Towards an Iris Device Qualification Test

Work Supported by the DHS Science and Technology Division

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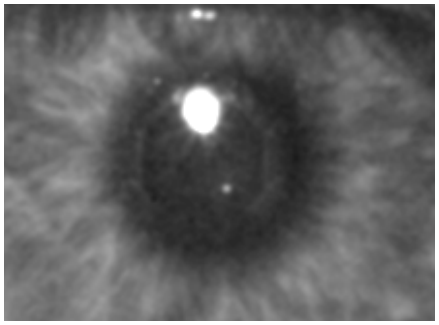
Why Develop a Qualification Test?

- Due diligence tool for selecting iris image collection devices for consideration in US Government applications
  - Goal: Unbiased Comparative Metrics
    - Inter-device (What is the best device for a given application?)
    - Intra-device versus application (what application is best suited for a given device?)

- Farther in the Future: Preliminary step for something to offer to ISO standards body for commercial industry

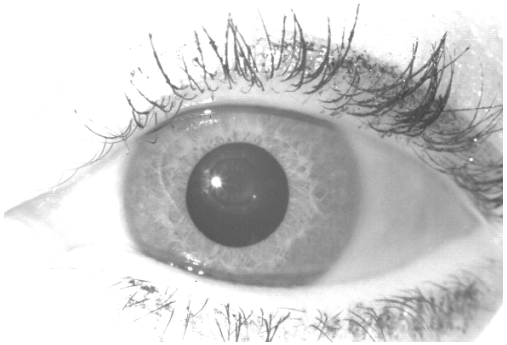
Why not use established image quality targets?

- Standard targets use information not representative of optical properties of eye
- Iris capture devices may require the presentation of face/periocular features, as well as features specific to the eye such as specular reflections from the cornea



Primary Specular Reflection

Face/periocular features



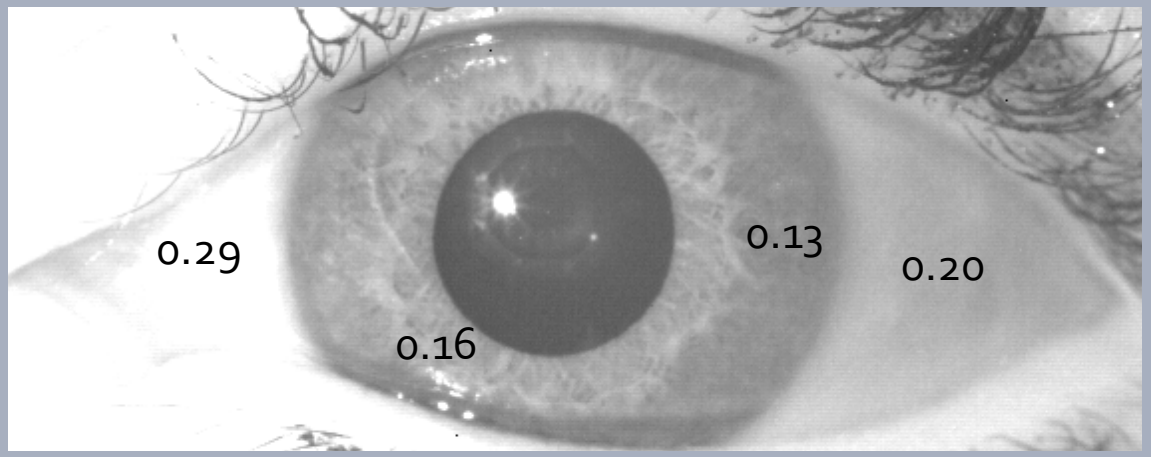
Iris border features and texture

Target Requirements

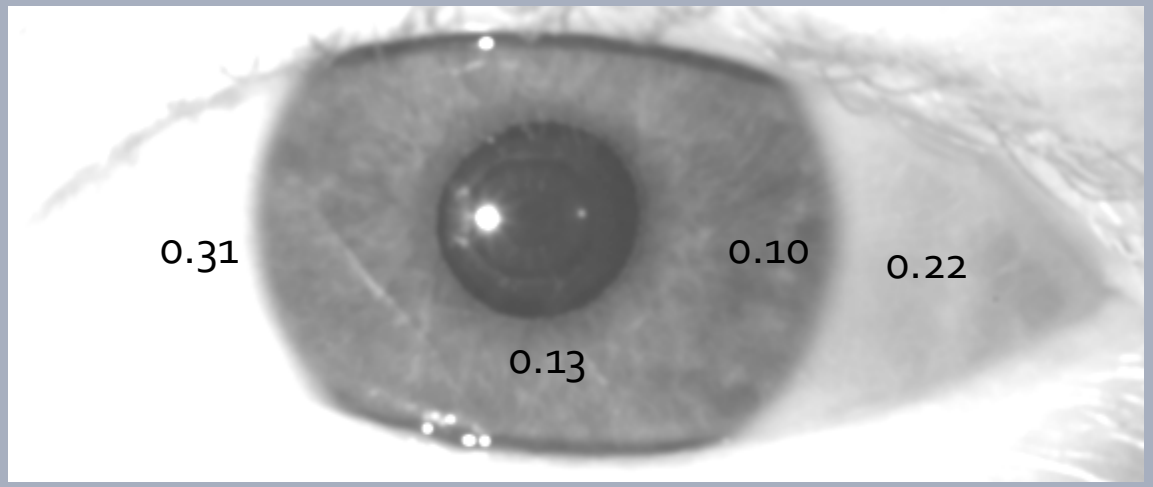
- Be able to capture iris images in the native operational mode of the tested device ("faceness"+"eyeness")
  - Without bias for or against a particular device
- Succinctly measure performance relevant to iris biometrics
  - Challenge lies in controlling and/or adequately sampling the many covariates.

Optical Properties of Eye/Iris: Albedo

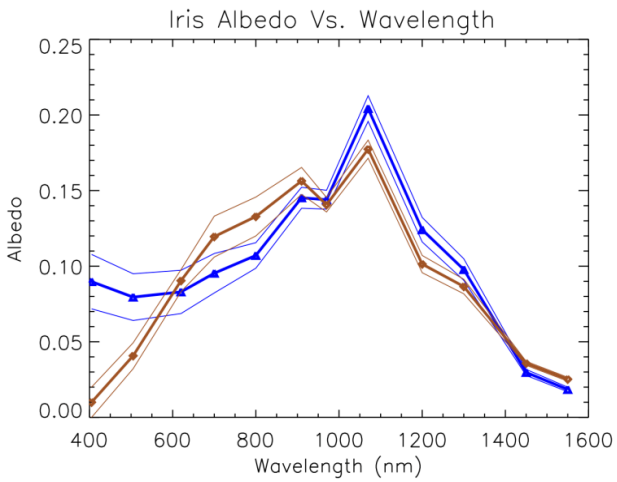
Brown Eye

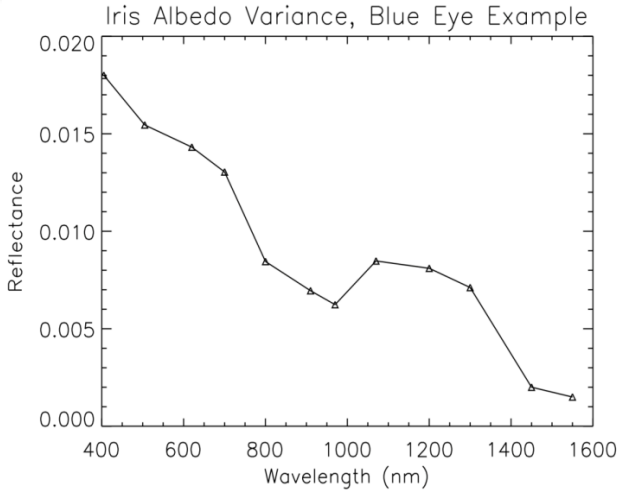


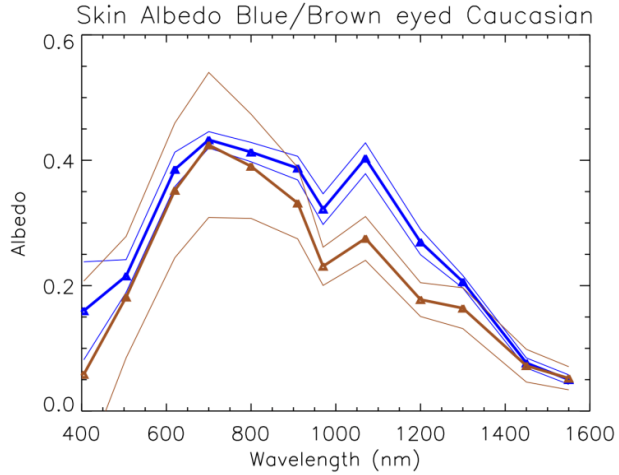
Blue Eye

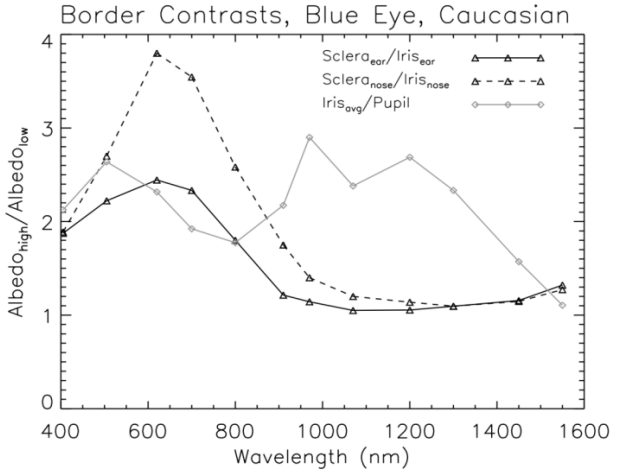


Observed Optical Properties of the iris





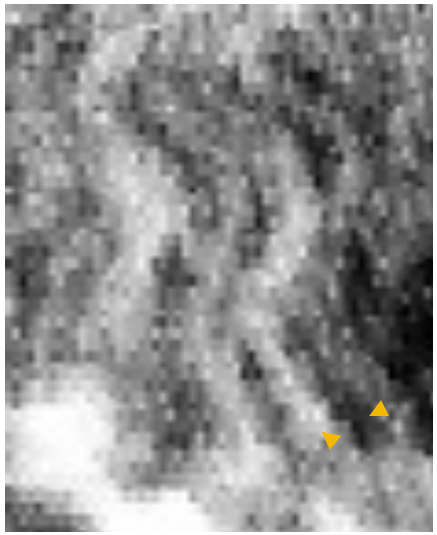




Observed Optical Properties of the Iris: Spatially Varying Albedo

Signal-to-Noise Ratio can be expressed as a function of device variables (assuming photon noise):

$$SNR_{850nm} \sim 10 \left(\frac{\gamma_a}{0.15}\right)\left(\frac{F_i}{1mW/cm^2}\right)^{1/2}\left(\frac{a}{0.12}\right)^{1/2}\left(\frac{Q}{0.1}\right)^{1/2}\left(\frac{t}{25msec}\right)^{1/2}\left(\frac{\ell}{0.5mm}\right)\left(\frac{d}{5mm}\right)\left(\frac{D}{50cm}\right)^{-1}$$



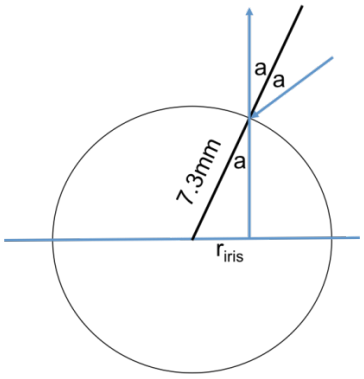
Iris Texture

$$a_{low} = a(1 - \frac{\gamma_a}{2})$$

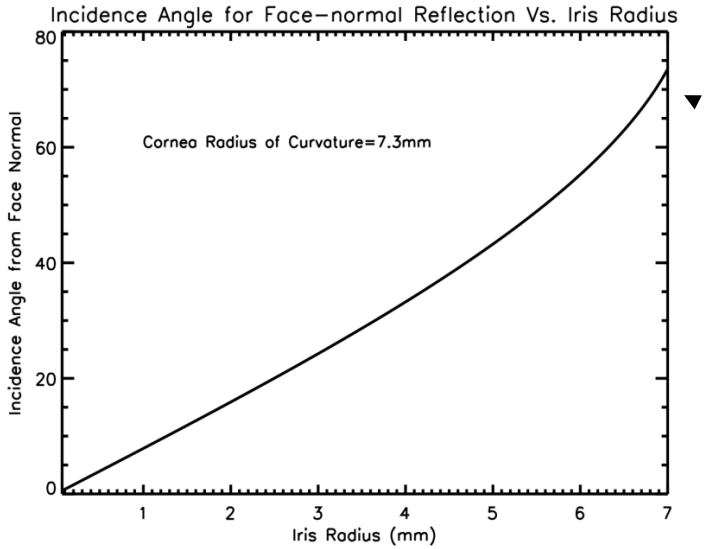
$$\Delta a = a_{high} - a_{low} = \gamma_a a$$

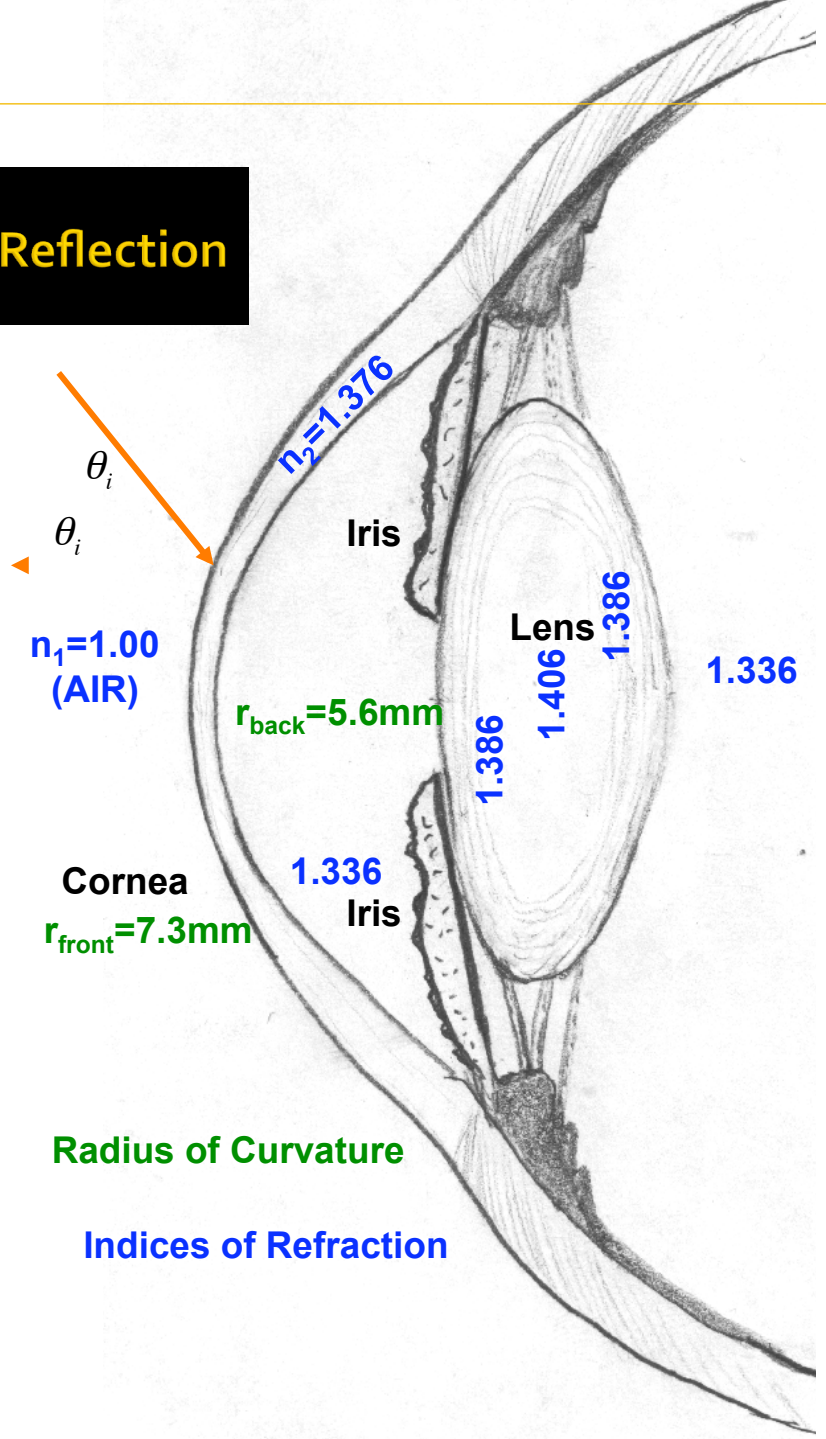
$$a_{high} = a(1 + \frac{\gamma_a}{2})$$

Optical properties of eye/iris: Specular Reflection



$$\theta_i = \sin^{-1}\left(\frac{\quad}{7.}\right)$$



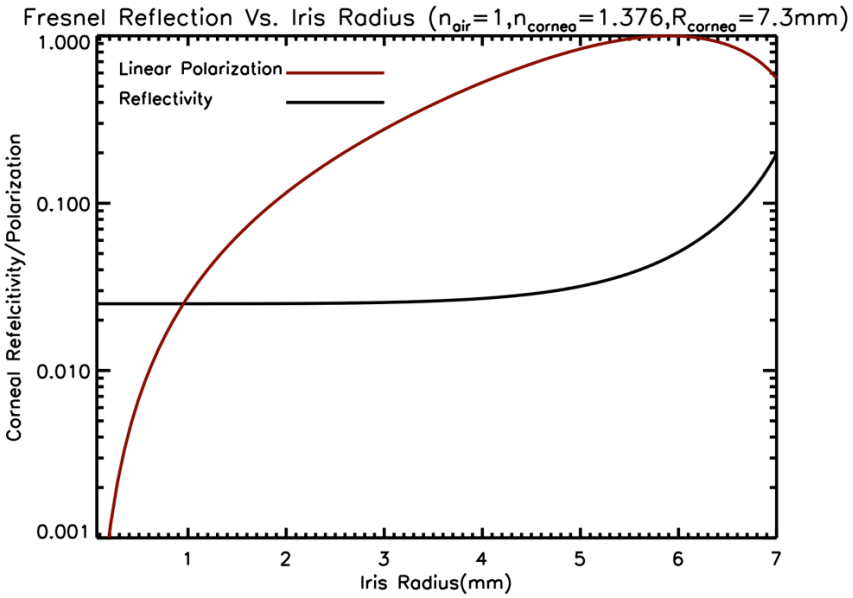


Fresnel Reflection Coefficients:
Estimate for Percent reflected off corneal

$$R_{\perp} = \left(\frac{n_1\cos\theta_i - n_2\cos\theta_t}{n_1\cos\theta_i + n_2\cos\theta_t}\right)^2$$

$$R_{\parallel} = \left(\frac{n_1\cos\theta_t - n_2\cos\theta_i}{n_1\cos\theta_t + n_2\cos\theta_i}\right)^2$$

$$< R >= \left(\frac{R_{\perp} + R_{\parallel}}{2}\right)$$

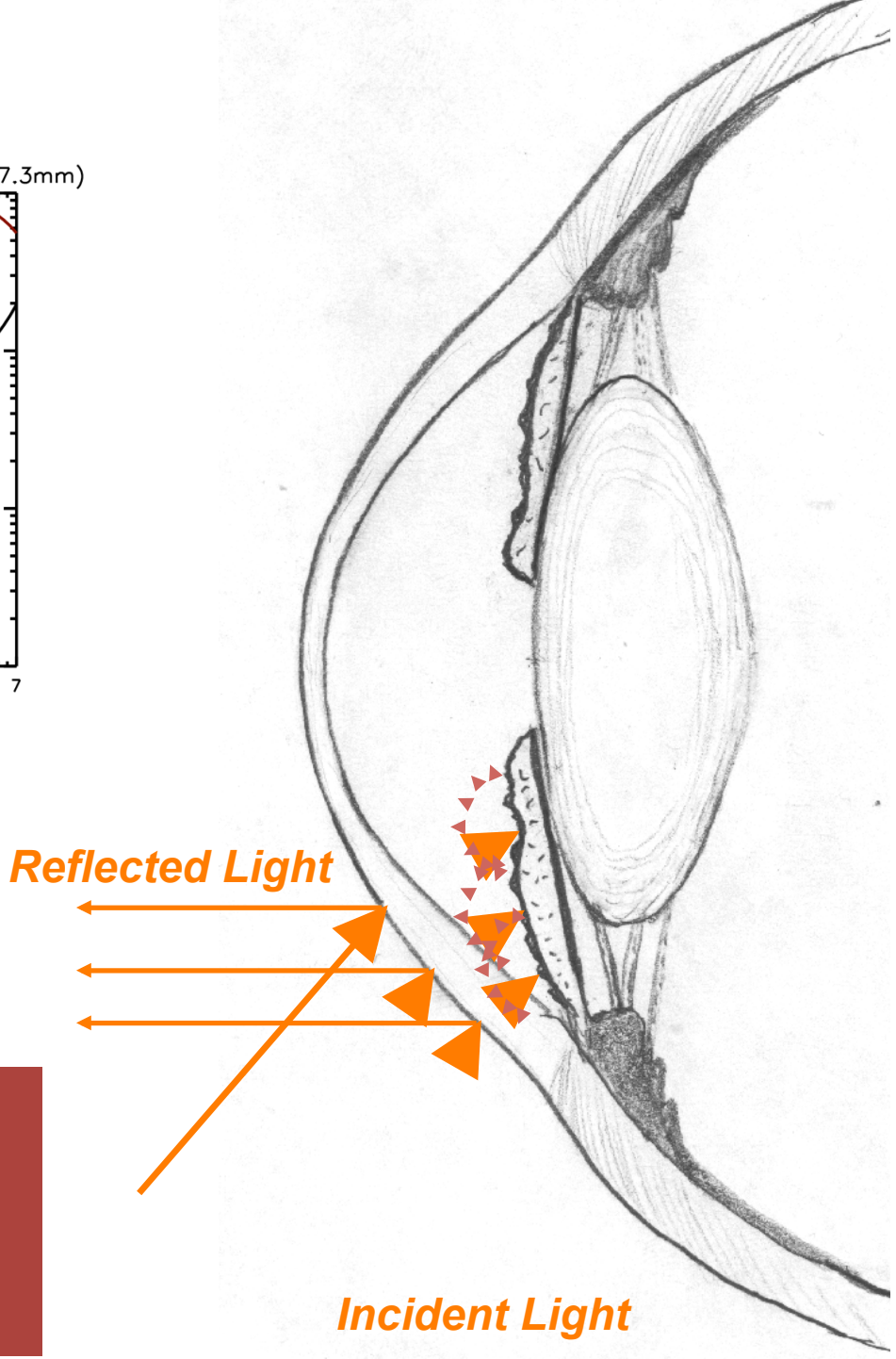


Cornea surface

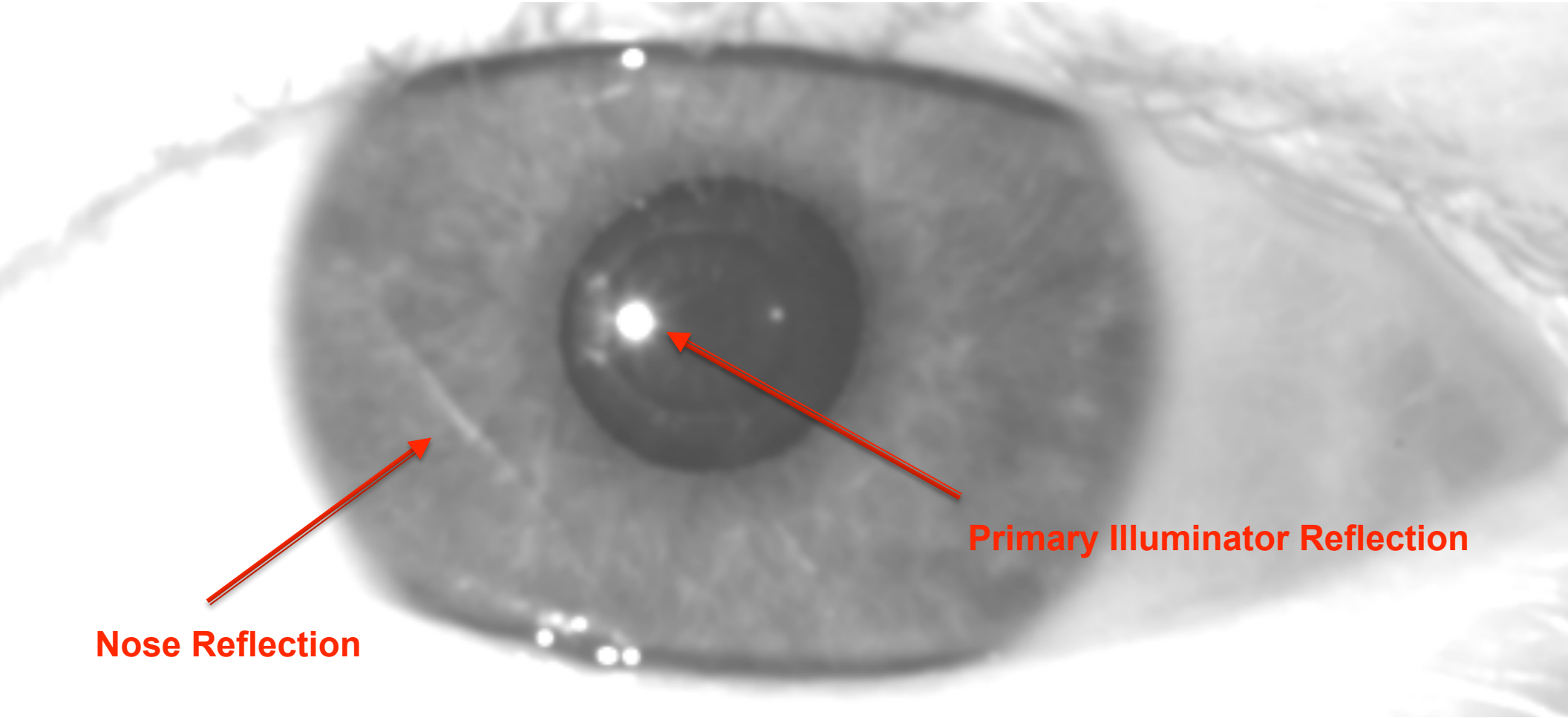
- Reflects ~2-3% of incident NIR light
- Fish-eye de-magnification
- Polarized

Iris surface

- Scatters ~10-16% of incident NIR Light
- Lambertian?

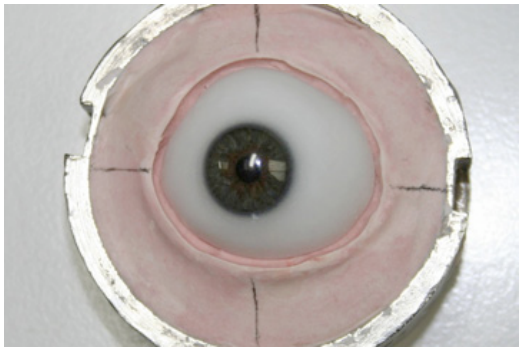


Specular Reflections



Target prototypes

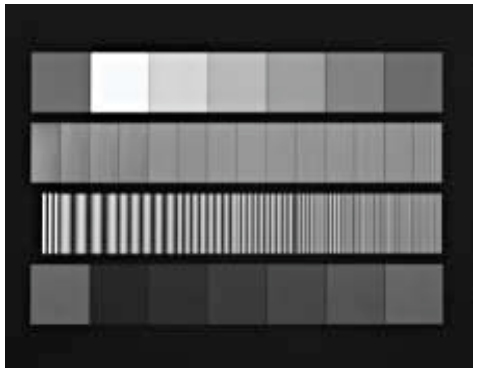
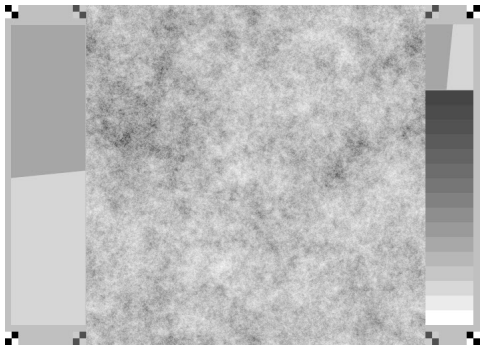
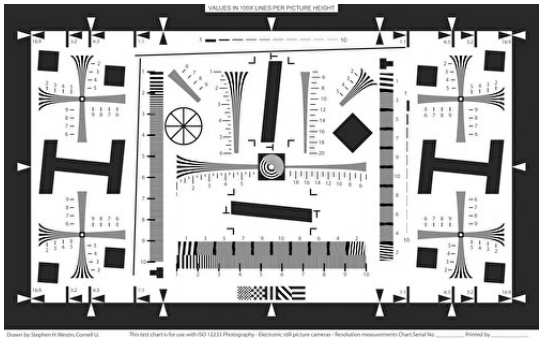
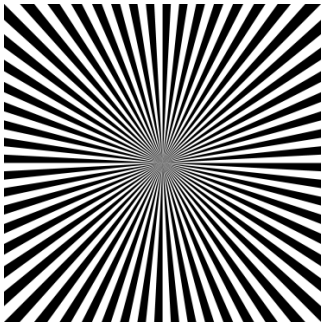
- Leverage methods used in making Prosthetic eyes and Hollywood Special effect
  - use casting process with Polymethyl Methacrylate (PMMA)
- Use high DPI printer to print out any target pattern, embed in 2 part casting mold, and polish…



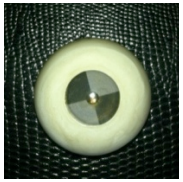
Candidate Metrics Considered

- Spatial Frequency Response (Modulation Transfer function)
- Linearity of detector response
- Specular Reflection Noise From Corneal Surface
- Contrast SNR Vs. spatial Frequency
  - Border Contrast
  - Iris texture
- Matching Algorithm-Based Intercomparison
  - Degradations specific to a matching algorithm

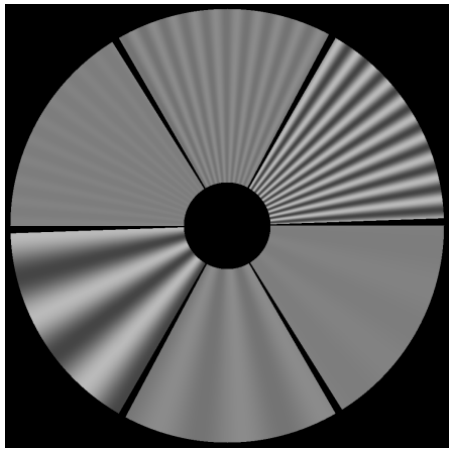
Target Pattern Selection

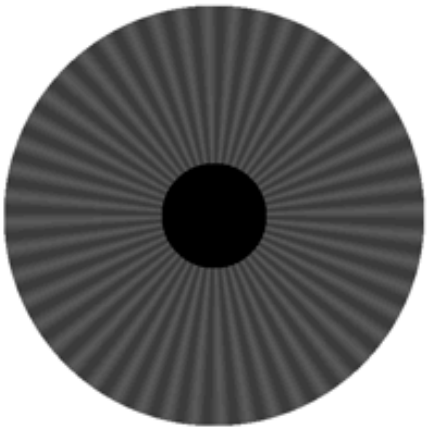





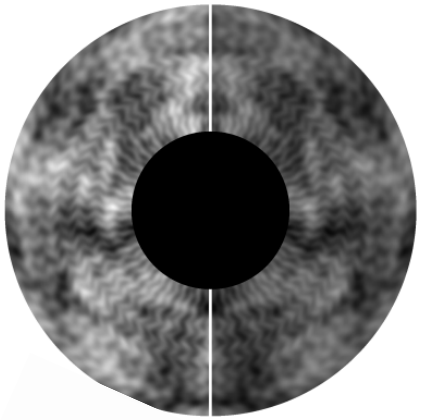
Goal to consolidate purposes into package which can pass device collection criteria

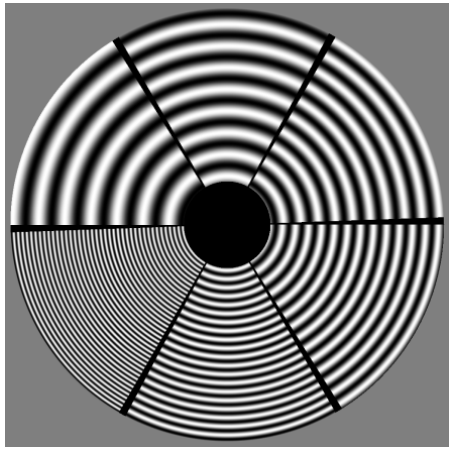


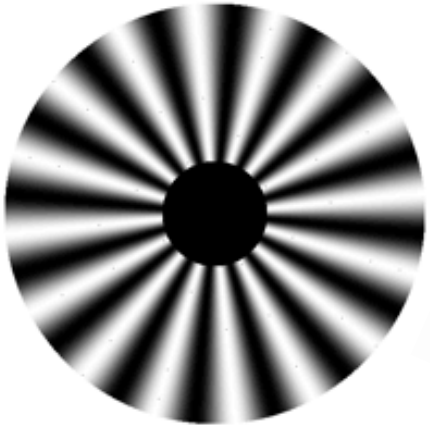

Target Patterns Considered



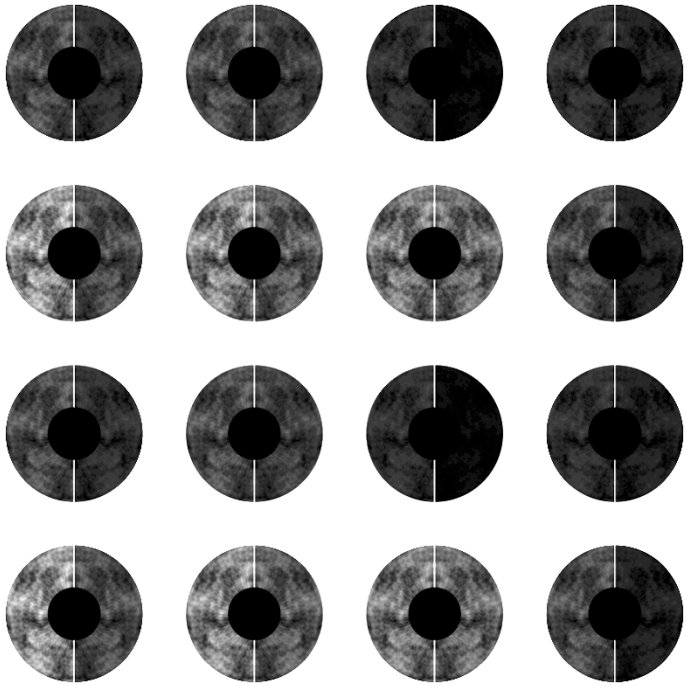




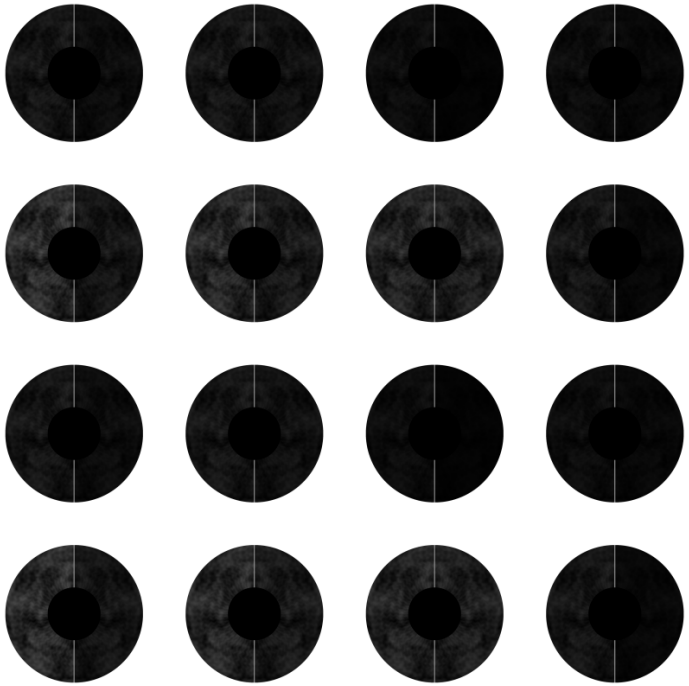




Albedo Calibration of Printer



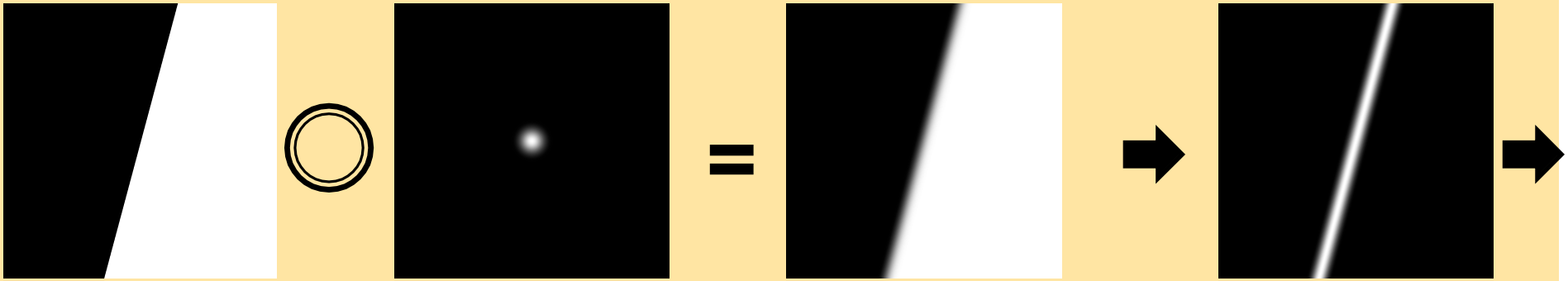
Creation Greyscale



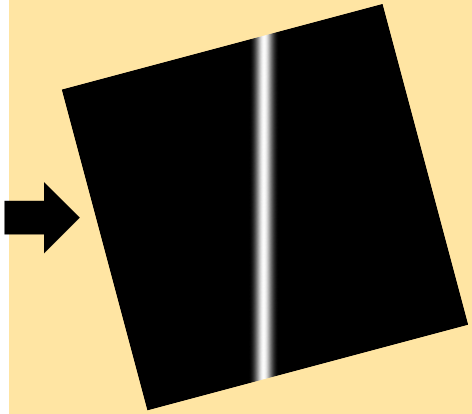
Printer Ink Albedo Calibrated Greyscale (low dynamic range!)

Method for MTF extraction

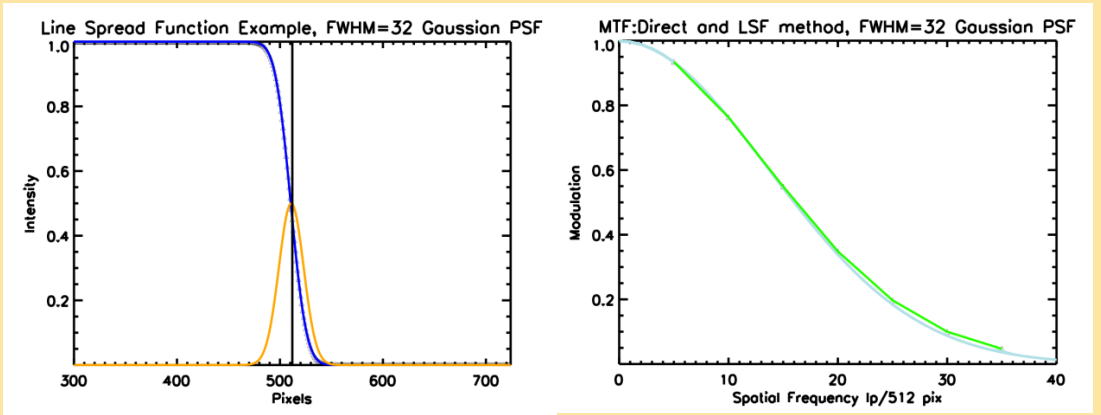
ISO 12233 slanted edge test



df/dx

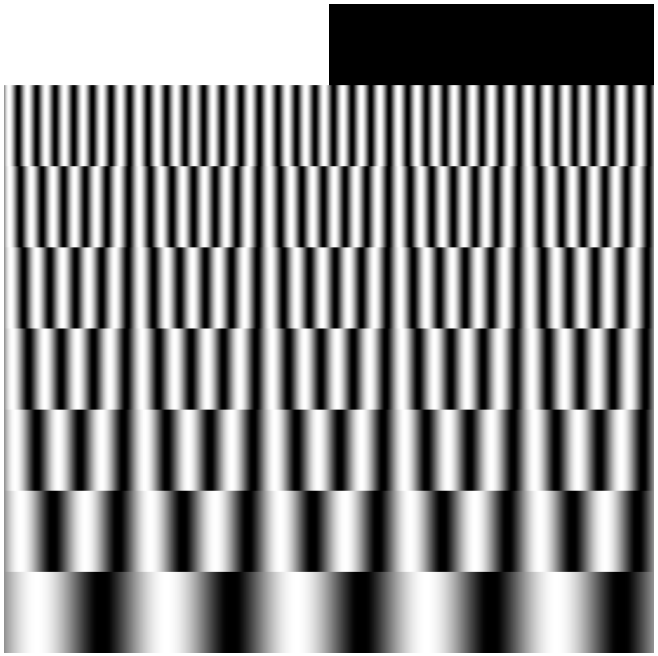


Rotate



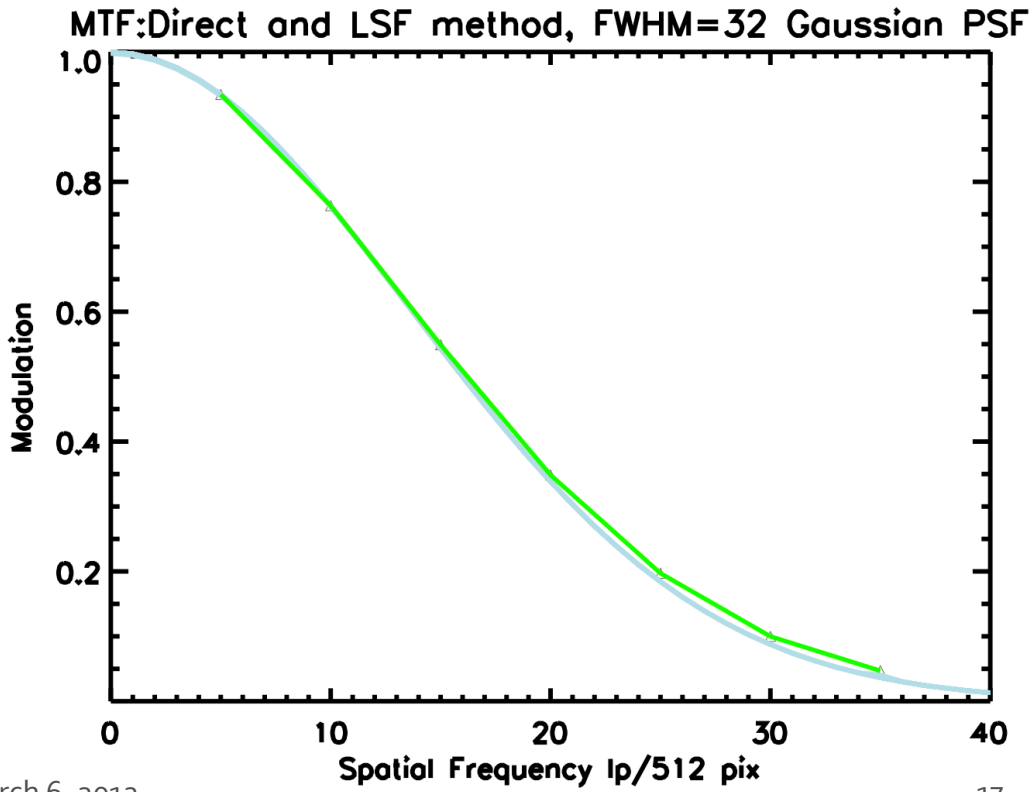
1d fft

Analysis Method: MTF

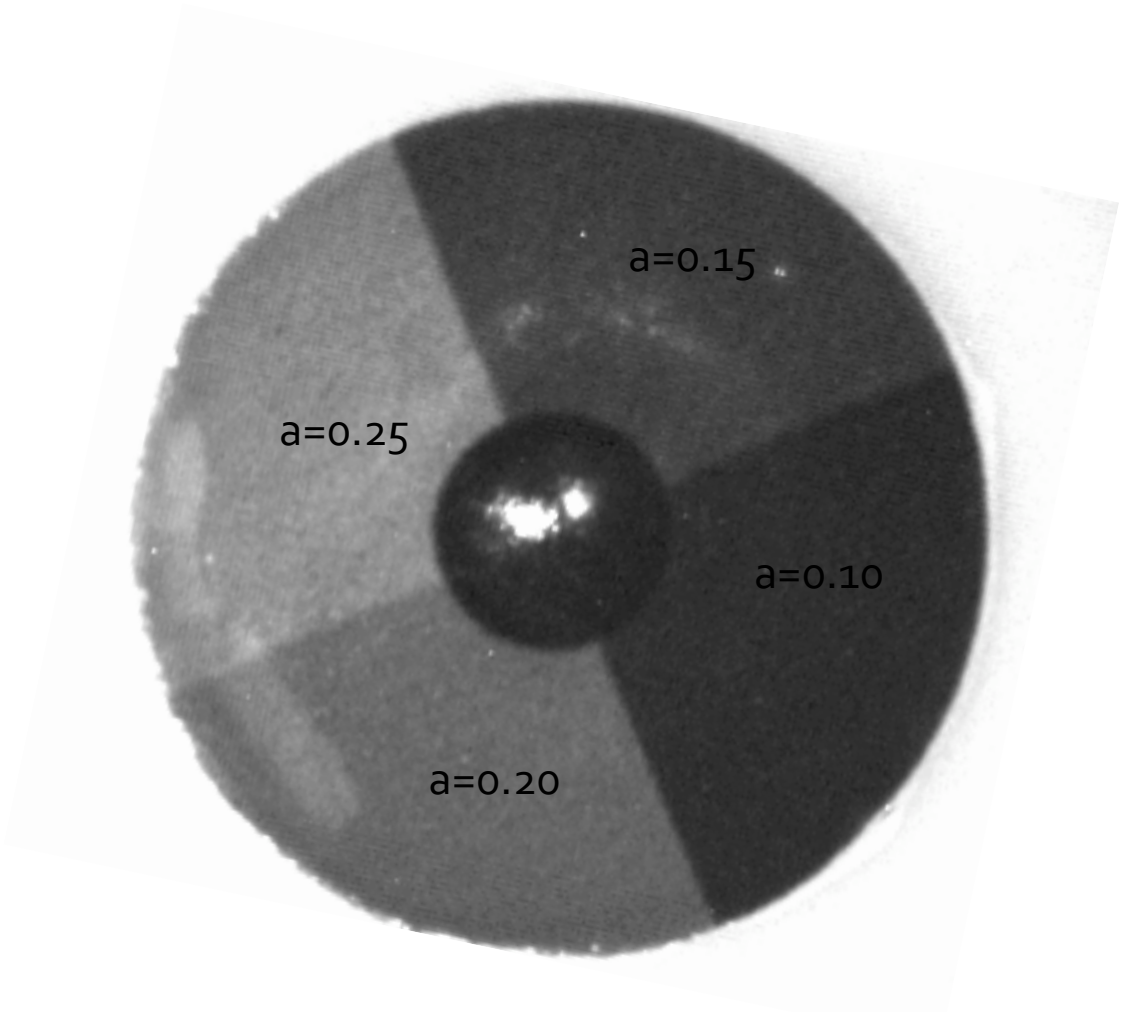


Both Edge and
Sin Modulation Information
Convolved with same PSF

ISO 12233 Edge method = **Blue**
Direct Modulation method = **Green**

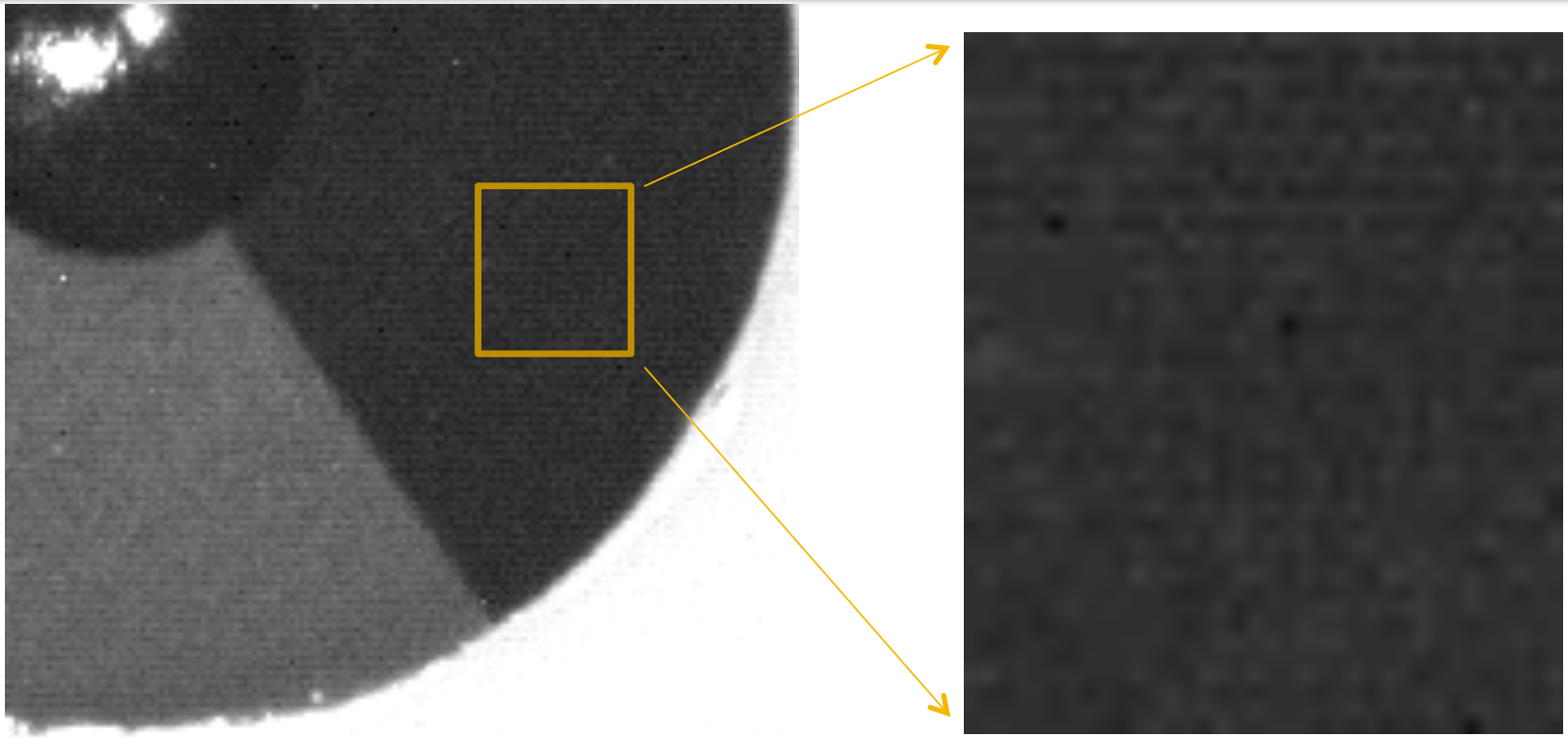


Analysis Method: Detector Linearity



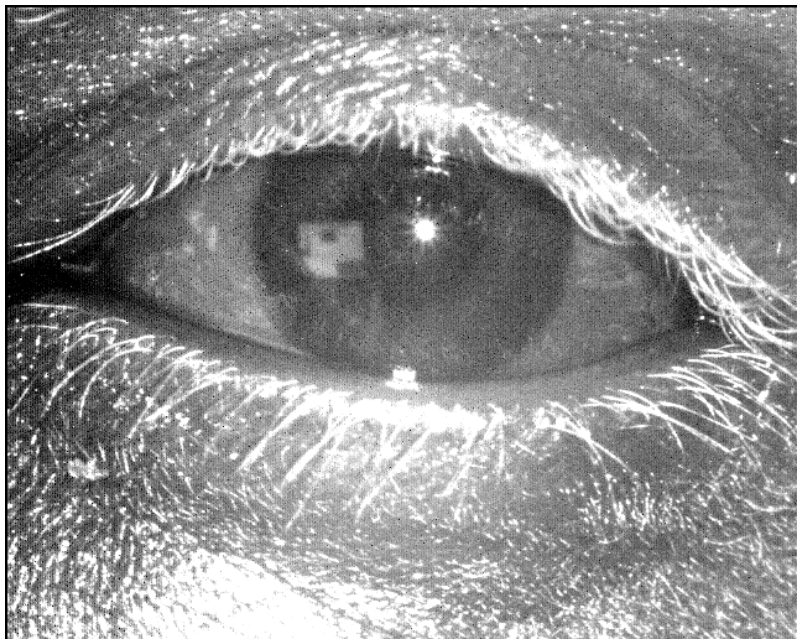
- Target has albedo calibrated graded steps
- Fit line to model, statistical analysis on errors
- Check systematics (specular reflections) by rotating target via test protocol

Analysis Method: Contrast SNR



- Establish Distribution Type (Gaussian)
- Calculate Standard Deviation versus cell size and albedo
- Propagate through definition of feature function (ridge, slope, spatial freq.)
- Use (hopefully) Gaussian Statistics for simplicity (i.e. 1,2,3.. Sigma Vs. feature type)

Analysis Method: Specular Reflection Noise



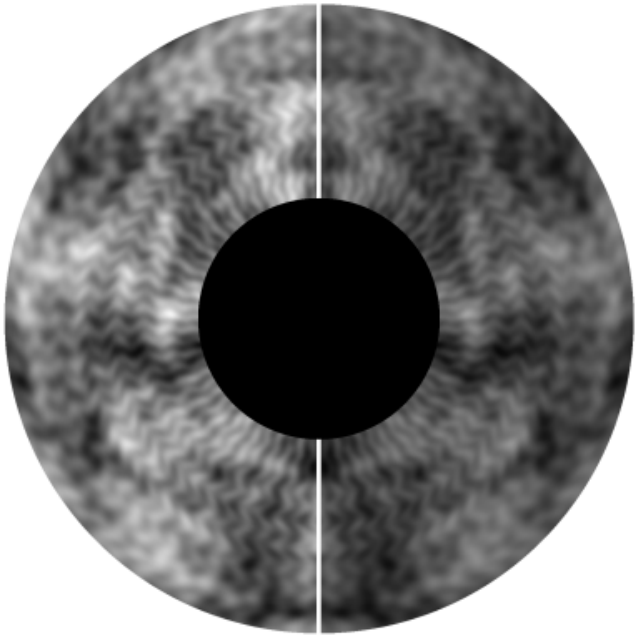
1550nm multispectral image
(Albedo of iris~2%)

- Use a dark, homogeneous low albedo
- Calibrate reflectivity of surface
  - -Need to do this still for corneal reflection, and target
- Control periocular Scene
  - -3-D scattering parameters!
  - - (could get complicated)

Analysis Method (Algo explicit Feedback)

- If the image can pass the algorithm segmenter, one can use encoding/matching as a metric with a ***controlled pattern.***

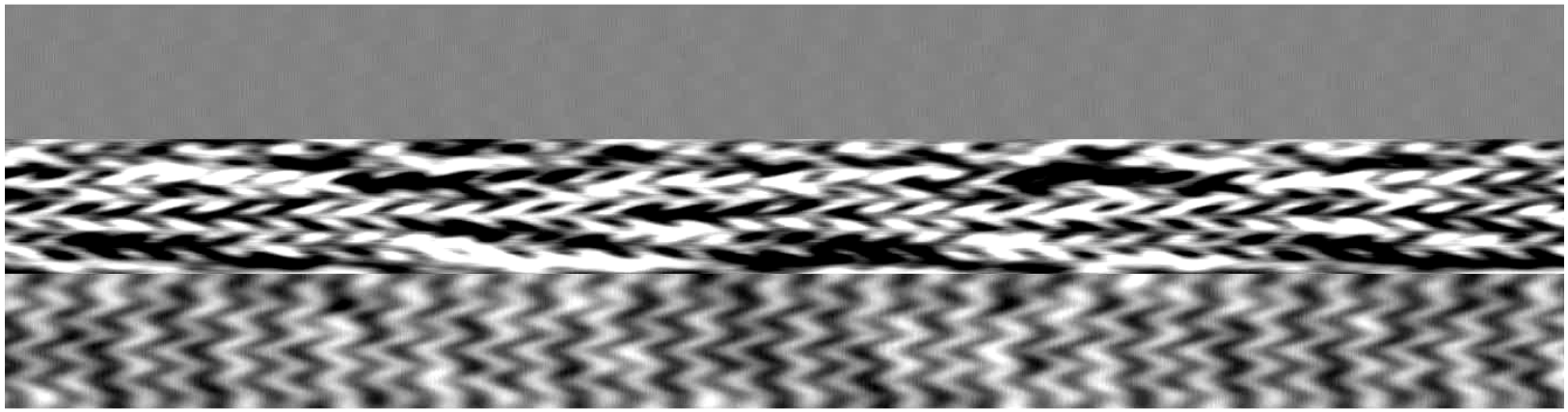
- Broadband Encoder Response



Illustrative example: Broadband Encoder Response

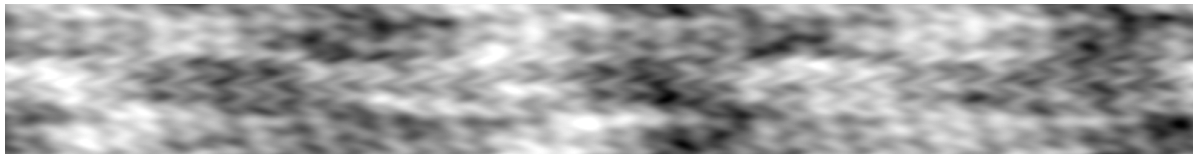
Psuedo-Polar Normaized

Encoded signal (3 Haar filters varying Spatial Freq. to make cube)

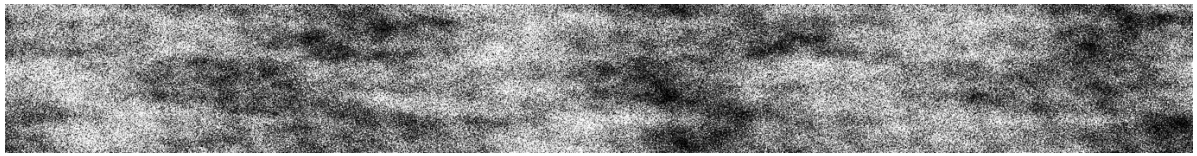


Illustrated Example: Broadband Encoder Response

Normalized Image (PRISTINE)



Normalized Image (Noisy)



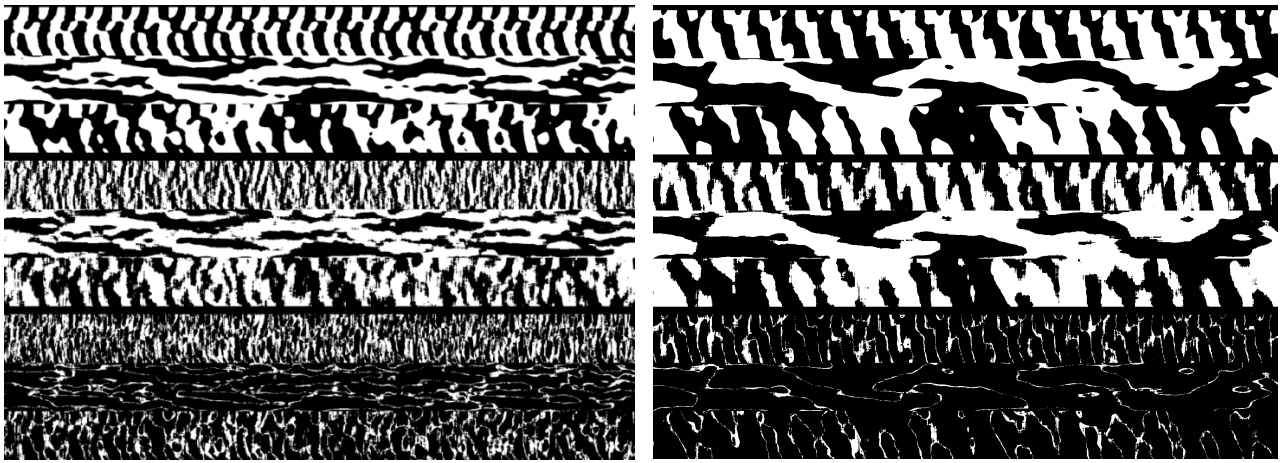
High Frequency

Middle Frequency

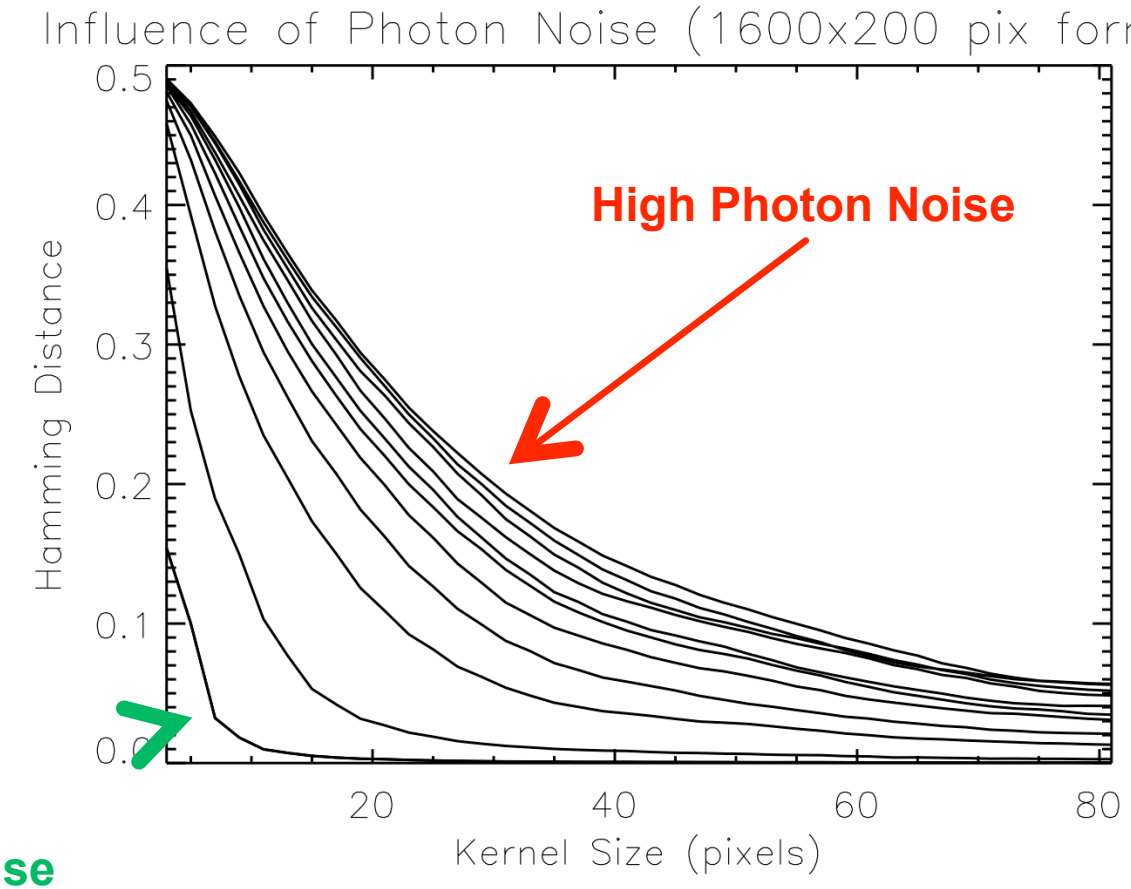
Template (PRISTINE)

Template (Noisy)

XOR RESULT



Influence of photon Noise (con't)



low Photon Noise

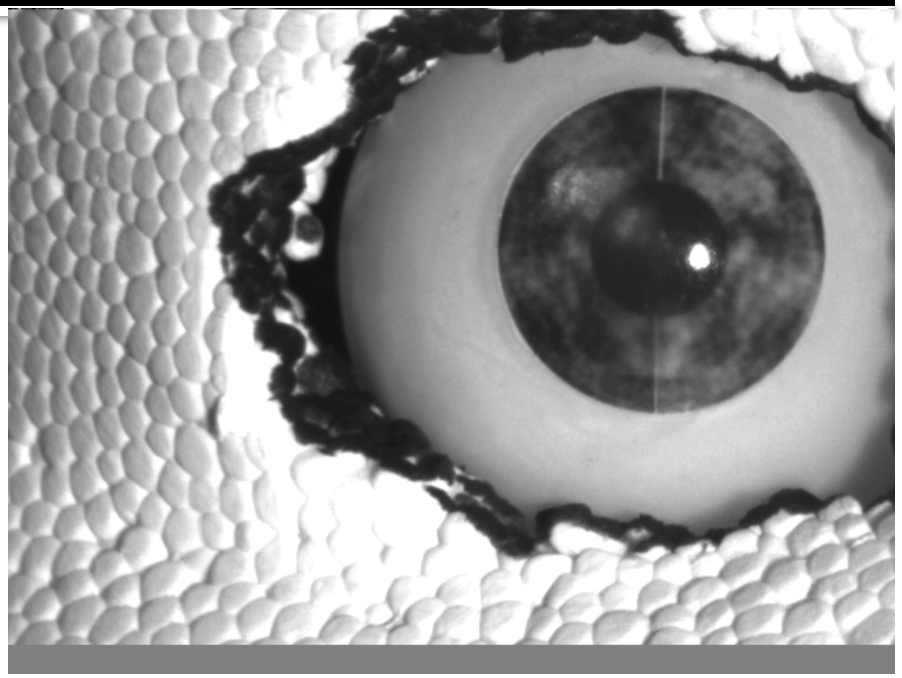
High Frequency

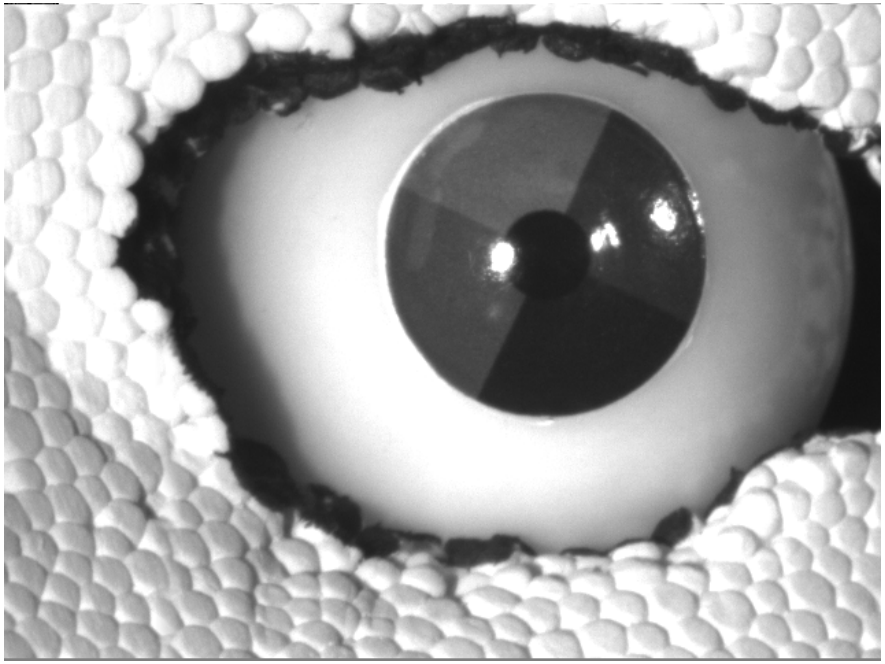
Low Frequency

Current Status

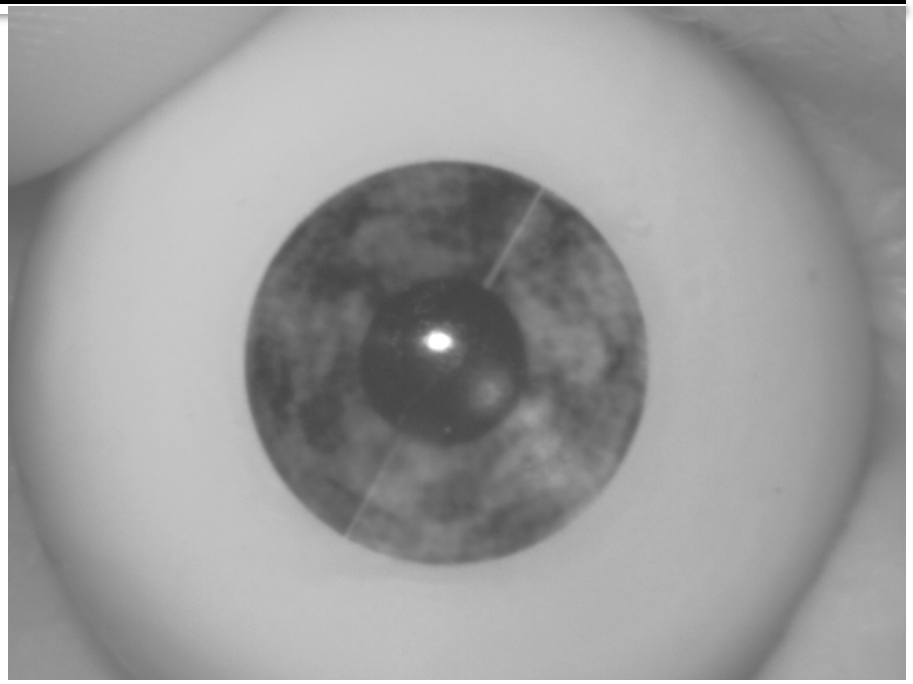
- Have calibrated multiple targets in albedo, and spatial frequency response (losses from printer)
- Have working "High Level" algorithms to process data to and produce output metrics mentioned in this presentation
- Have collected using 3 devices

Captures with Real Devices – D1

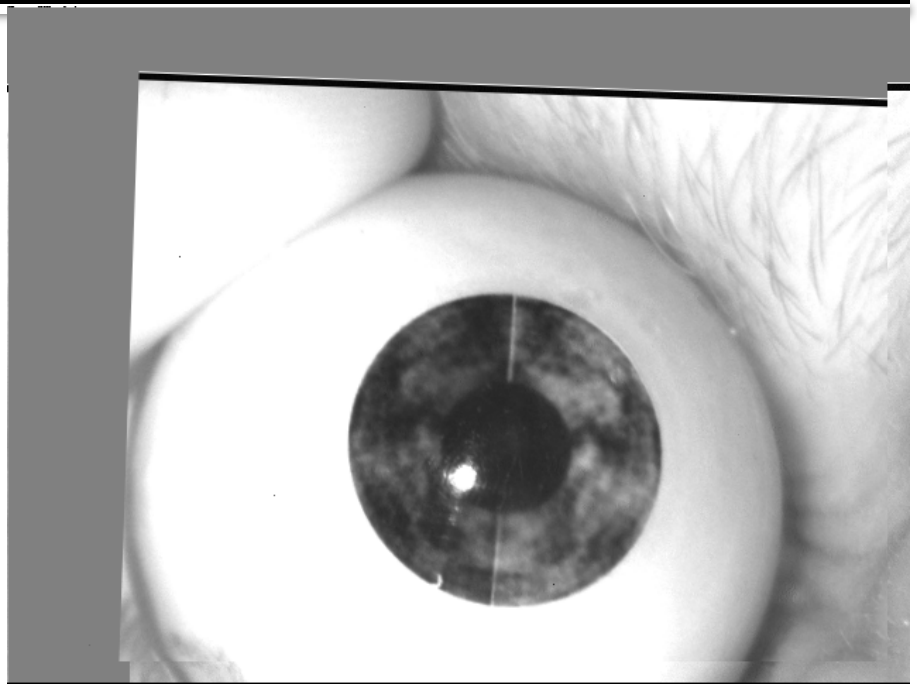


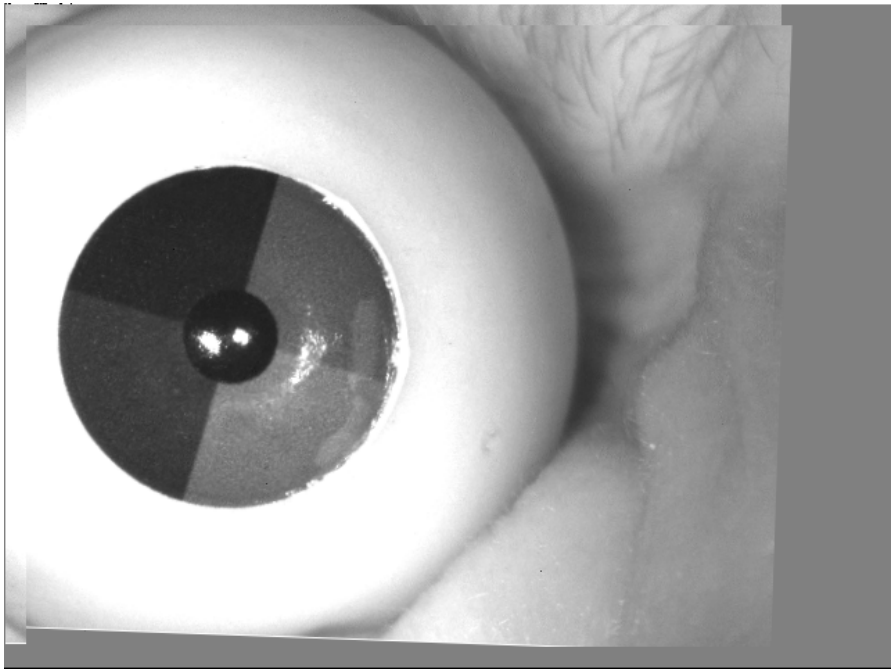


Captures with Real Devices – D2



Captures with Real Devices – D3





- Needs to be tied to matching accuracy
- Application Dependent?
- Guidance from ISO standards and NIST studies?

work ahead immediate future

- Identifying target manufacturers
- Calibration of specular reflection –Realistic 3-D Face Scene
- Iterative improvements on metrics

Acknowledgements

Work Supported by ***DHS S&T…***

IDQT Development roadmap