Focus Value

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Outline

- Auto Focus
- Focus Formula
- Focus Value Curve
- Focus Value Curve Fitting

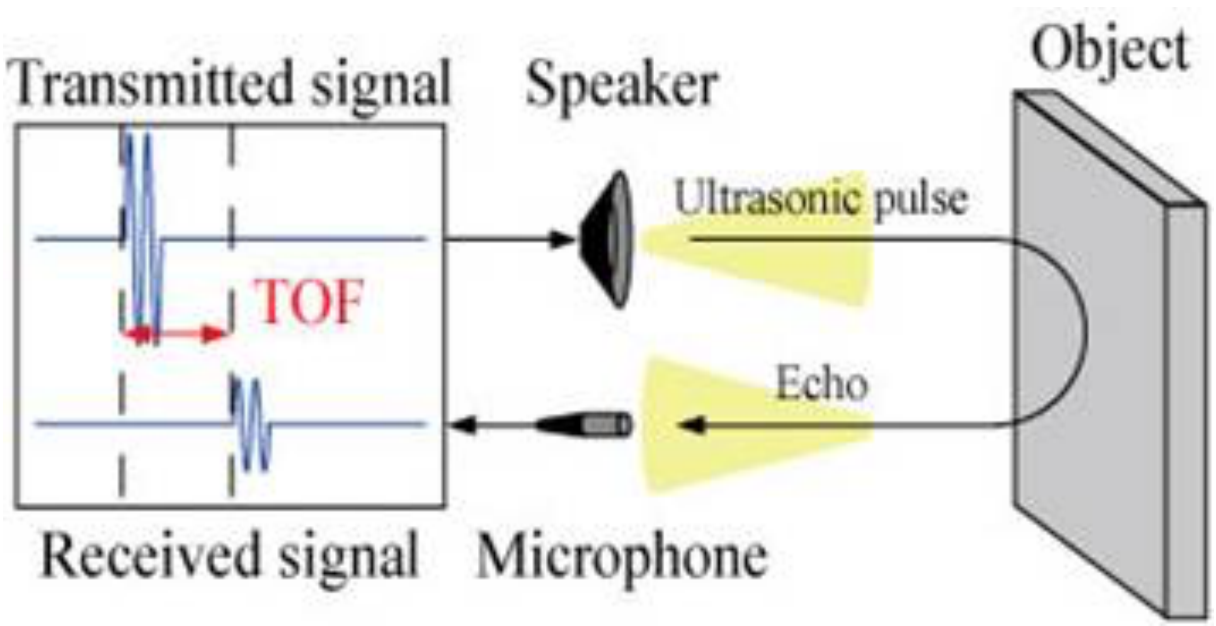
Auto Focus

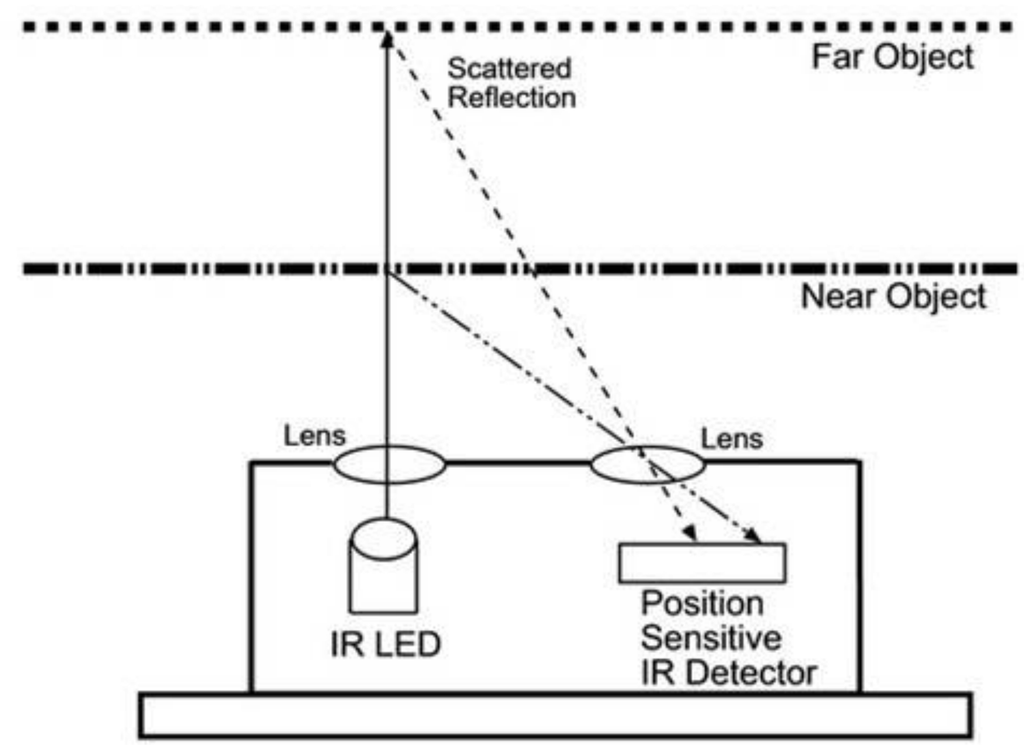
- Active Autofocus

- Passive Autofocus

Active Autofocus

- Measure distance to the subject independently of the optical system, and subsequently adjust the optical system for correct focus.
- Ex: ultrasonic sound waves, infrared (IR) ray.





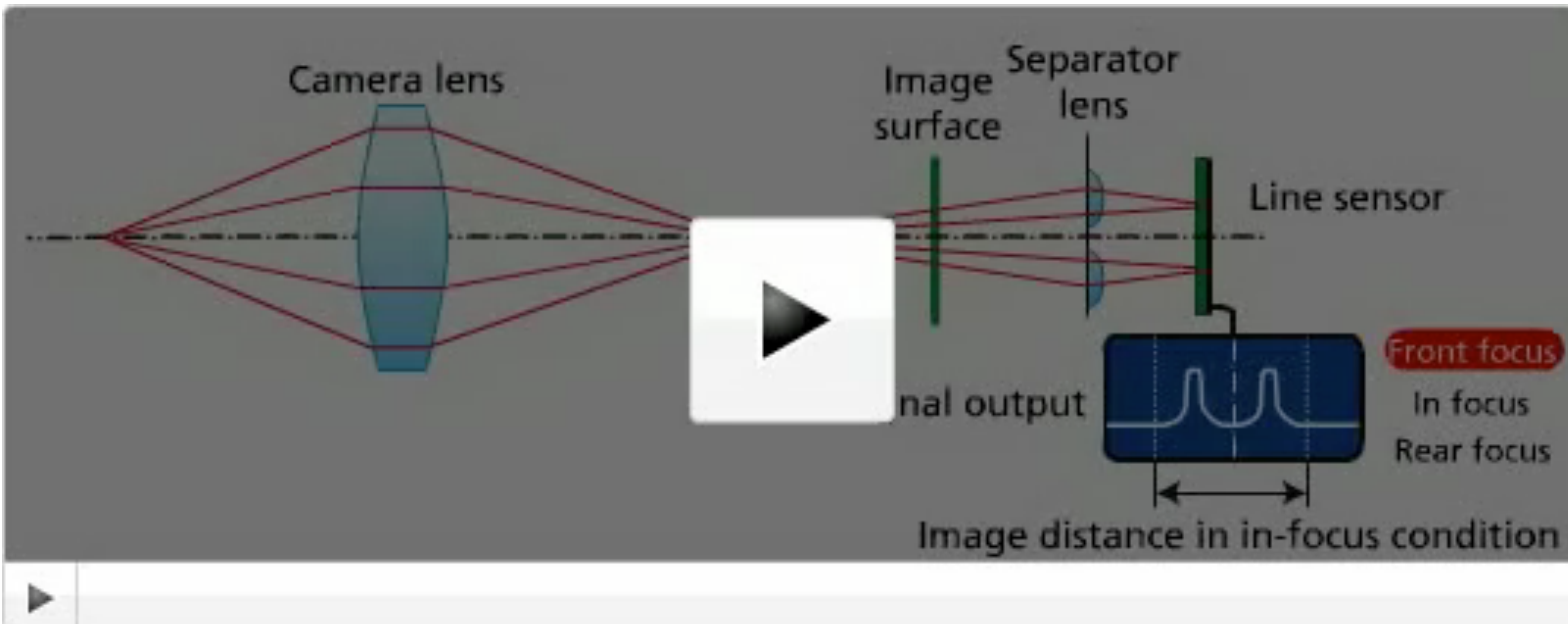
TOF: Time Of Flight
LED: Light-Emitting Diode

Passive Autofocus

- Determine correct focus by performing passive analysis of the image that is entering the optical system.
- Can be achieved by phase detection or contrast measurement.

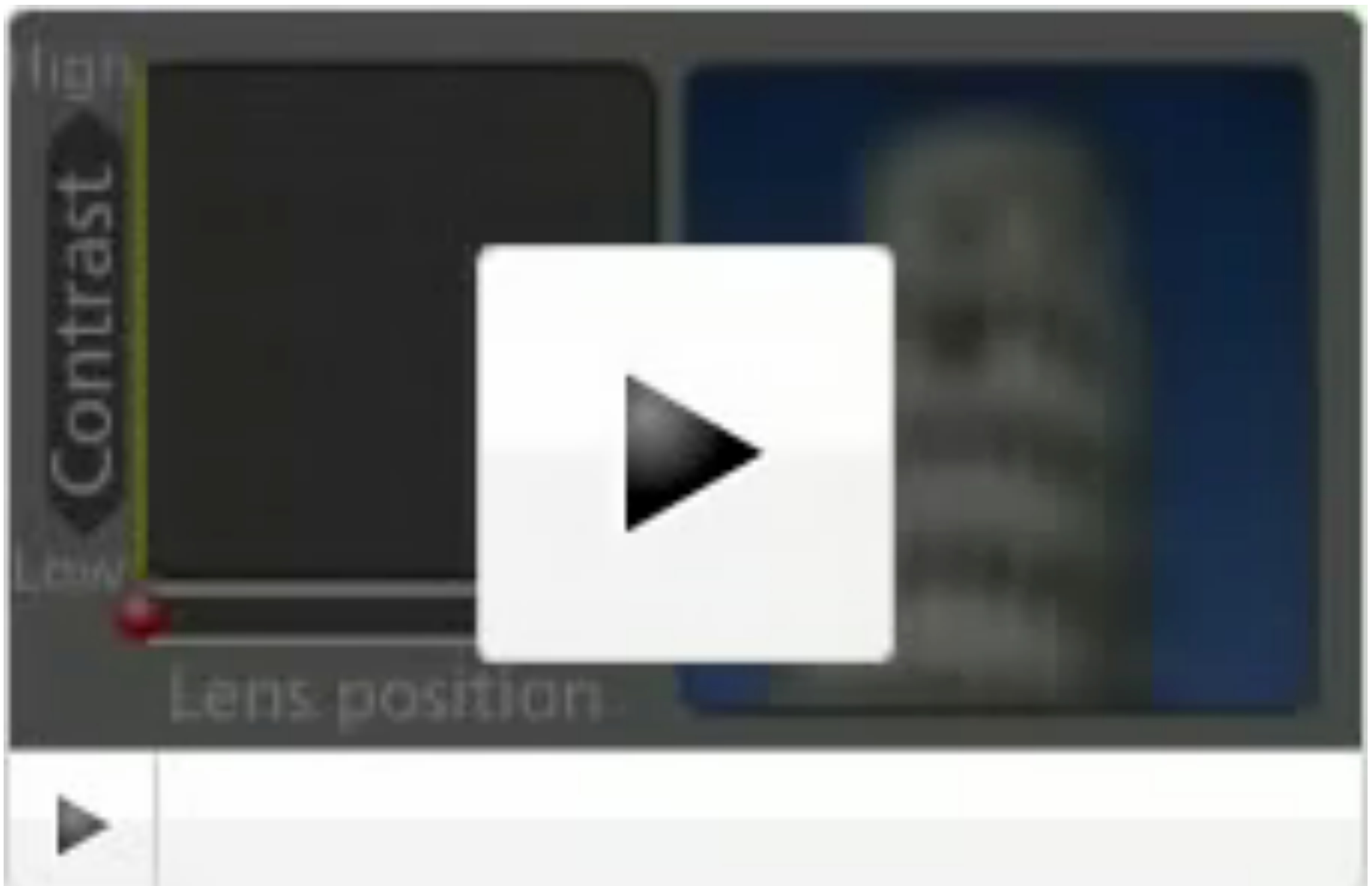
Passive Autofocus

- Phase Detection:

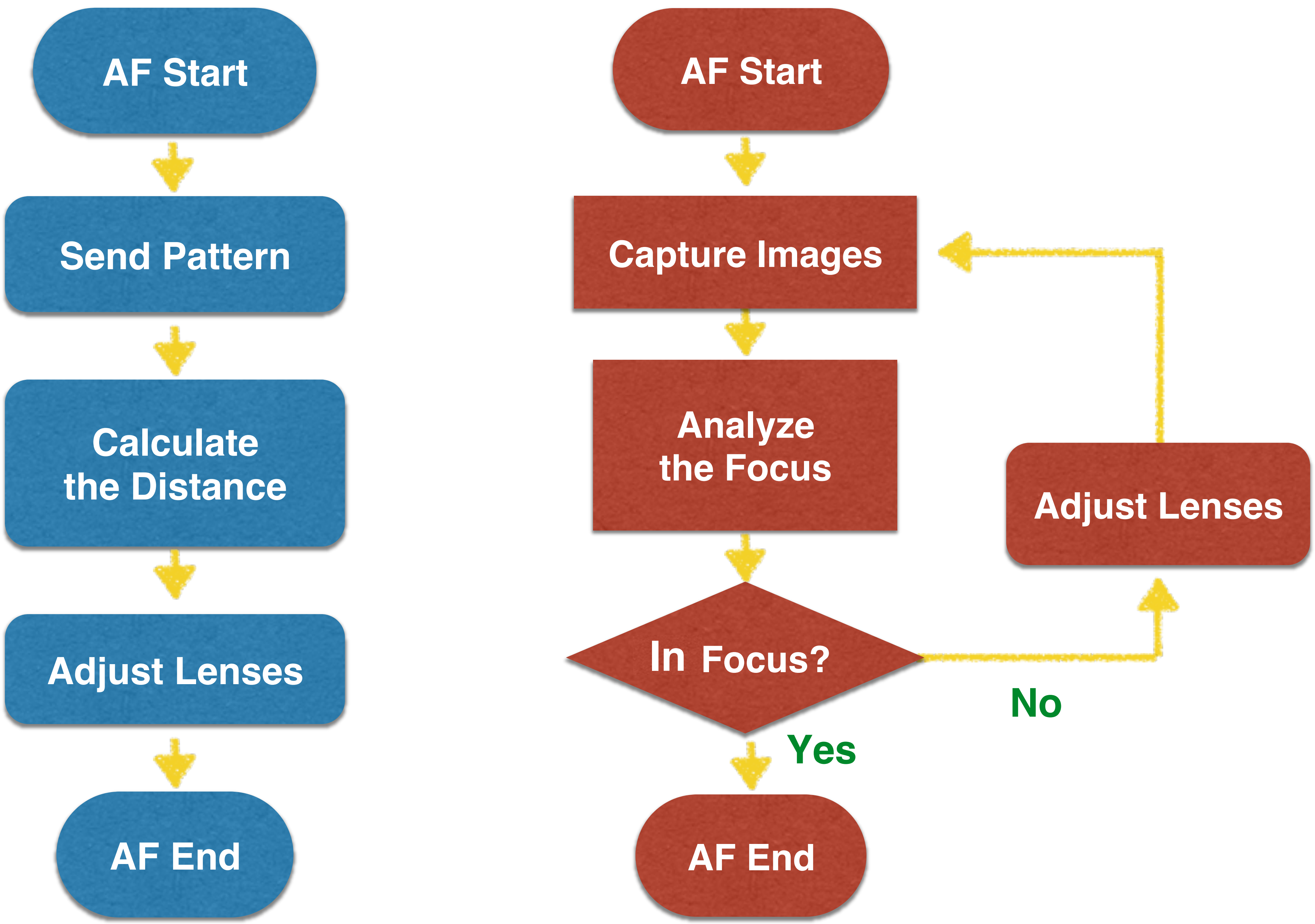


Passive Autofocus

- Contrast Detection:



Active / Passive



Comparison of Active and Passive AutoFocus

	Advantages	Disadvantages
Active Autofocus	Fast	- High Cost - Need space to place sensors
Passive Autofocus	Simple	- Mistake in darker or lighter scene

Focus Formula

- Robert
- Prewitt
- Laplacian
- Sobel

Robert

- Derived by first-order difference.

$$f'(x) = \lim_{x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x} = f(x+1) - f(x)$$

- Simplest but sensitive for noise.

1	
	-1

	1
-1	

$$FV = \sum_{(r,c)} f(\mathrm{r,c}) \text{-} f(\mathrm{r+1,c+1}) + \sum_{(r,c)} f(\mathrm{r,c+1}) \text{-} f(\mathrm{r+1,c})$$

Prewitt

- One direction is calculated by first-order difference, another is average.

- Compared to Robert is relatively insensitive for noise.

-1		1
-1		1
-1		1

-1	-1	-1
1	1	1

$$FV = \sum_{(r,c)} f(\text{r-1,c+1}) + f(\text{r,c+1}) + f(\text{r+1,c+1}) - f(\text{r-1,c-1}) - f(\text{r,c-1}) - f(\text{r+1,c-1})$$
$$+ \sum_{(r,c)} f(\text{r+1,c-1}) + f(\text{r+1,c}) + f(\text{r+1,c+1}) - f(\text{r-1,c-1}) - f(\text{r-1,c}) - f(\text{r-1,c+1})$$

Sobel

- Improved from Prewitt.

1	1
-1	-1

X

1	1
1	1

- The nearer pixels have the higher weight.

-1		1
-2		2
-1		1

-1	-2	-1
1	2	1

$$FV = \sum_{(r,c)} f\big(\text{r-1,c+1}\big)+2\times f\,(\text{r,c+1})+f\,(\text{r+1,c+1})\ \text{-}f\big(\text{r-1,c-1}\big)\text{-}2\times f\big(\text{r,c-1}\big)\text{-}f\,(\text{r+1,c-1})$$

$$+\sum_{(r,c)} f\big(\text{r+1,c-1}\big)+2\times f\,(\text{r+1,c})+f\,(\text{r+1,c+1})\text{-}f\big(\text{r-1,c-1}\big)\text{-}2\times f\big(\text{r-1,c}\big)\text{-}f\,(\text{r-1,c+1})$$

Laplacian

- Derived by second-order difference.

$$f''(x) = f'(x+1) - f'(x) = f(x+2) - 2\times f(x+1) + f(x)$$

- Only use without noise.

	1	
1	-4	1
	1	

or

1	1	1
1	-8	1
1	1	1

$$FV = \sum_{(r,c)} f(\mathrm{r,c+1}) + f(\mathrm{r+1,c}) + f(\mathrm{r,c-1}) + f(\mathrm{r-1,c}) - 4\times f(\mathrm{r,c})$$

Focus Value Curve

- Robert
- Prewitt
- Sobel
- Laplacian
- Test

Focus Formula

1	
	-1

+

	1
-1	

Robert

-1	-1	-1
1	1	1

+

-1		1
-1		1
-1		1

Prewitt

-1	-2	-1
1	2	1

+

-1		1
-2		2
-1		1

Sobel

^2

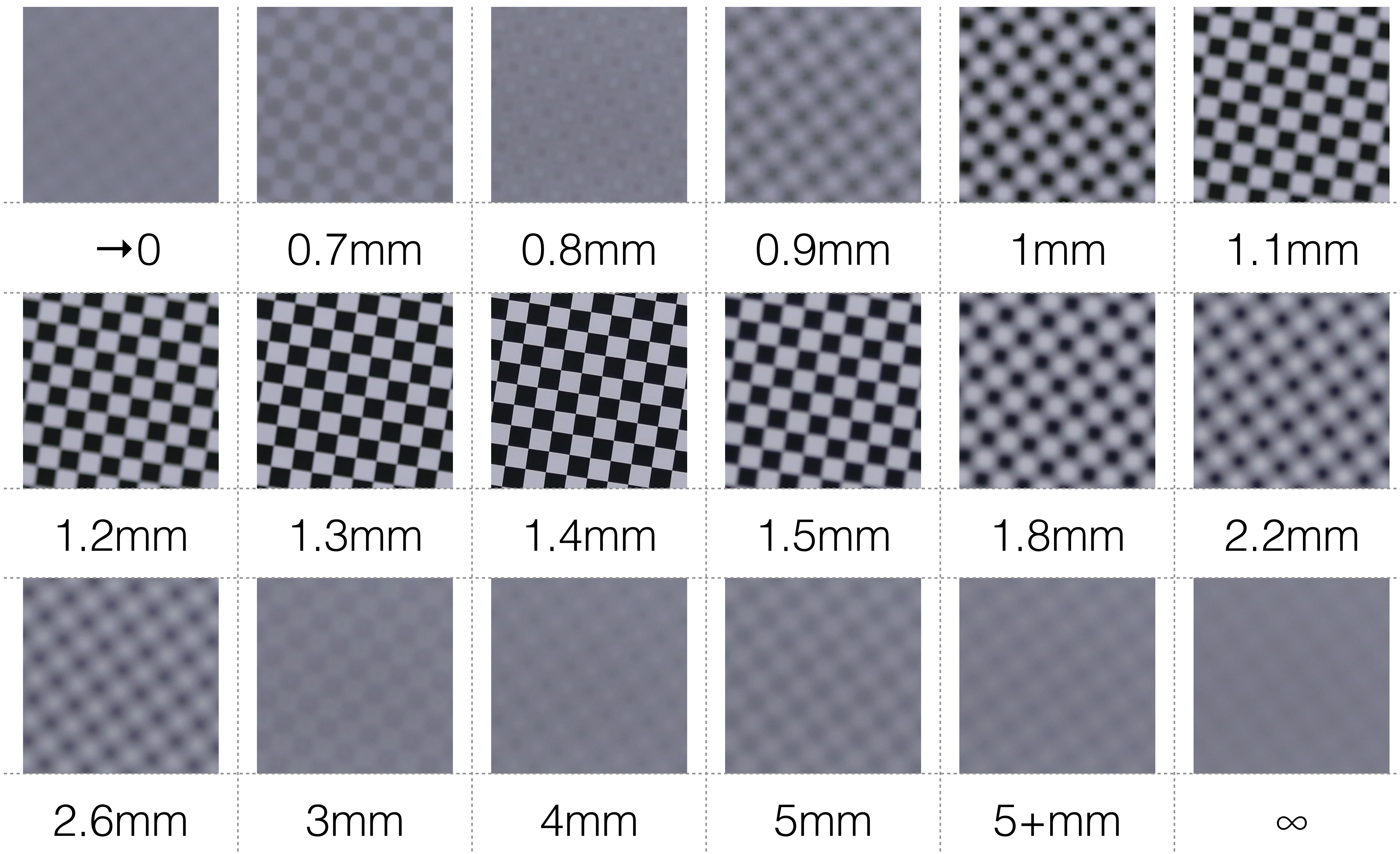
	1	
1	-4	1
	1	

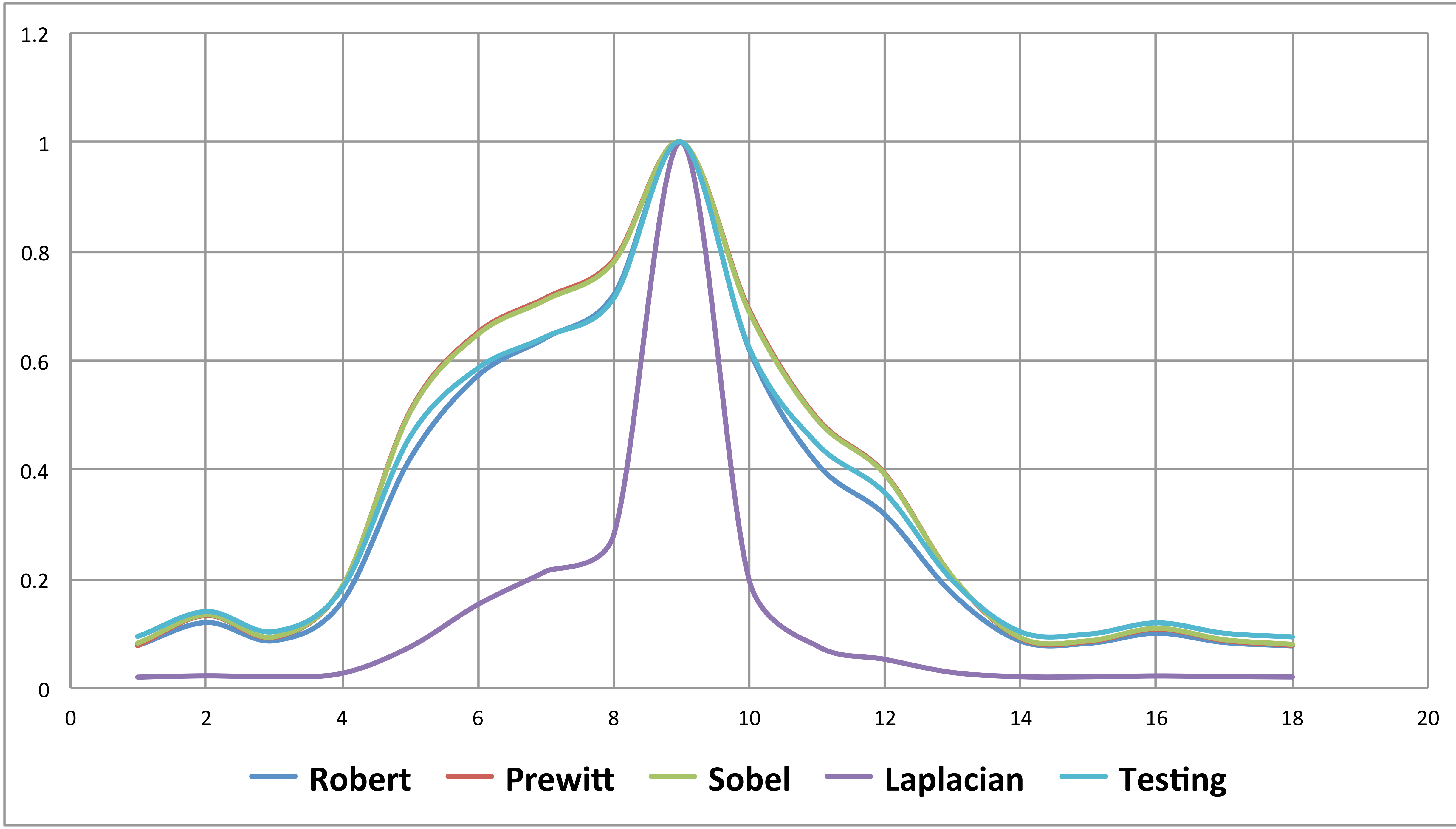
Laplacian

	a	
b	c	d
	e	

|a-c|+|b-c|+|d-c|+|e-c|

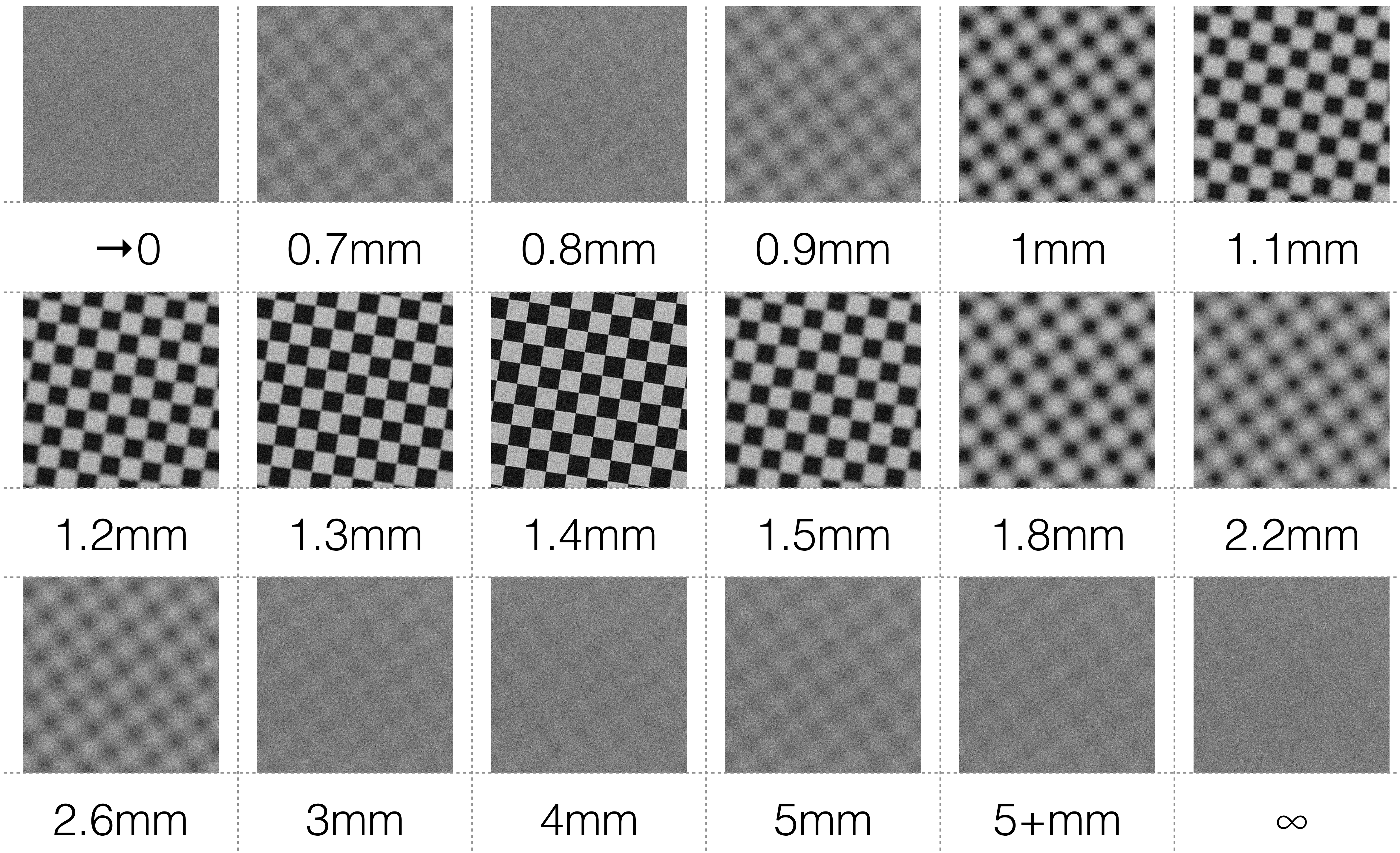
500x500 pixels

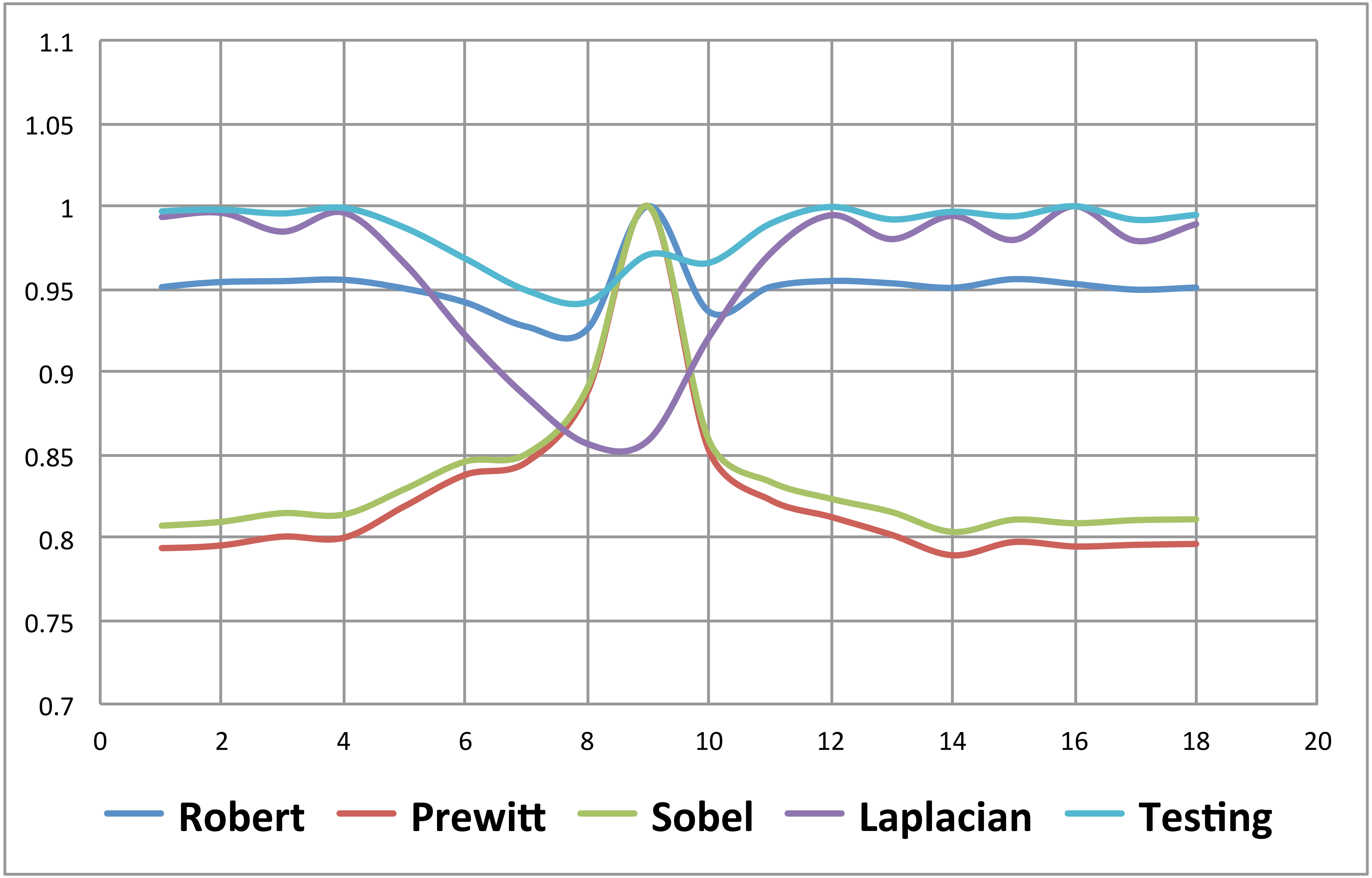




Original Image 500x500 pixels

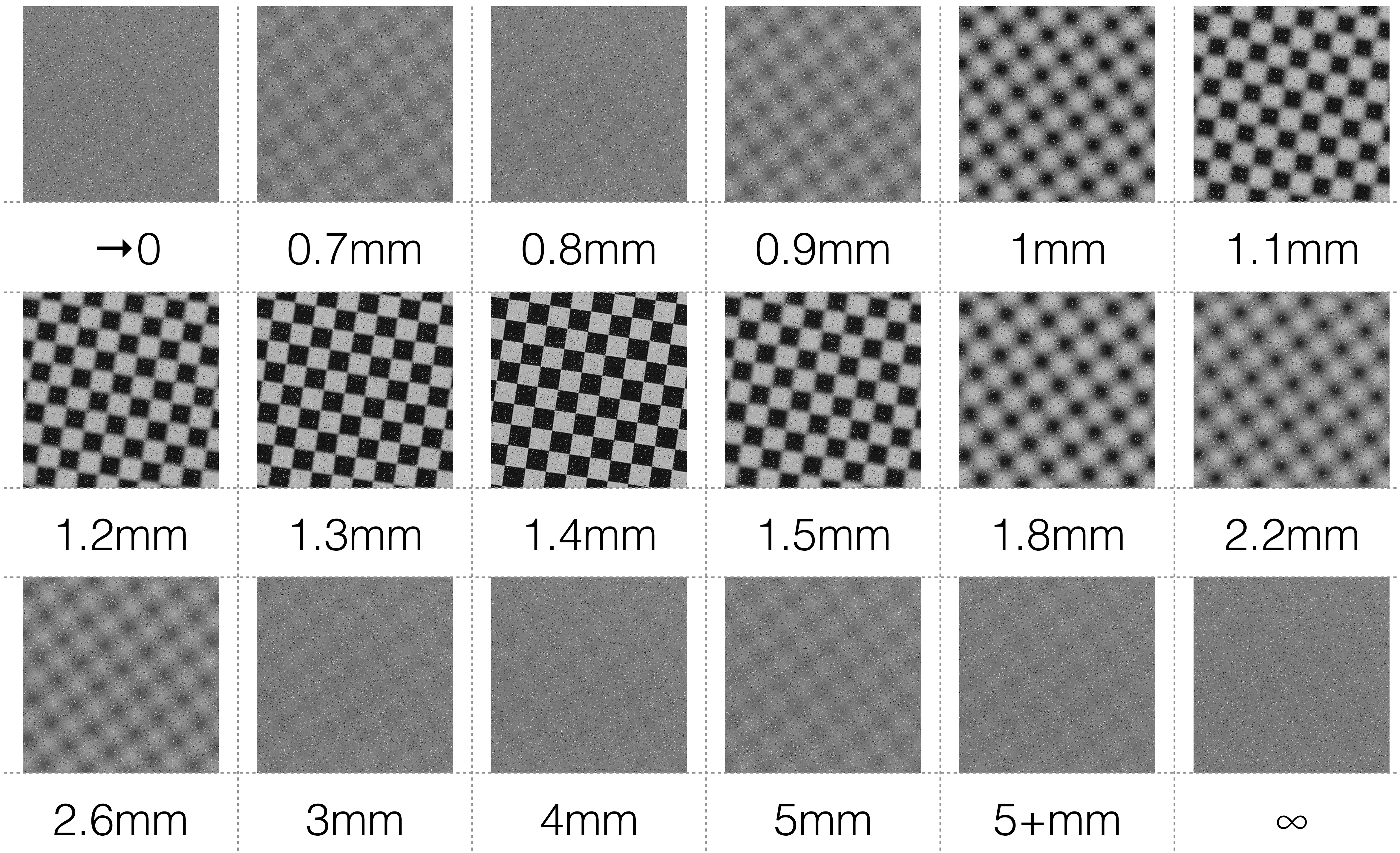
Add Gaussian Noise

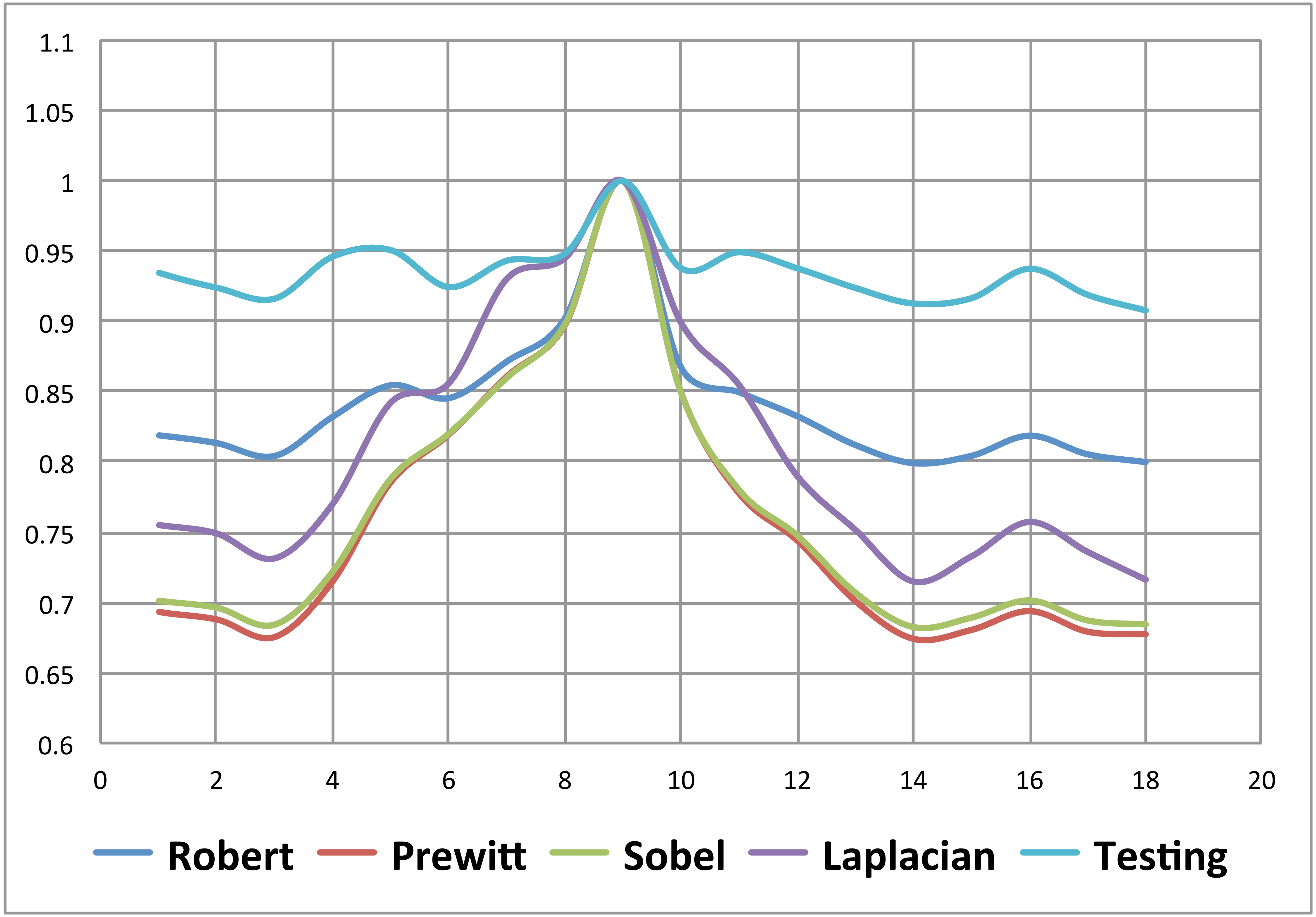




Add Gaussian Noise

Add Salt and Pepper Noise (5%)

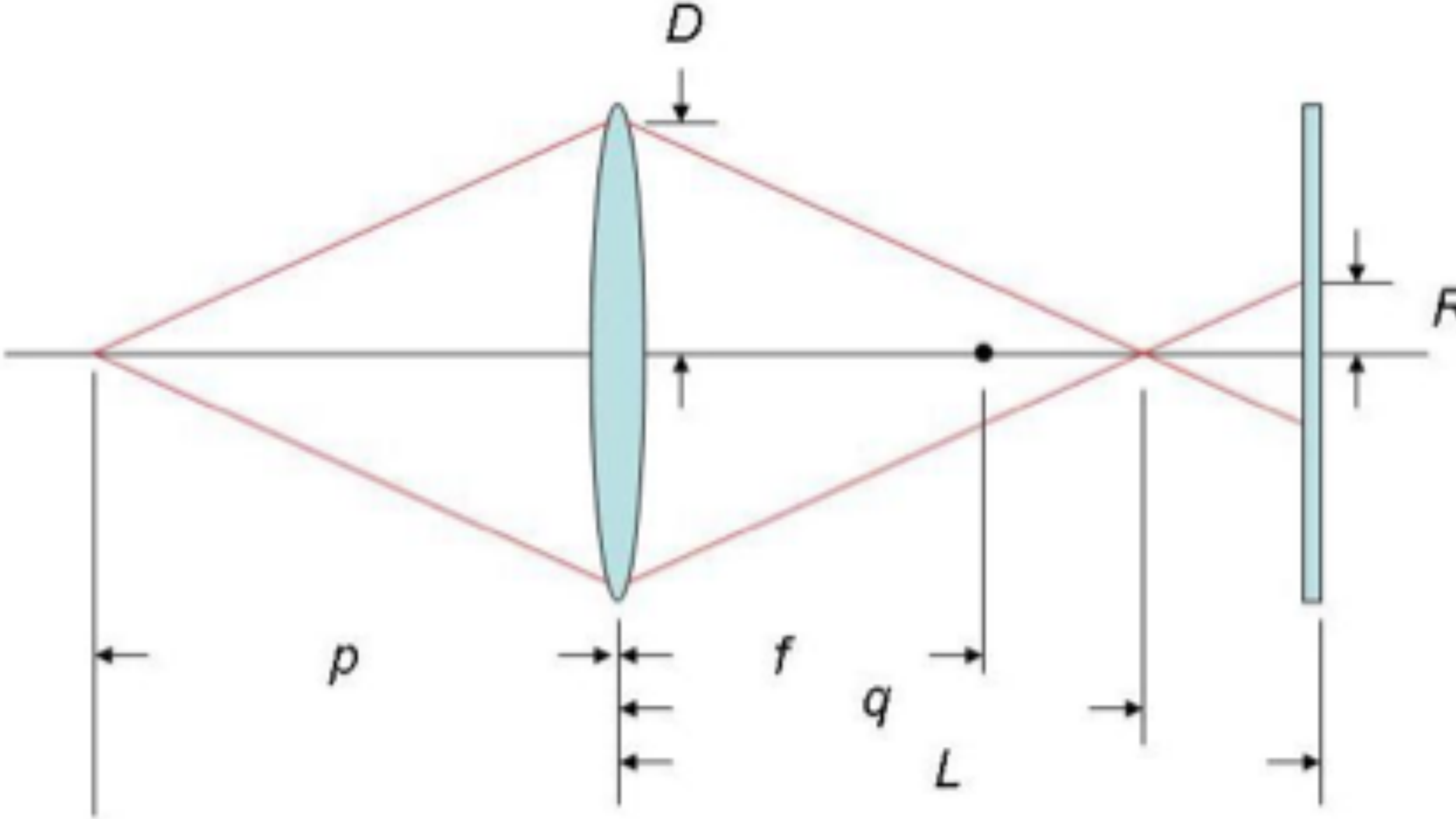




Add Salt and Pepper Noise (5%)

Curve Fitting

$$FV = \frac{c_1}{k + |x - x_0|^2}$$



R: Blur Circle Radius
D: Aperture Length
p: Object

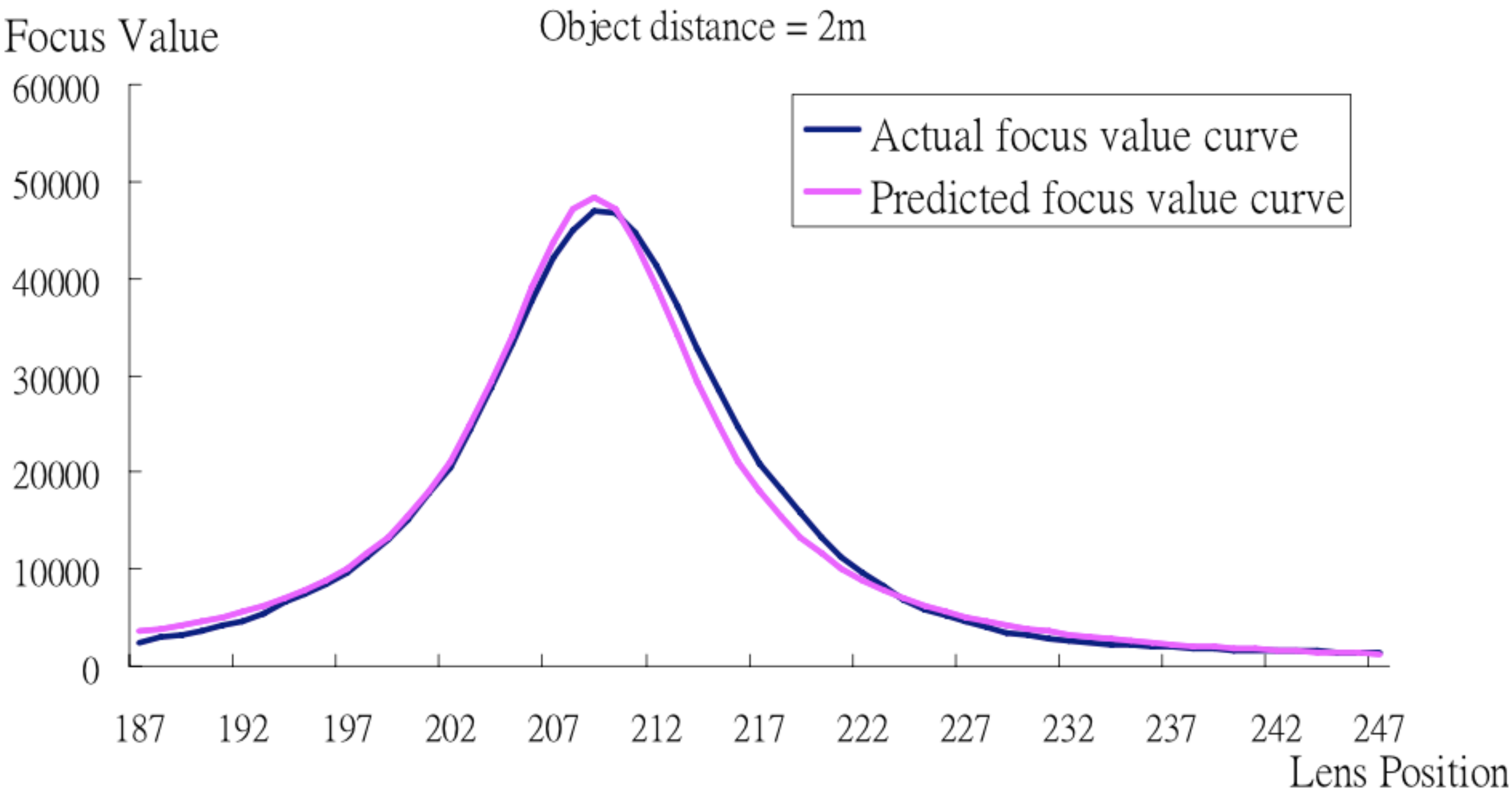
q: Focused Points
f : Focus Length
L: Distance between Lens and Image Detector

$$FV = \frac{c_1}{k + \left| x - x_0 \right|^2},$$

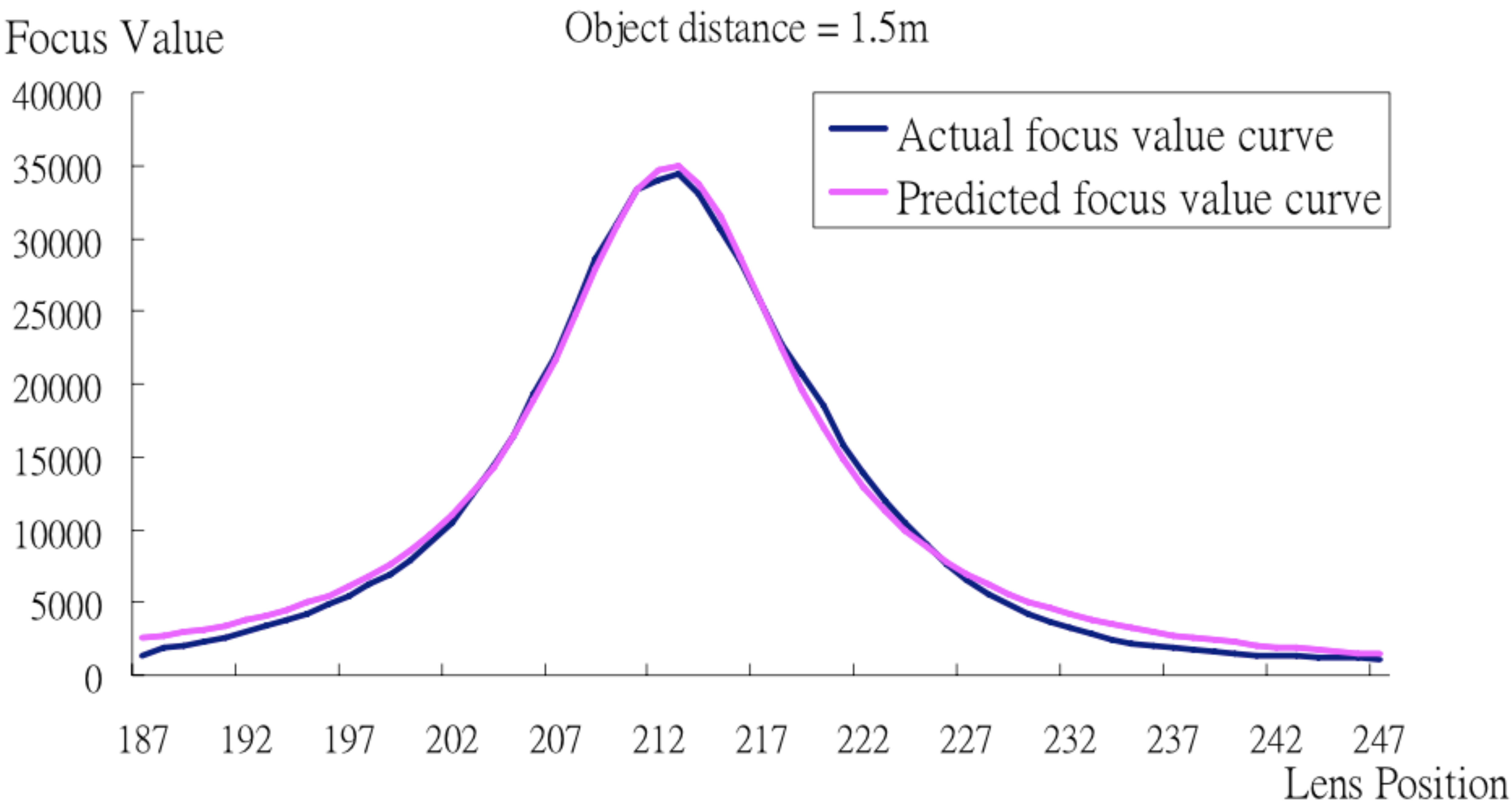
where

c_1: a constant to fit parameter $(\frac{q^2}{D^2})$
x: to fit the lens position (L)
x_0: to fit the best-focused lens position (q)
k: a constant denoting minimum radius of CoC

CoC: Circle of Confusion



Object distance = 2m
Focus Value
60000
50000
40000
30000
20000
10000
0
Actual focus value curve
Predicted focus value curve
187
192
197
202
207
212
217
222
227
232
237
242
247
Lens Position



Object distance = 1.5m
Focus Value
40000
35000
30000
25000
20000
15000
10000
5000
0
Actual focus value curve
Predicted focus value curve
187
192
197
202
207
212
217
222
227
232
237
242
247
Lens Position

Spatial Frequency Response

MTF: Modulation Transfer Function

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Resolution Test

- Most important test part of digital imaging: “resolution” and “color.”

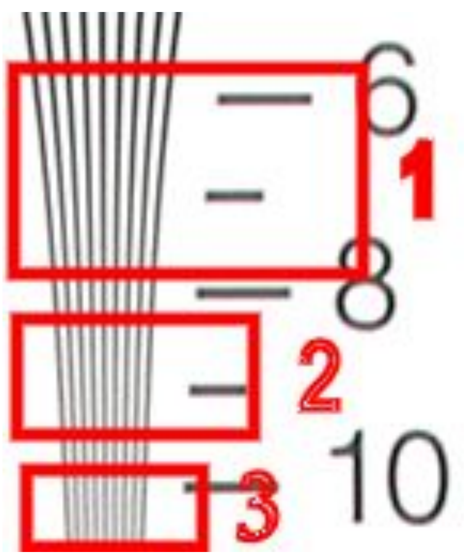
- Resolution test means that a measure is calculated at the transition point of image from clear to blurred. Limited to optical material and other factors, every shot and digital camera has a resolution limit.

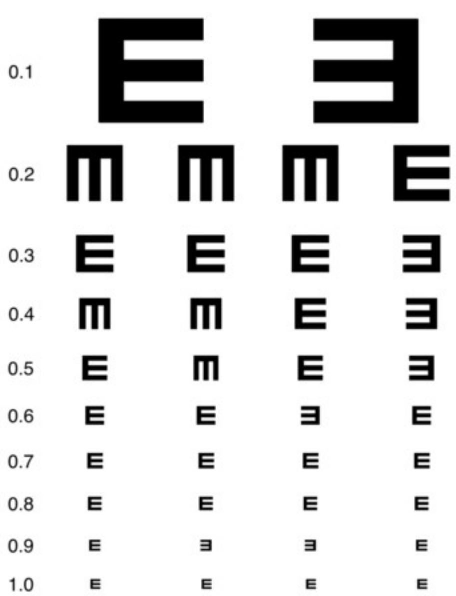
- Resolution test uses scientific methods to calculate the resolution limit.

Modulation Transfer Function

- MTF is the oldest method used by most people.
- The main idea of MTF is to use contrast to test the lens resolution. Users have to understand "spatial frequency.”
- Spatial frequency: how often sinusoidal components of the structure repeat per unit of distance.

Spatial Frequency





- Originally, sufficient contrast can easily identify the two lines.
- When the spatial frequency increases, that is, when the lines lie more closely, the contrast is gradually reduced.
- Finally, attenuation contrast to all turned gray, no longer distinguish between black and white stripes to, it means that the resolution of the lens has been to the limit.

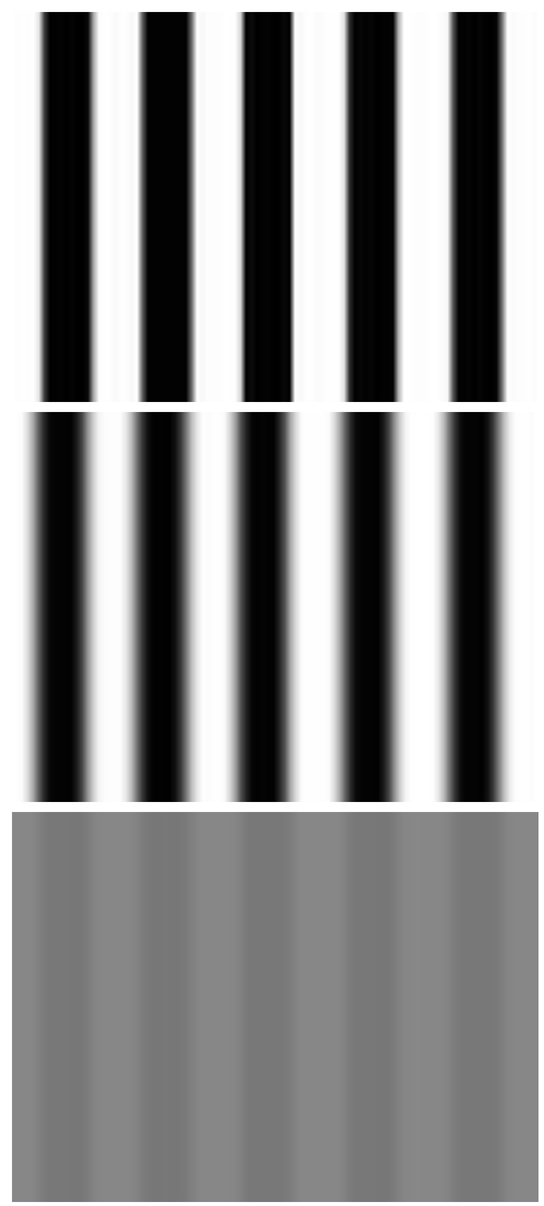
Contrast

Spatial frequency

small [1]

[2]

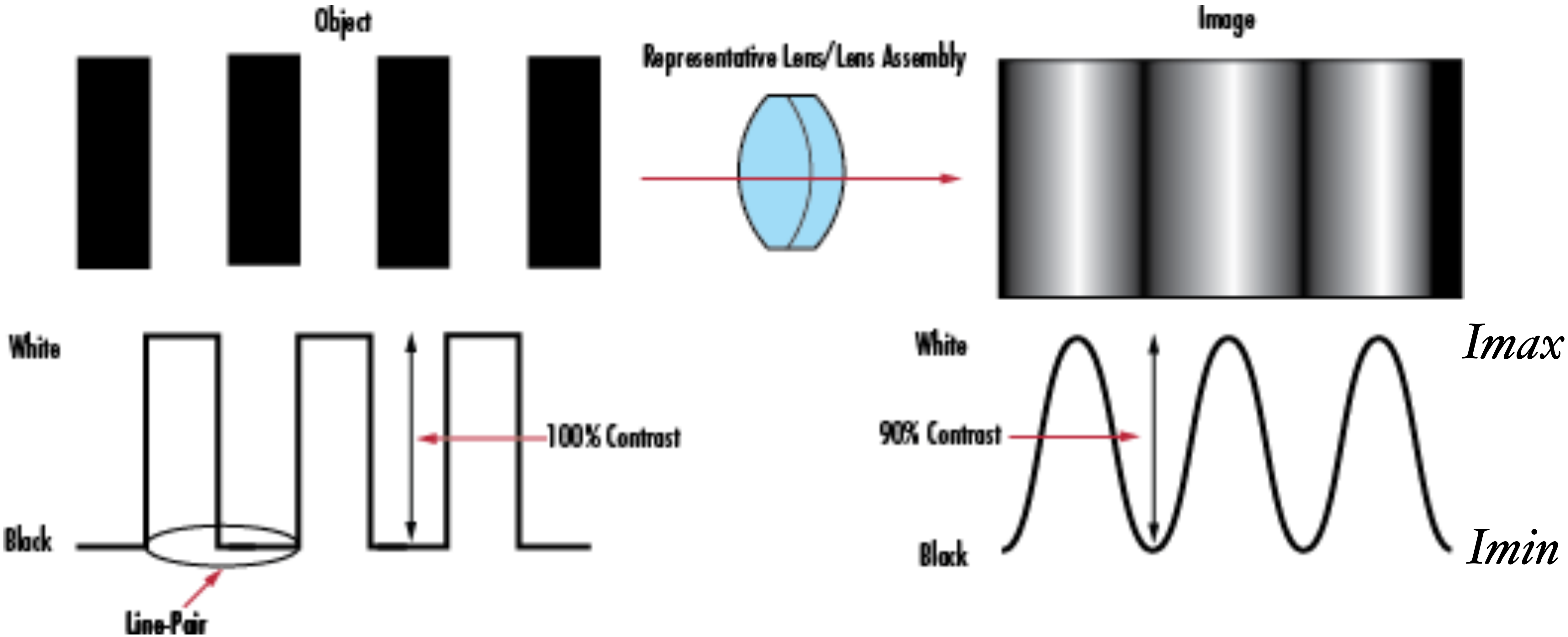
large [3]



[1] 100% of the contrast ratio, it may occur only under ideal conditions.

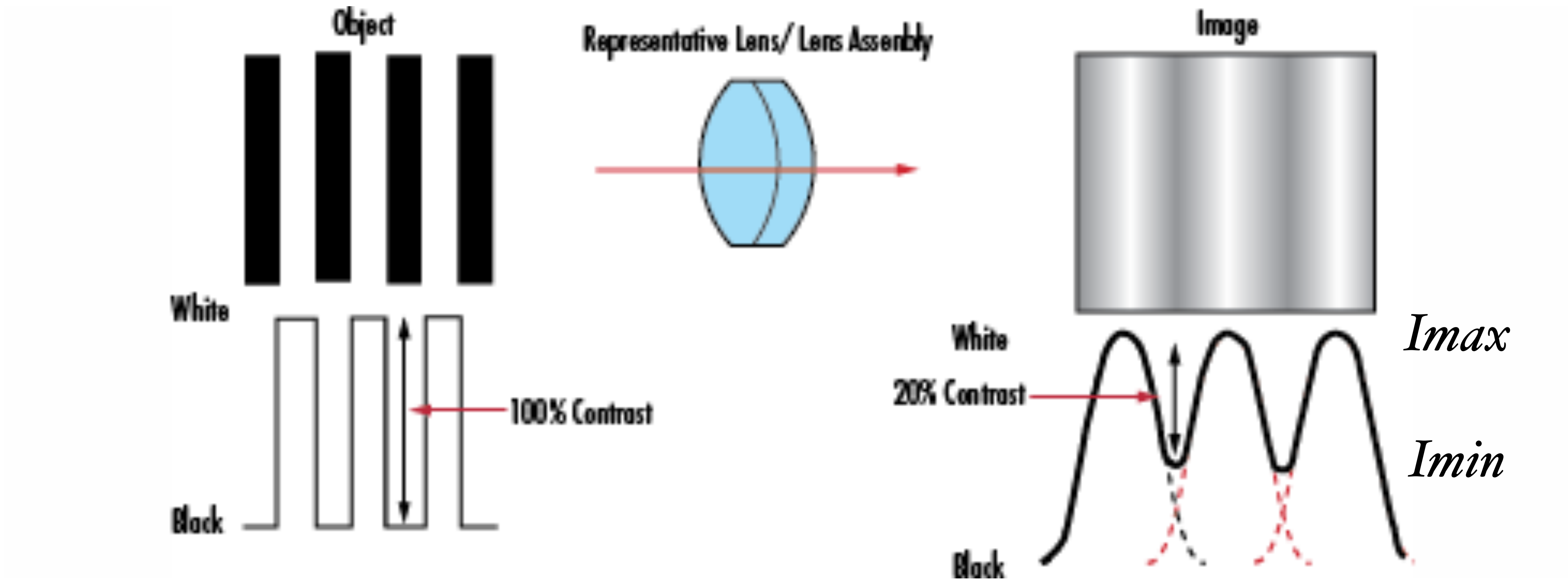
[2] Resolution is poorer, but the contrast acceptable.

[3] Both Resolution and contrast can not compare. (Lens has reached the limit.)



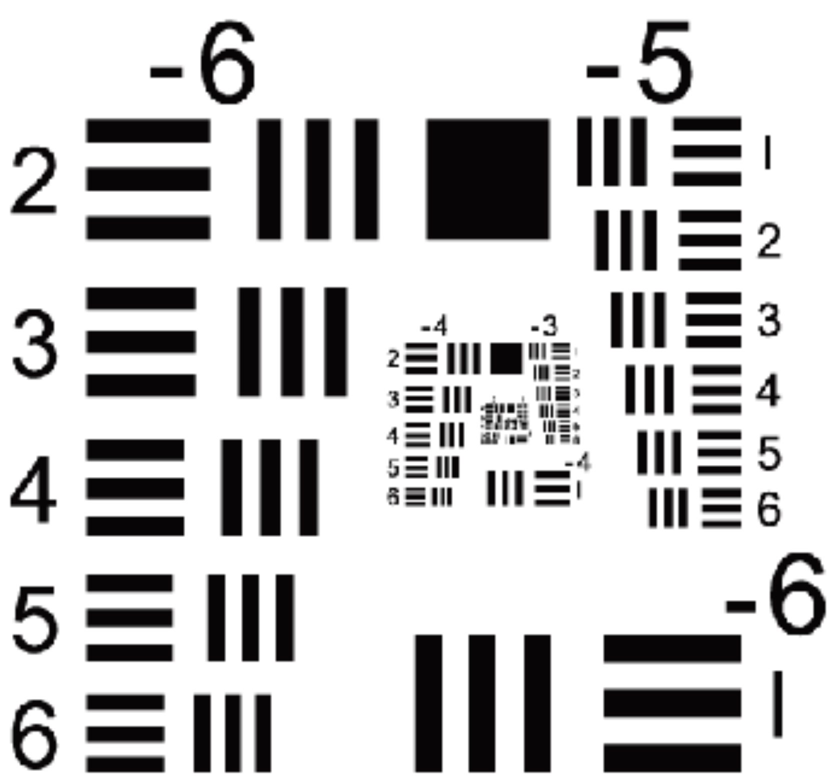
$$\text{Contrast} = \frac{Imax - Imin}{Imax + Imin}$$

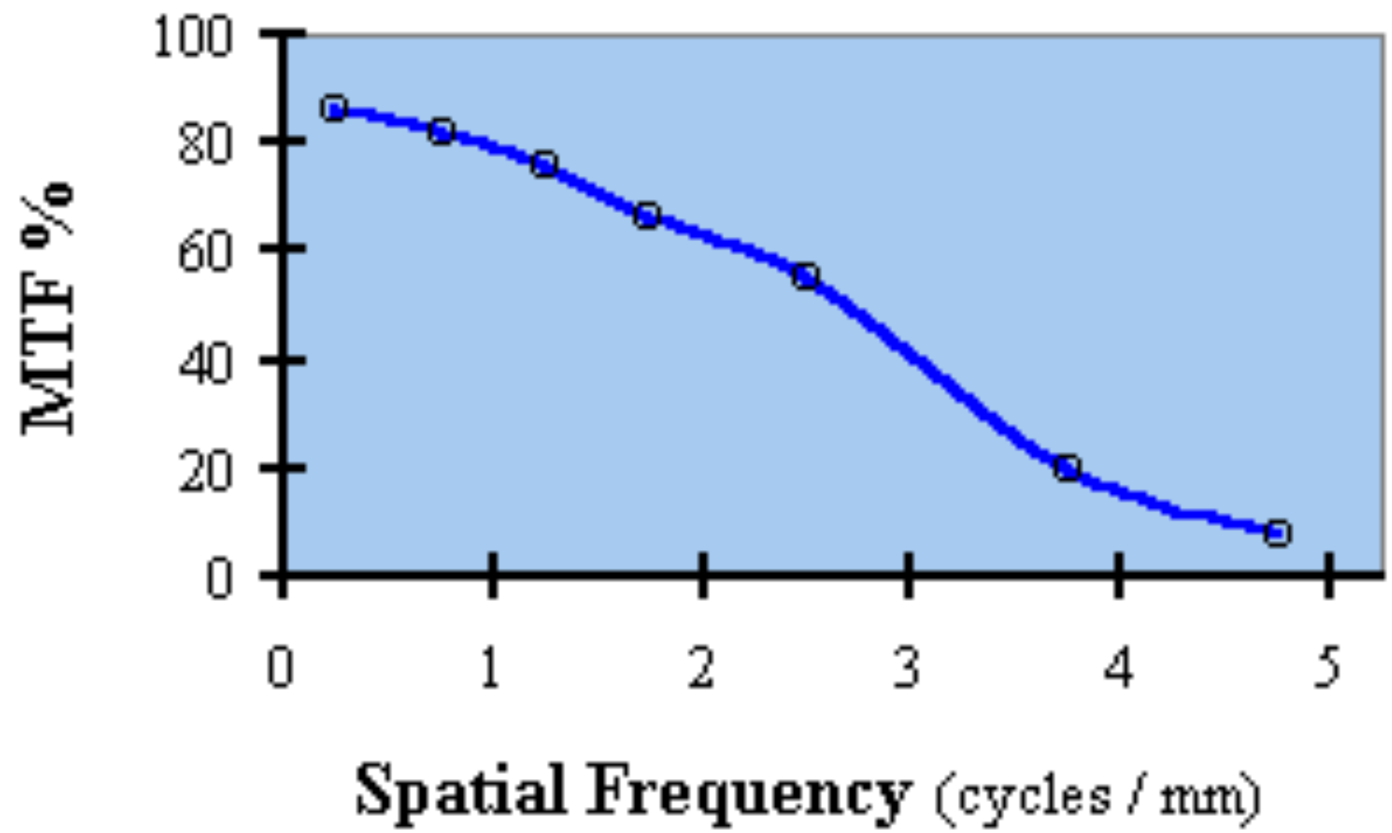
$$\text{MTF} = \frac{ContrastOut}{ConstrastIn}$$



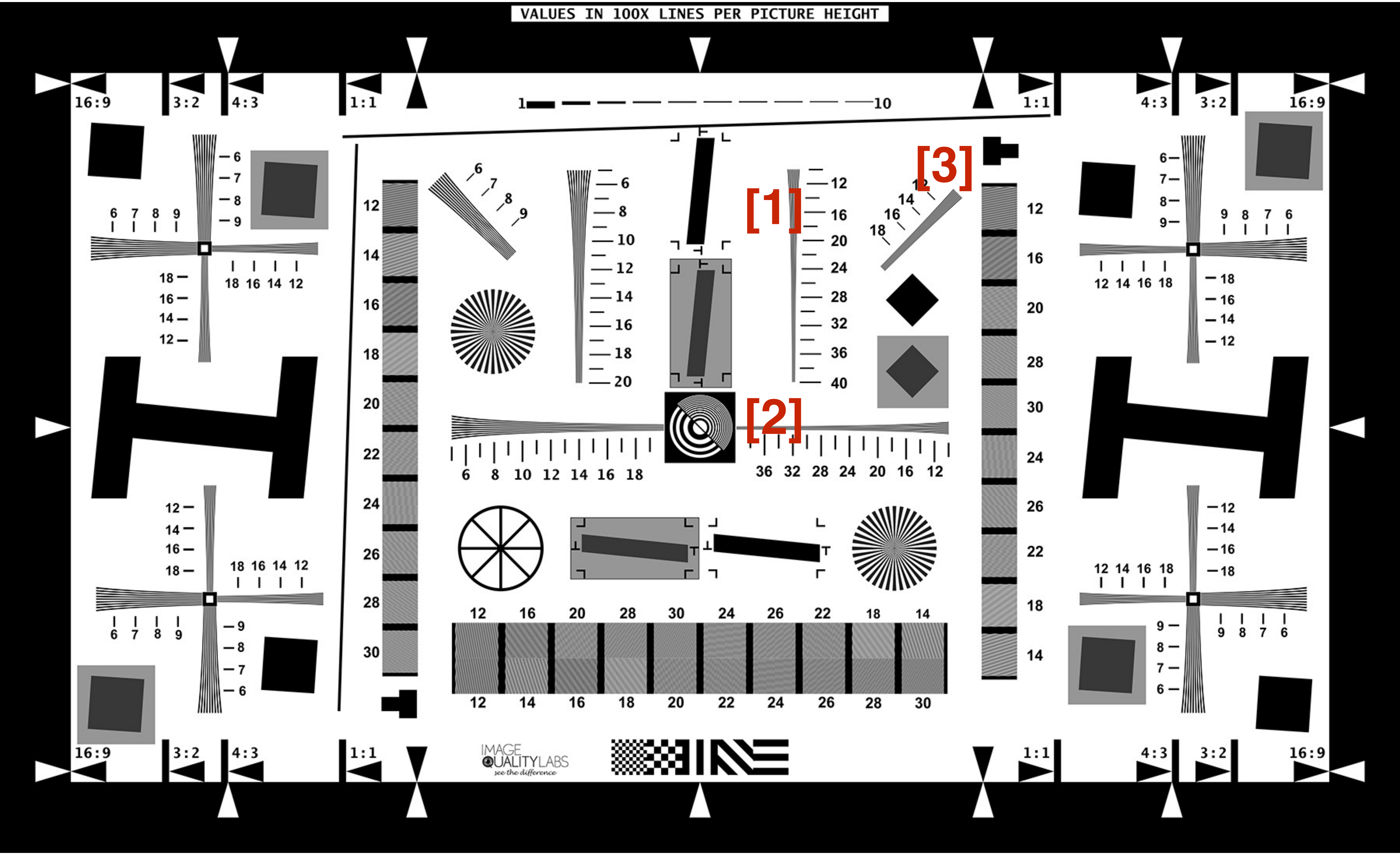
$$\text{Contrast} = \frac{Imax - Imin}{Imax + Imin}$$

$$\text{MTF} = \frac{ContrastOut}{ConstrastIn}$$


-6
-5
2
3
4
5
6
1
2
3
4
5
6
-6
1

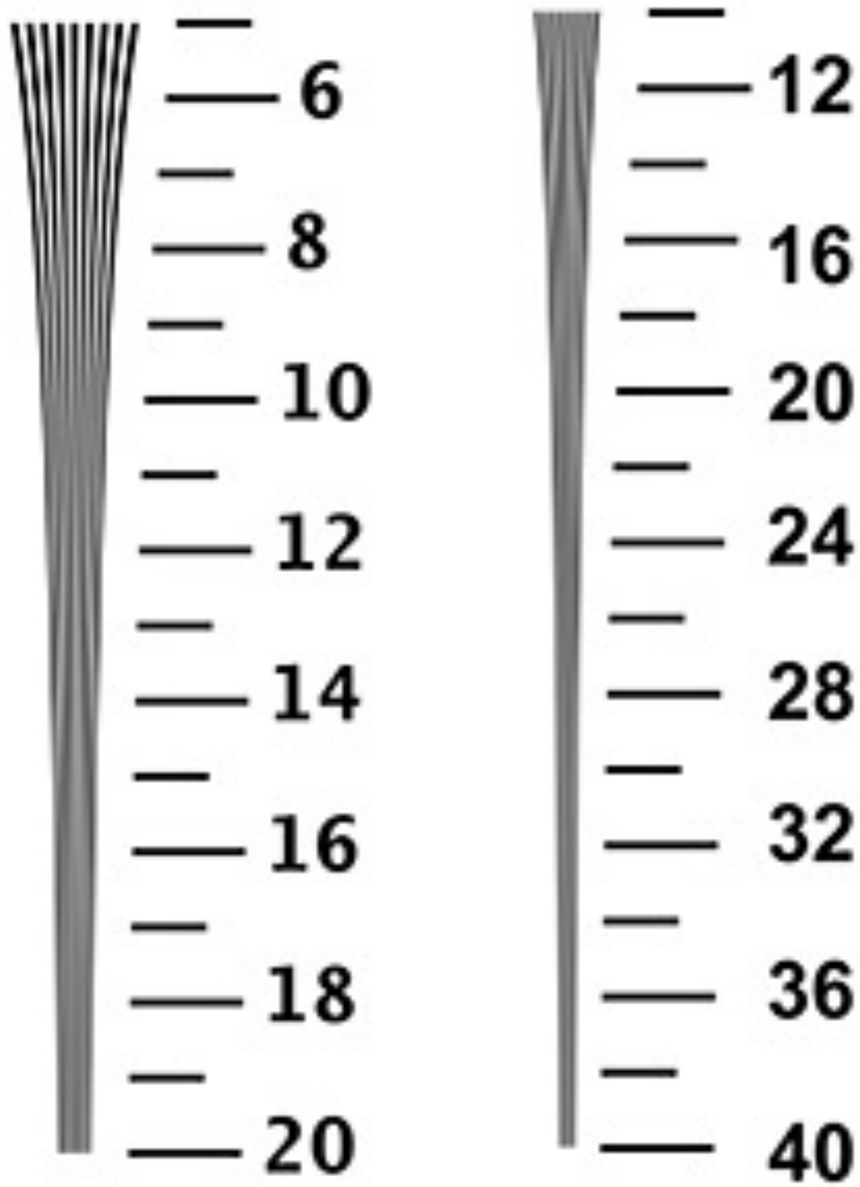

MTF %
100
80
60
40
20
0
0
1
2
3
4
5
Spatial Frequency (cycles / mm)

PIMA / ISO 12233

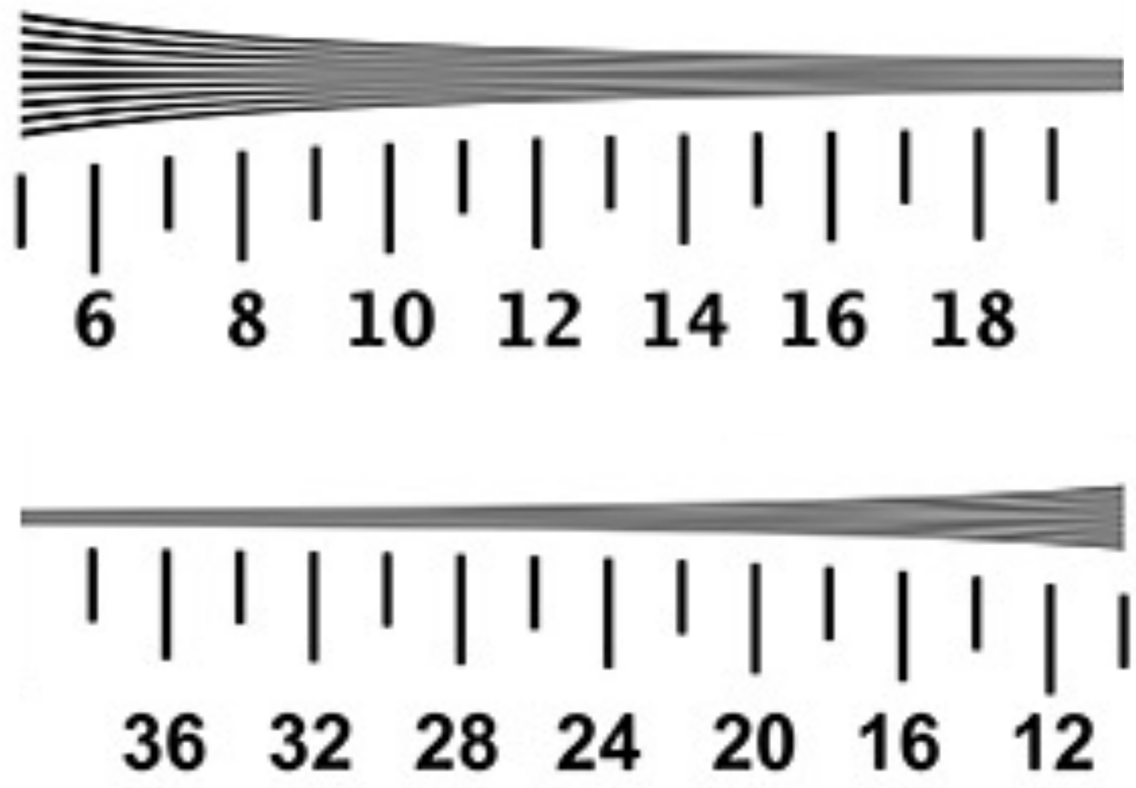


ISO: International Standards Organization

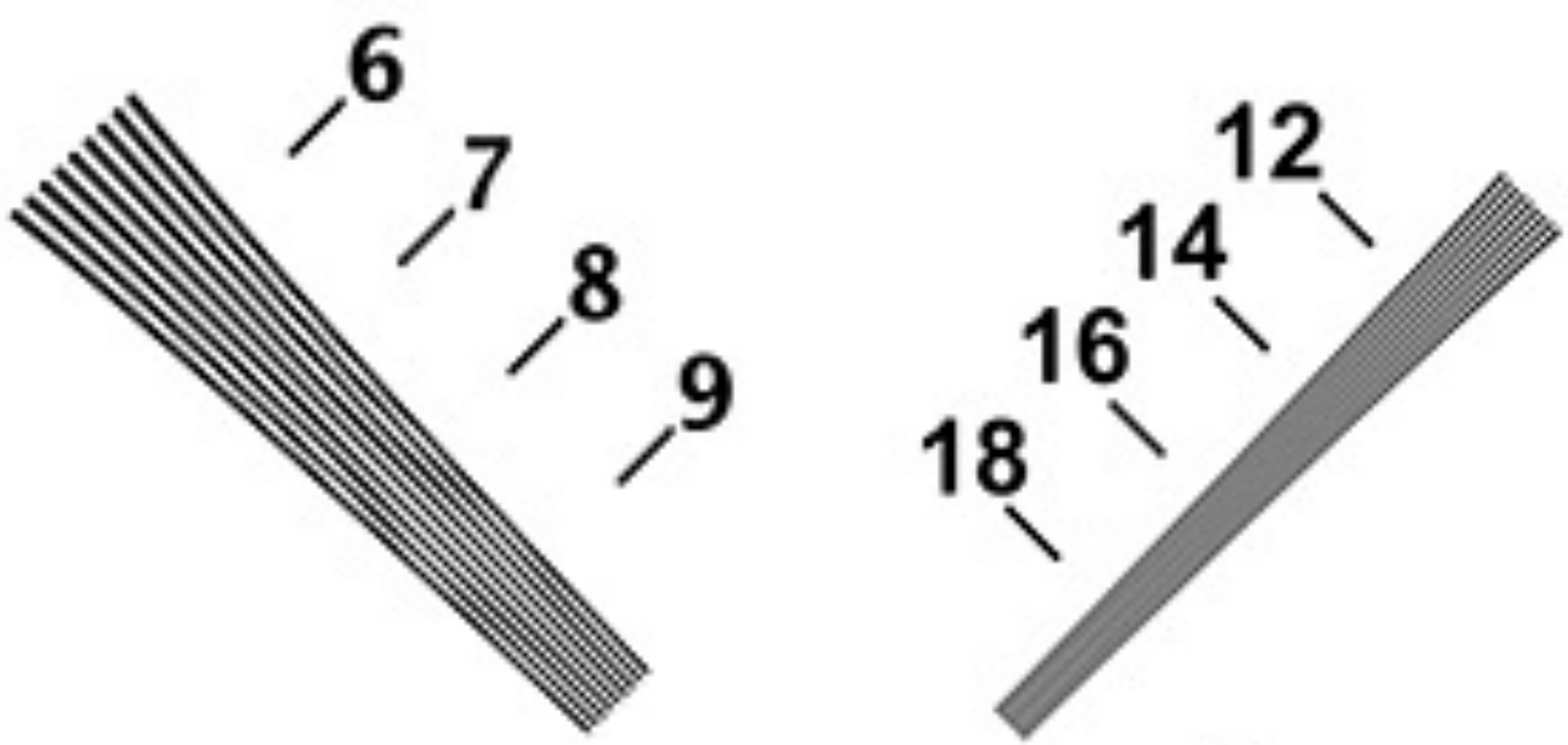
PIMA: Photographic and Imaging Manufacturers Association



[1] Vertical Resolution



[2] Horizontal Resolution

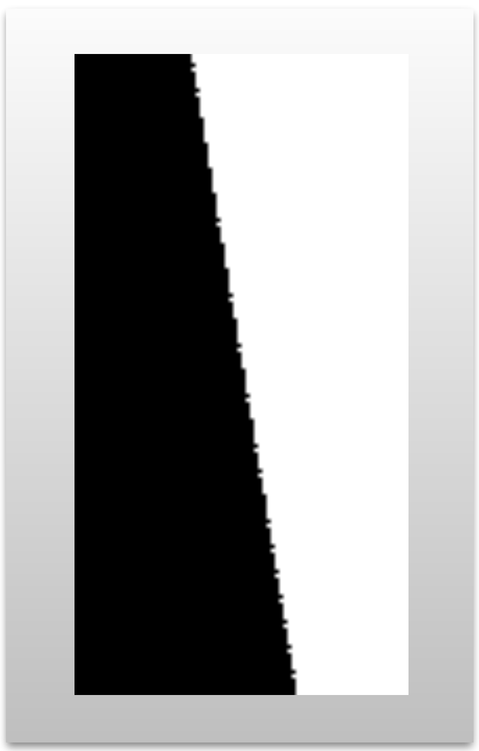


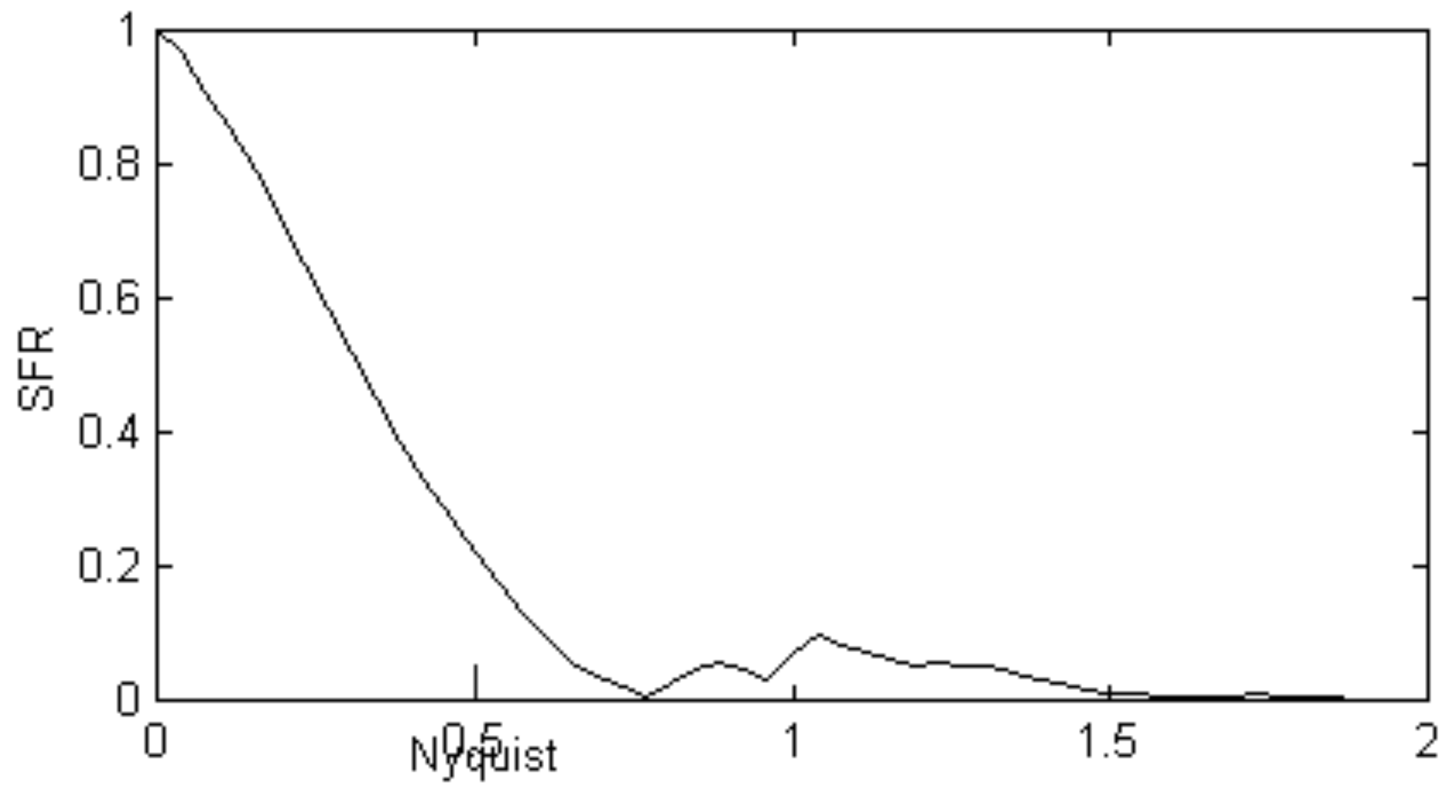
[3] Diagonal Resolution

Spatial Frequency Response

- SFR is simplified version of MTF.
- MTF requires expensive sinusoidal patterns, and needs to convert large amounts of data. Therefore, PIMA developed this low-cost SFR as a substitute.
- SFR is mainly used to measure the spatial frequency and increases lines of a single image of the impact.

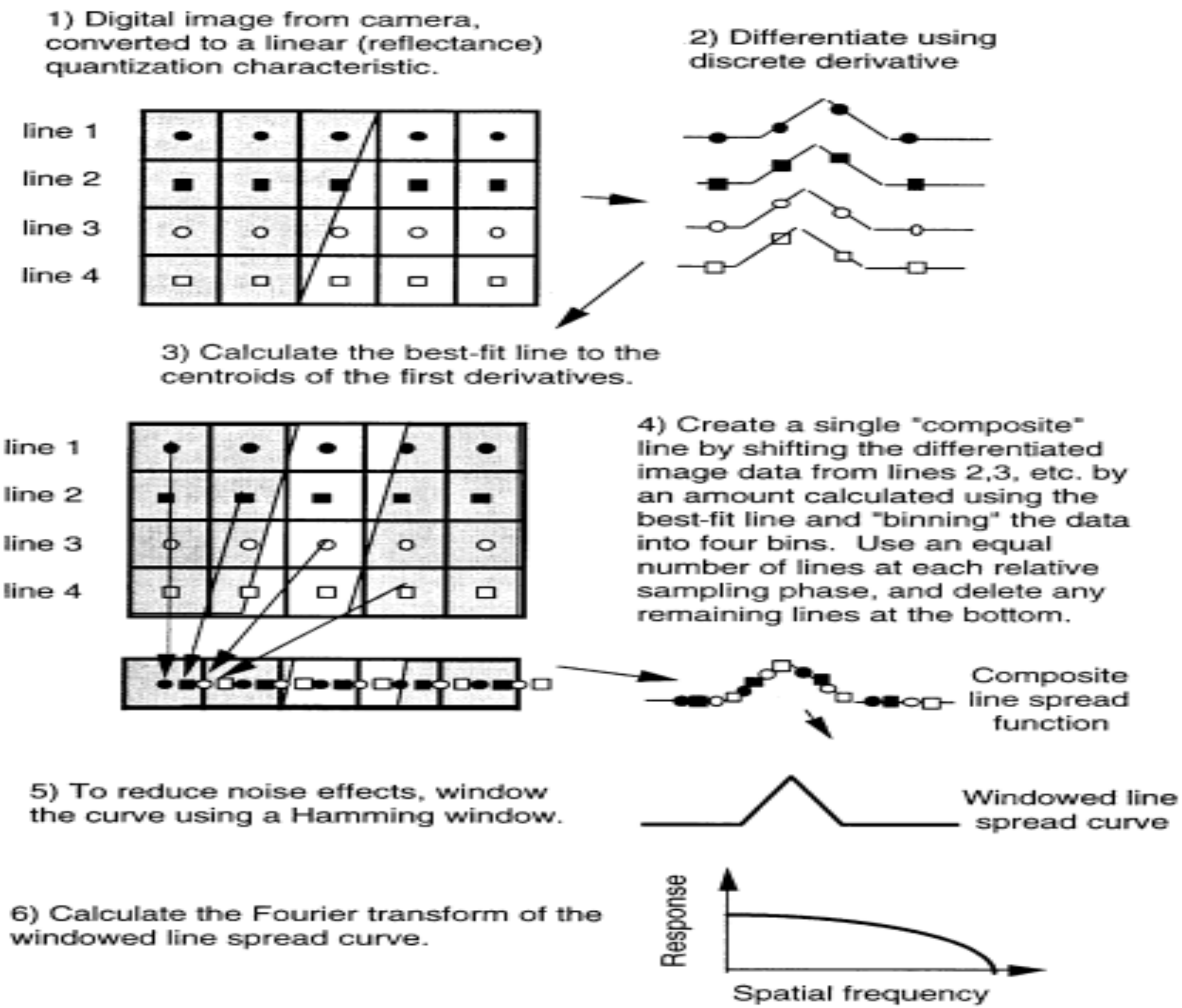
Spatial Frequency Response





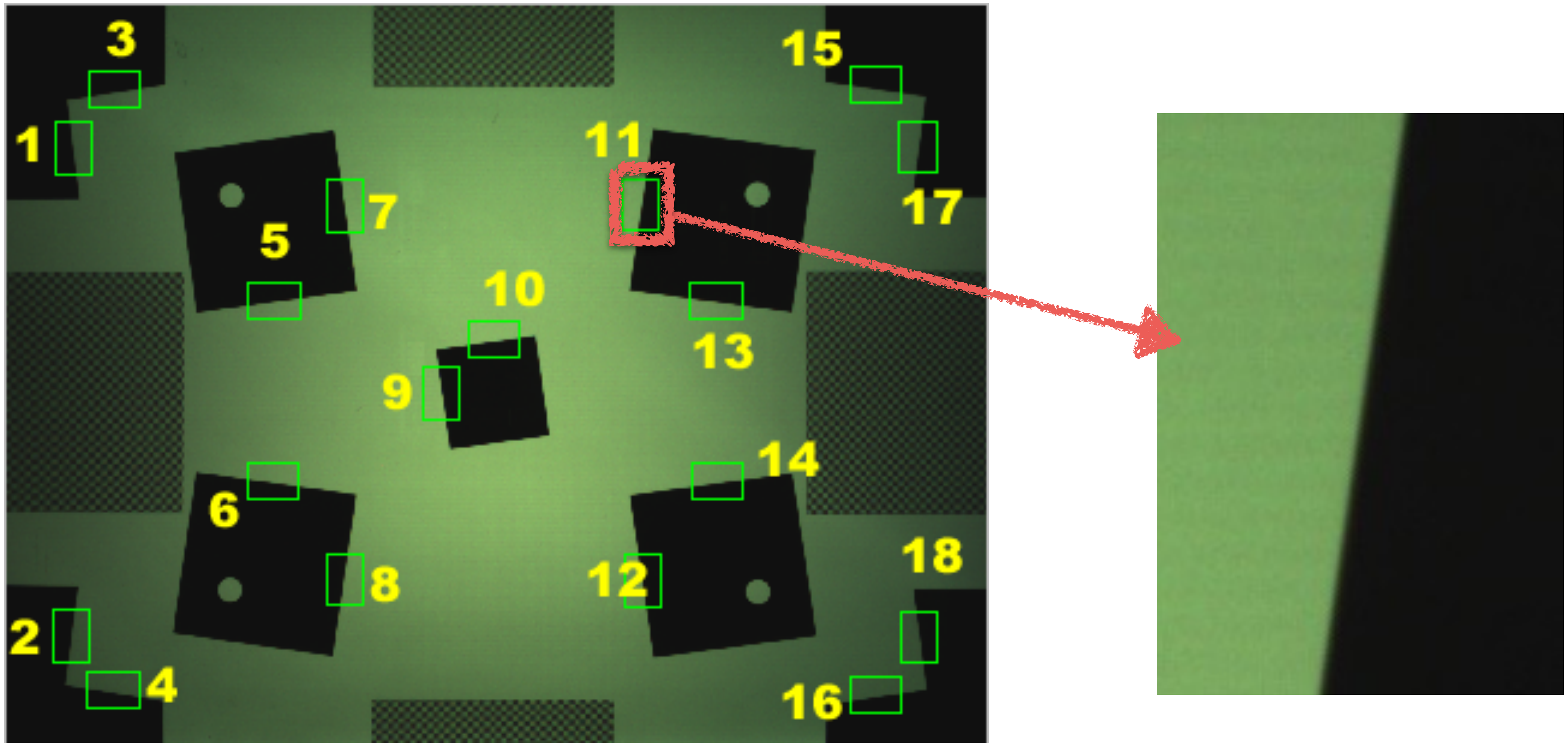
- SFR only needs one black and white slanted-edge, then can convert a value roughly equivalent to the MTF.

Flowchart


1) Digital image from camera, converted to a linear (reflectance) quantization characteristic.
2) Differentiate using discrete derivative
line 1
line 2
line 3
line 4
3) Calculate the best-fit line to the centroids of the first derivatives.
line 1
line 2
line 3
line 4
4) Create a single "composite" line by shifting the differentiated image data from lines 2,3, etc. by an amount calculated using the best-fit line and "binning" the data into four bins. Use an equal number of lines at each relative sampling phase, and delete any remaining lines at the bottom.
Composite line spread function
5) To reduce noise effects, window the curve using a Hamming window.
Windowed line spread curve
6) Calculate the Fourier transform of the windowed line spread curve.
Response
Spatial frequency

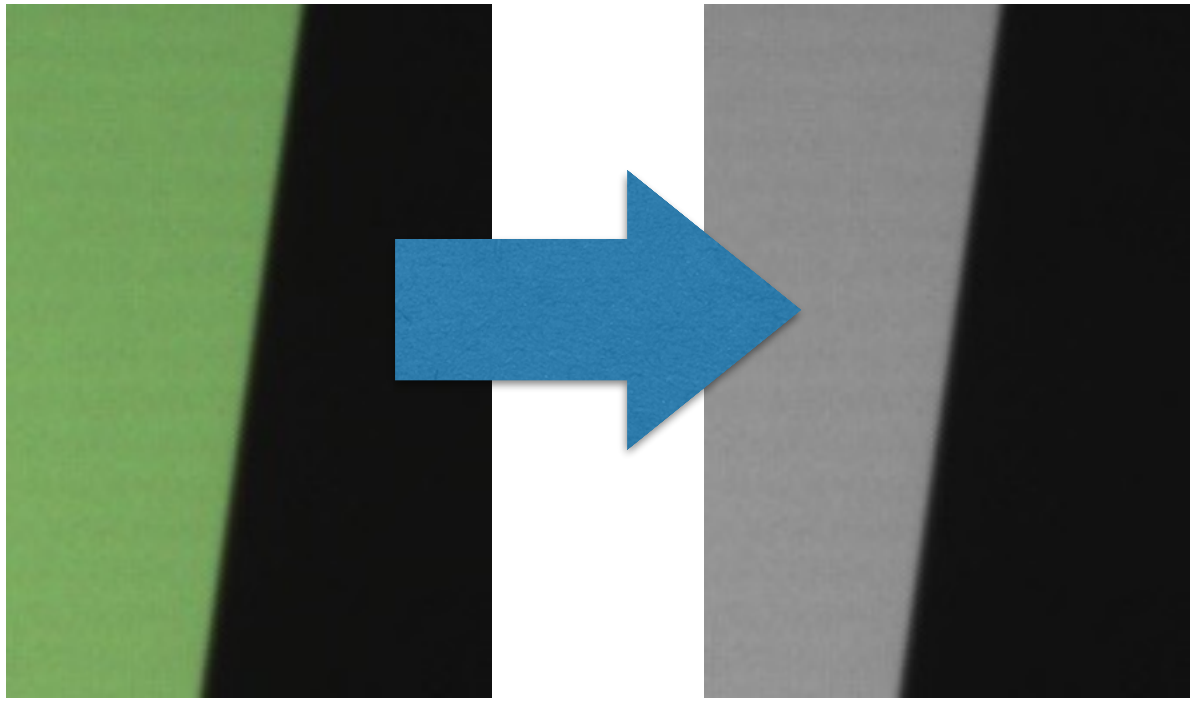
Enter ROI

- Slanted-edge: Top-down, white to black



RGB to Gray

- Gray = R*0.299 + G*0.587 + B*0.114
- Reduced 50% brightness
- Brightness between left and right must be at least 20% difference



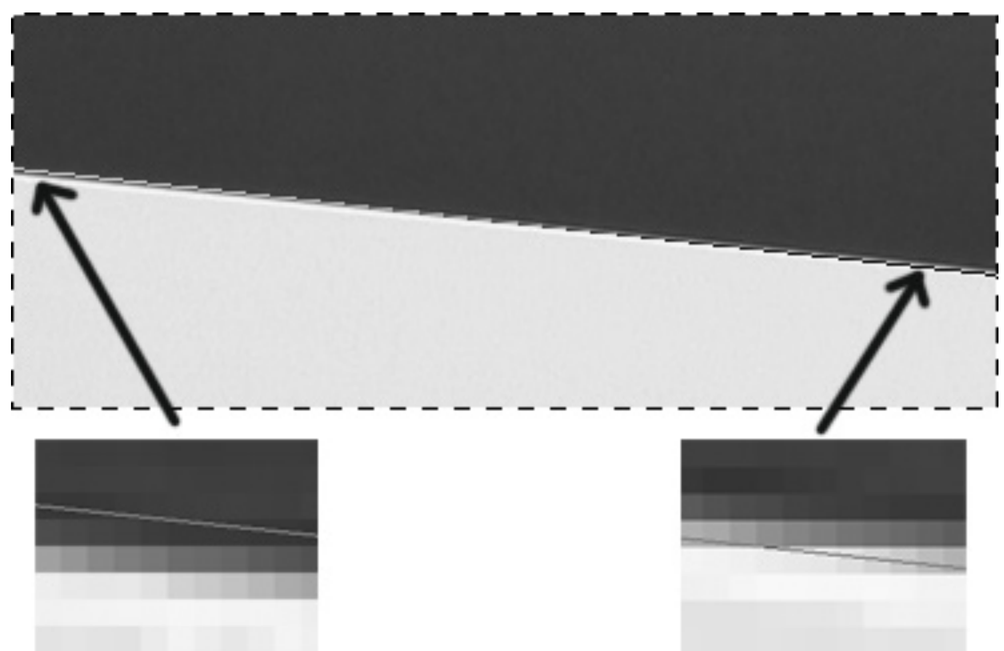
Edge Detection and Align

- Minimizing edge detection errors is most critical for getting sensible results. It's the first step, and the most important too.

- The edge is usually detected by analyzing the line spread function for each pixel line. ISO 12233 mentions the use of the finite-difference schemes [-1, 0, 1] and [-1, 1].

Edge Detection and Align

- Edge detection errors may spoil the test results not only when "bad" images are tested, but even in very common cases



❒ An example of a slope calculation error when finding "pure" centroids. In this case, the results are meaningless.

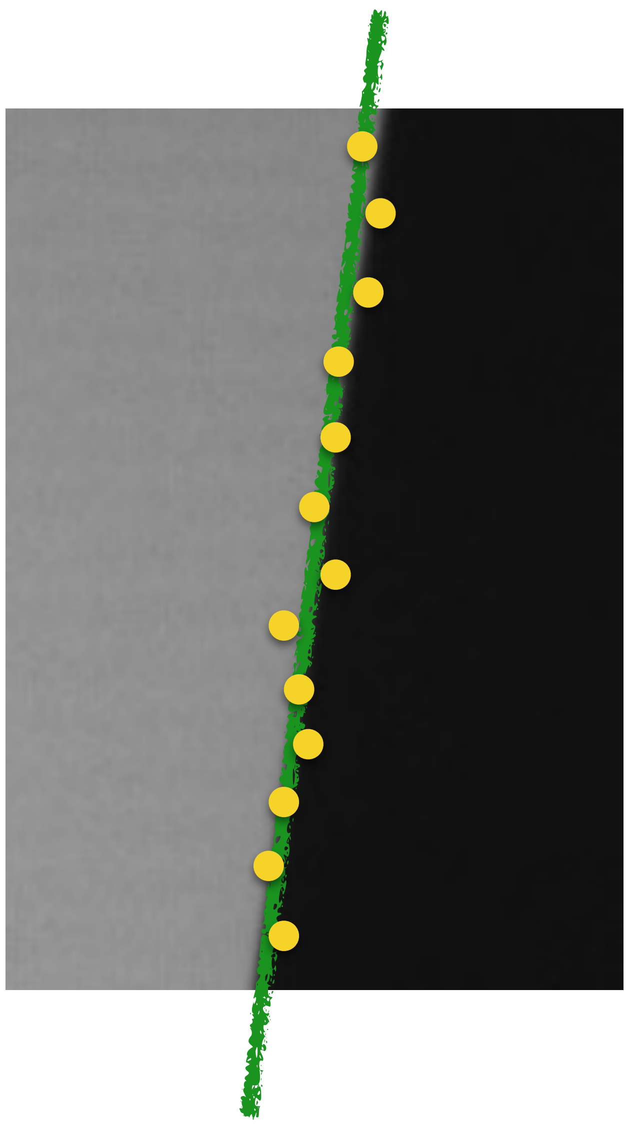
Edge Detection and Align

- Three options for edge detection:

  1. Centroid
  2. Centroid + Hamming
  3. Intensity based

Edge Detection and Align

- Edge detector: [1 0 -1]

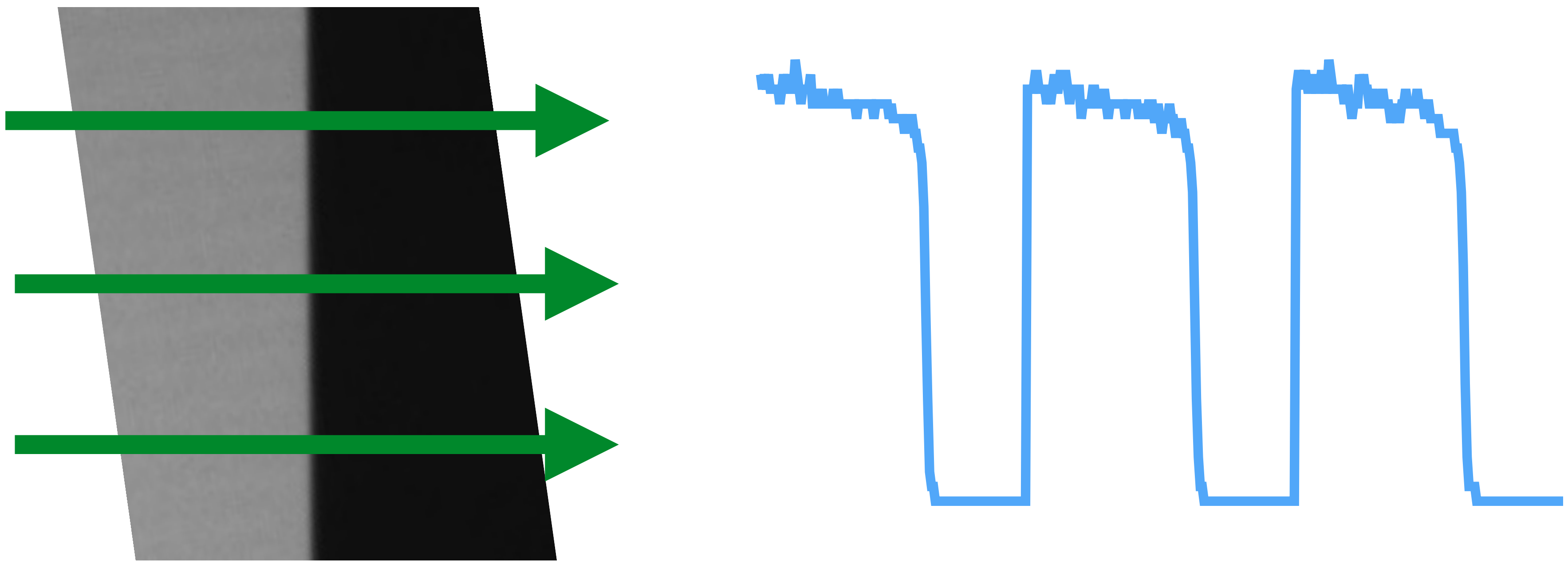


$$slope = \frac{\sum_{i=1}^{n}\left[(x_i - \bar{x}) \times (y_i - \bar{y})\right]}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

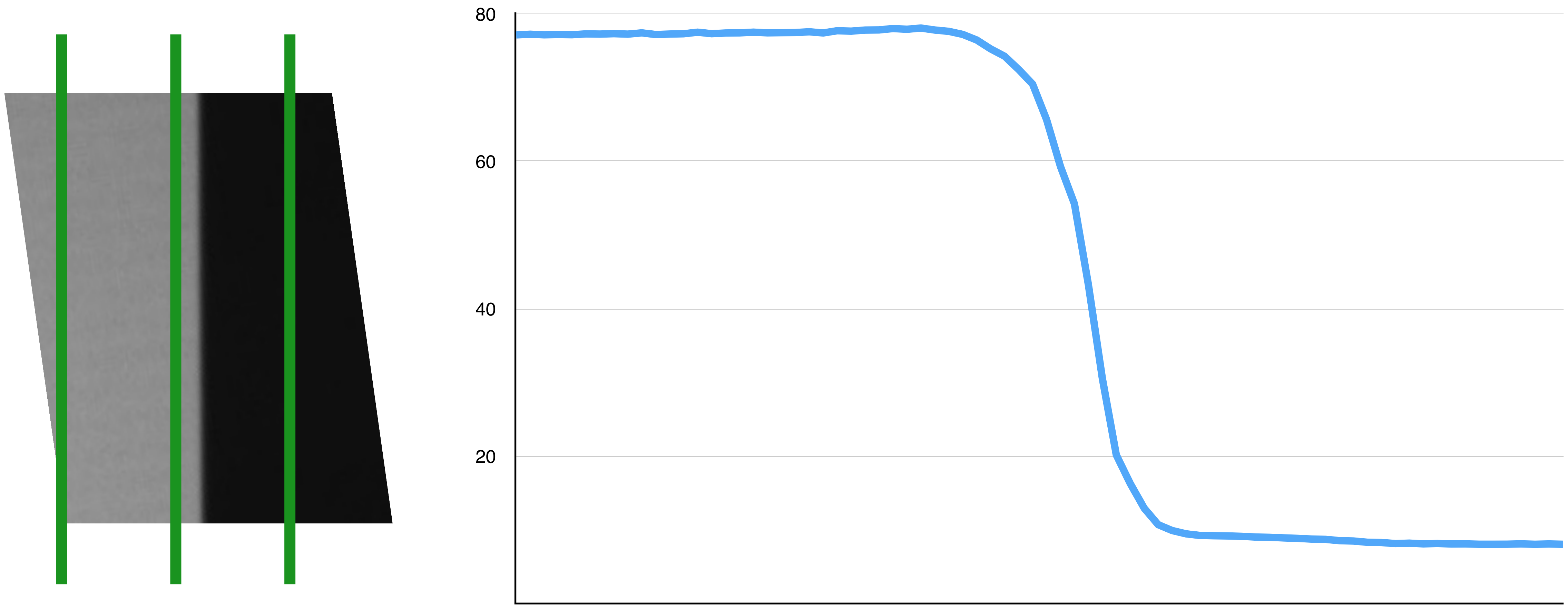
$$intercept = \bar{y} - slope \times \bar{x}$$

Edge Spread Function

- At this step, the intensities for all lines are accumulated and averaged, with taking the displacement of the edge into consideration.



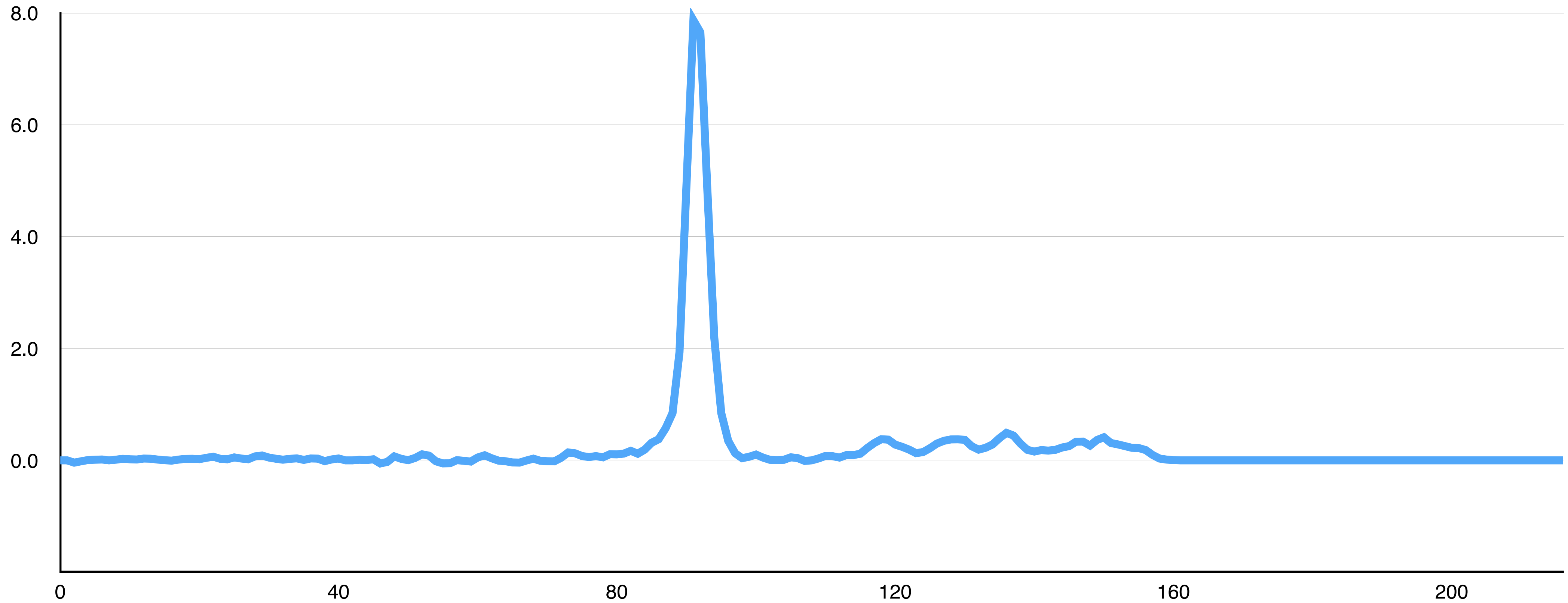
Edge Spread Function



- Average intensity of each column

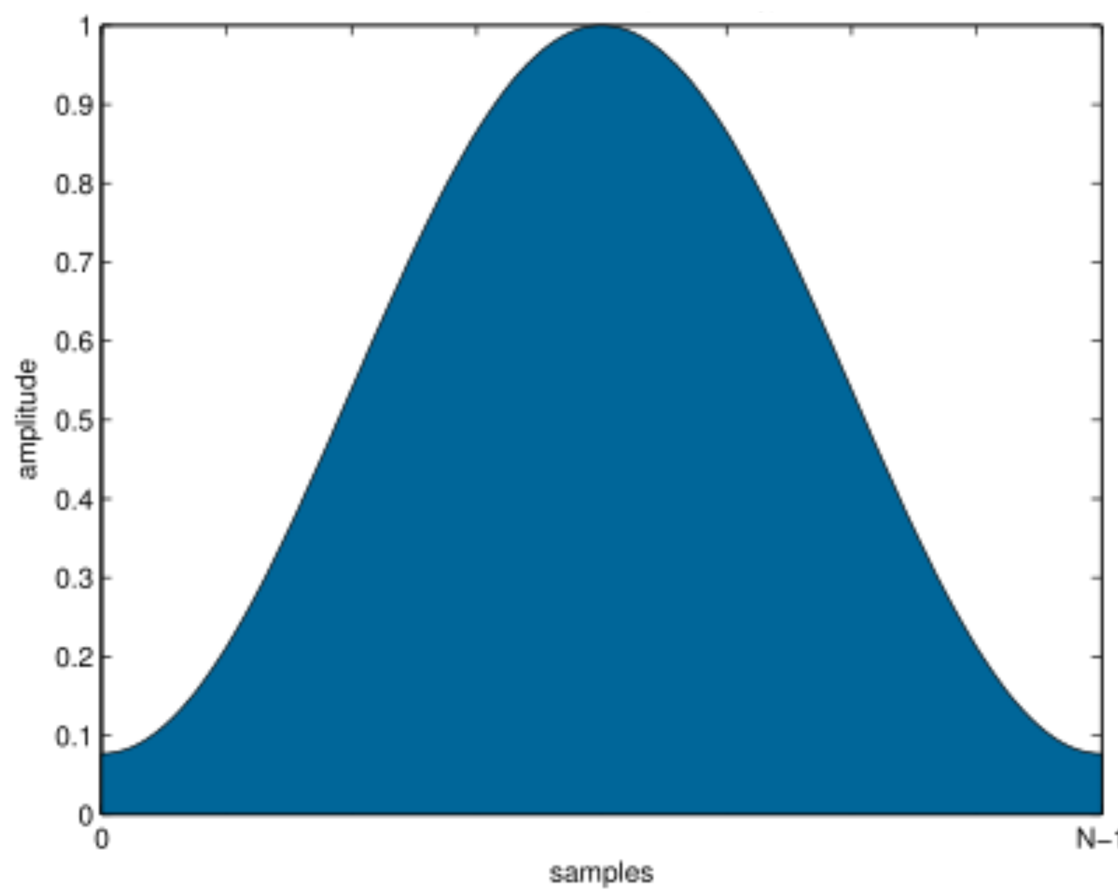
Line Spread Function

- LSF is the first derivative of ESF by [-1 0 1].
- Two difference schemes: [-1, 0, 1] and [-1, 1].



Hamming Window

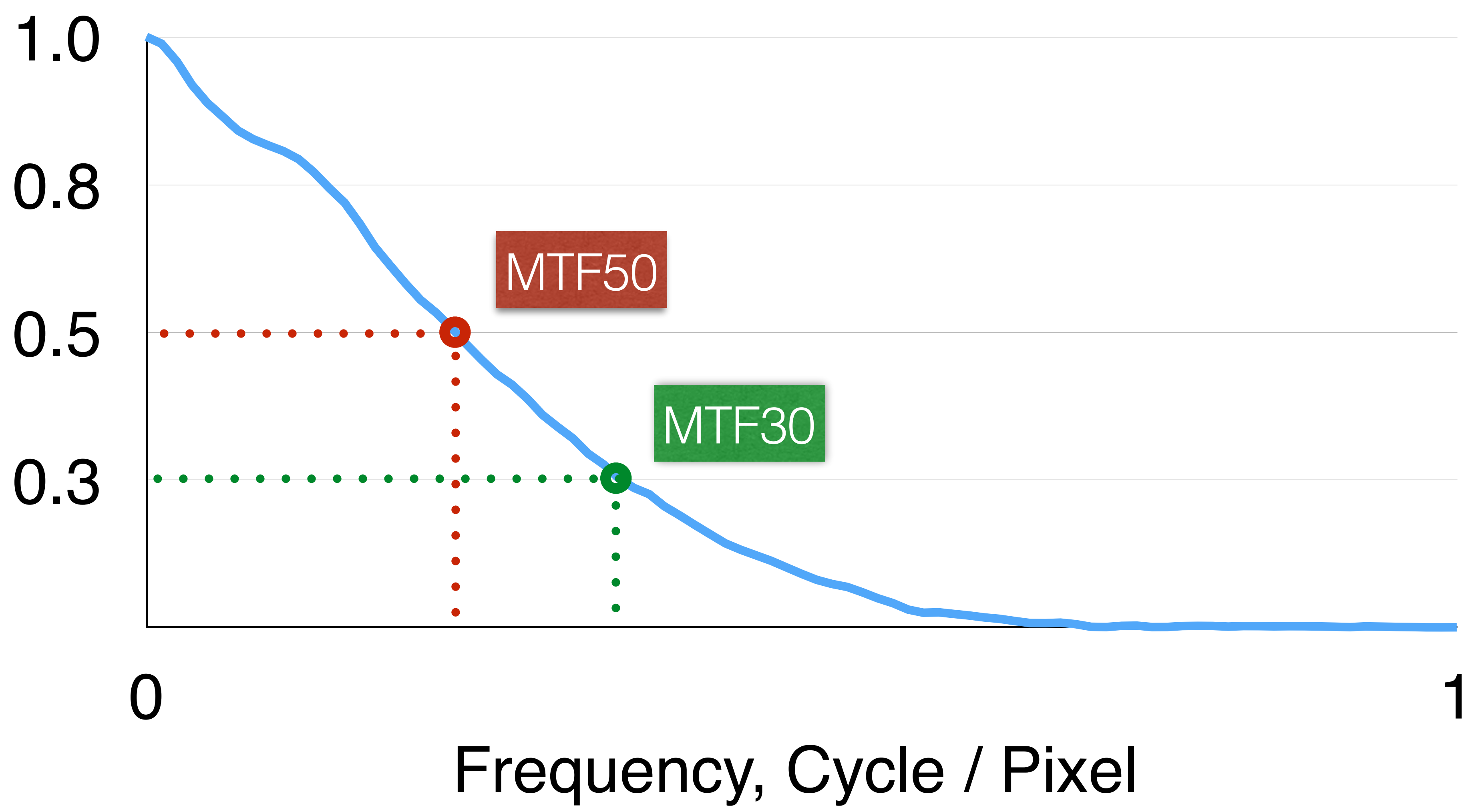
- After the LSF is calculated, the Hamming window is applied to the LSF.



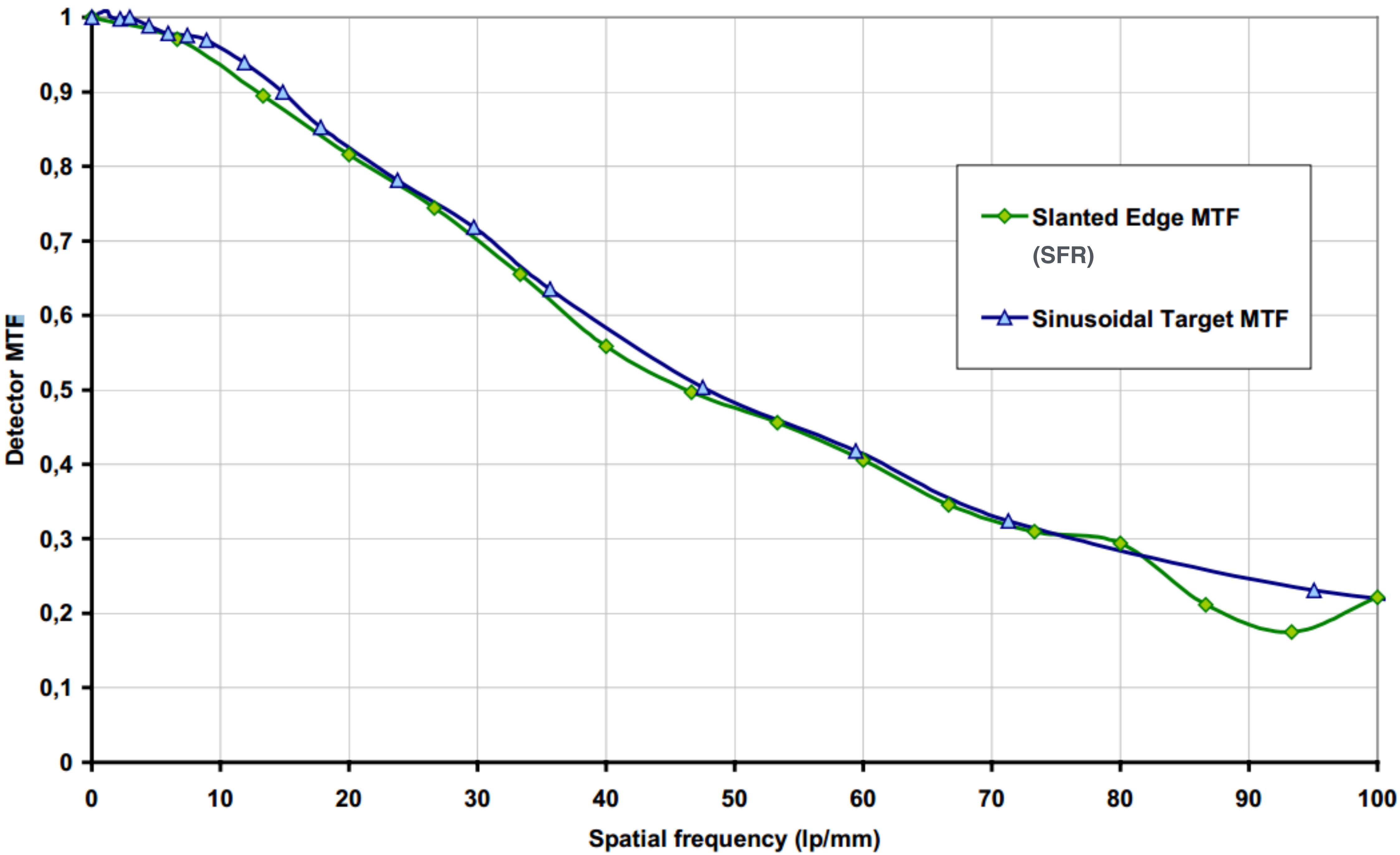
- $w(n) = 0.53836 - 0.46164\ \cos\left(\frac{2\pi n}{N-1}\right)$

Discrete Fourier Transform

- The SFR is an absolute value of the Fourier transform of the LSF.



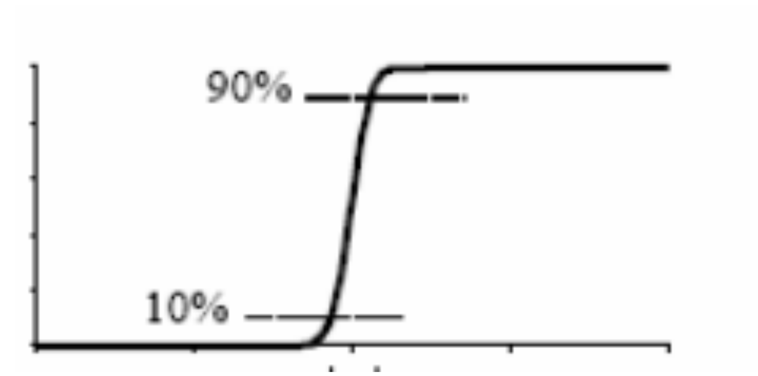
SFR vs MTF



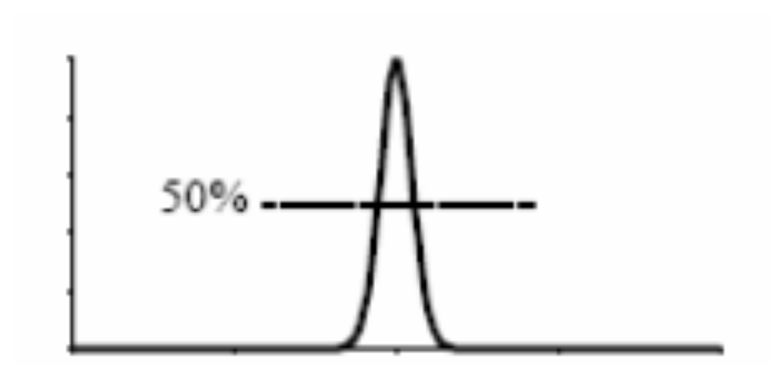
Detector MTF
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
10
20
30
40
50
60
70
80
90
100
Spatial frequency (lp/mm)
Slanted Edge MTF
(SFR)
Sinusoidal Target MTF

Smooth

- ESF Avg
  [0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1]
- ESF 10%~90%



- LSF 50%(↑)

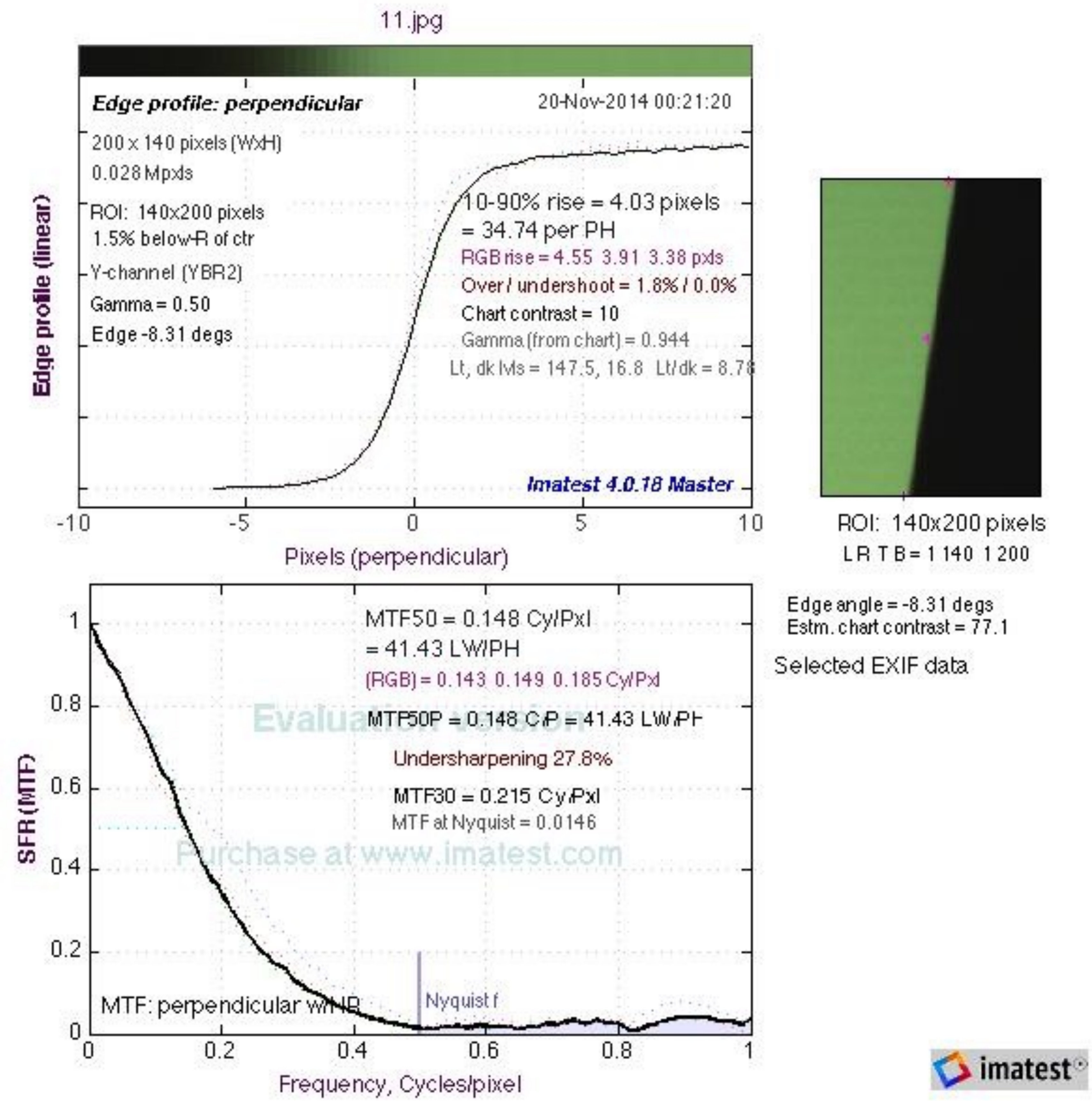


Imatest

- Imatest is a good software for digital imaging testing.

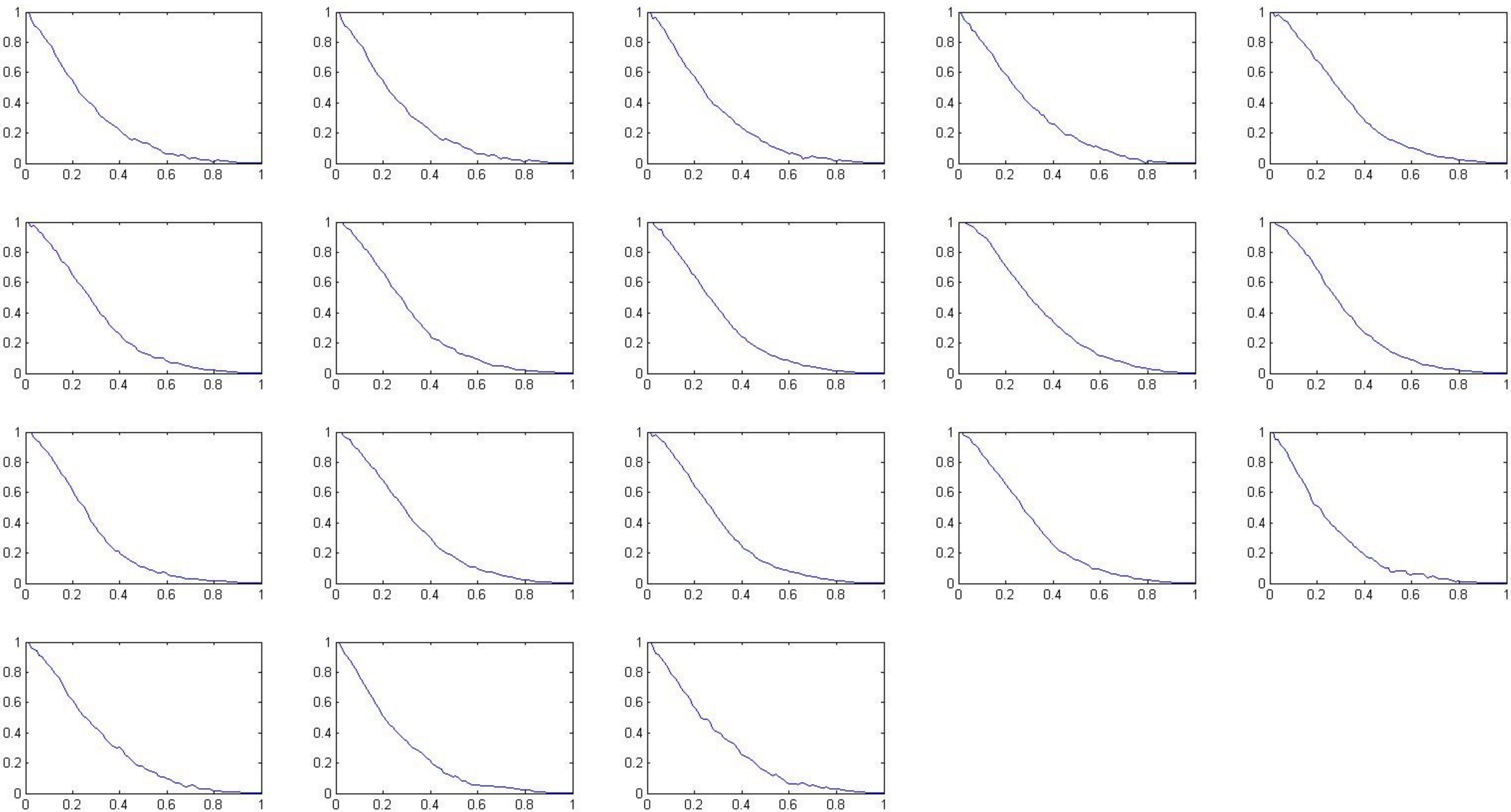
- Imatest covers SFR, color, and noise concurrently for printers, scanners, etc. Complete the test content.

- System is built on the well-known mathematical computing platform “Matlab” with high reliability.

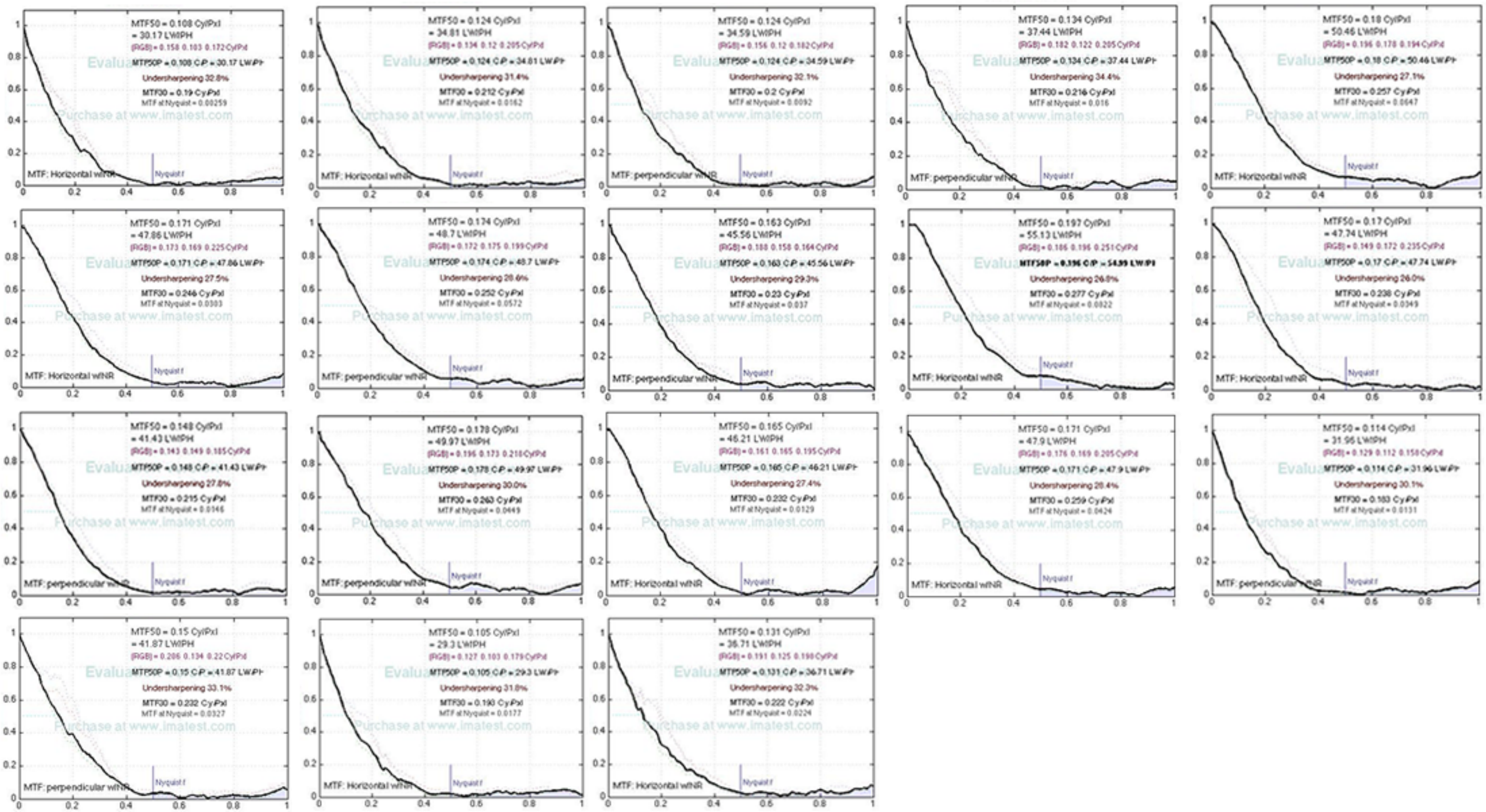


EXIF: Exchangeable Image File Format

MySFR

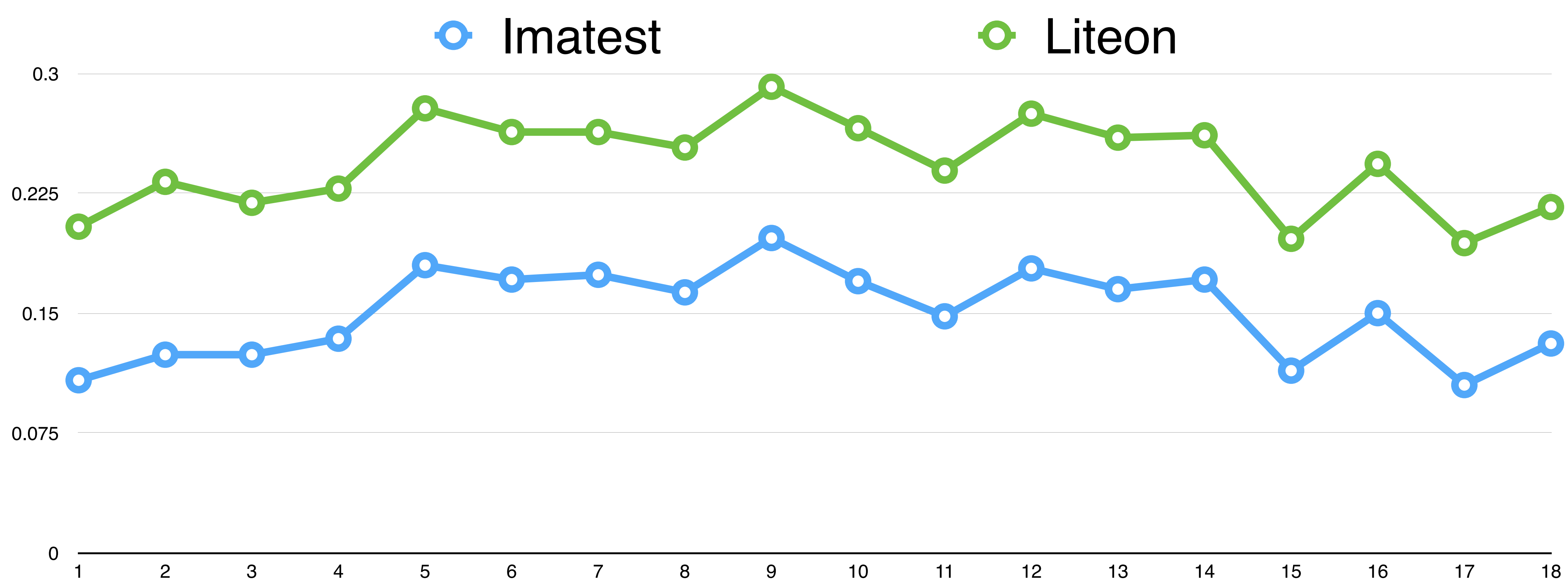


Imatest MTF


MTF50 = 0.108 Cy/Pxl = 30.17 LW/PH
Undersharpening 32.8%
MTF: Horizontal w/NR
MTF50 = 0.124 Cy/Pxl = 34.81 LW/PH
Undersharpening 31.4%
MTF: Horizontal w/NR
MTF50 = 0.124 Cy/Pxl = 34.59 LW/PH
Undersharpening 32.1%
MTF: perpendicular w/NR
MTF50 = 0.134 Cy/Pxl = 37.44 LW/PH
Undersharpening 34.4%
MTF: perpendicular w/NR
MTF50 = 0.18 Cy/Pxl = 50.46 LW/PH
Undersharpening 27.1%
MTF: Horizontal w/NR
MTF50 = 0.171 Cy/Pxl = 47.86 LW/PH
Undersharpening 27.5%
MTF: Horizontal w/NR
MTF50 = 0.174 Cy/Pxl = 48.7 LW/PH
Undersharpening 28.6%
MTF: perpendicular w/NR
MTF50 = 0.163 Cy/Pxl = 45.56 LW/PH
Undersharpening 29.3%
MTF: perpendicular w/NR
MTF50 = 0.197 Cy/Pxl = 55.13 LW/PH
Undersharpening 26.8%
MTF: Horizontal w/NR
MTF50 = 0.17 Cy/Pxl = 47.74 LW/PH
Undersharpening 26.0%
MTF: Horizontal w/NR
MTF50 = 0.148 Cy/Pxl = 41.43 LW/PH
Undersharpening 27.8%
MTF: perpendicular w/NR
MTF50 = 0.178 Cy/Pxl = 49.97 LW/PH
Undersharpening 30.0%
MTF: perpendicular w/NR
MTF50 = 0.165 Cy/Pxl = 46.21 LW/PH
Undersharpening 27.4%
MTF: Horizontal w/NR
MTF50 = 0.171 Cy/Pxl = 47.9 LW/PH
Undersharpening 26.4%
MTF: Horizontal w/NR
MTF50 = 0.114 Cy/Pxl = 31.96 LW/PH
Undersharpening 30.1%
MTF: perpendicular w/NR
MTF50 = 0.15 Cy/Pxl = 41.87 LW/PH
Undersharpening 33.1%
MTF: perpendicular w/NR
MTF50 = 0.105 Cy/Pxl = 29.3 LW/PH
Undersharpening 31.8%
MTF: Horizontal w/NR
MTF50 = 0.131 Cy/Pxl = 36.71 LW/PH
Undersharpening 32.3%
MTF: Horizontal w/NR

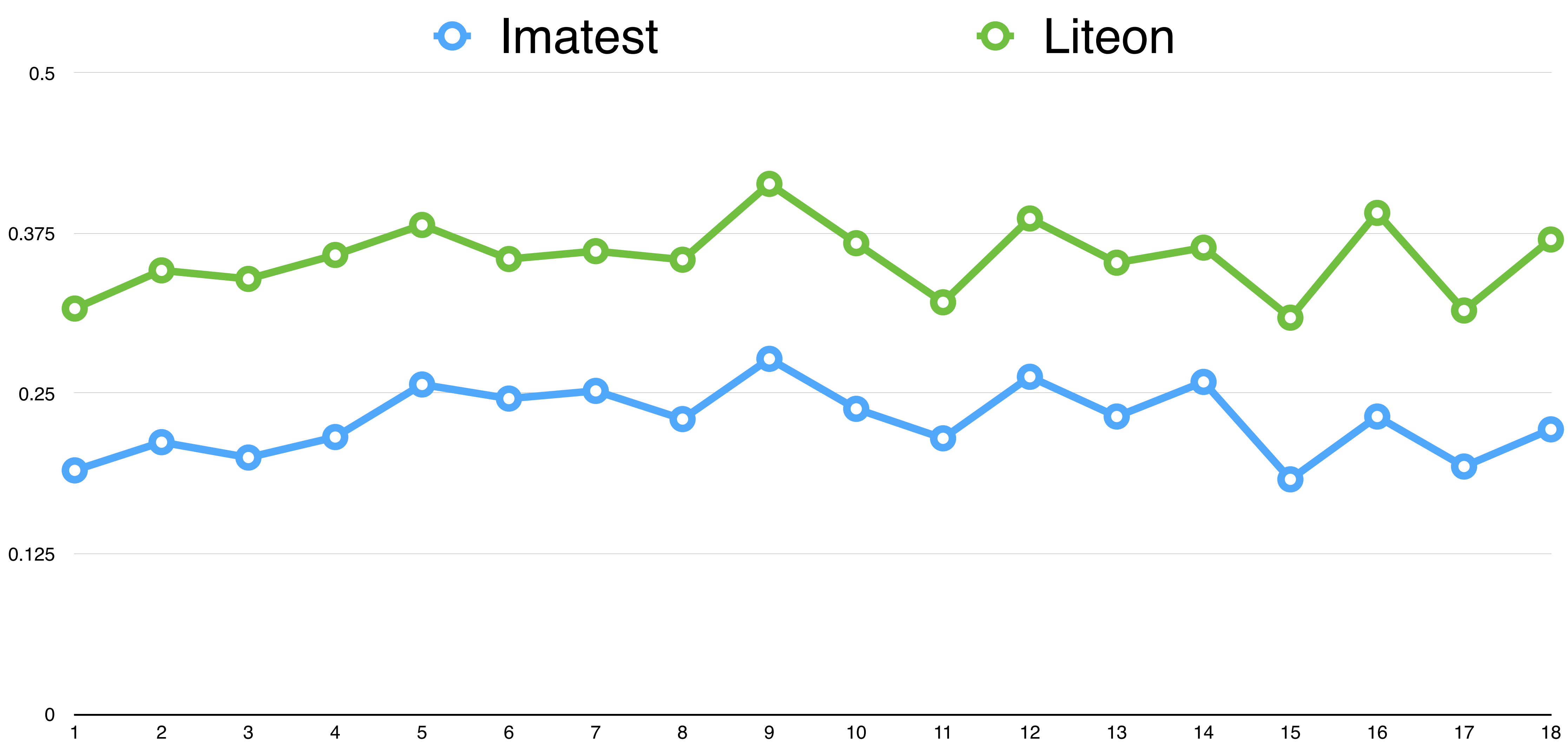
Accuracy

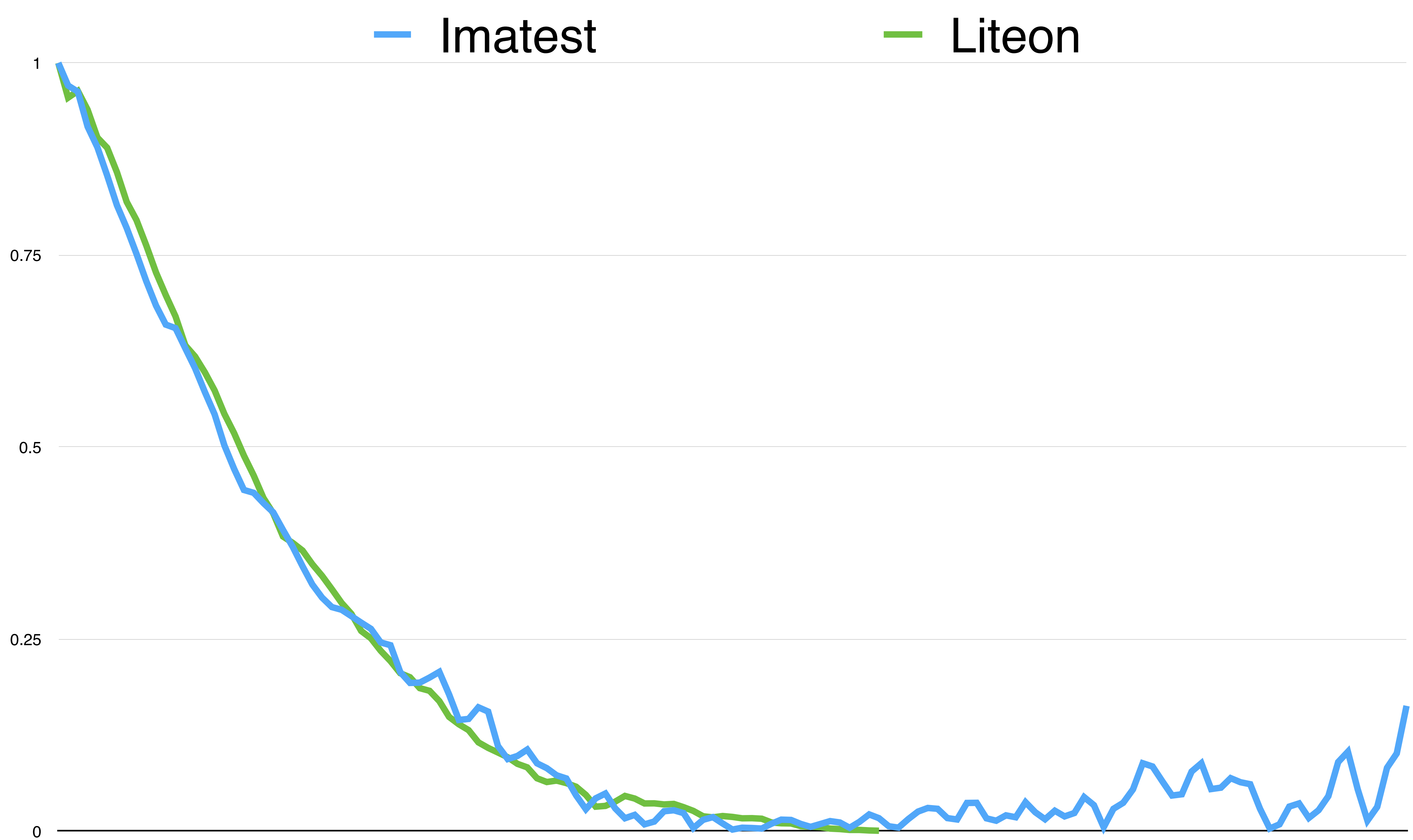
- Our result compared with Imatest has about 9% difference at MTF50.



Accuracy

- Our result compared with Imatest has about 12% difference at MTF30.





Imatest
Liteon
1
0.75
0.5
0.25
0

Reference

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