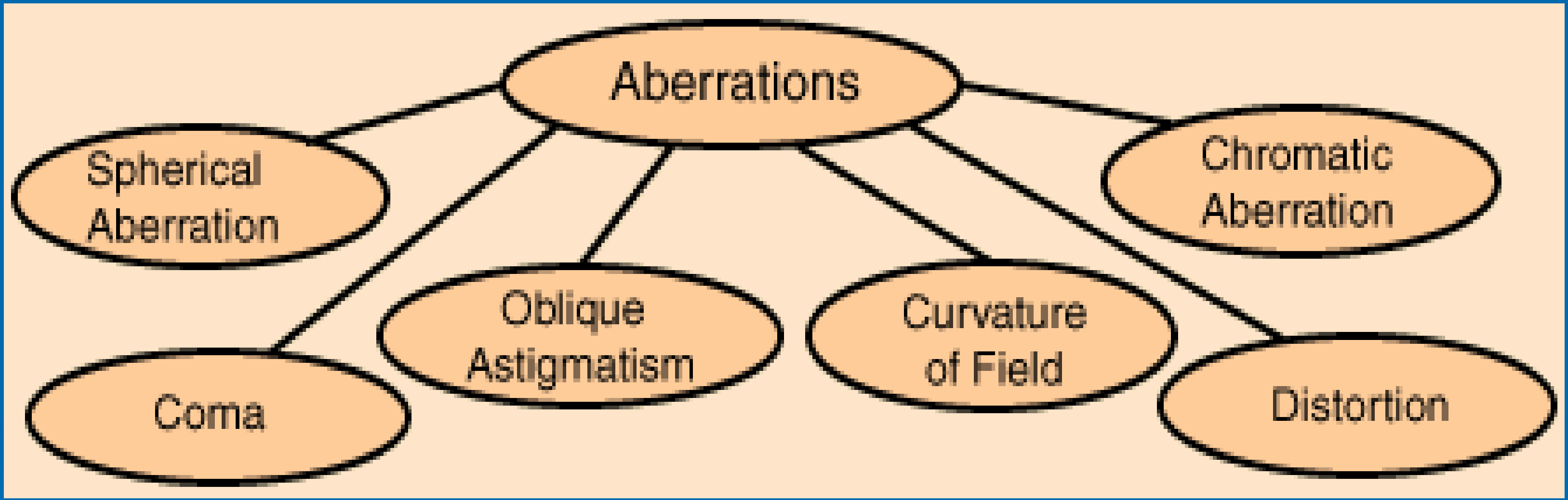
Digital Signal Processing of Image

- MTF can be increased by digital sharpening.
- Excessive sharpening will produce overshoot or ringing on edges.
- Edge profile will show this distortion
- The edge profile can be produced by commercial software [Imatest].

Lens Aberrations

- Aberrations are deviations from an ideal lens
- Every lens has aberrations
  - The lens designer uses multiple optical elements to reduce aberrations.

Common Lens Aberrations



Illustrations courtesy of Dr. Rod Nave
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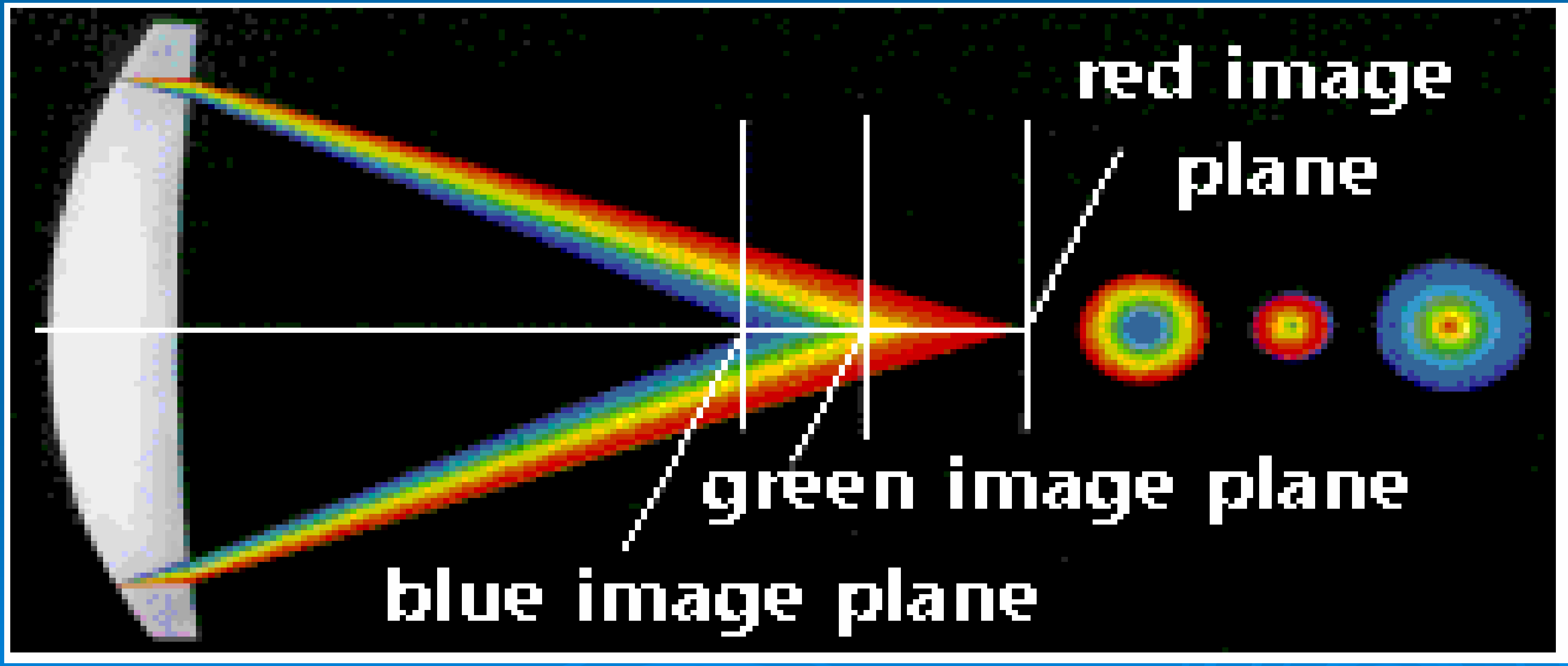
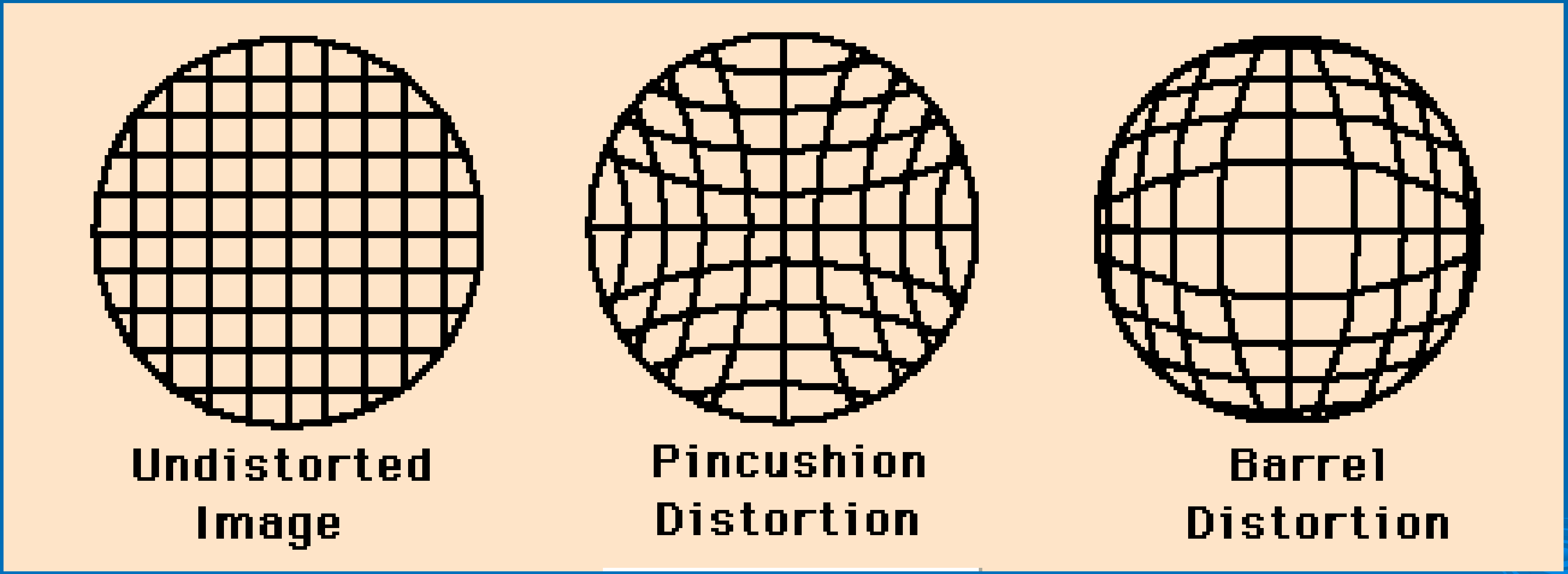
Georgia State University
Atlanta, GA 30303-3083

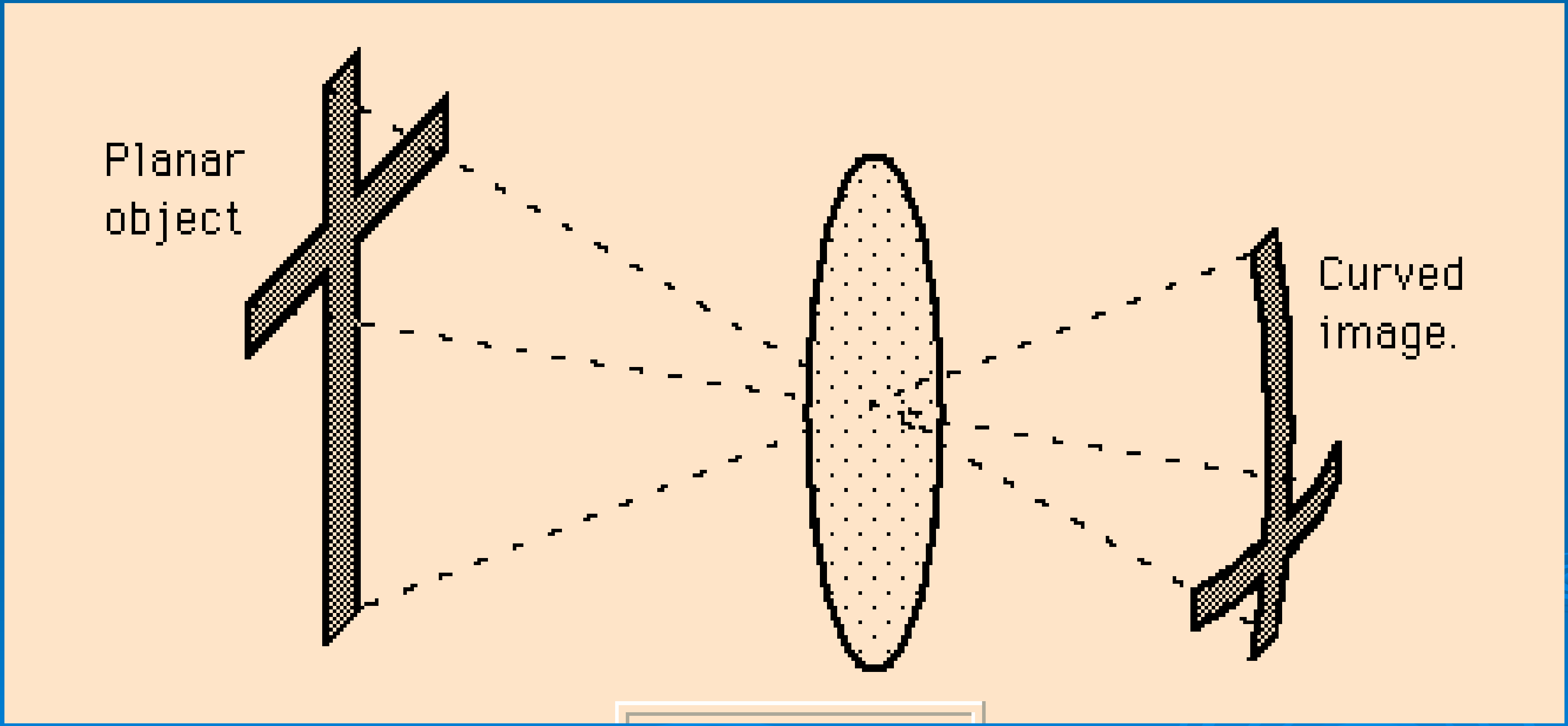
Chromatic Aberration Light of Different Wavelengths Focus at Different Distances



Distortion

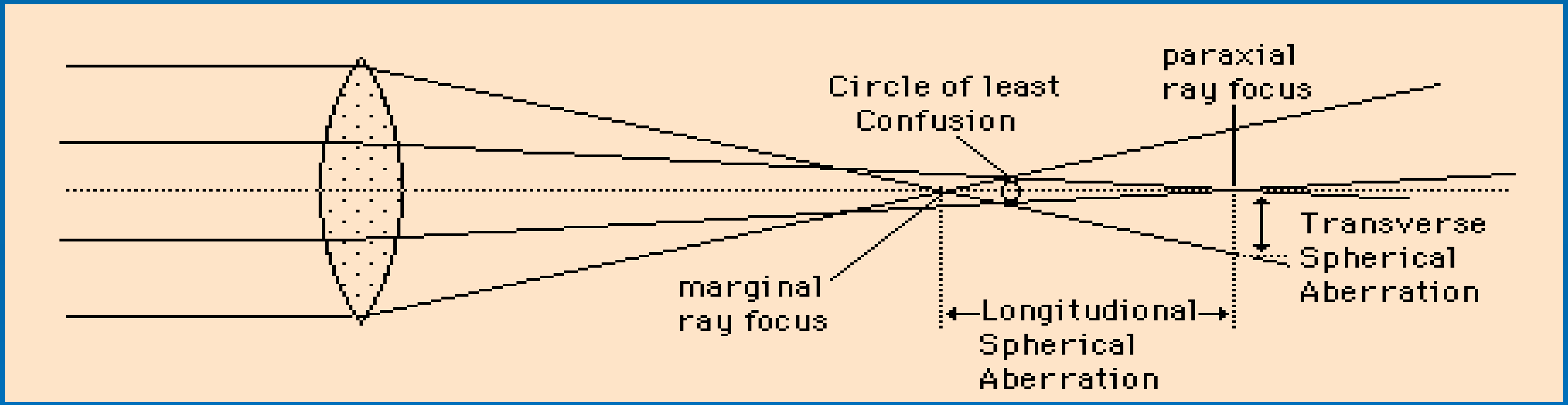

Undistorted Image
Pincushion Distortion
Barrel Distortion

Curvature of Field

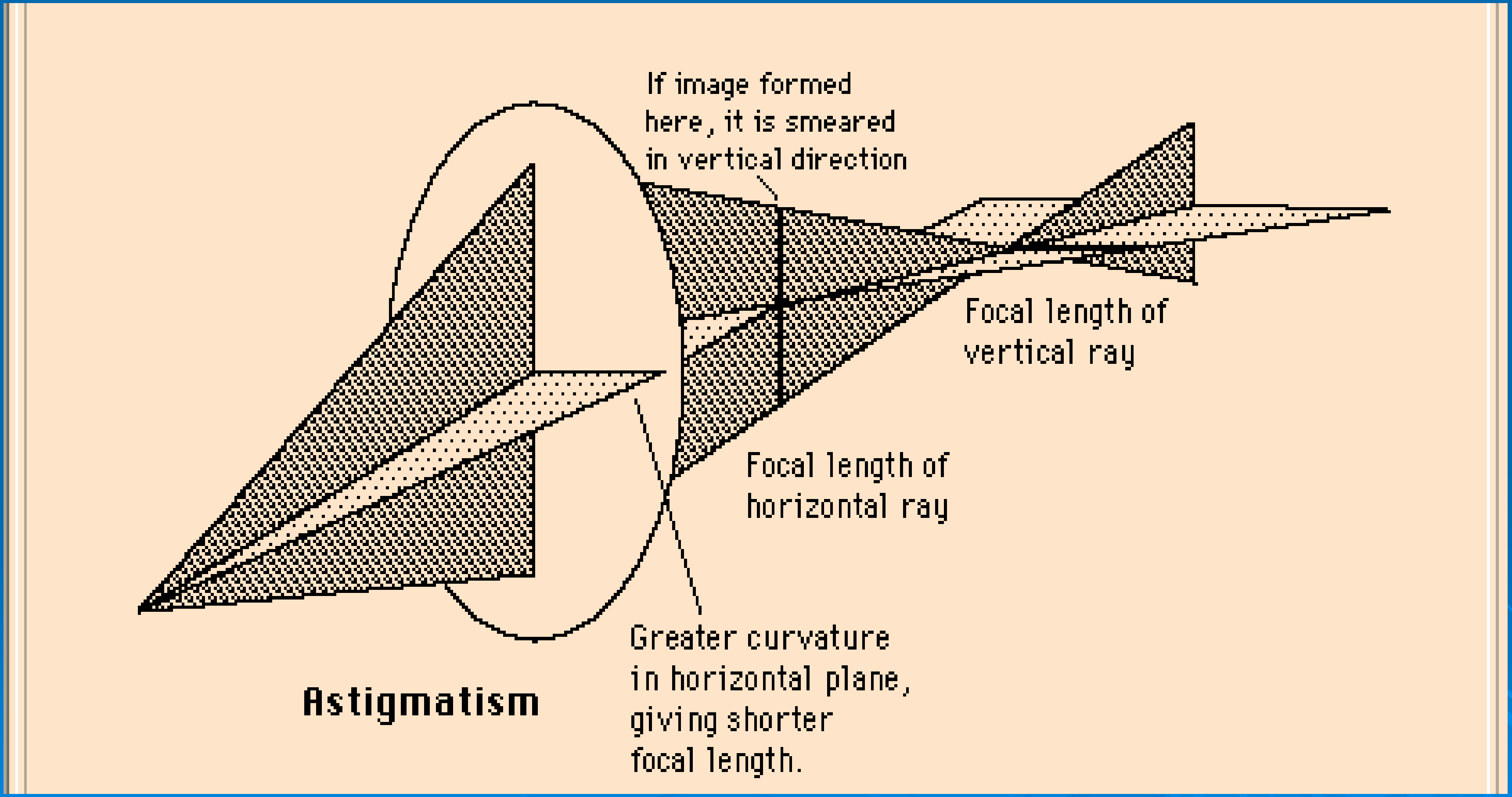


Spherical Aberration

Rays Focus at Different Distances Depending on Position on Lens



Astigmatism



Calculated Optical Characteristics

- focal length in mm: 16.4
- f-number: 8
- maximum permissible circle of confusion in mm : .07
- object width in mm: 120
- iris diameter in mm: 7
- wavelength of illumination in NANOMETERS: 840
- pupil magnification : 2.591

- Height of field 96.1971 mm (3.78729 inches)
- Horizontal pixels on iris = 175

- DIFFRACTION LIMITS
- Rayleigh limit on sensor (from peak to first zero of airy disk): 8.1984 microns
- Rayleigh limit on object: 93.696 microns
- Rayleigh MTF limit on sensor: 121.975 lp/mm
- Rayleigh MTF limit on object: 10.6728 lp/mm
- MTF50 on sensor 56.5476 lp/mm
- MTF50 on object: 4.94792 lp/mm
- MTF60 on sensor: 48.631 lp/mm
- MTF60 on object: 4.25521 lp/mm

Illuminator

Illuminator Requirements

Uniform illumination over the area of the eye

- Sufficient intensity to maximize signal/noise ratio in sensor.
- Wavelength range that produces sufficient contrast of retinal features.
- Levels of illumination that are safe for the subject's eye

Effects of Illumination Wavelength

Brown Iris | Blue Iris

Visible Illumination

Infrared Illumination

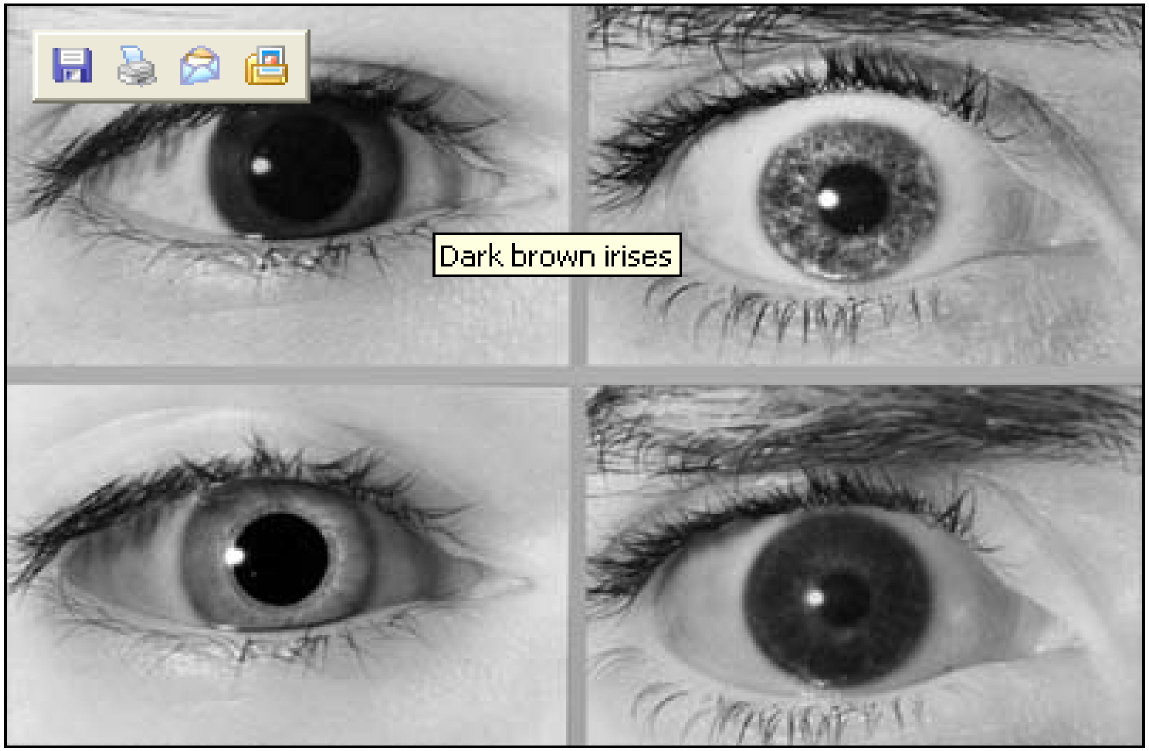


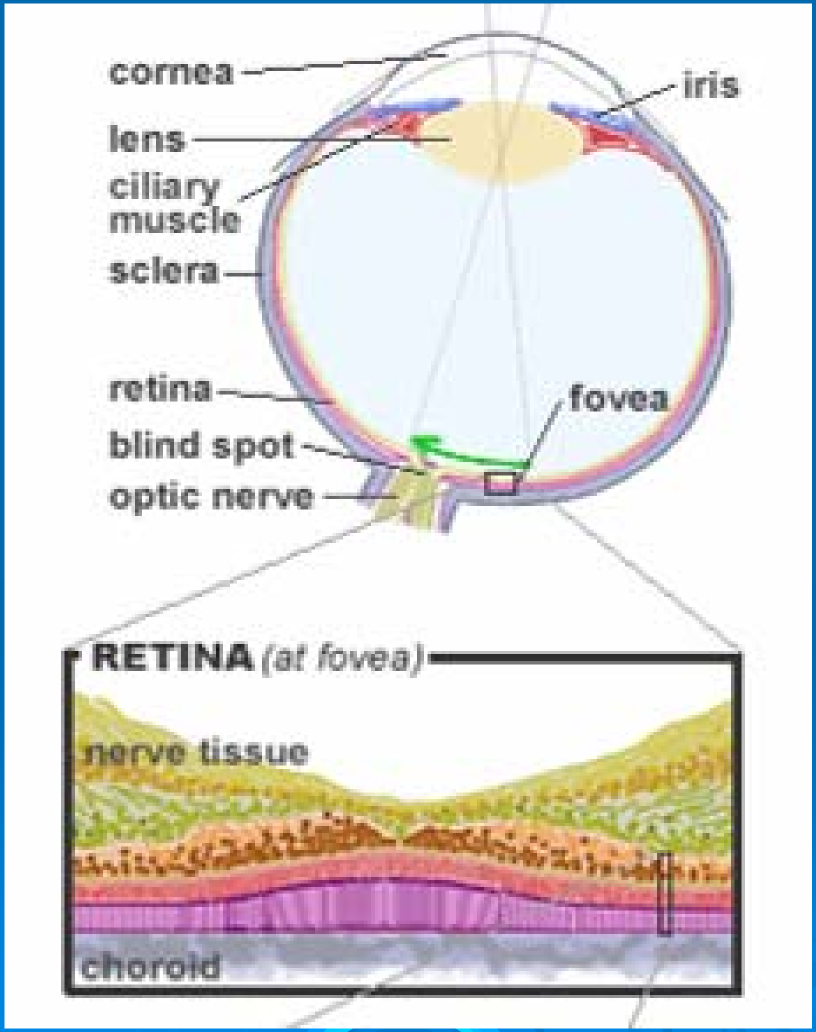
Figure 74 (above). Dark brown irises often record lighter with infrared photography than blue ones, as can be seen in this comparison. The brown eye is on the left, the blue eye on the right; with panchromatic controls on the top and the infrared records below. Notice the detail in the irides of the brown eye with infrared. Image © Williams.

http://msp.rmit.edu.au

Illuminator Safety

- High illumination levels can cause permanent eye damage
  - NIR illumination is particularly hazardous
  - The eye does not respond with protective mechanisms (aversion, blinking, pupil contraction)
- Application requirements call for high light levels
  - Depth of field strongly affects usability
    - Typically achieved by increasing f-number
    - Required light level increases as square of f-number
  - Short exposure time reduces motion artifact
    - Required light level varies inversely with exposure time
  - Signal/noise ratio is improved as light level increases

Structure of the Human Eye



LED Eye Safety Standards

- See References
  - [ACGIH]
  - [ICNIRP]
  - [ICNIRP 2000]
  - [IEC]
  - [ANSI]

Is This a Real Problem?

- There is no reported case of retinal injury from a single LED.
- “Only because of the extraordinary worst-case assumptions built into some current product safety standards could one reach the conclusion that an LED or IRED poses a safety hazard.” [ICNIRP 2000]
- Multiple LED illuminators can easily exceed the 10/mw /cm^2 safety limit
  - Many illuminators use arrays of LEDs.
- New LED technologies are increasing brightness, so the situation bears watching.

Camera

The NIR Camera

- Interfaces sensor to computer
- Controls image acquisition, display, and control.
- Corrects for pixel-pixel gain and offset variations
- Must not have NIR block filter installed
  - NIR block filter is installed on nearly all commercial cameras to reduce blurring from focal length differences between visible and NIR light.
- Must not have anti-aliasing diffuser installed
  - Often used to avoid aliasing effects from under-sampling

Subject Interface

Subject Interface

- Both eye and head position must be controlled
  - Cold mirror target with crosshairs
  - Audible feedback
  - Forehead and/or chin rest.
- Eye motion during exposure causes image blurring
- Saccadic motion blur
  - eye moves approximately .001”, 60 times/sec
  - may limit image resolution

NIST Iris Imaging Platform

Design Specifications

- Captures two irises in a single 6.3 mega-pixel NIR image
  - MTF_{60} (Modulation Transfer Function) greater than 3 lp/mm at 840 nm with less than 10% overshoot on edge profile
  - Image distortion less than 2%
- Field of View (horizontal): 120mm
- Pixels on 7mm iris: 175
- Lens, camera, and cold mirror target optimized for NIR (700-900nm)
- Illuminator is eye-safe at controlled distance
- Rigid, accurate platform for stable optical alignment
- Maximize use of COTS components
- GUI user interface to view, capture, and save images
- Eye and Head position controlled
  - Cold mirror eye target
  - Forehead rest
- Sustained image capture rate of 5 images/sec

Camera Specifications

- Pixelink PL-A 781
- Pixel count: 2208 x 3000
- Pixel pitch: 3.5 microns
- Frame Rate 5 fps at 2208 x 3000 pixels
  - Region of interest selection
- Bit depth: 8 or 10
- Spectral Responsivity: > 4 DN (Digital Numbers)/(nJ/cm^2)
- FPN (Fixed Pattern Noise) < 1% (pixel-pixel offset)
- PRNU (Photo Response Non-Uniformity)< 2% (pixel-pixel gain)
- Each pixel is dynamically corrected for FPN and PRNU
- Defective pixels are replaced with mean of surrounding pixels
- Read Noise < 1.4 digital numbers
- Dynamic Range: 56.7db

Lens Specifications

- Schneider Cinegon 1.8/16
- Broadband lens
  - NIR corrected optics
  - NIR lens coatings
- Distortion < 2% at maximum image size (10.5mm)
- Relative illumination 60% at maximum image extent
- Modulation > 75% at 30 lp/mm, f/8.0

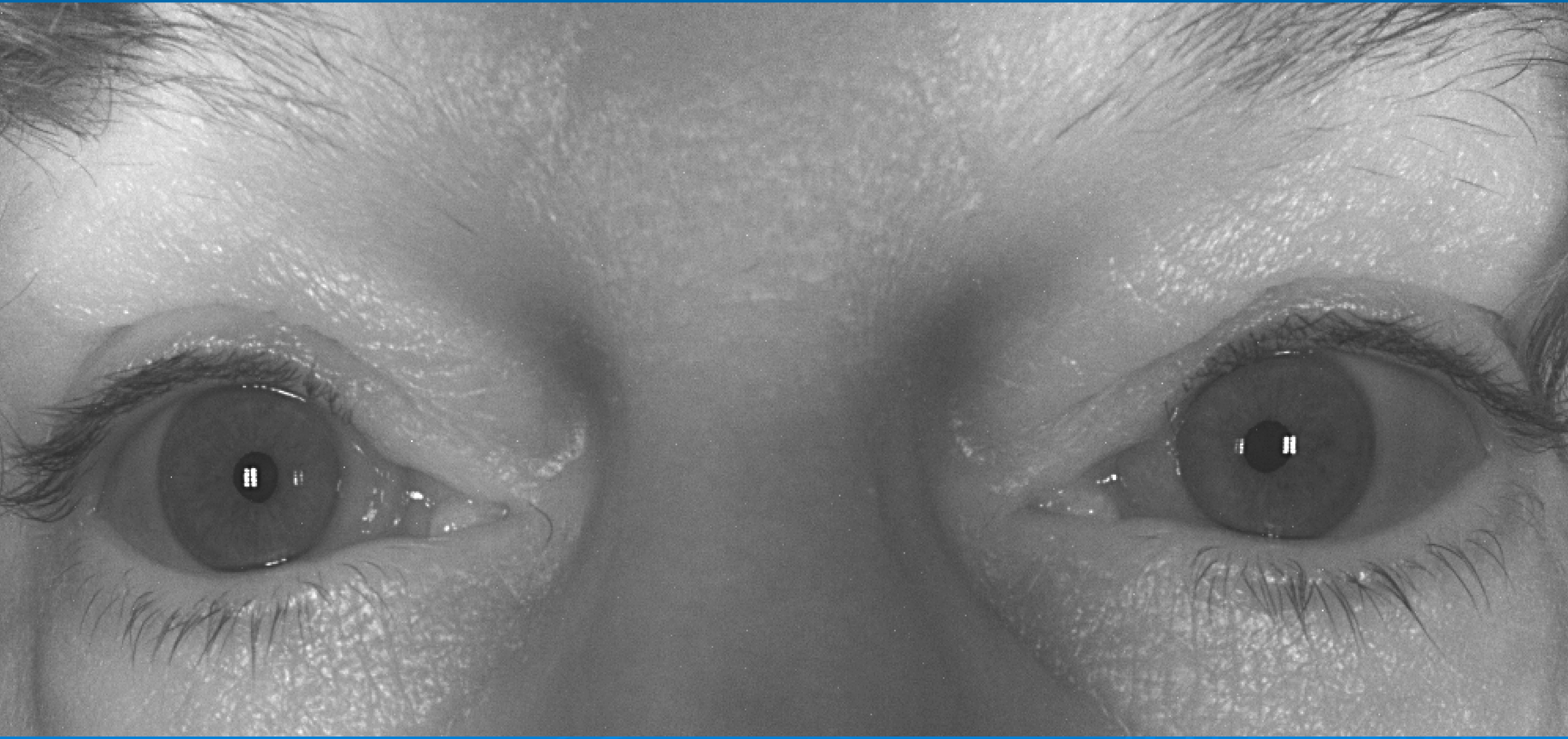
Illuminator Specifications

- Safe at controlled viewing distance
- Less than 10mw/cm^2 on subject meets all applicable safety specifications
- Eye illumination uniformity – 2% (after correction by camera)
- 840 nanometer center wavelength

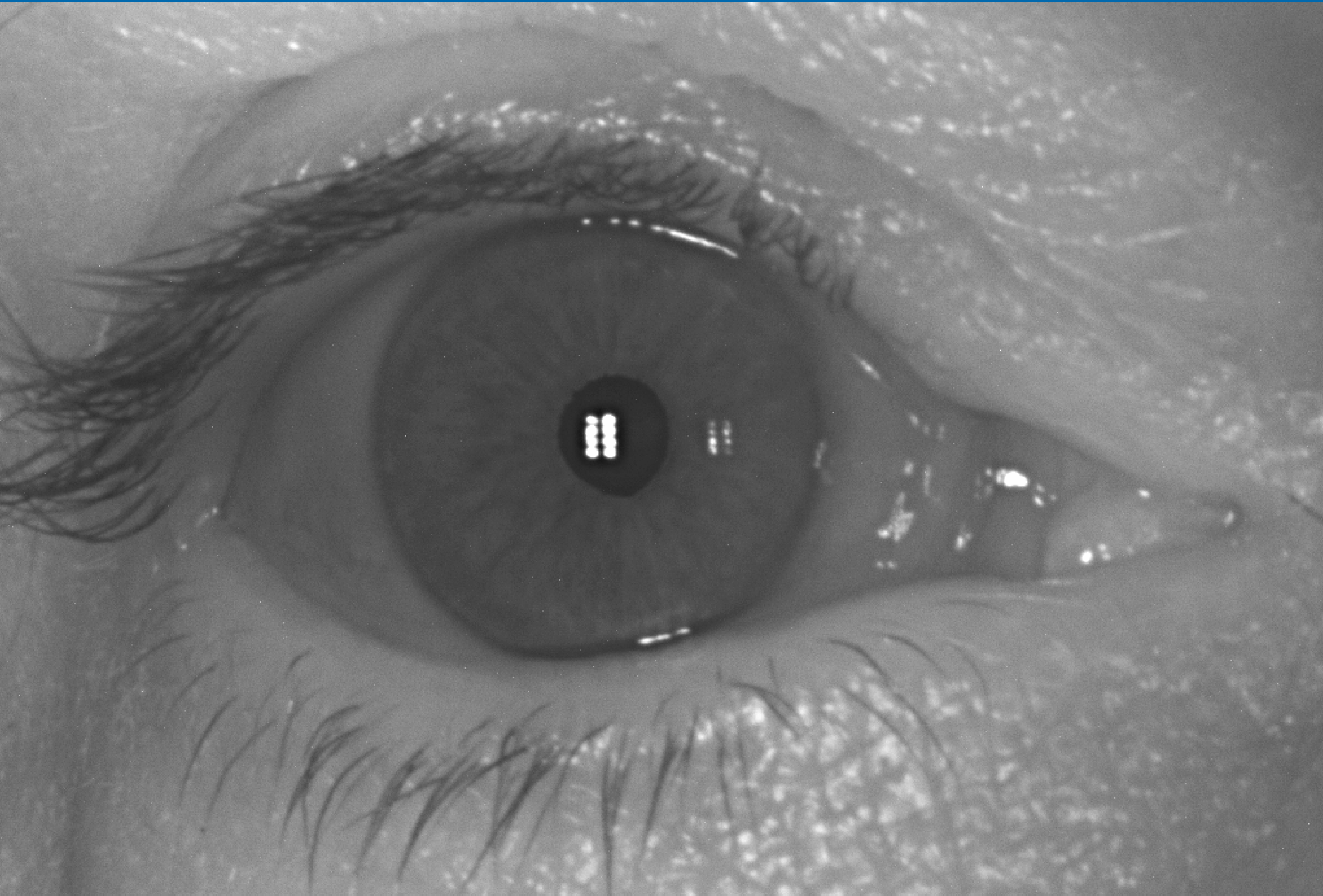
Imaging Results

Non-enhanced images

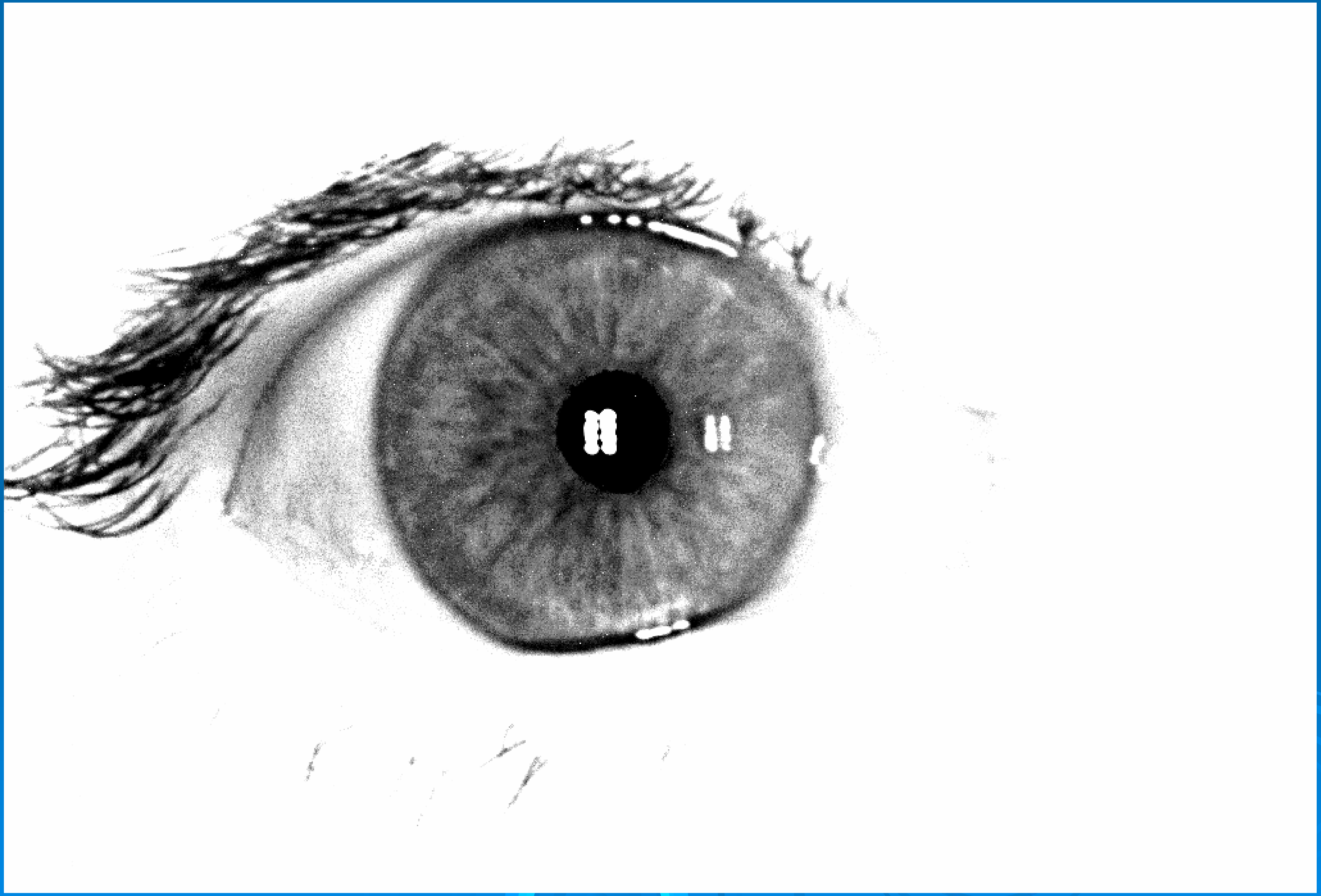
Two Blue Eyes



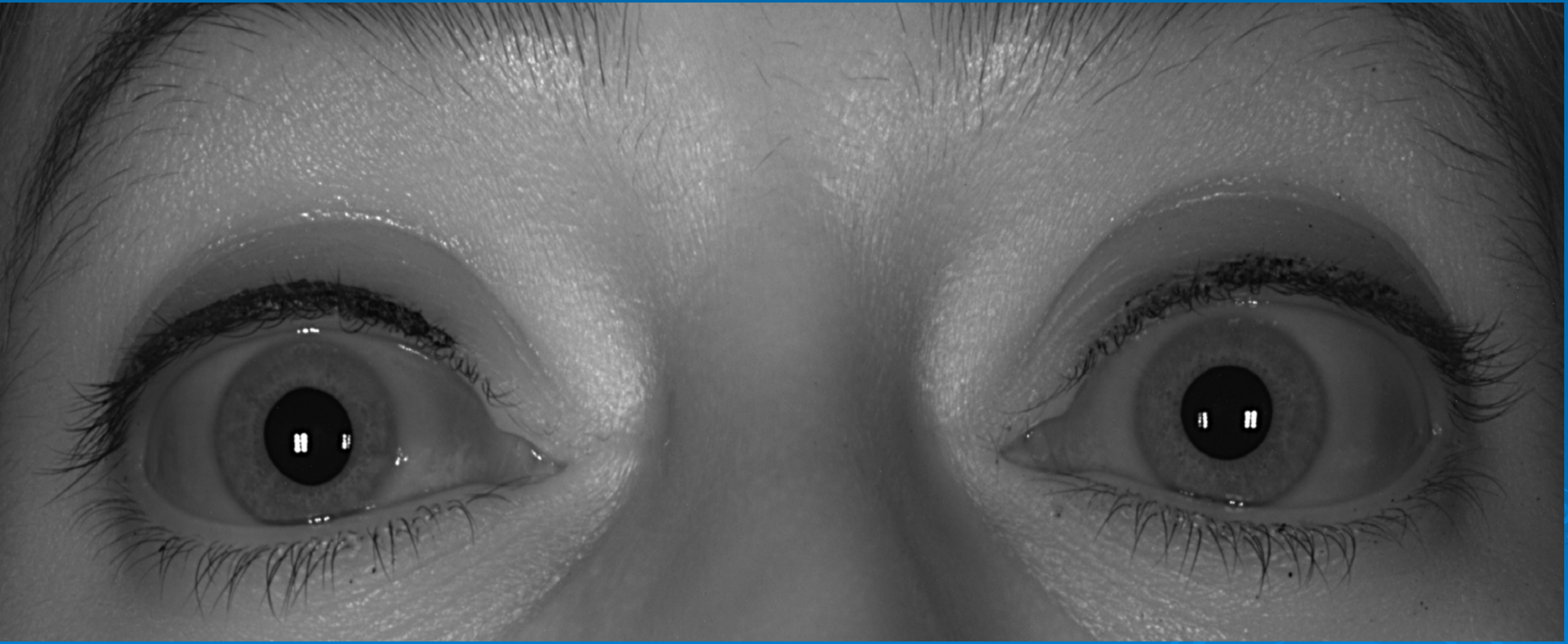
Single Blue Eye



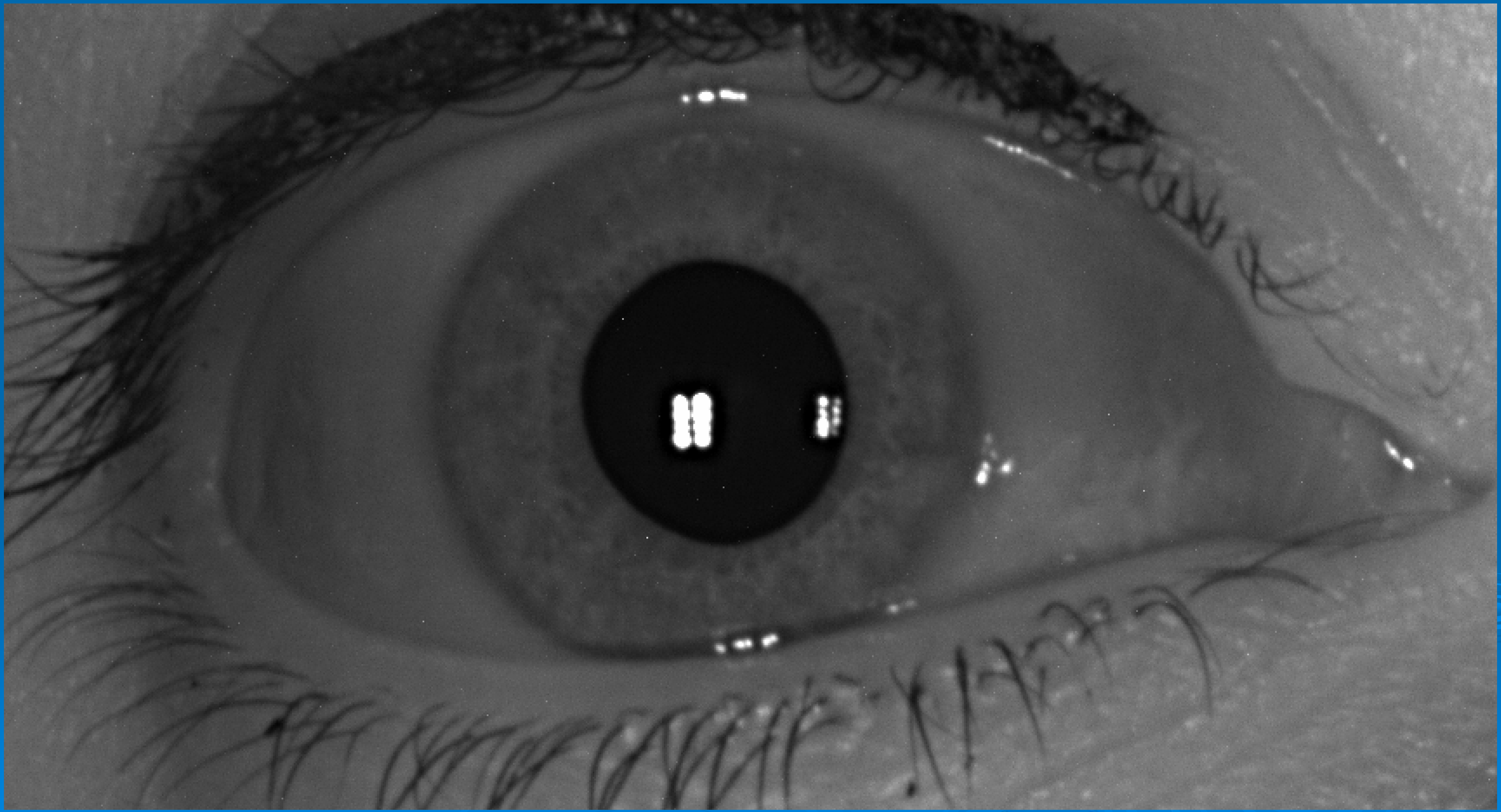
Single Blue Eye Enhanced



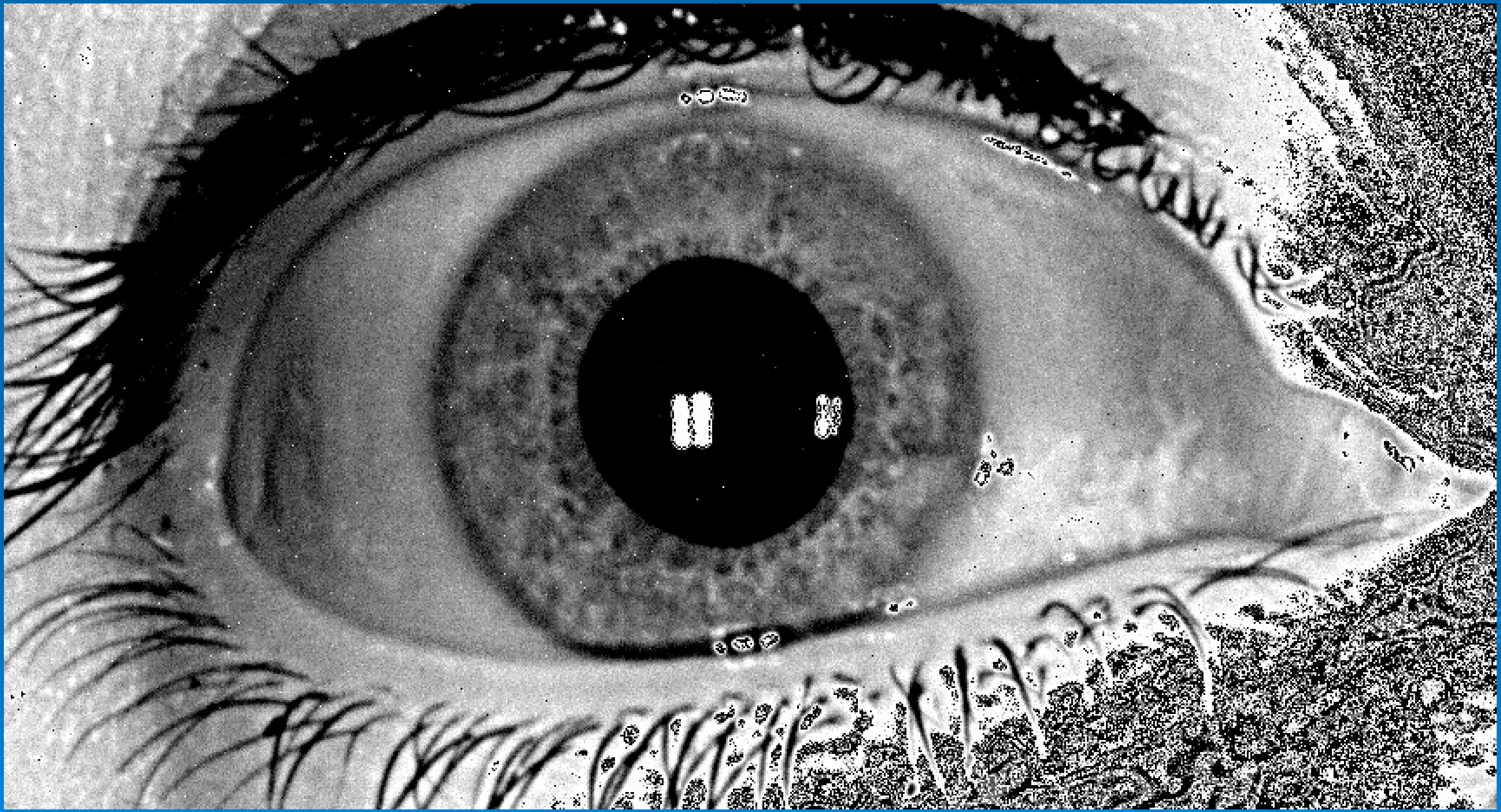
Two Brown Eyes



One Brown Eye



One Brown Eye Enhanced



References

- [Gamassi] M. Gamassi, et al, Accuracy and Performance of Biometric Systems, IMTC 2004, 2004.
- [Daugman] John Daugman, *How Iris Recognition Works*
- [IBG] International Biometrics Group, *Independent Testing of Iris Recognition Technology Final Report*, May 2005.
- [ACGIH] American Conference of Government Industrial Hygienists, “Eye Safety With Near Infra-Red Illuminators”, 1981.
- [ICNIRP 2000] “ICNIRP statement on light-emitting diodes (LEDs) and Laser Diodes: Implications for Hazard Assessment”, Health Physics, Vol. 78, Number 6.
- [ICNIRP] International Commission on Non-ionizing Radiation Protection, “Guidelines on Limits of Exposure to Broad-Band Incoherent Optical Radiation (0.38 to 3µM)”, 1997.
- [IEC] 60825-1 International Electrotechnical Commission, “Safety of laser products, Part1: Equipment classification, requirements and user’s guide”, 2001
- [ANSI] American National Standards Institute. “American National Standard for the safe use of lasers and LEDs used in optical fiber transmission systems. Orlando, FL: Laser Institute of America; ANSI Z136.2 1988 (2nd edition,1988).
- [CIE] Commission International de l’Eclarirage. “Photobiological safety standards for lamps.” Vienna: CIE; Report of TC 6-38; CIE 134-3-99; 1999.