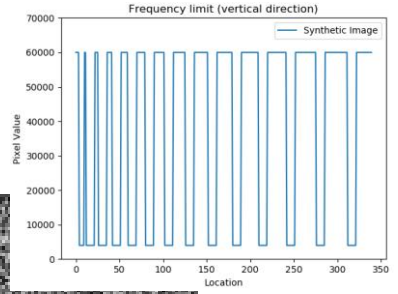
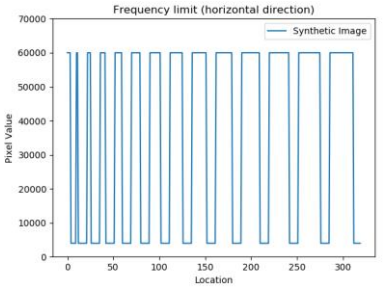
Synthetic Target1

- 16 – bit, 1024x1280
- Max pixel value : 60000
- Min pixel value : 4000

Frequency limit:

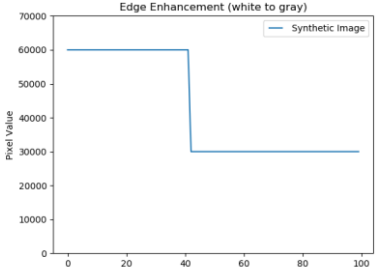
Test if a low frequency information is lost.

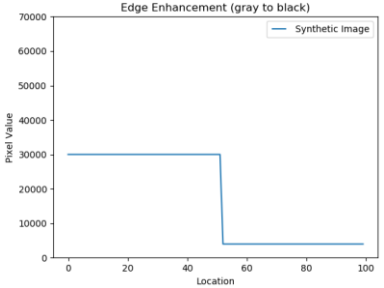


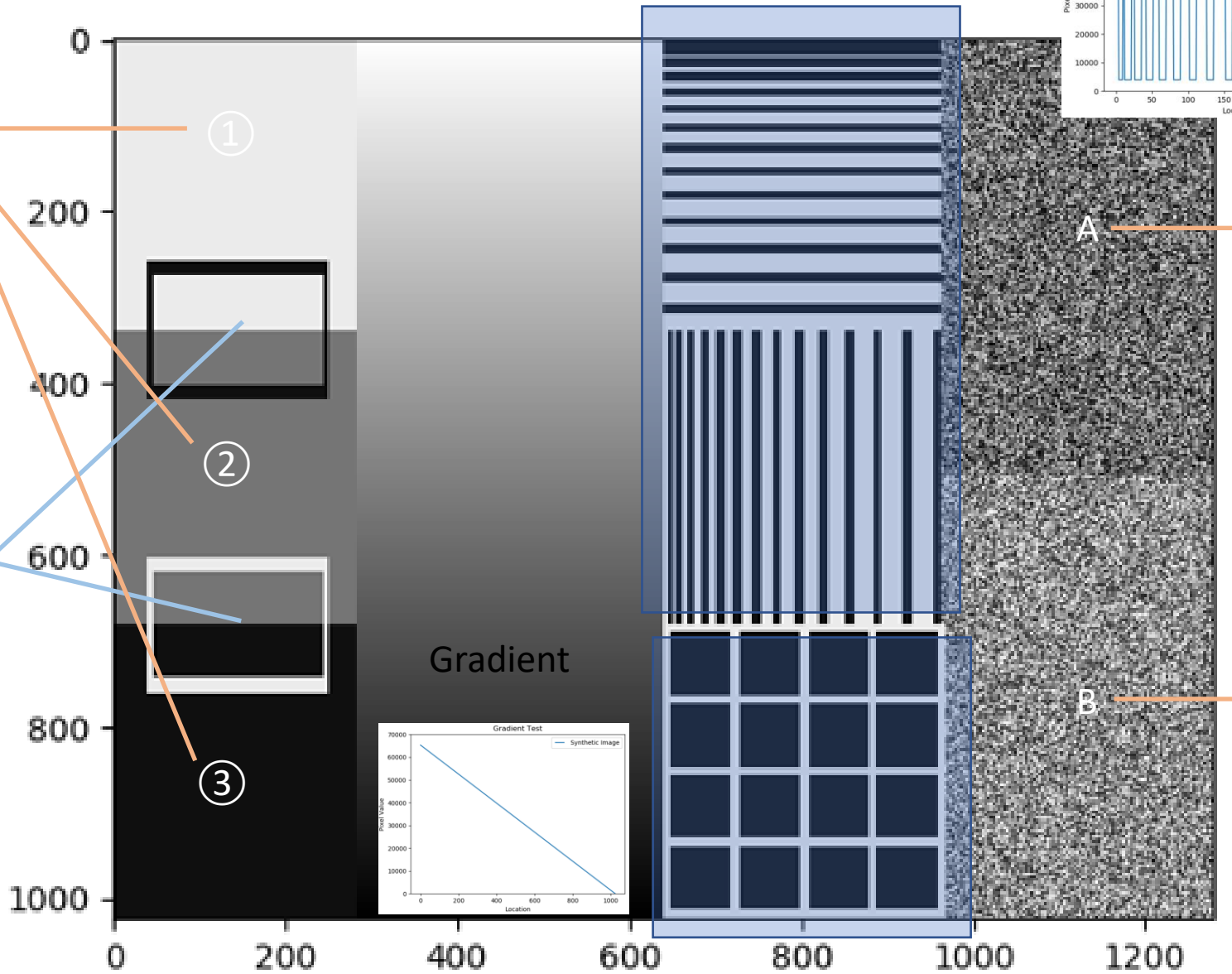


Uniformity test

Edge enhancement





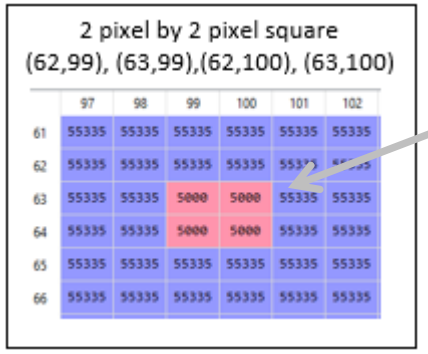


Random noise:

Test if algorithms boost random noise

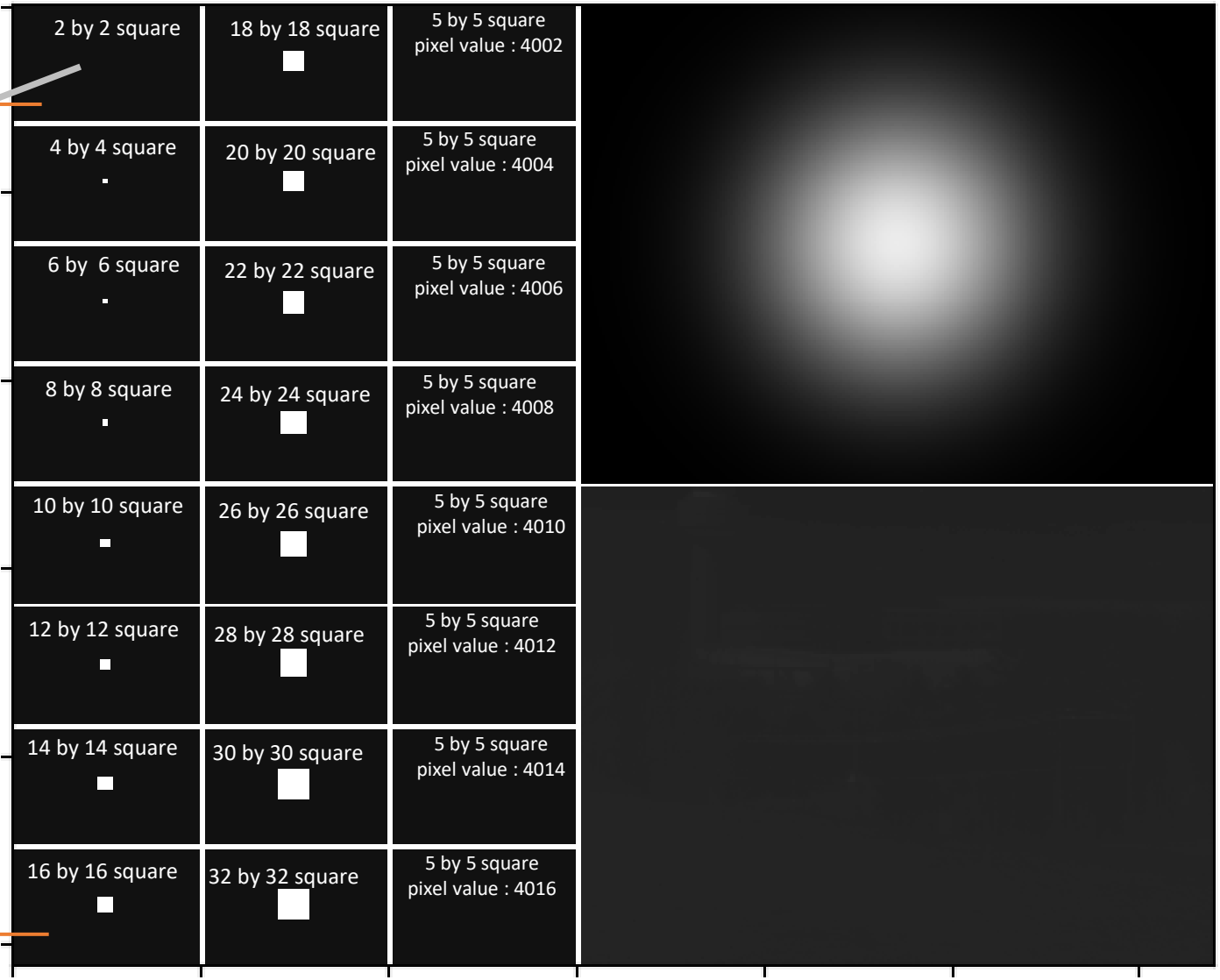
Synthetic Target2

- 16 – bit, 1024x1280
- Max pixel value : 60000
- Min pixel value : 4000



Minimum intensity:

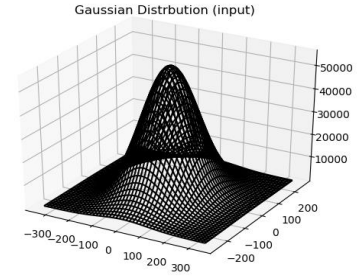
What is the minimum difference in pixel value that algorithms can detect?

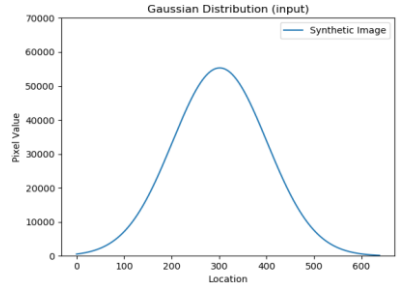


Size of objects:

Test if the size of objects change

Gaussian distribution





Global contrast enhancement:

Test if it increases global contrast.

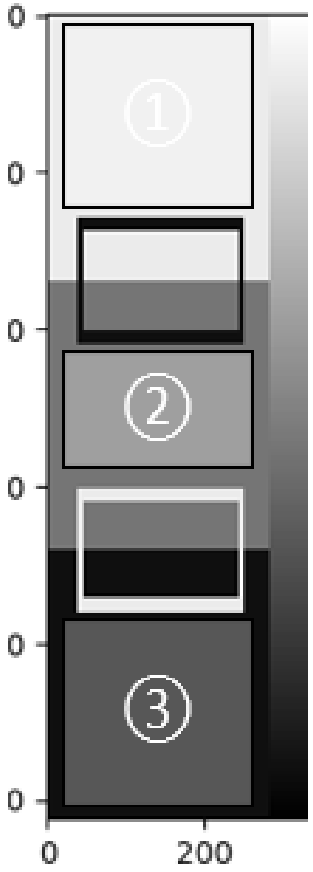
Result of global contrast enhancement

Result of Synthetic Targets

	Target 1					Target 2			
	Uniformity	**Edge Enhancement**	**Gradient (brightness)**	**Frequency limit**	**Random noise (Entropy)**	**Size of object**	**Noticeable pixel value difference**	**Gaussian distribution**	**Global contrast enhancement**
CLAHE	Good	No	Brighter	Less than 2 pixel/cycle	Increased	Not changed	Less than 2-pixel value	Failed	Yes
Image pyramid	Good	Yes	Brighter	Less than 2pixel/cy	Decreased	Not changed	Less than 2-pixel value	Passed	No
Multiscale Morphology	Good	No	Not changed	Less than 2 pixel	Decreased	Not changed	Less than 2-pixel value	Passed	No

- CLAHE increased global contrast.
- Image pyramid increased local contrast as well as edge enhancement.
- Multiscale Morphology increased contrast based on the size of the object within the filters used in the algorithm. (3 by 3, 5 by 5, 7 by 7, and 9 by 9 in our algorithm.)

Synthetic Target1



Uniformity test

Standard deviation and mean of selected areas

①
Rectangular area under the white background
Mean pixel value: 60000
Standard deviation : 0

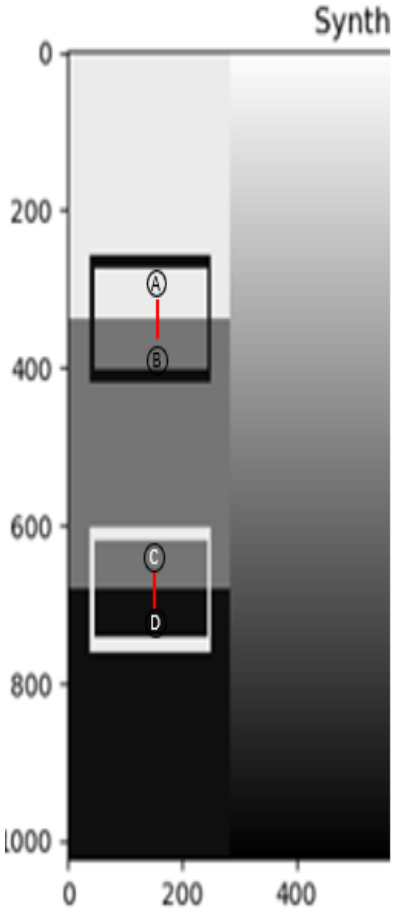
②
Rectangular area under the gray background
Mean pixel value: 30000
Standard deviation : 0

③
Rectangular area under the black background
Mean pixel value: 4000
Standard deviation : 0

	Area 1 (white)		Area 2 (gray)		Area 3 (black)	
	Mean	STD	Mean	STD	Mean	STD
Input Target	60000	0	30000	0	4000	0
CLAHE	60000	0	30000	0	4000	0
Image pyramid	65535	0	60000	0	8000	0
Multiscale Morphology	60000	0	30000	0	4000	0

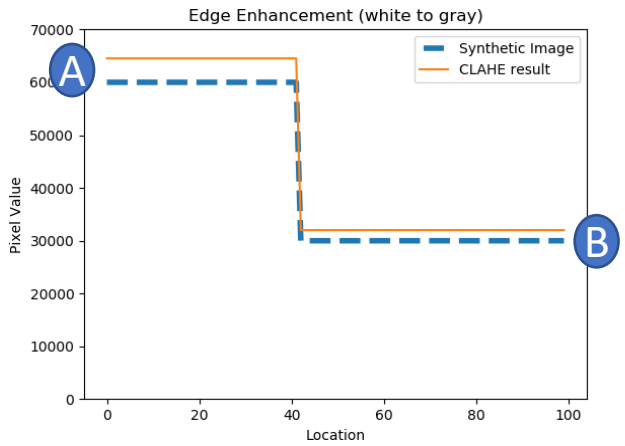
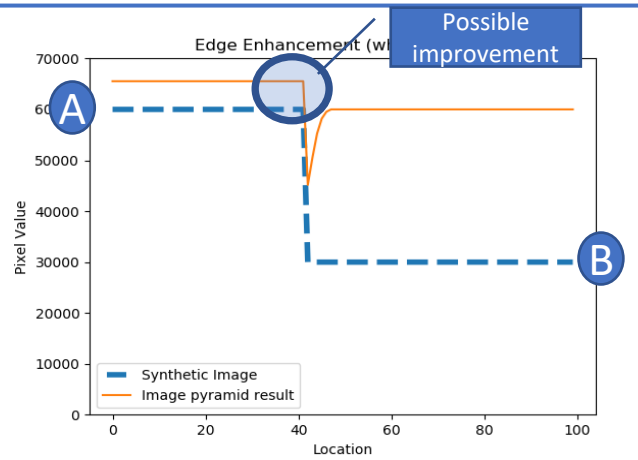
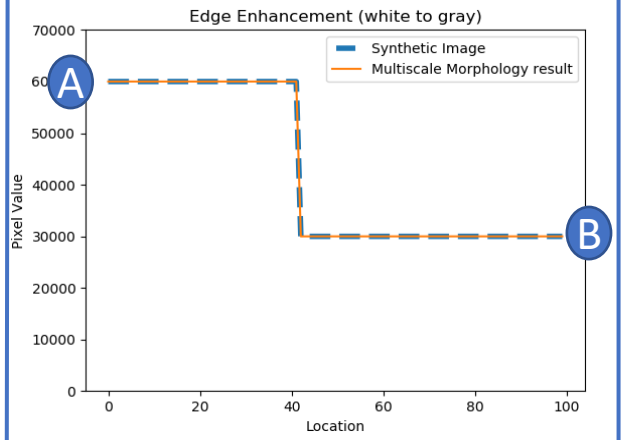
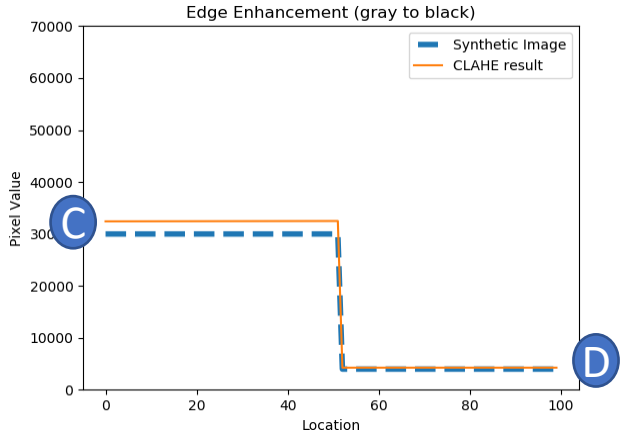
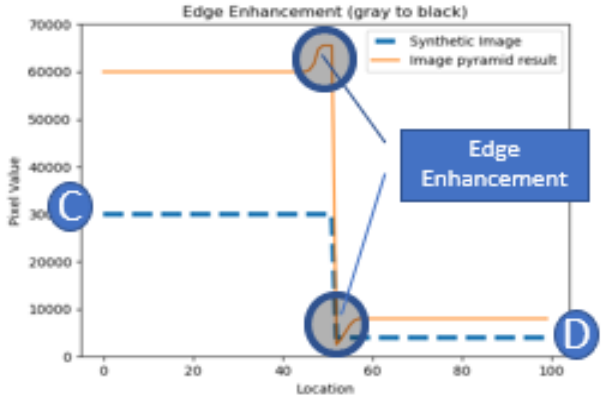
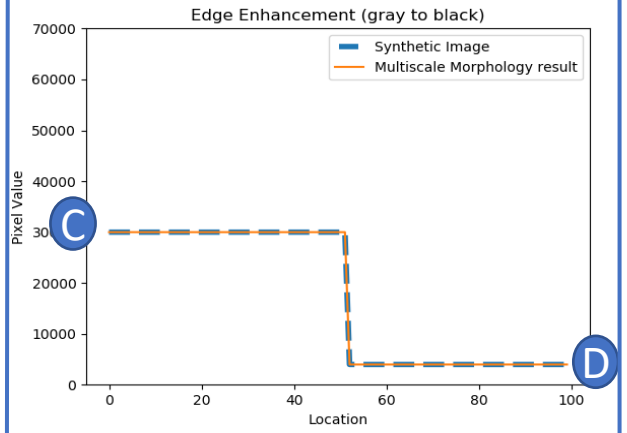
All three algorithms produced a uniform area.

Synthetic Target1

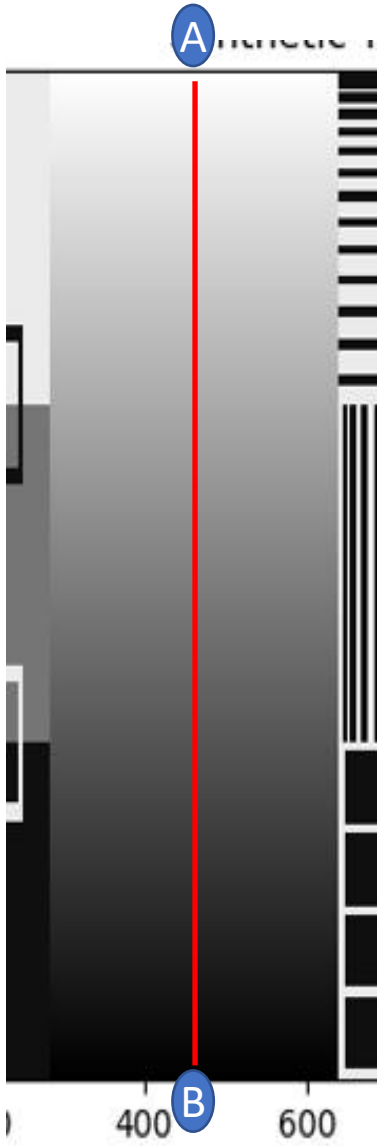


Edge enhancement

Intensity profile from A to B (from white to gray) and C to D (from gray to black)

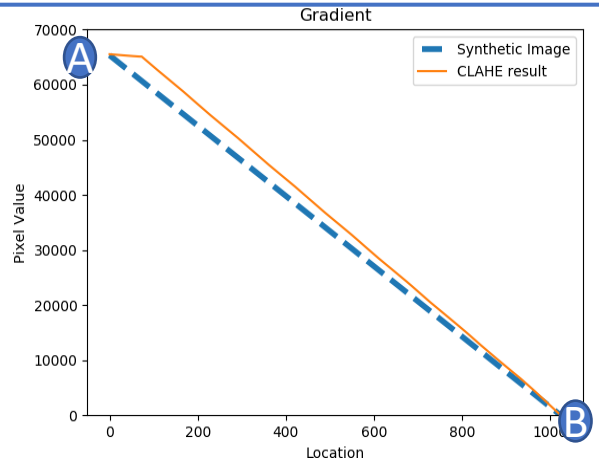
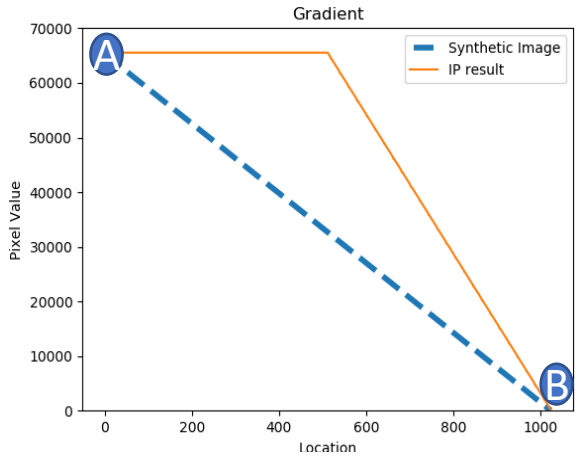
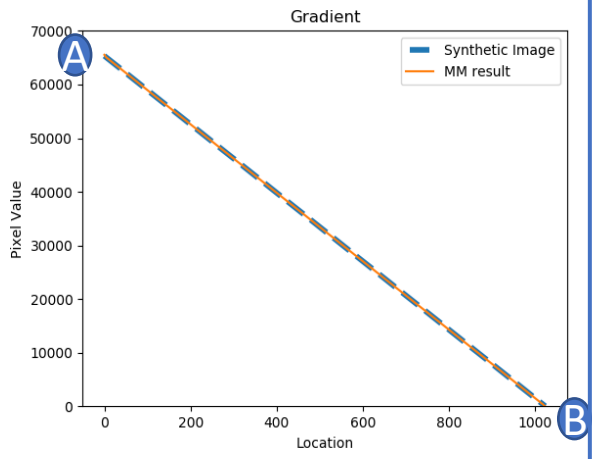
	CLAHE	Image Pyramid	Multiscale Morphology
White to Gray			
Gray to Black			
Comment	CLAHE stretched the contrast over the sharp edge.	Image Pyramid showed edge enhancement effect. However, there is possible improvement for the higher pixel values (bright), if it constrains the exceeding pixels under the maximum pixel value.	Multiscale Morphology didn't have the edge enhancement effect. It preserved the edges exactly.

Synthetic Target1

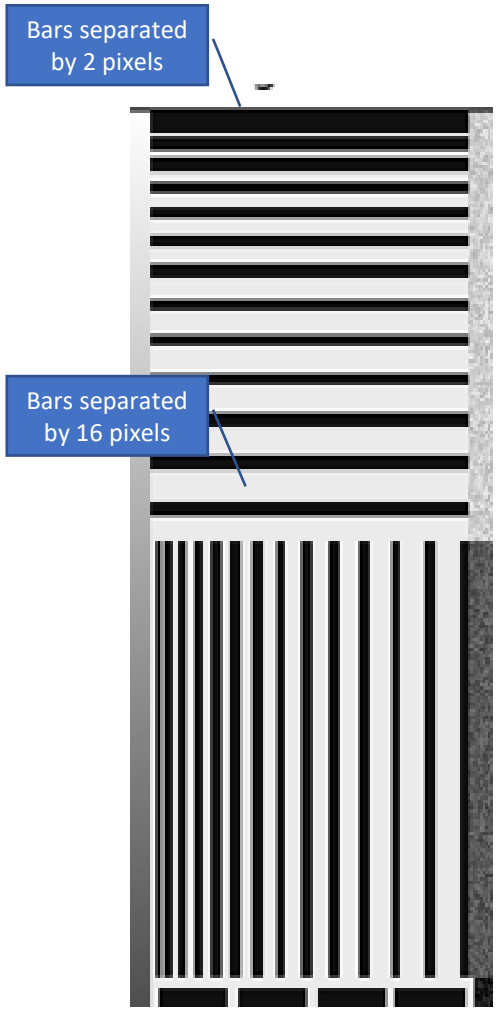


Gradient

Intensity profile from A to B (from white to black)

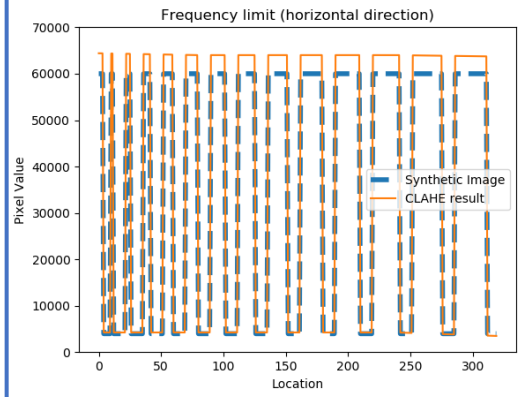
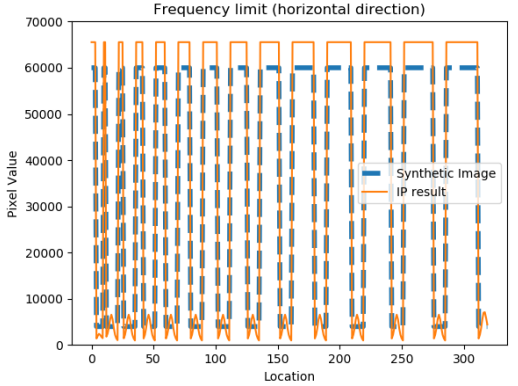
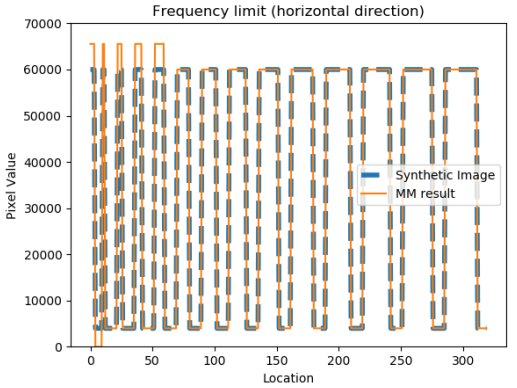
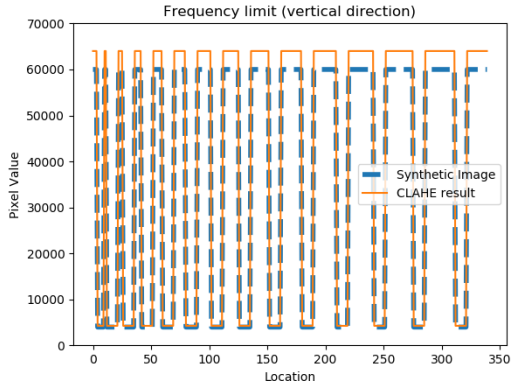
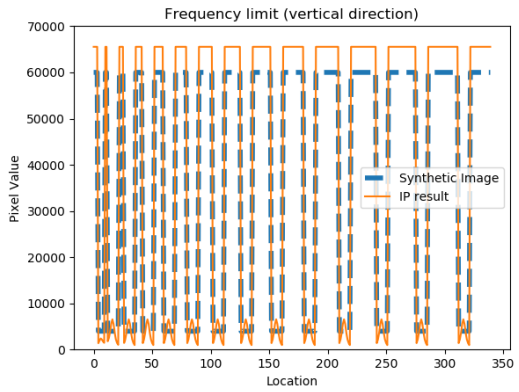
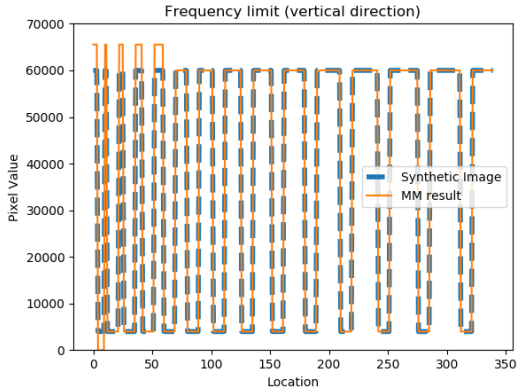
	CLAHE	Image Pyramid	Multiscale Morphology
Gradient			
Comment	CLAHE changed the brightness. There are some pixels that exceed the maximum value, and those pixels are set to the max value. Because exceeding pixels are capped to the max value, some details in the bright area may be lost.	Image Pyramid changed the brightness more significantly and more pixels are capped.	Multiscale Morphology didn't change the brightness of the gradient.

Synthetic Target1

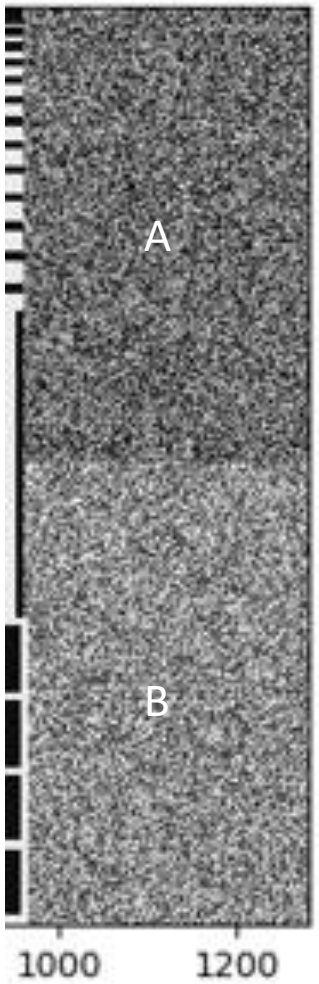


Frequency limit

Each bar is separated by a distance from 2 pixels to 16 pixels.

	CLAHE	Image Pyramid	Multiscale Morphology
Horizontal direction			
Vertical direction			
Comment	The three algorithms preserved all frequencies without losing details.		

Synthetic Target1



Random noise test

- Entropy was used to measure the random noise.
- Entropy has the maximum value for the histogram with uniform distribution.
  (Julio César Mello Román, *Entropy and Contrast Enhancement of Infrared Thermal Images Using the Multiscale Top-Hat Transform*, 2019)

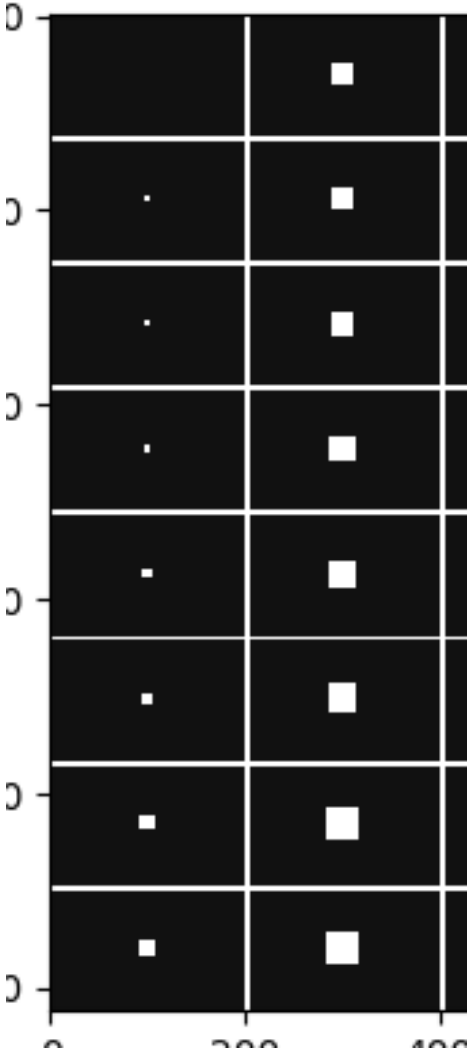
	Area A (Black background)	Area B (White background)
Input Target	0.96	0.96
CLAHE	0.97	0.98
Image pyramid	0.51	0.52
Multiscale Morphology	0.31	0.31

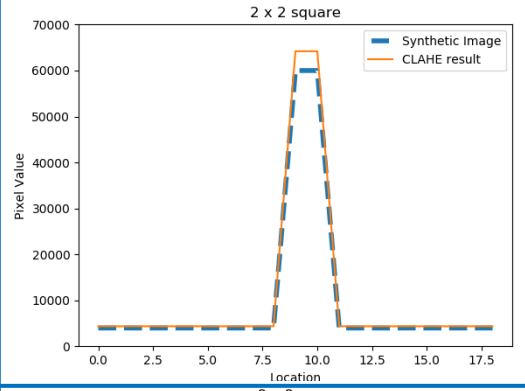
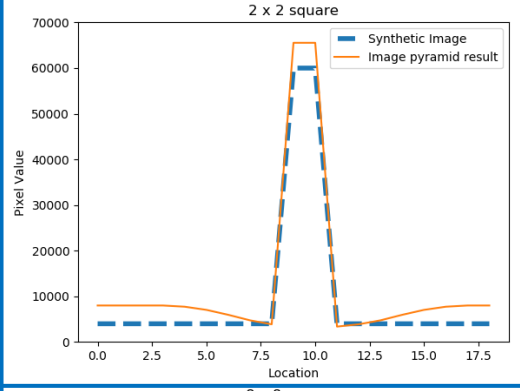
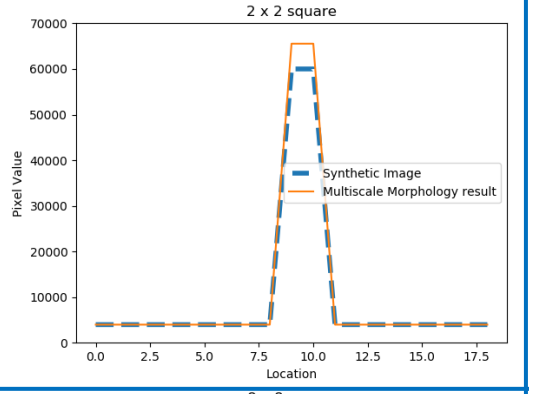
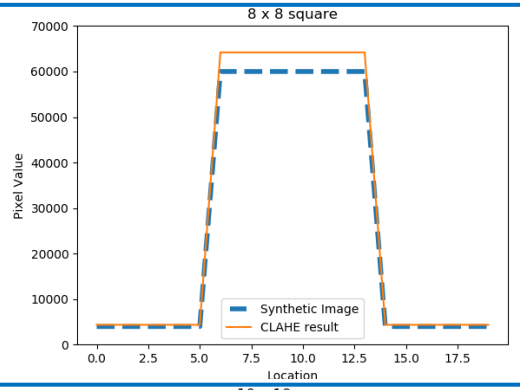
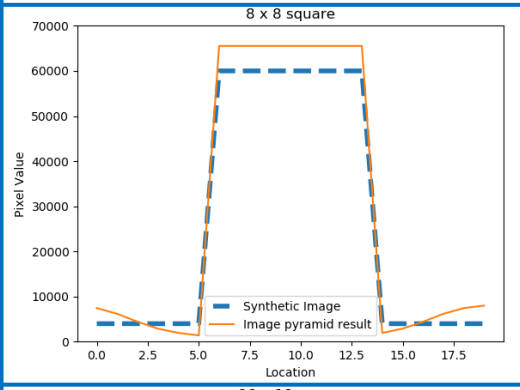
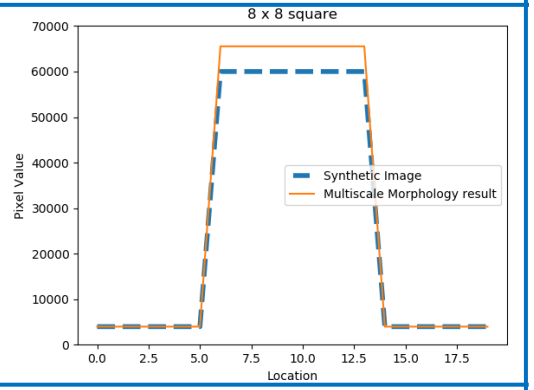
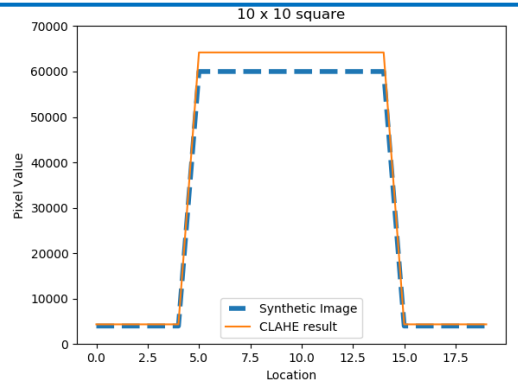
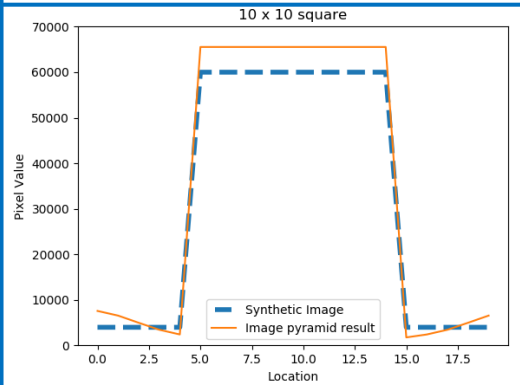
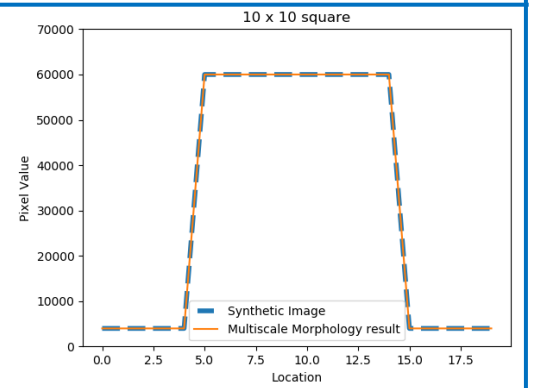
The entropy of the results were lower than entropy of the target (image pyramid and multiscale morphology).
The random noise is reduced, and the noise turned into the background.
The entropy of CLAHE is high because it distributed random noise over the image while it expanded the global contrast.

Synthetic Target2

Size of objects:

Tested 16 squares
(2-pixel square to 16-pixel square)



	CLAHE	Image Pyramid	Multiscale Morphology
2 by 2			
8 by 8			
10 by 10			
Comment	The size of objects didn't change. CLAHE increased the contrast on all the squares.	The size of objects didn't change. IP not only increased the contrast but also increased the edge enhancement on all the squares.	MM increased the contrast on the squares less than 10 pixels. That is because the biggest filter used in the algorithm was 9 by 9.

Synthetic Target2

5-pixel squares with pixel value increased by 2.
Background pixel value is 4000.

Pixel value : 4002

Pixel value : 4004

Pixel value : 4006

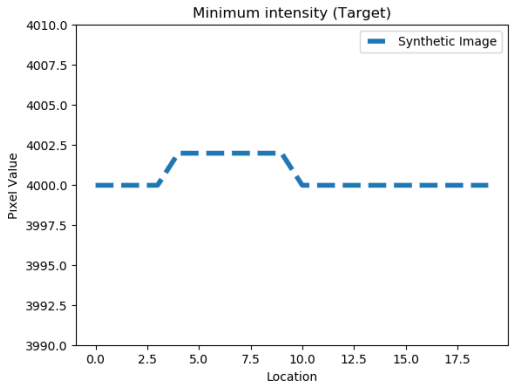
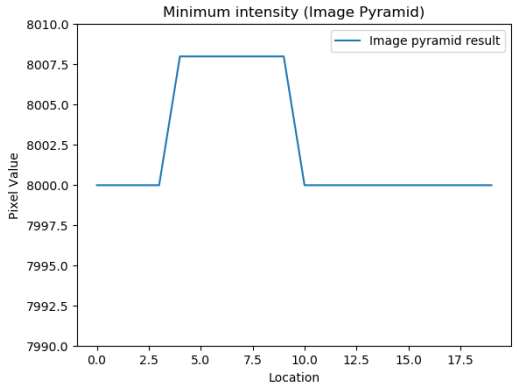
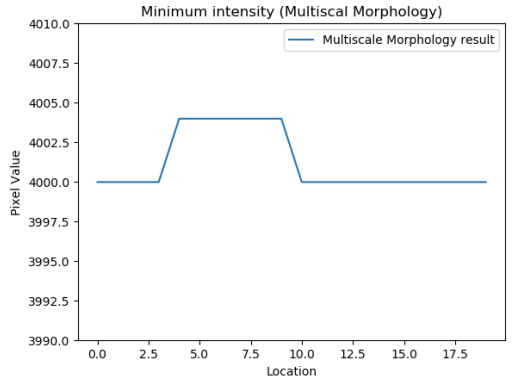
Pixel value : 4008

Pixel value : 4010

Pixel value : 4012

Pixel value : 4014

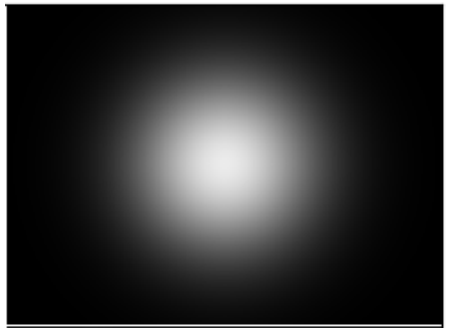
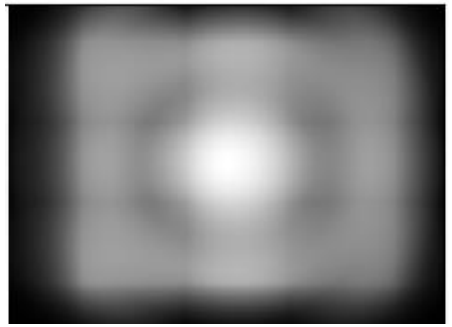
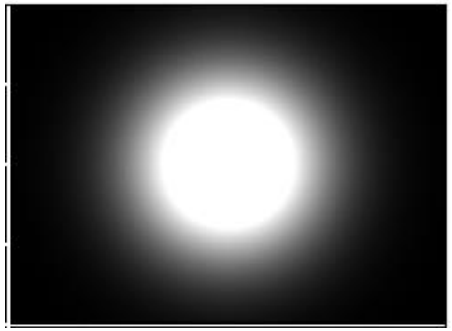
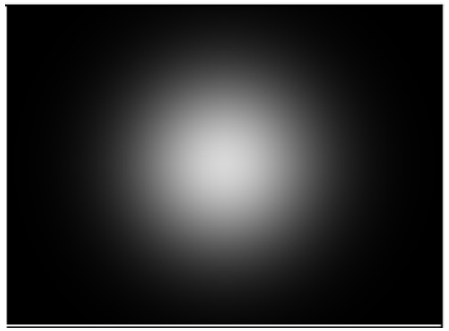
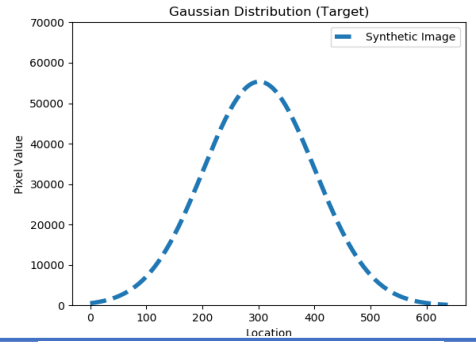
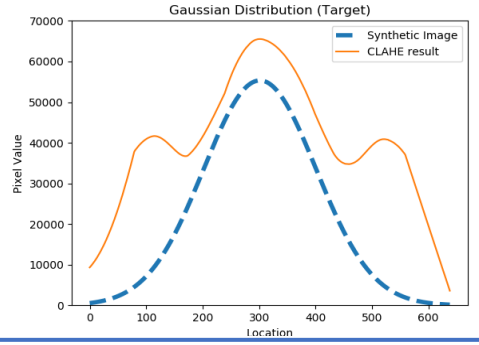
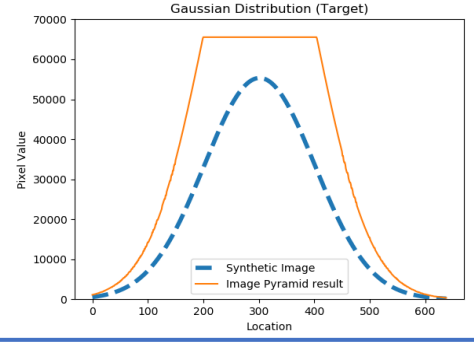
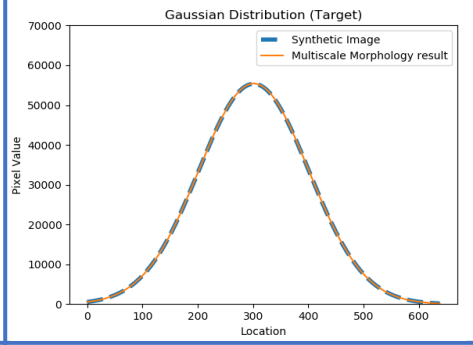
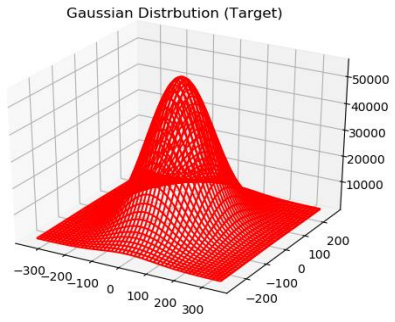
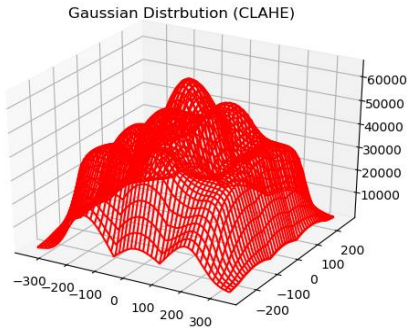
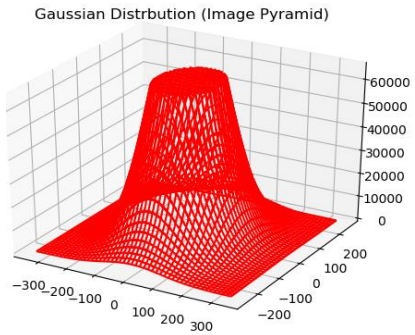
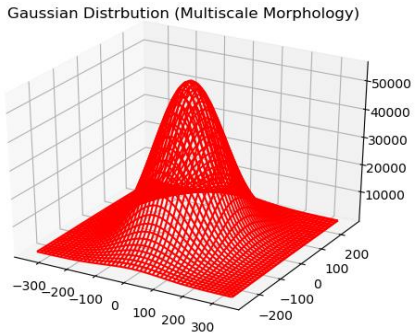
Pixel value : 4016

Target	Image Pyramid	Multiscale Morphology
		
The first square in the target image increased pixel values by 2.	Image Pyramid separated the first square from the background. Now, the difference between the square and the background is 8.	Multiscale Morphology separated the square as well. The difference is 4, which is smaller than image pyramid.

Algorithms successfully identified an object and a background when the object only had a 2-pixel value difference.

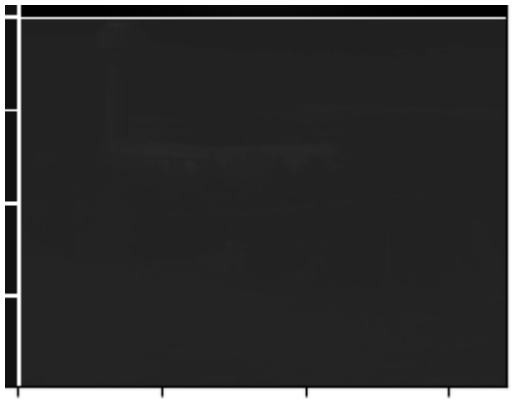
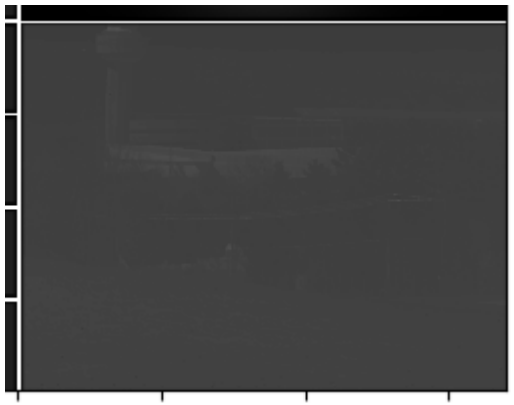
Synthetic Target2

Gaussian distribution

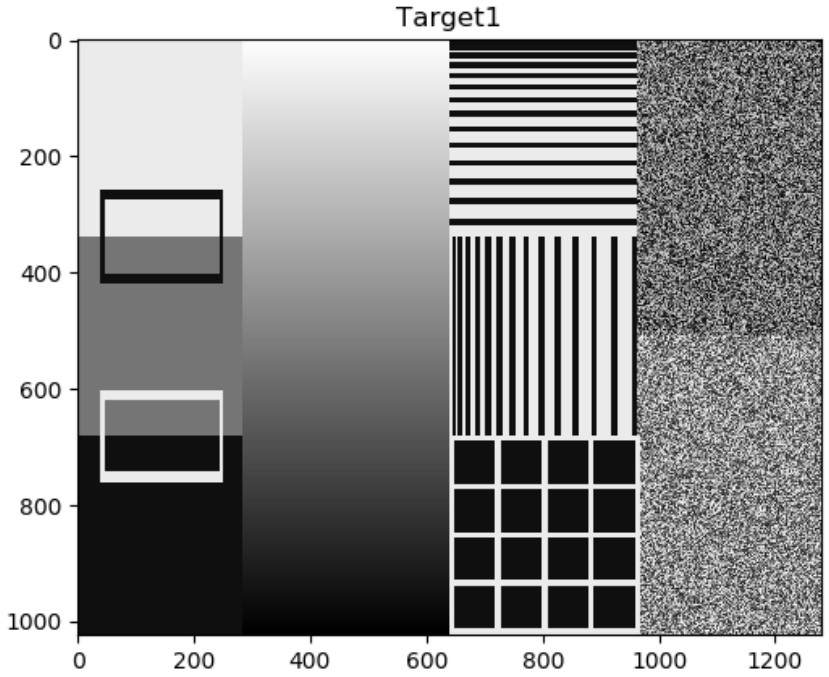
	Target	CLAHE	Image Pyramid	Multiscale Morphology
image				
profile				
3D plot				
Comment		CLAHE unsuccessfully produced the Gaussian distribution.	IP increased brightness. Some pixels are exceeded.	MM didn't change the brightness.

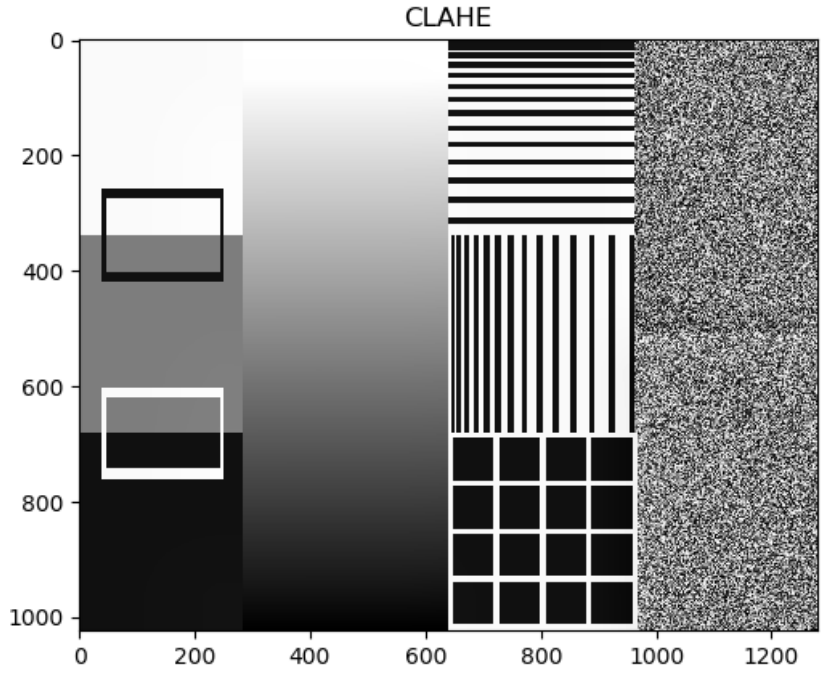
Synthetic Target2

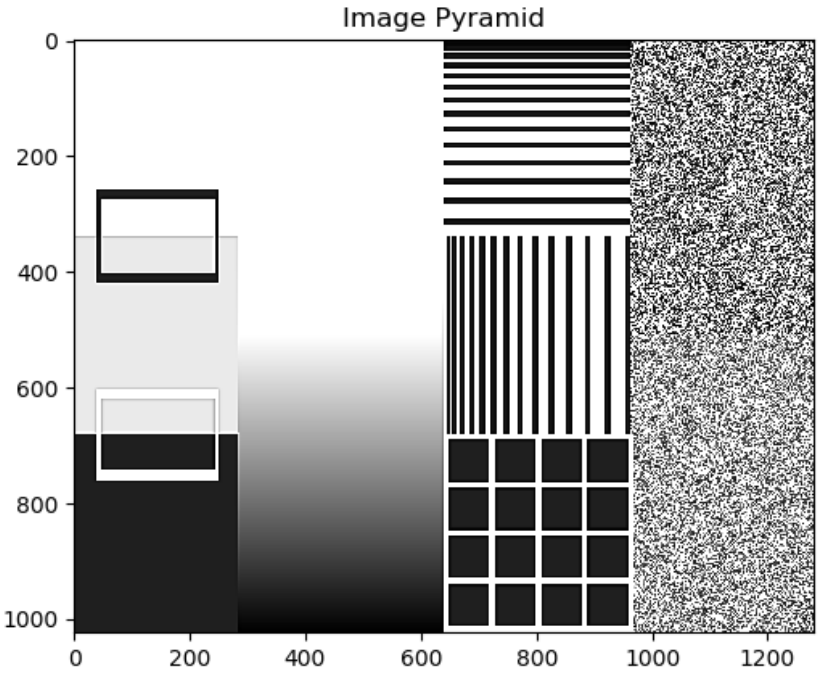
Global contrast enhancement

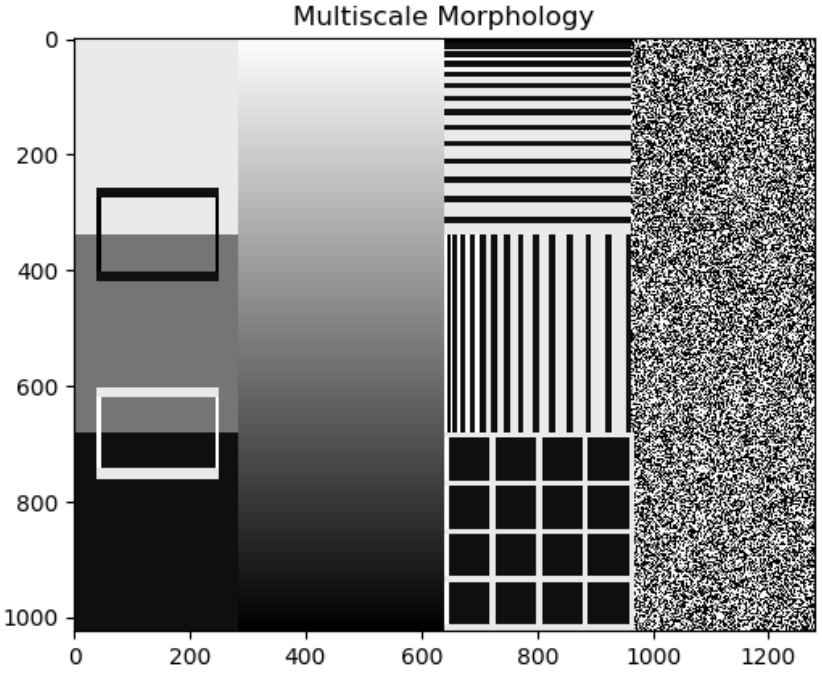
	Target	CLAHE	Image Pyramid	Multiscale Morphology
Image				
Comment	Only CLAHE increased the global contrast.			

Result of Synthetic Target1









Result of Synthetic Target2