High Dynamic Range Imaging

Applied Physics Lecture

(Slides from MS Thesis of Melvin Estonactoc)

High Dynamic Range Imaging

- Improve the image intensity representation of a camera

Brief History

1963 – Charles Wyckoff

- high dynamic range film was used by chemically fabricating a multilayer of photographic emulsion with different sensitivities to time of exposures to the impinging light.

- example of a scene captured using the technique is a nuclear explosion

1990's – onwards

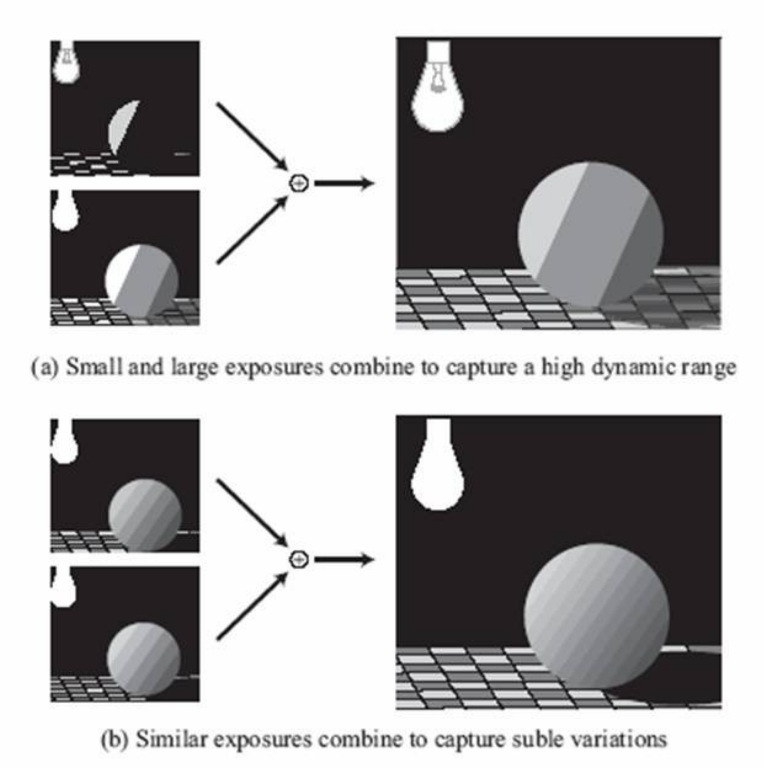
- HDR imaging in digital cameras using multiexposure capture

High Dynamic Range Imaging

Sequential Exposure Variation – Static Scene

Exposure for each image is controlled and varied by the f-number of the imaging optics or the detector exposure time.

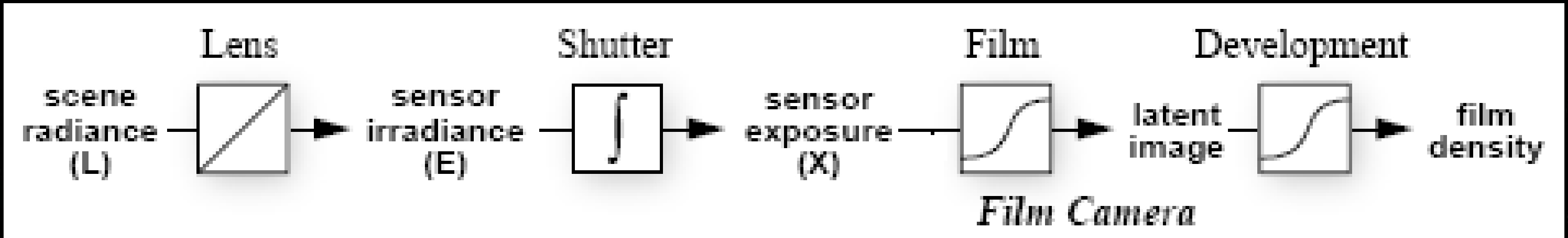
Figure. Capturing a single scene at different exposures. (a) Low and high exposures produced an HDR image but no subtle variations. (b) Same exposure produced subtle variations but with limited dynamic range.


(a) Small and large exposures combine to capture a high dynamic range

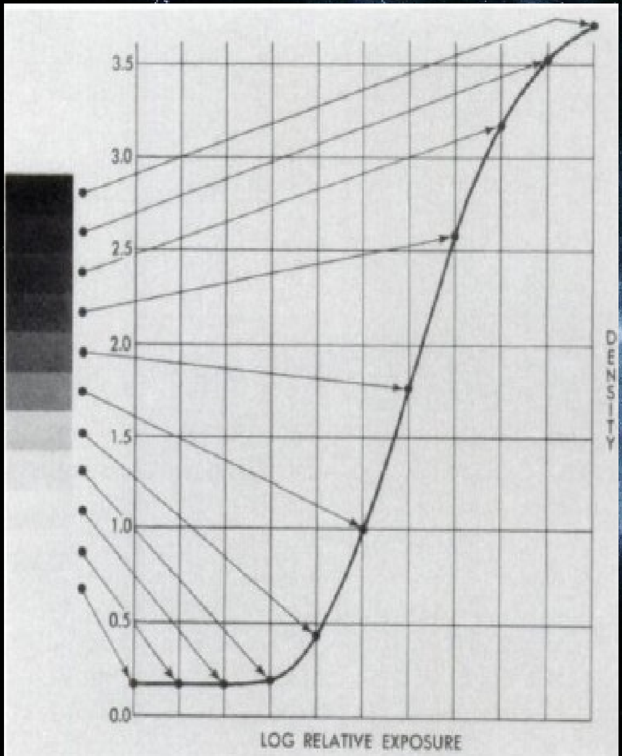
(b) Similar exposures combine to capture suble variations

Combining these images is numerically possible to produce a single HDR image.

Film Camera Model



Film camera image acquisition flowchart.



Reciprocity Law,

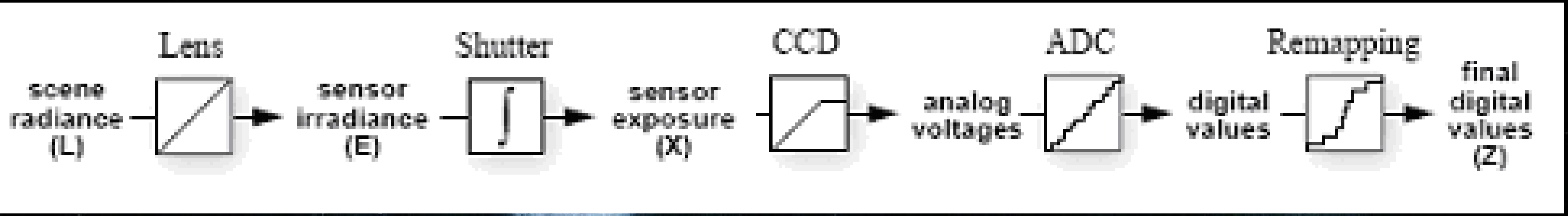
$$X = E\,\Delta t, \text{ (Exposure)} \qquad (1)$$

Optical density,

$$OD = \log 10\,(Eo/\,E) \qquad (2)$$

Typical characteristic (H-D) curve of a mammographic film.

Digital Camera Model

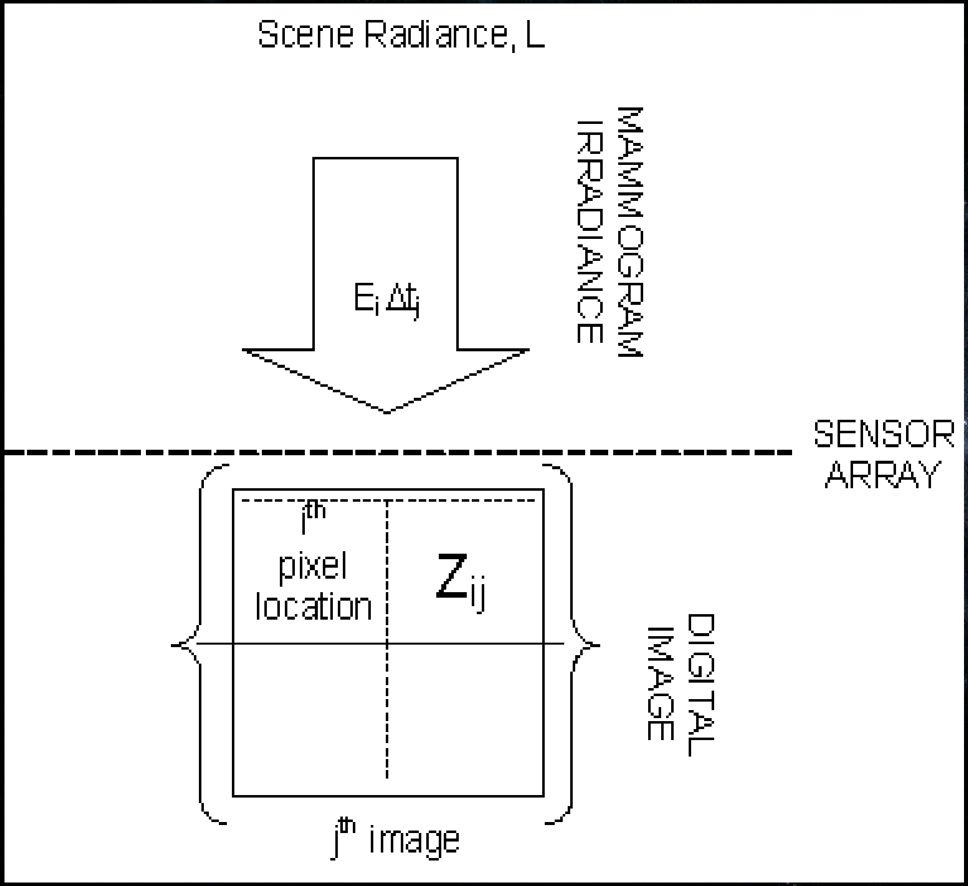


Digital Image Acquisition Flowchart.

$Z = f\,(X)$, (pixel value)	(3)
$X = f^{-1}\,(Z) = E\Delta t$	(4), (5)
$E = X/\Delta t$	(6)
$E = f^{-1}\,(Z)/\,\Delta t$	(7)

High Dynamic Range Imaging

Debevec-Malik Algorithm – Response Function Recovery



$$Zij = f(Ei\ \Delta tj) \qquad (8)$$

$$f^{-1}(Zij) = Ei\Delta tj \qquad (9)$$

High Dynamic Range Imaging

Debevec-Malik Algorithm – Response Function Recovery

$$\ln[f^{-1}(Z_{ij})] = \ln(E_i \Delta t_j) \tag{10}$$

$$g(Z_{ij}) = \ln(E_i) + \ln(\Delta t_j) \tag{11}$$

i ranges over pixels and j ranges over the different exposure durations

Z_{ij} and Δt_j are known quantities and E_i, and g, are the unknowns.

To determine the estimate values of irradiances E_i's by recovering the function g satisfying Equation (11) in a least square error sense.

High Dynamic Range Imaging

Debevec-Malik Algorithm – Response Function Recovery

Letting Zmax and Zmin be the maximum and minimum integer values of the pixel, N be the number of pixel locations in the image and P the numbers of images, leads to the minimization of the following objective function

$$O = \underbrace{\sum_{i=1}^{N} \sum_{j=1}^{P} \left[g(Z_{ij}) - \ln E_i - \ln \Delta t_j \right]^2}_{\text{optimum least-square error}} + \underbrace{\lambda \sum_{z=Z_{min}+1}^{Z_{max}-1} g''(z)^2}_{\text{smoothing term}}, \quad (12)$$

where,

$$g'' = g(z-1) - 2g(z) + g(z+1) \quad (13)$$

High Dynamic Range Imaging

Debevec-Malik Algorithm – Response Function Recovery

To reduce the influence of saturated pixels and pixel values overridden by the noise of the camera, a weighting function w(Zij) that gives more importance towards the middle gray values is introduced.

$$w(z) = \begin{cases} z - Z_{min} & \text{for } z \leq \frac{1}{2}\left(Z_{min} + Z_{max}\right) \\ Z_{max} - z & \text{for } z > \frac{1}{2}\left(Z_{min} + Z_{max}\right) \end{cases} \qquad (14)$$

High Dynamic Range Imaging

Debevec-Malik Algorithm – Response Function Recovery

$$O = \sum_{i=1}^{N} \sum_{j=1}^{P} \left\{ w(Z_{ij}) \left[g(Z_{ij}) - \ln E_i - \ln \Delta t_j \right] \right\}^2 + \lambda \sum_{z=Z_{min}+1}^{Z_{max}-1} \left(w(Z_{ij}) g''(z) \right)^2 \qquad (15)$$

The best possible solutions to the objective function that is quadratic in g(z)'s and Ei's are obtained using singular value decomposition (SVD), which is a method of choice for solving most linear least-squares problems.

High Dynamic Range Imaging

Debevec-Malik Algorithm – HDR Image Pixel Values

After solving g,

$$\ln E_i = g(Z_{ij}) - \ln \Delta t_j \qquad (16)$$

To recover the irradiance per pixel, P images of varying exposures are obtained and combined. Since parts of these images will once again have saturated or underexposed values, we employ once again a weighted average over P images using w(Zij) to Equation (16) to obtain a more reliable estimate of Ei, that is,

$$\ln E_i = \frac{\sum_{j=1}^{P} w(Z_{ij})\left(g(Z_{ij}) - \ln \Delta t_j\right)}{\sum_{j=1}^{P} w(Z_{ij})} \qquad (17)$$

High Dynamic Range Imaging

HDR Optical Density Image

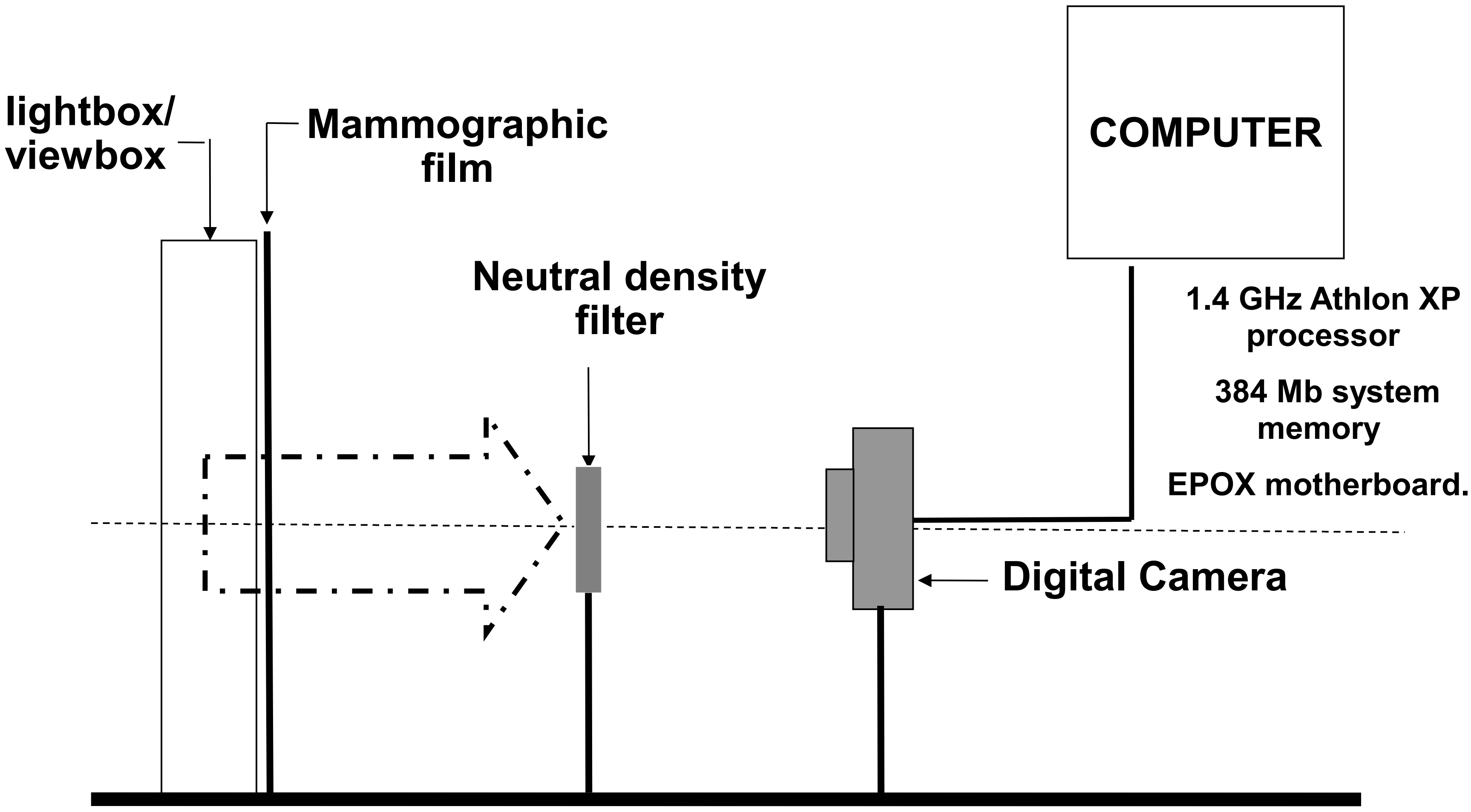
From equation (17)

$$OD = \log 10(Eo/ Ei) \qquad (18)$$

Pixel OD values

$$ODi = \log 10(Eo,i) - \log 10(Ei) \qquad (19)$$

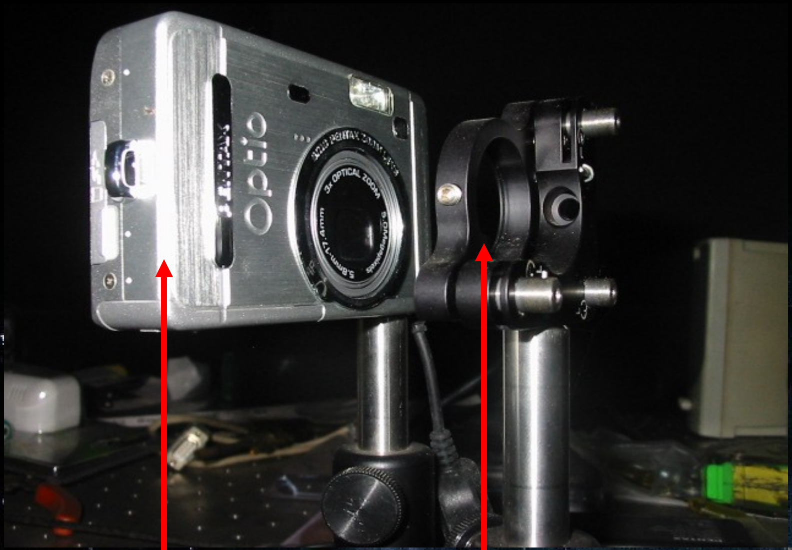
Mammographic Film Digitization/ Image Acquisition



Imaging/ Digitizer set-up schematic diagram.

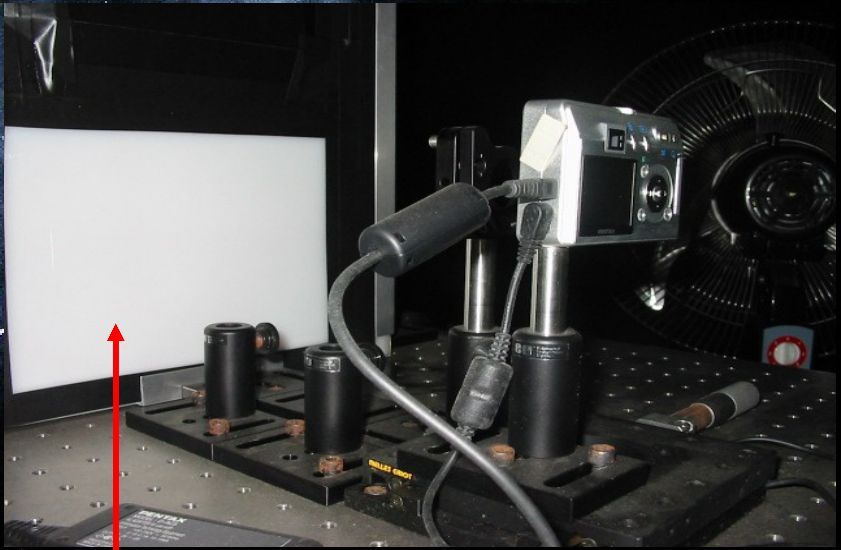
METHODOLOGY

Parameter	Setting
F-number	5.6
ISO speed ratings	400
Subject distance range	Macro
Metering Mode	Pattern
Pixel Dimension	1028 x768 pixels
Exposure Values	(-)2 to (+)2, 1/3EV increment

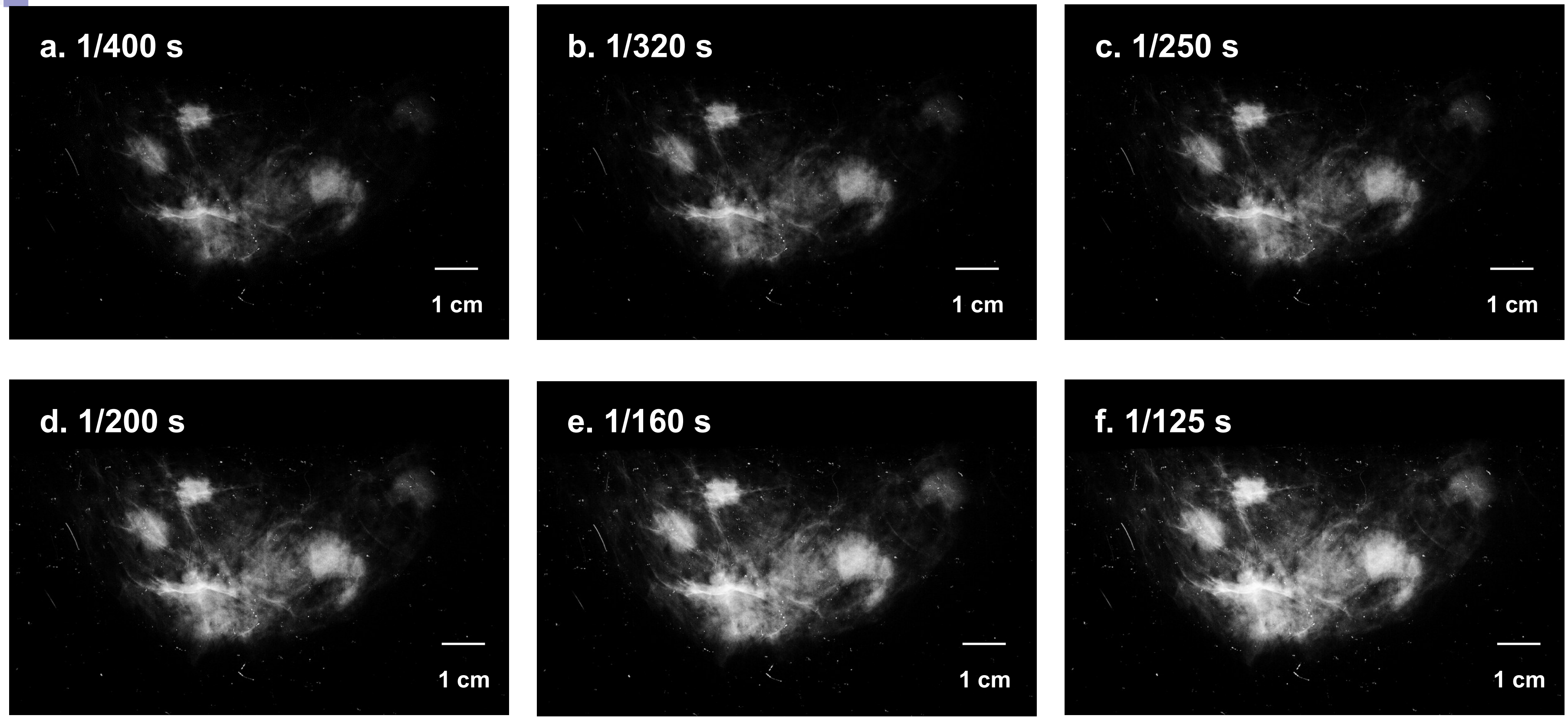


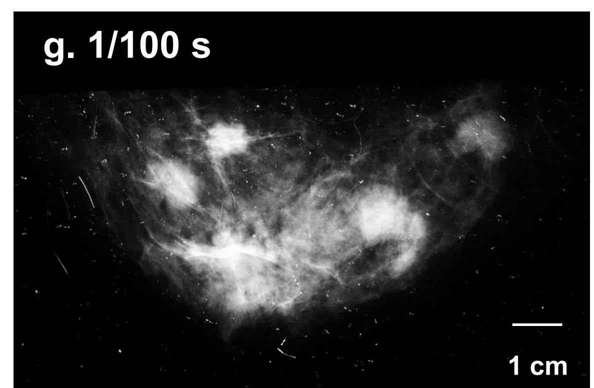
Pentax Optio S50 Digital Camera

ND filter optical mount



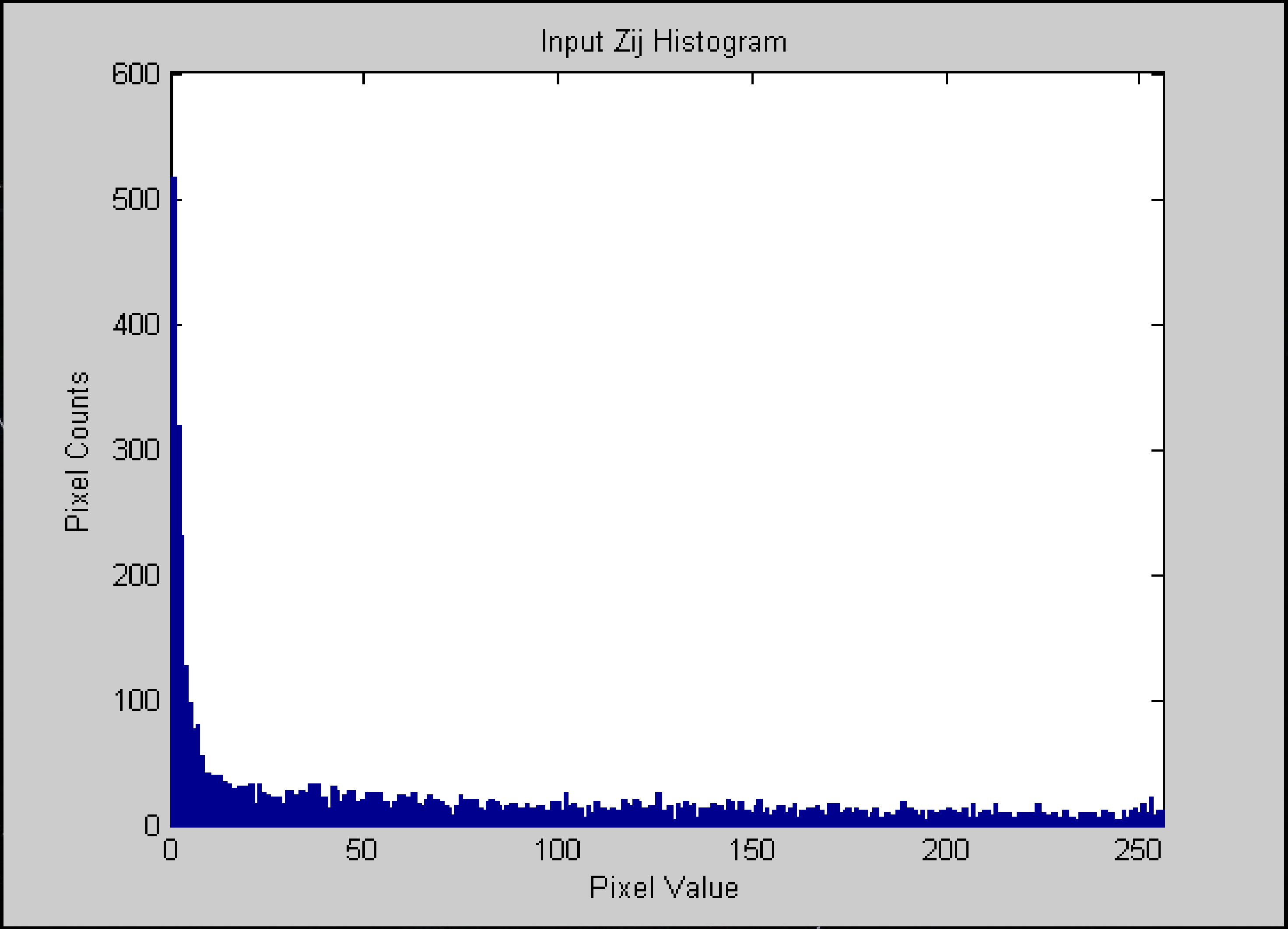
Lightbox/ Viewbox





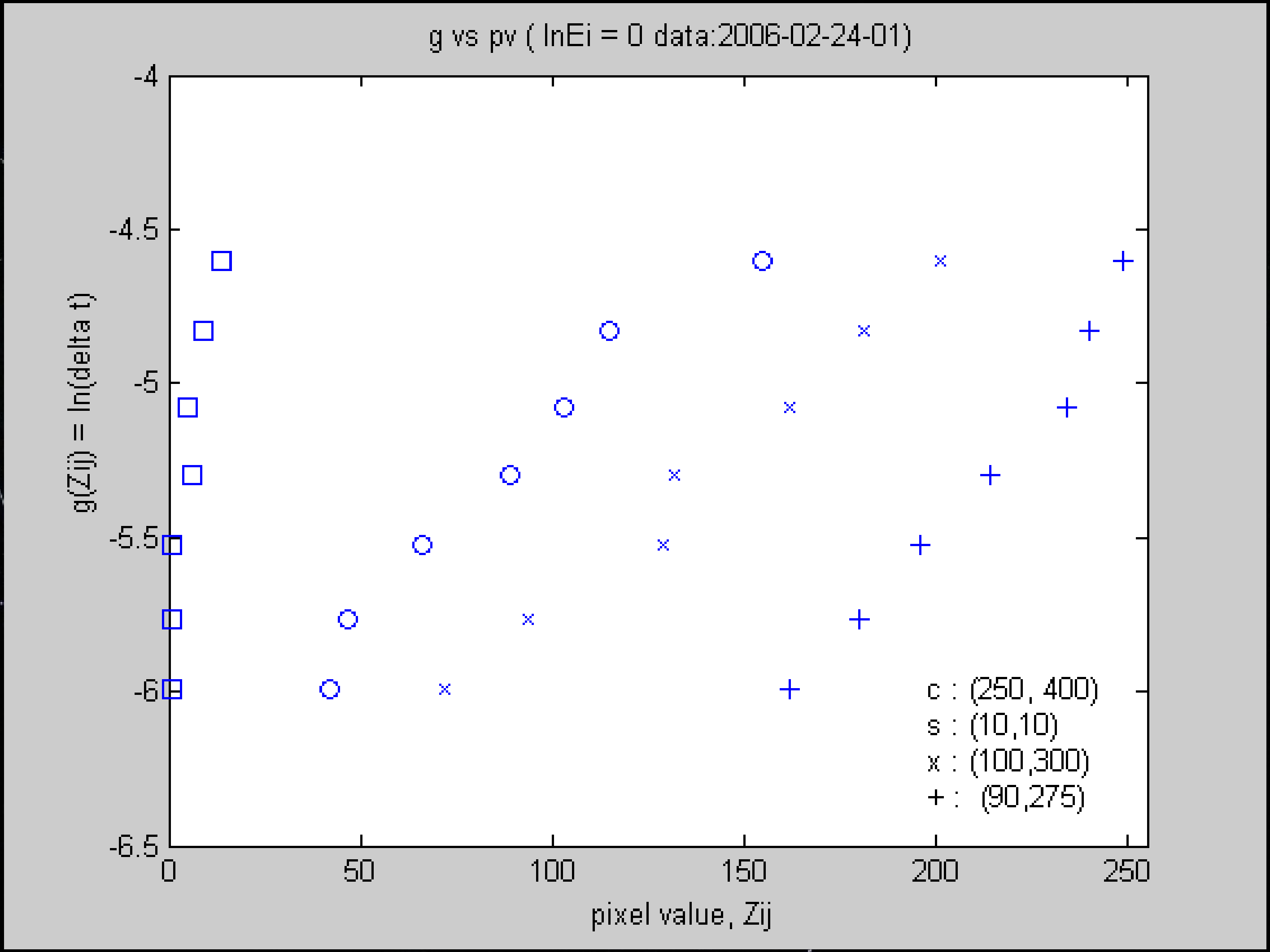
Figures (a-g). Grayscale digital images of the mammogram captured in order of increasing exposure time. DSC f-number is f/5.6 for all images. Cropped image size is 500 x 800 pixels.

RESULTS



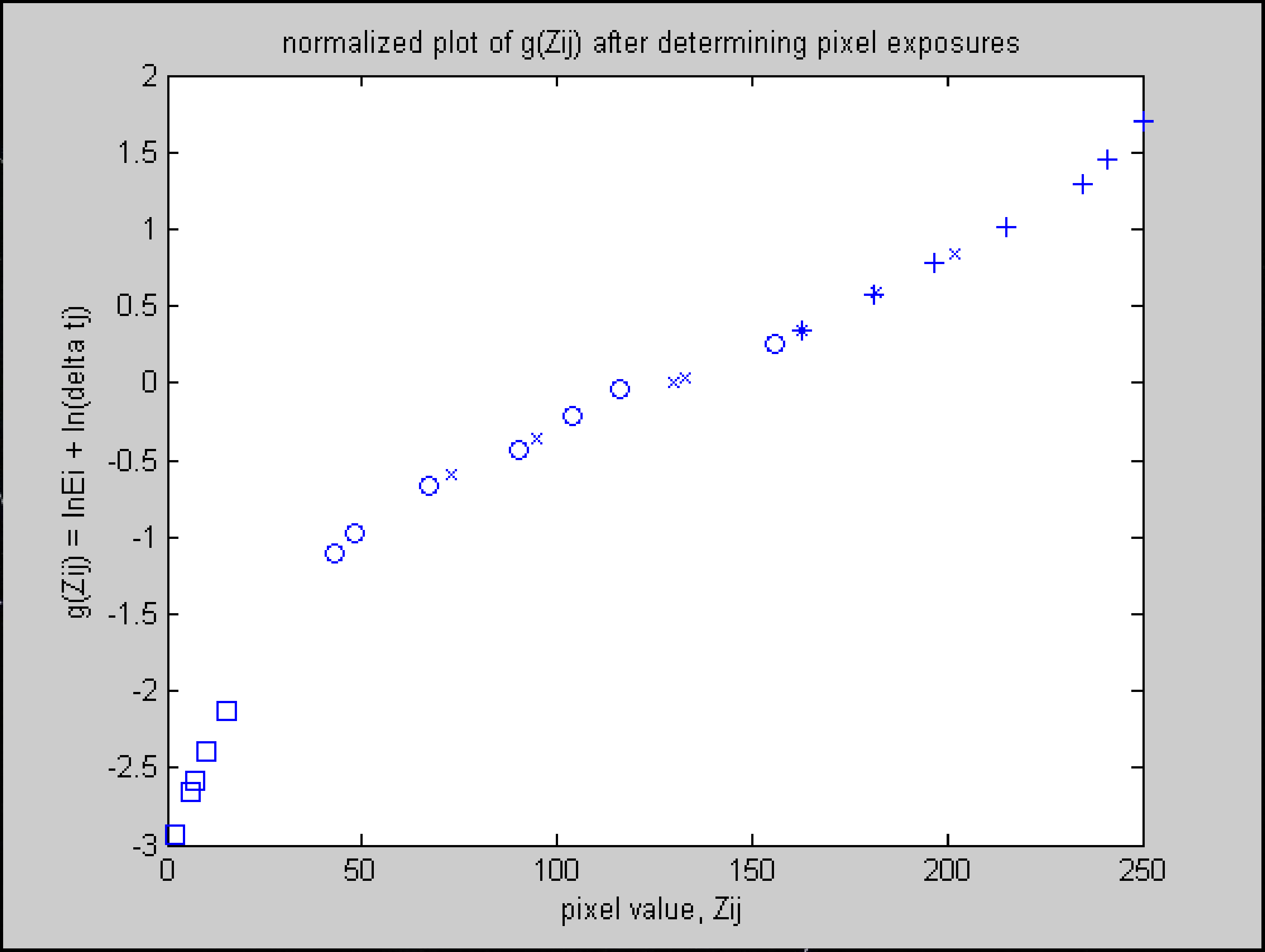
Histogram of the input pixel matrix from the selected pixels of each image.

RESULTS



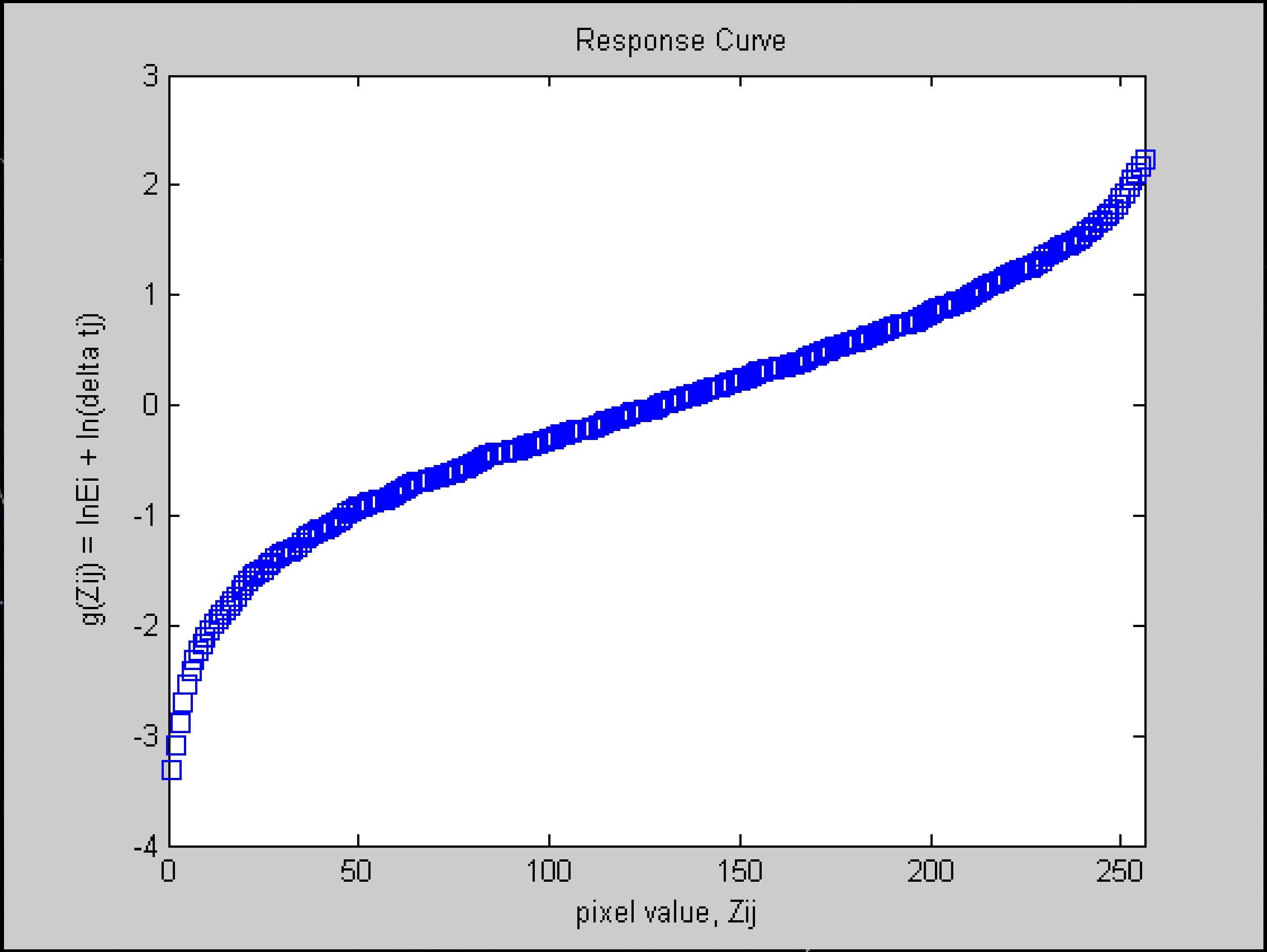
Samples of the response curve derived from the digital values of 4 pixel locations for 7 different known exposures using the equation g(Zij) = log(Ei) + log(Δtj) where logEi = 0 initially.

RESULTS



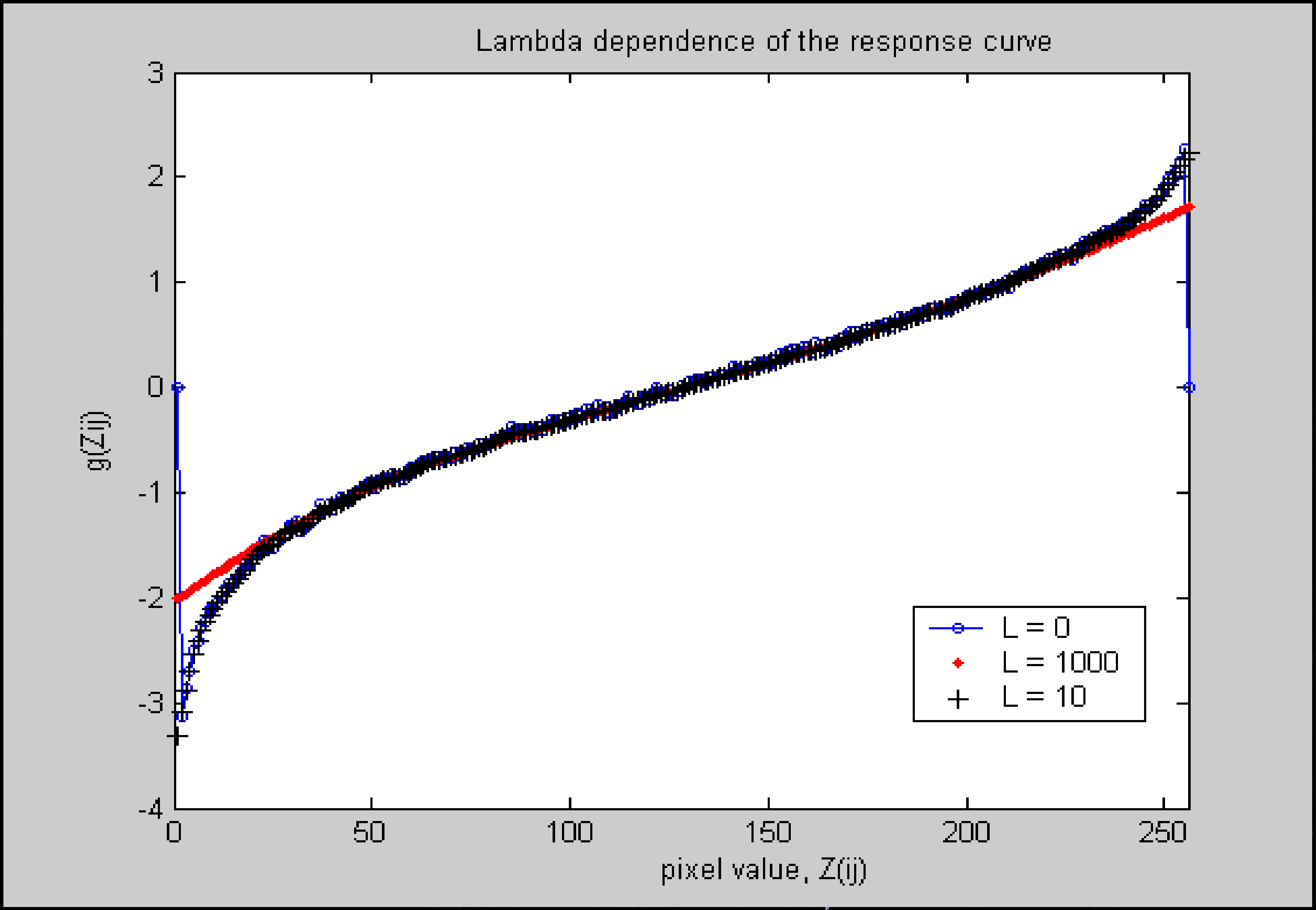
Aligned response curve of the segments in Figure 3.4 after determining Ei's.

RESULTS



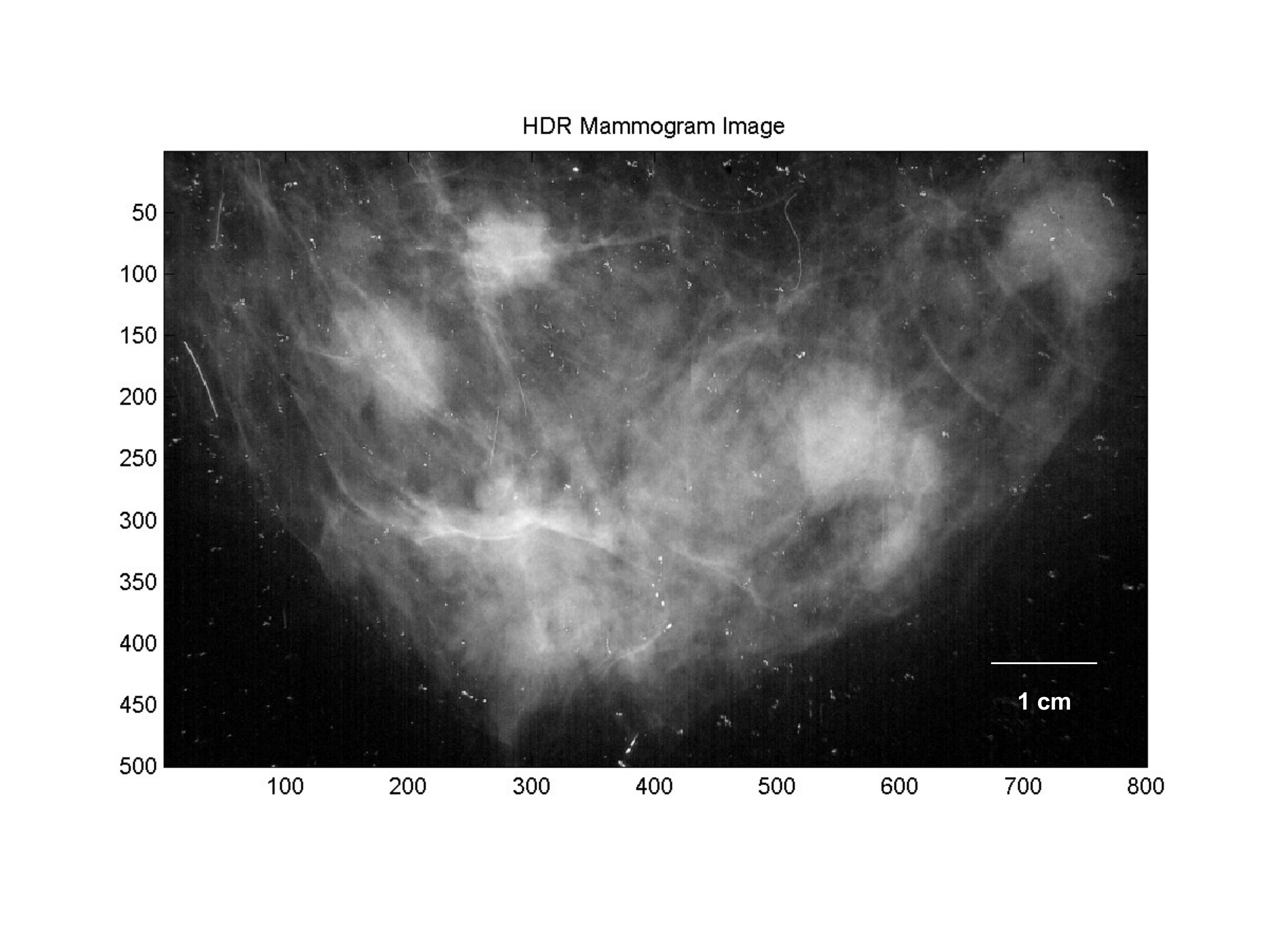
The system response curve determined by the Debevec-Malik algorithm.

RESULTS



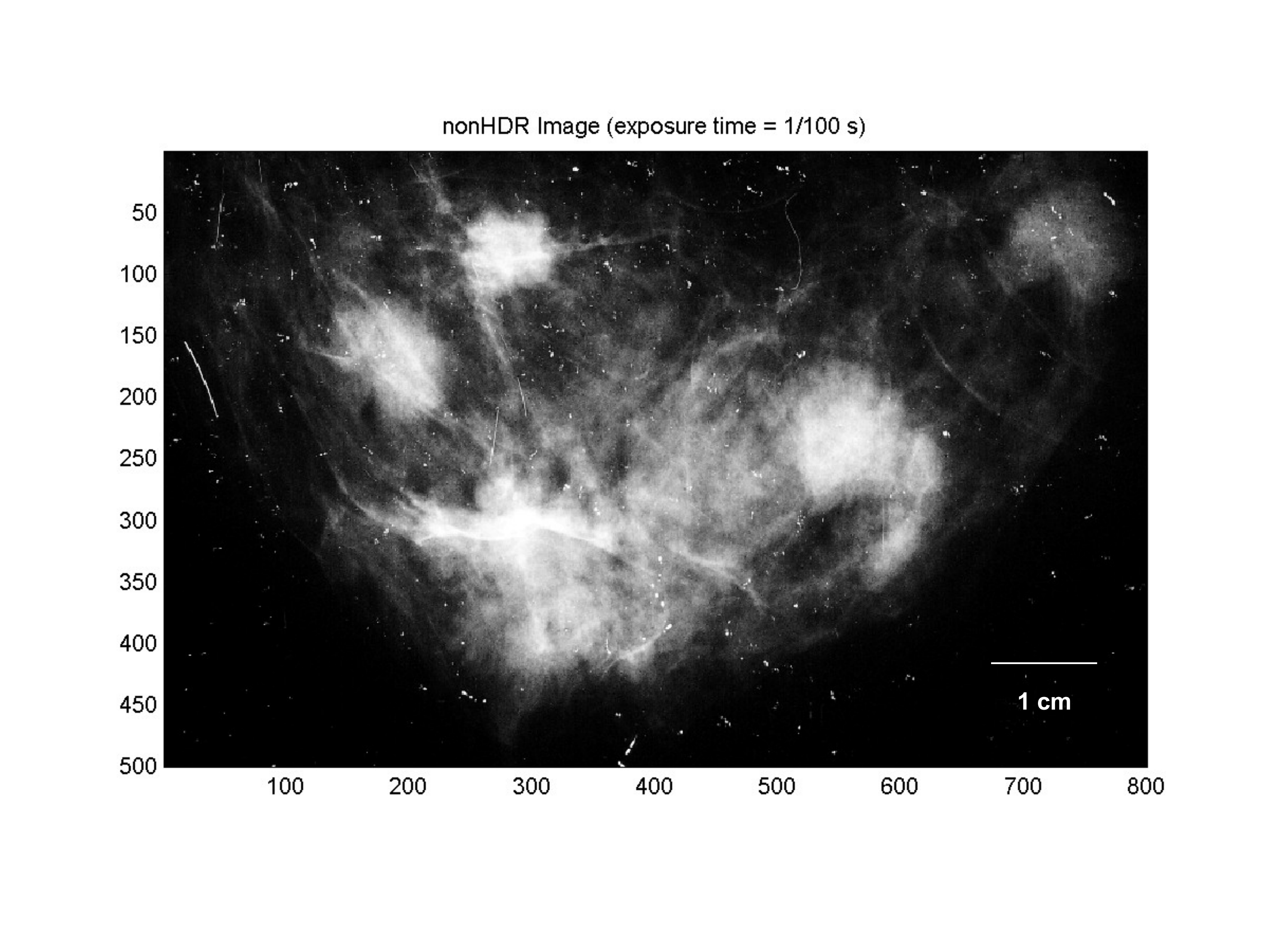
Smoothness factor, lambda, dependence of the response curve.

RESULTS



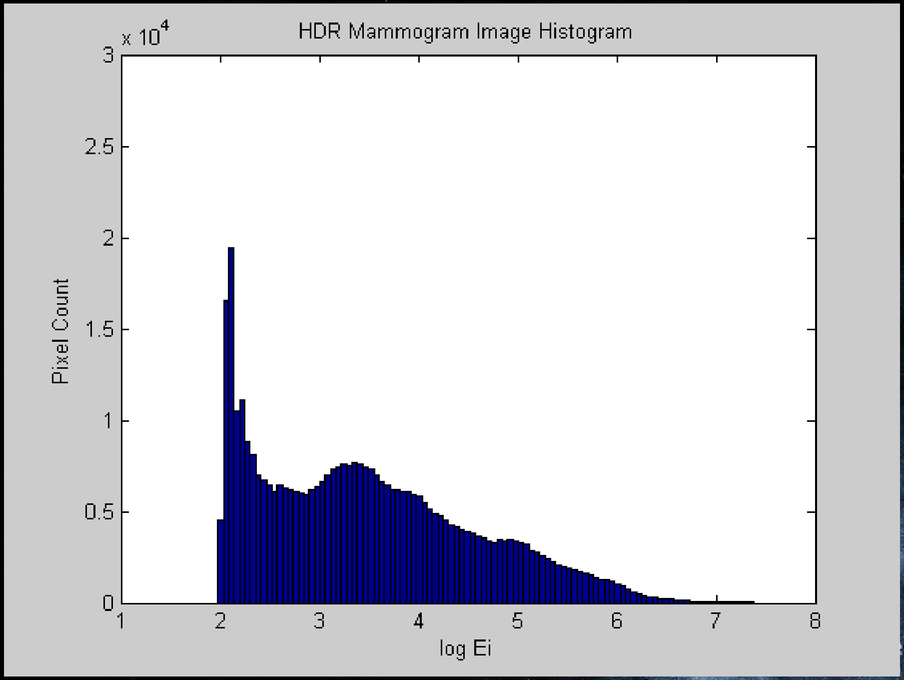
Reconstructed HDR mammogram image mapped into grayscale. Computed relative Ei values = [7.2549, 1.6117e+003].

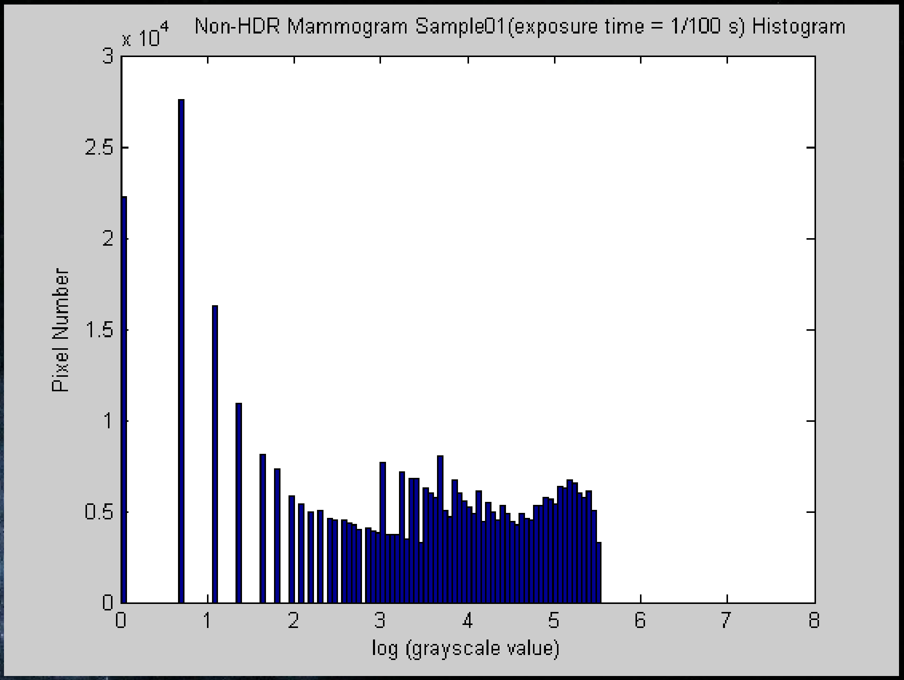
RESULTS



Non-HDR mammogram JPEG image format represented by 8-bit intensity gray levels. DSC exposure time is 1/100 s.

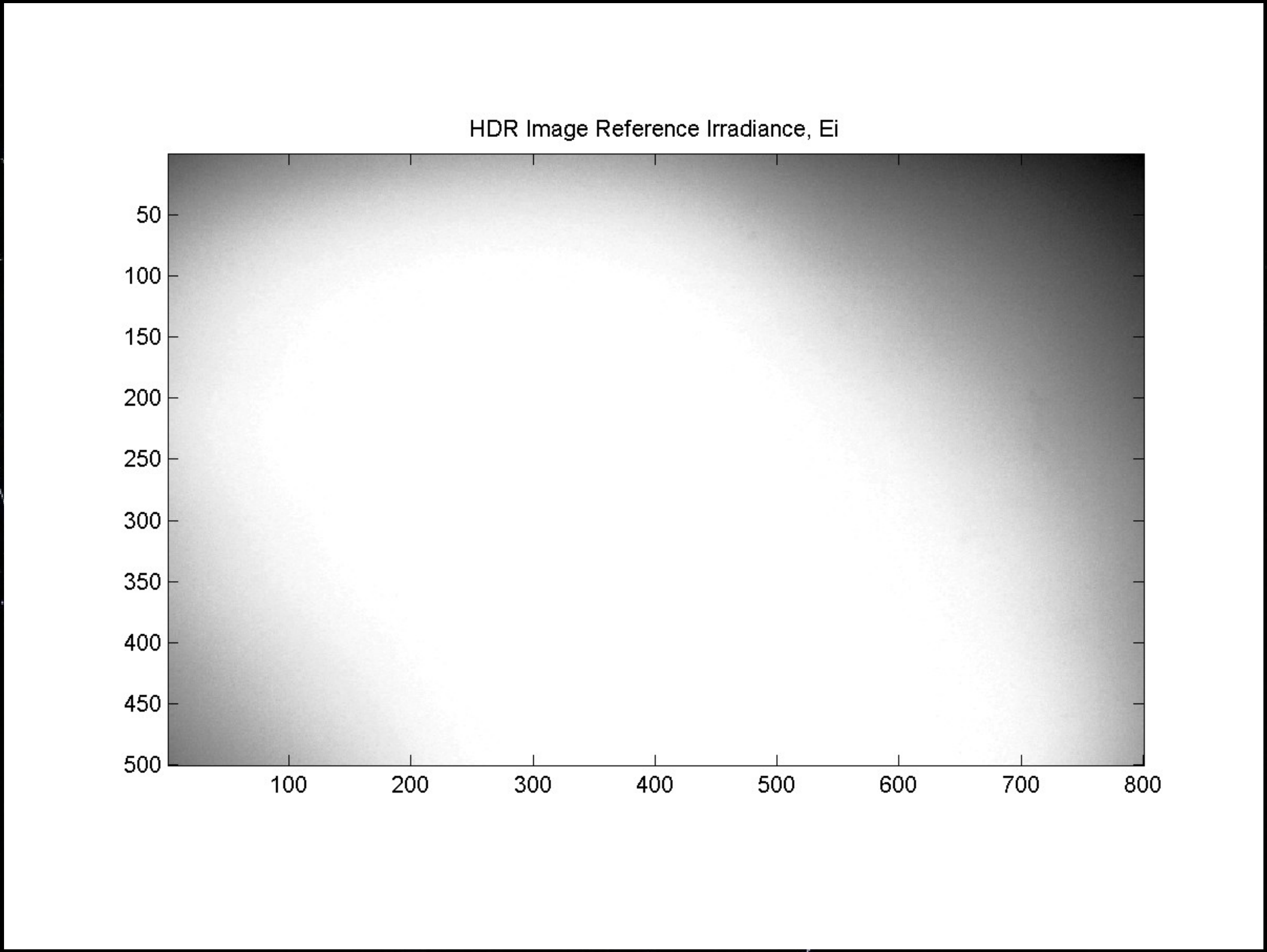
RESULTS





Mammogram Image Histograms. (a) HDR-OD image (b) LDR JPEG image

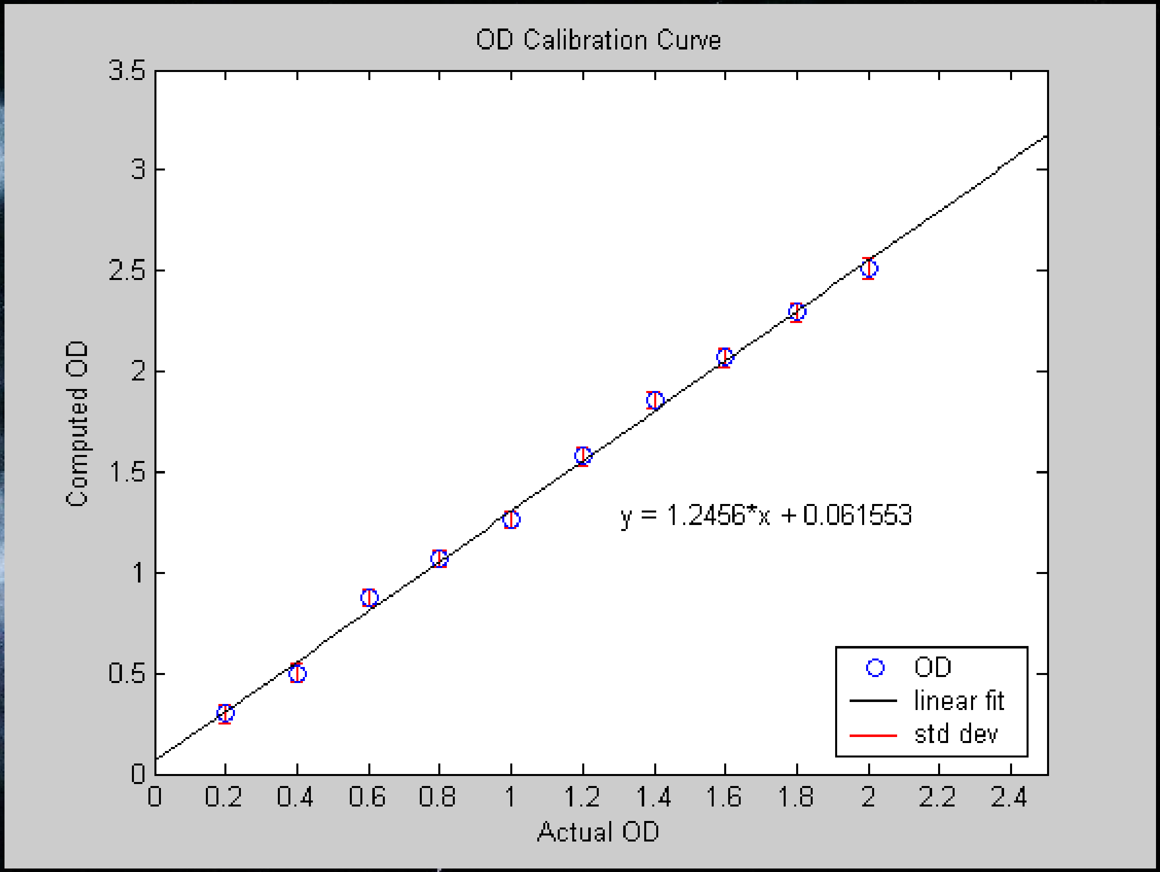
RESULTS



HDR image of the reference irradiance. Eo values [5.9838e+003, 1.7228e+004].

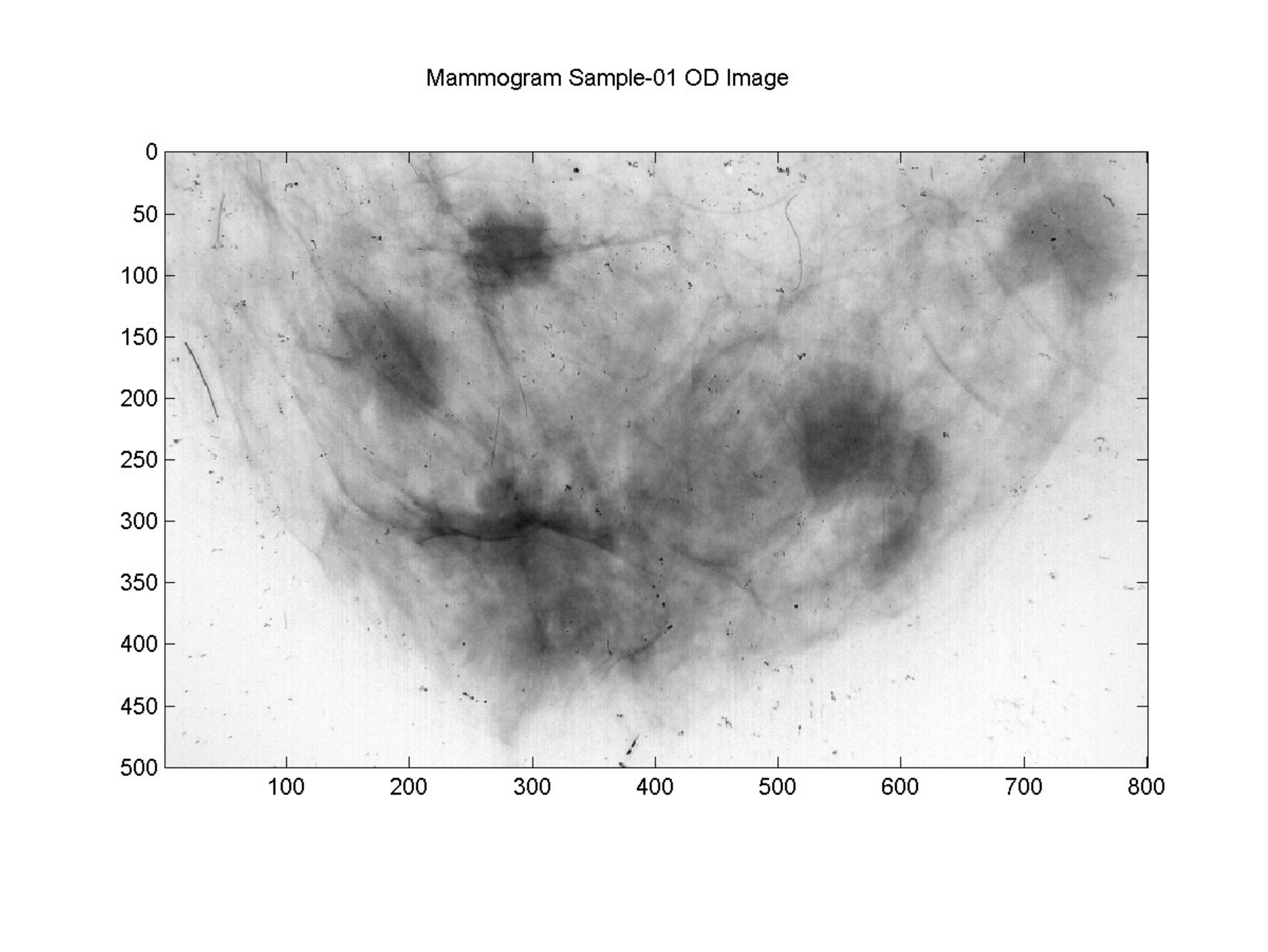
RESULTS

Actual OD	Computed Mean OD
0.2	0.2998 ± 0.0443
0.4	0.4992 ± 0.0436
0.6	0.8734 ± 0.0429
0.8	1.0733 ± 0.0418
1.0	1.2641 ± 0.0422
1.2	1.5769 ± 0.0420
1.4	1.8547 ± 0.0420
1.6	2.0711 ± 0.0457
1.8	2.2940 ± 0.0486
2.0	2.5104 ± 0.0526



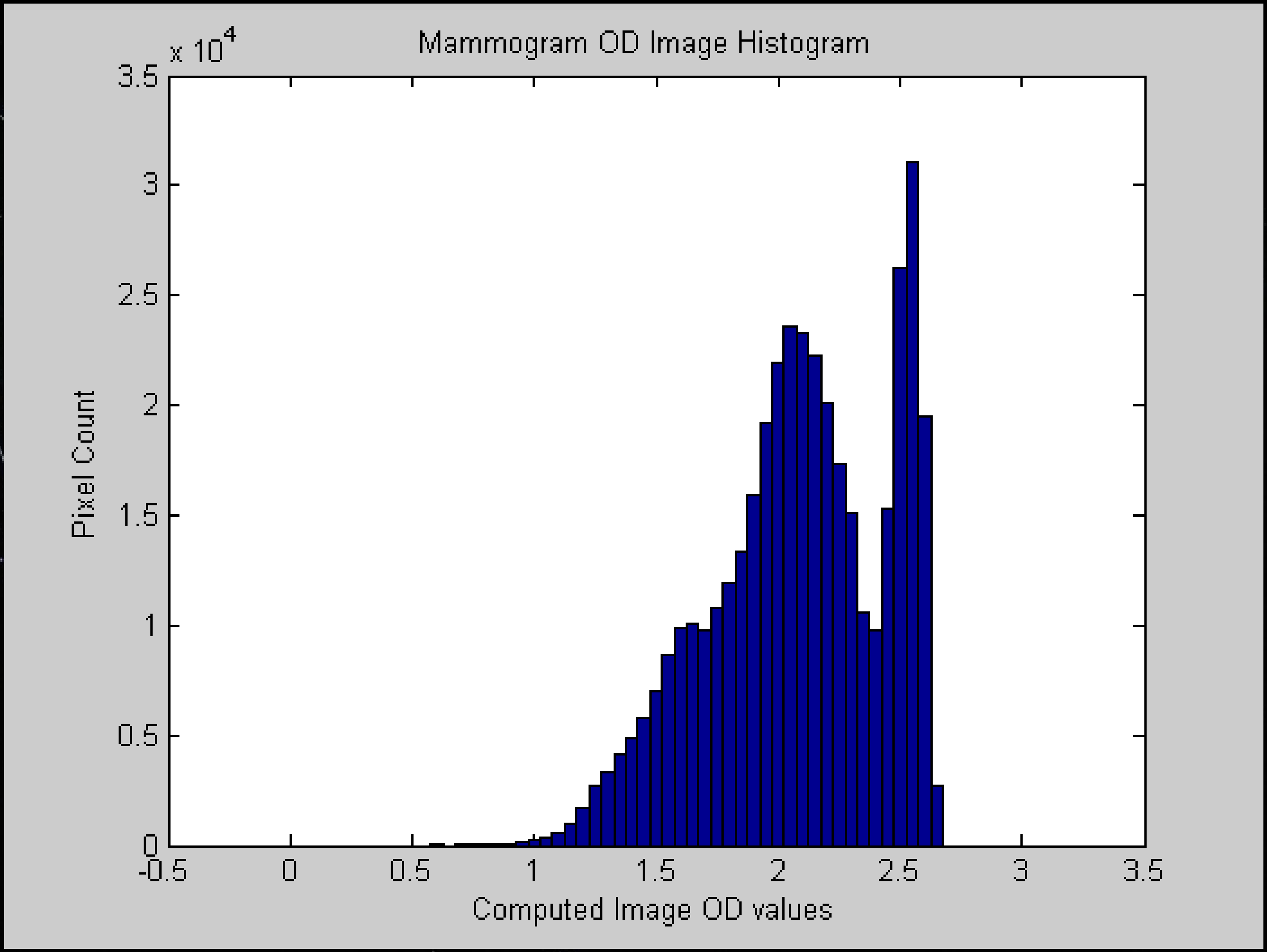
Optical density calibration curve.

RESULTS



Calibrated OD image of an HDR mammogram image.

RESULTS



HDR-OD image histogram.

High Dynamic Range Imaging of Magnetized Sheet Plasma

Leo Mendel D. Rosario, Julie Anne S. Ting, Rommel Paulo B. Viloan, Beverly Anne T. Suarez, Michelle Marie S. Villamayor, Roy B. Tumlos, Maricor N. Soriano, and Henry J. Ramos

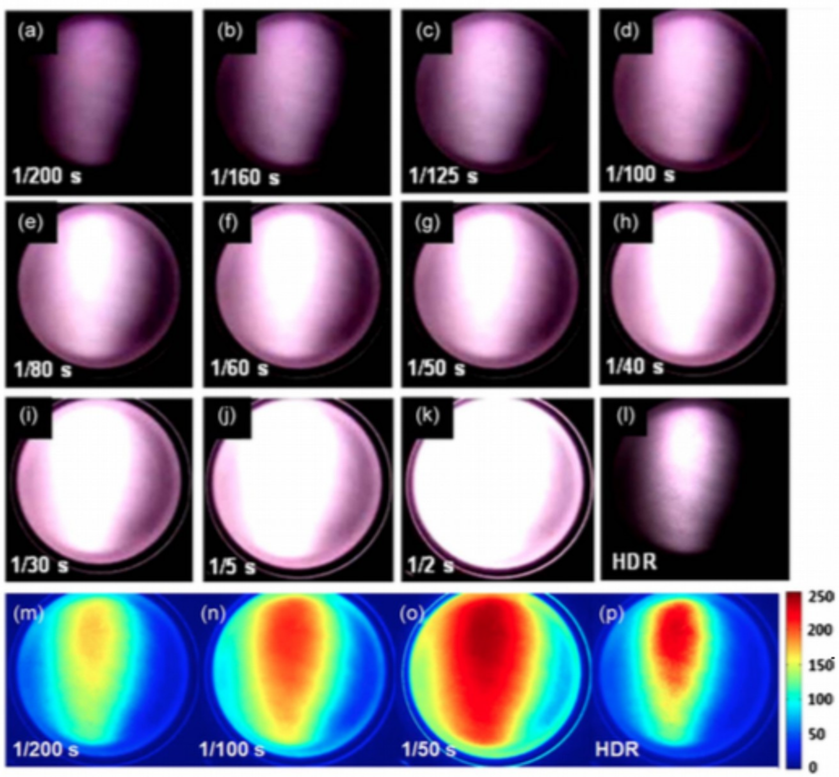


Fig. 1. Contrast-stretched LDR images of a magnetized sheet plasma taken at various shutter speeds: (a) 1/200, (b) 1/160, (c) 1/125, (d) 1/100, (e) 1/80, (f) 1/60, (g) 1/50, (h) 1/40, (i) 1/30, (j) 1/5, and (k) 1/2 s. (l) False-color images of (m) 1/200, (n) 1/100, and (o) 1/50 s, and (p) HDR image. A jet color map is used for the scaling of the intensity values of the images.

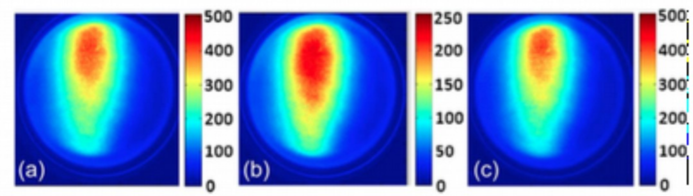


Fig. 2. Radiance maps obtained from the response functions for various channels: (a) red, (b) green, and (c) blue.

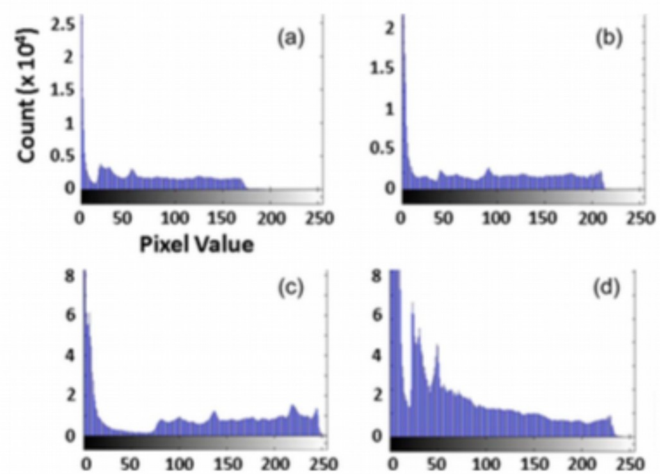


Fig. 3. Intensity histograms of LDR images taken at various shutter speeds of (a) 1/200, (b) 1/100, and (c) 1/50 s and (d) of linear tone mapped HDR image.

https://www.youtube.com/watch?v=nPfcwT4Fcy8

NASA's New High Dynamic Range Camera Records Rocket Test