Principles of Biomedical Ultrasound and Photoacoustics
hw02: Speckle Statistics

Due on Thursday, Nov 16, 2017

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1 Introduction

In this homework, we will use Matlab tool **Field2** to simulate speckle scattering.

2 Part I

In this part, we need to create a complex array with 10000 dimension, which magnitude is uniform distribution [0, 1] and phase [0, 2π]. We name this array as **origin array**.

2.a Histogram of the Amplitude and Intensity

Figure 1 shows the historgram of amplitude and intensity of origin array.

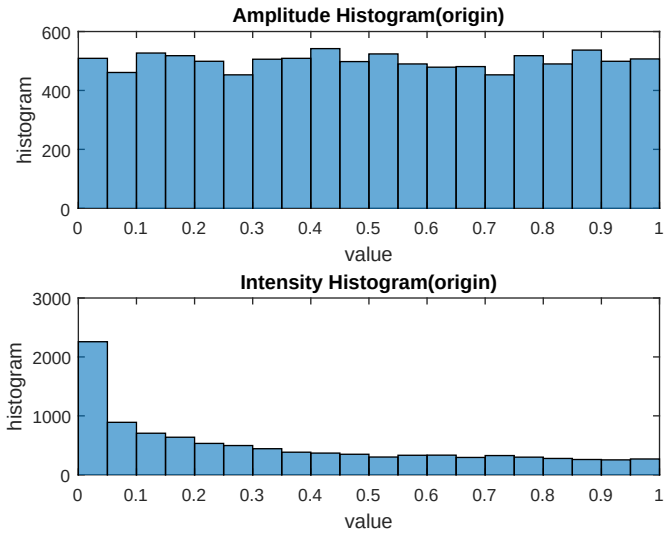

Figure 1: Histogram of amplitude (top) and intensity (bottom) of origin array

In Figure 1, we can see the distribution of amplitude is exactly uniform distribution. Because intensity is $amplitude^2$ and value between [0, 1] will decay exponentially, so the distribution will move left.

2.b Histogram and Ratio of new array

Now we create an new array with size **N (= 10000, 5000, 2000, 1000, 500)**, which value is the sum of **M (= 1, 2, 5, 10, 20)** consecutive data:

$$val(i) = \sum_{k=(i-1)*M}^{i*M} origin(k)$$

And then plot their histogram and calculate ratio of mean and standard deviation as a function of M. Figure [2, 3, 4, 5, 6, 7, 8, 9, 10, 11] show the histogram result and Figure [12, 13, 14, 15, 16] show the ratio as a function of M.

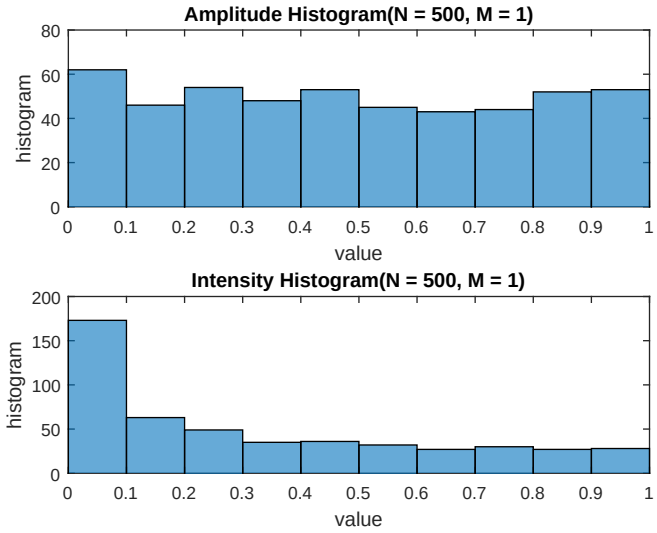

Figure 2: Histogram of amplitude (top) and intensity (bottom) of new array (N = 500, M = 1)

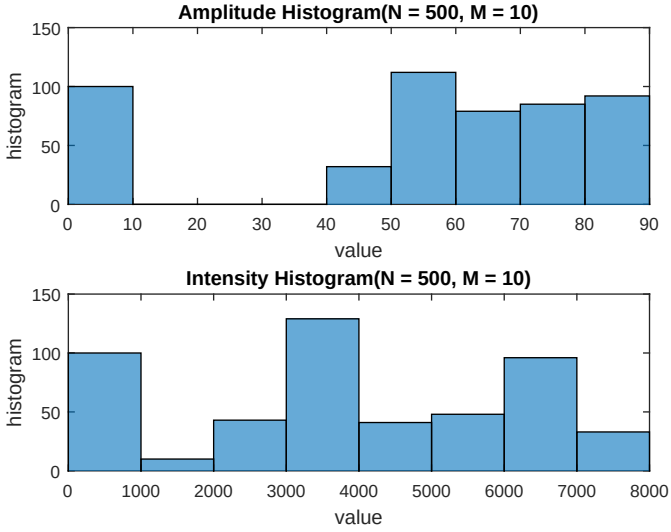

Figure 3: Histogram of amplitude (top) and intensity (bottom) of new array (N = 500, M = 10)

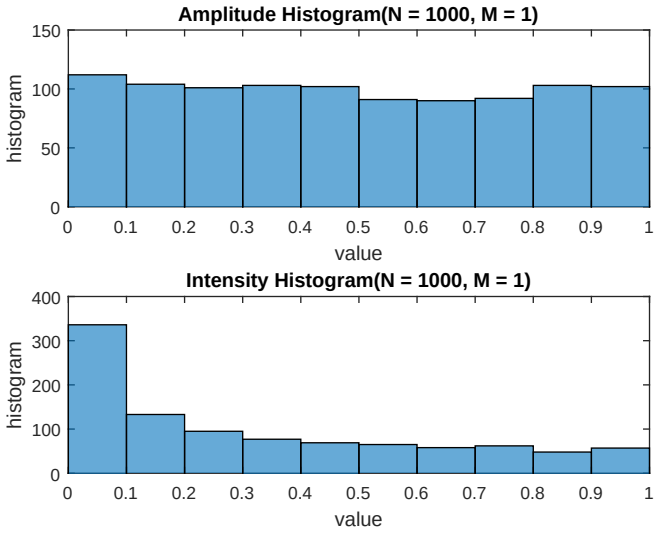

Figure 4: Histogram of amplitude (top) and intensity (bottom) of new array (N = 1000, M = 1)

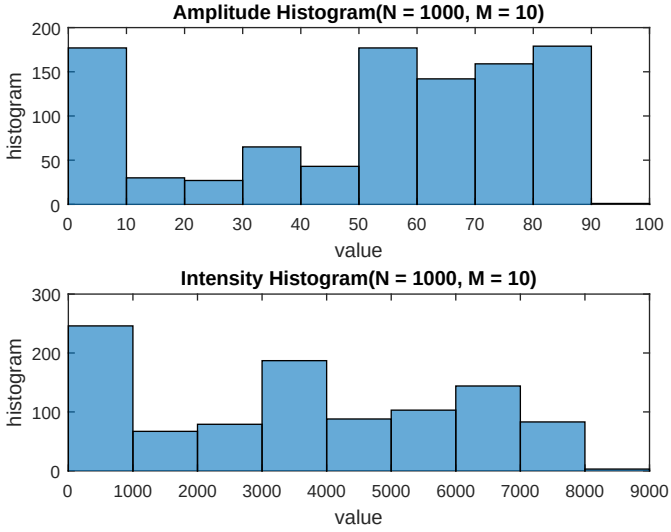

Figure 5: Histogram of amplitude (top) and intensity (bottom) of new array (N = 1000, M = 10)

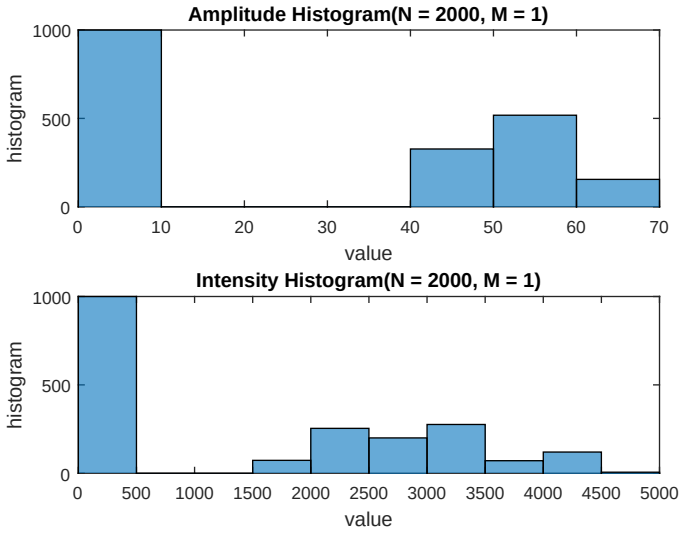

Figure 6: Histogram of amplitude (top) and intensity (bottom) of new array (N = 2000, M = 1)

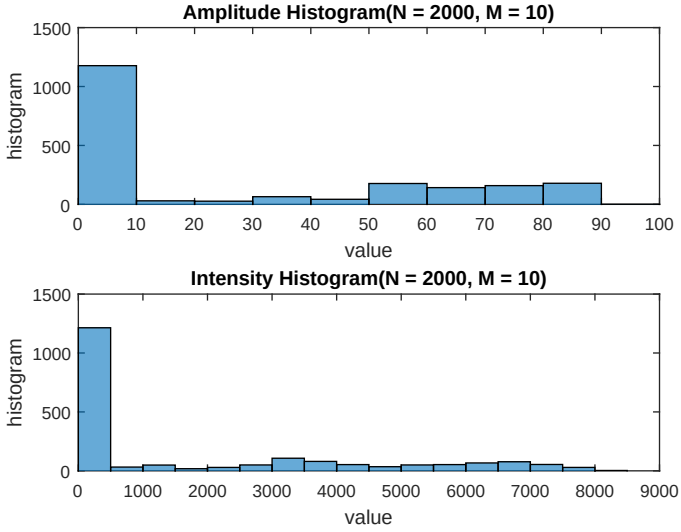

Figure 7: Histogram of amplitude (top) and intensity (bottom) of new array (N = 2000, M = 10)

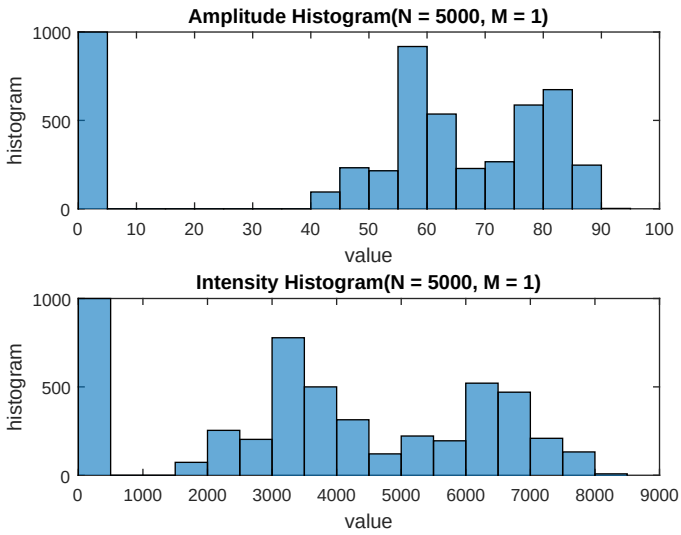

Figure 8: Histogram of amplitude (top) and intensity (bottom) of new array (N = 5000, M = 1)

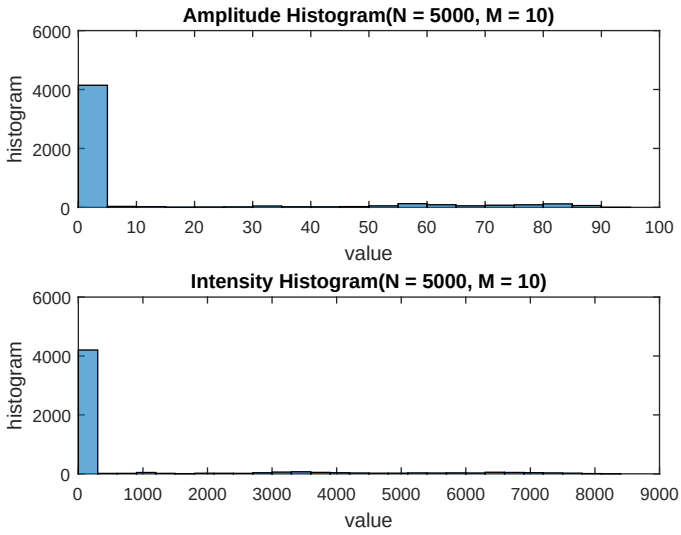

Figure 9: Histogram of amplitude (top) and intensity (bottom) of new array (N = 5000, M = 10)

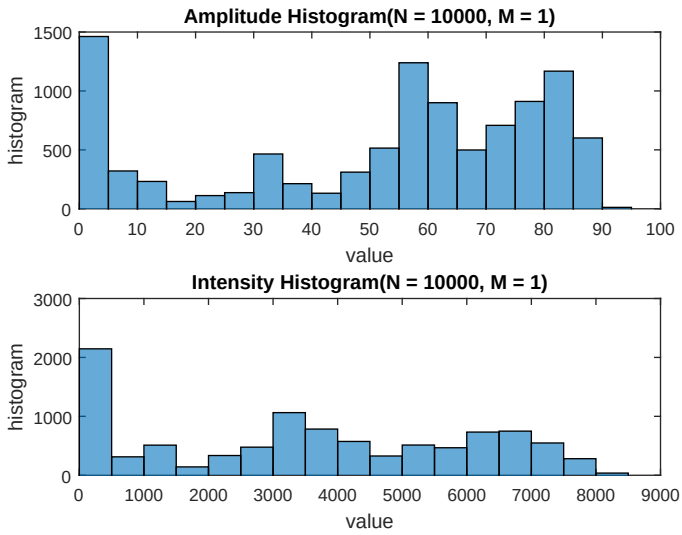

Figure 10: Histogram of amplitude (top) and intensity (bottom) of new array (N = 10000, M = 1)

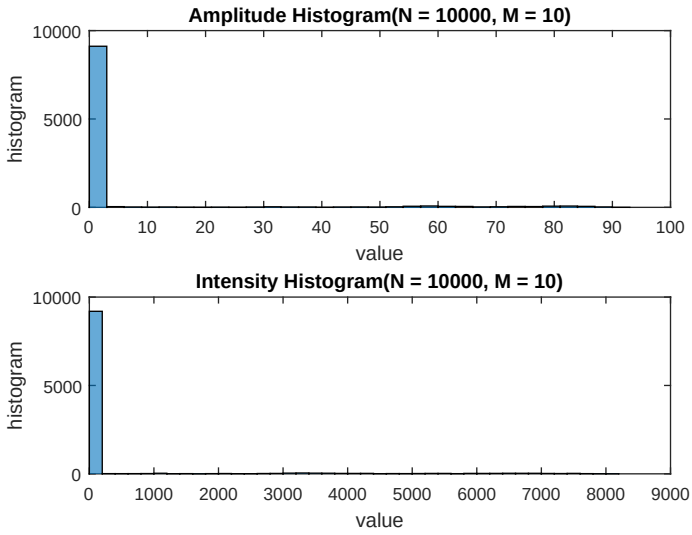

Figure 11: Histogram of amplitude (top) and intensity (bottom) of new array (N = 10000, M = 10)

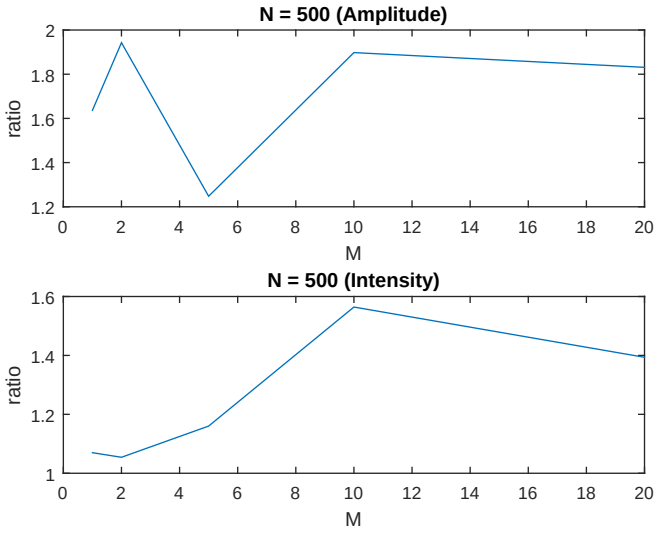

Figure 12: Ratio of mean and standard deviation (N = 500)

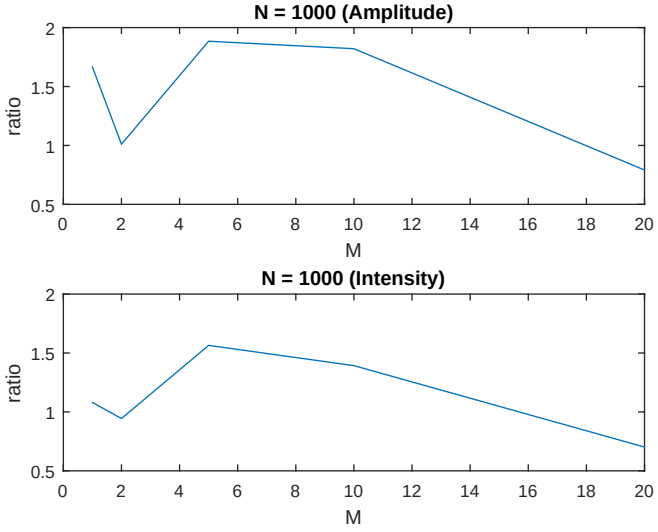

Figure 13: Ratio of mean and standard deviation (N = 1000)

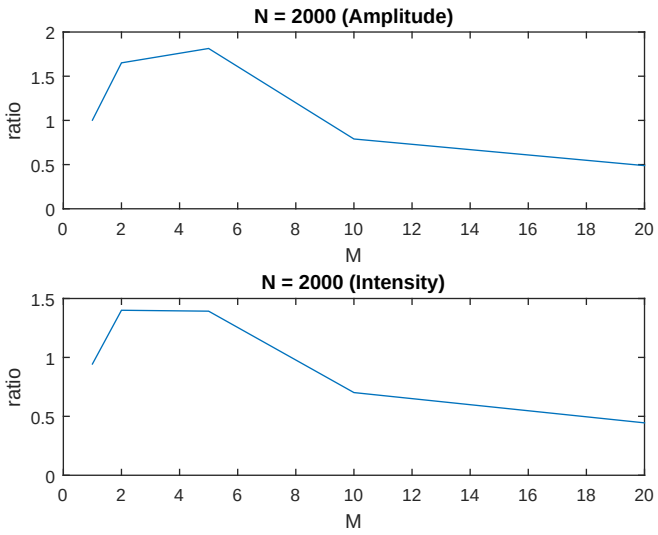

Figure 14: Ratio of mean and standard deviation (N = 2000)

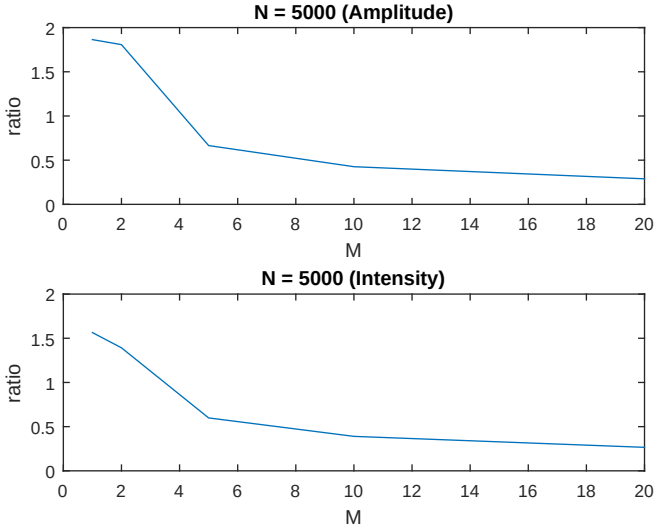

Figure 15: Ratio of mean and standard deviation (N = 5000)

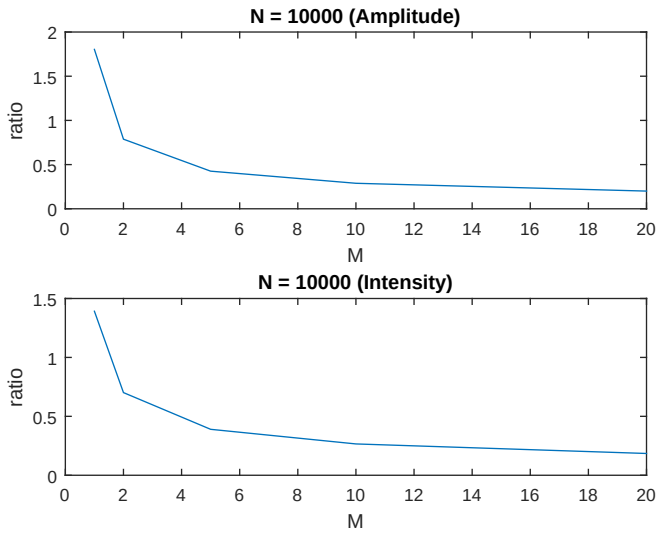

Figure 16: Ratio of mean and standard deviation (N = 10000)

2.c Repeat (a) and (b) with phase distribution [0, π]

Now we change the phase distribution of origin array from [0, 2π] to [0, π]. Figure 17 shows the histogram of amplitude and intensity of origin array with phase distribution [0, π]. Figure [18, 19, 20, 21, 22, 23, 24, 25, 26, 27] show histogram for different N and M. Figure [28, 29, 30, 31, 32] show the ratio.

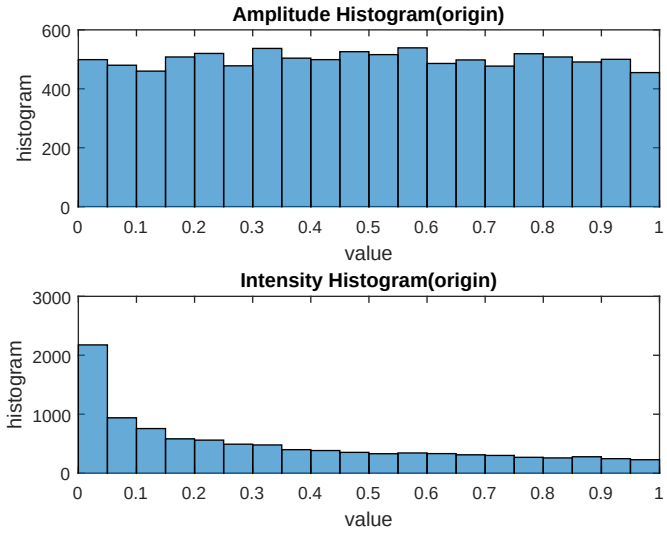

Figure 17: Histogram of amplitude (top) and intensity (bottom) of origin array (phase = [0, π])

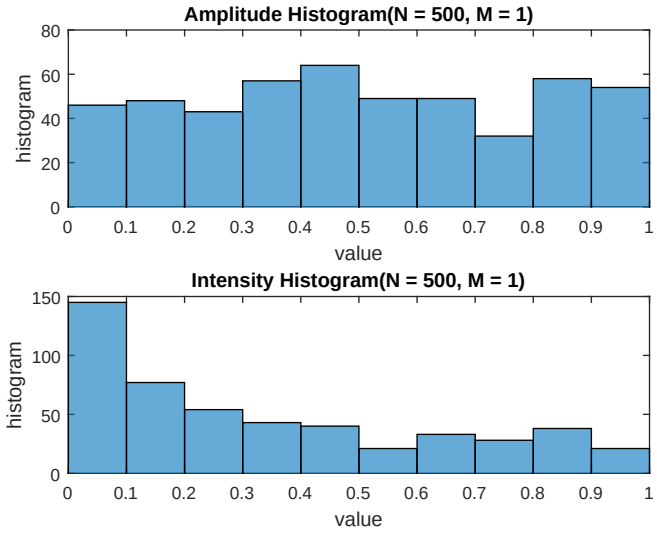

Figure 18: Histogram of amplitude (top) and intensity (bottom) of array (N = 500, M = 1, phase[0, π])

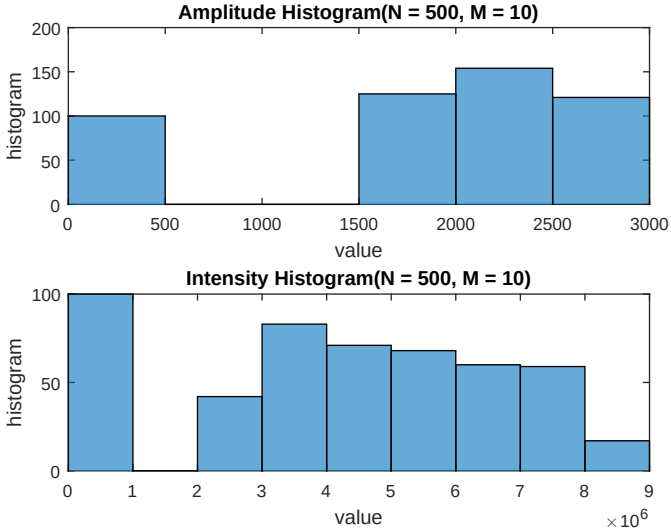

Figure 19: Histogram of amplitude (top) and intensity (bottom) of array (N = 500, M = 10, phase[0, π])

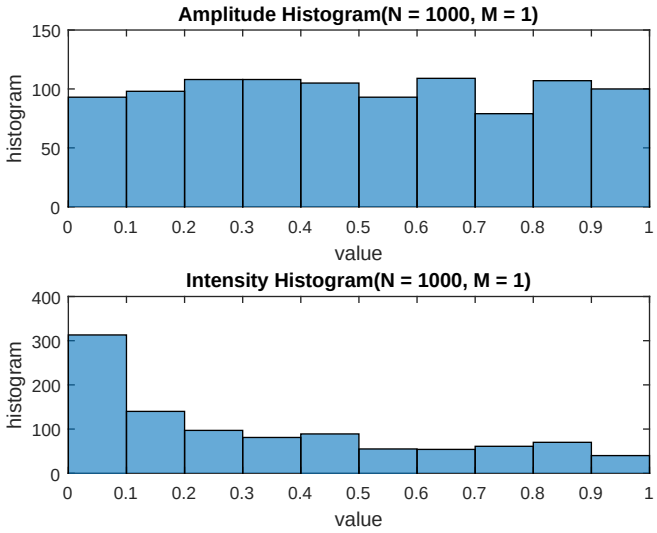

Figure 20: Histogram of amplitude (top) and intensity (bottom) of array (N = 1000, M = 1, phase[0, π])

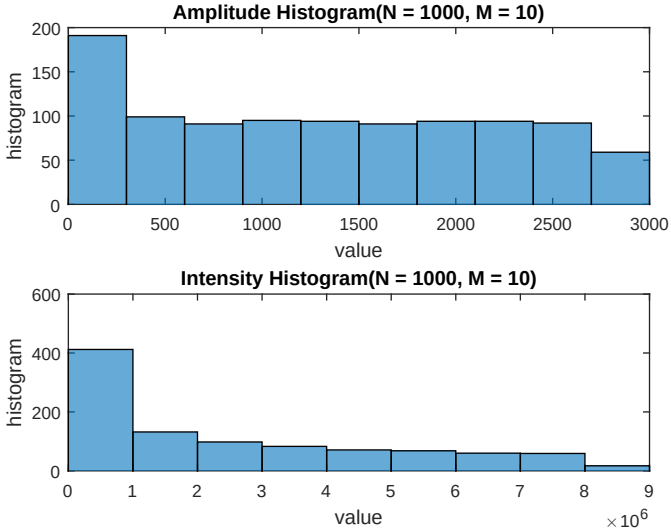

Figure 21: Histogram of amplitude (top) and intensity (bottom) of array (N = 1000, M = 10, phase[0, π])

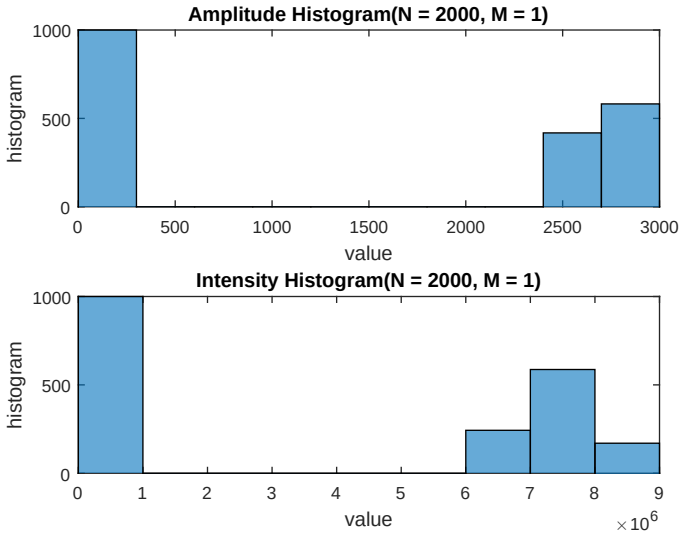

Figure 22: Histogram of amplitude (top) and intensity (bottom) of array (N = 2000, M = 1, phase[0, π])

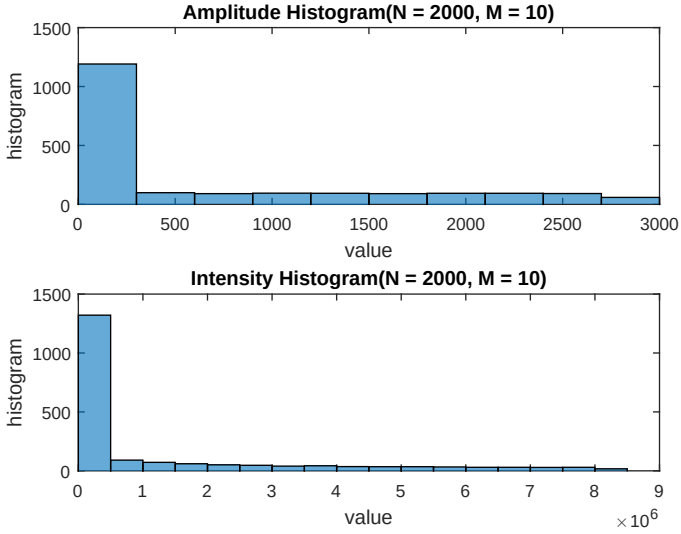

Figure 23: Histogram of amplitude (top) and intensity (bottom) of array (N = 2000, M = 10, phase[0, π])

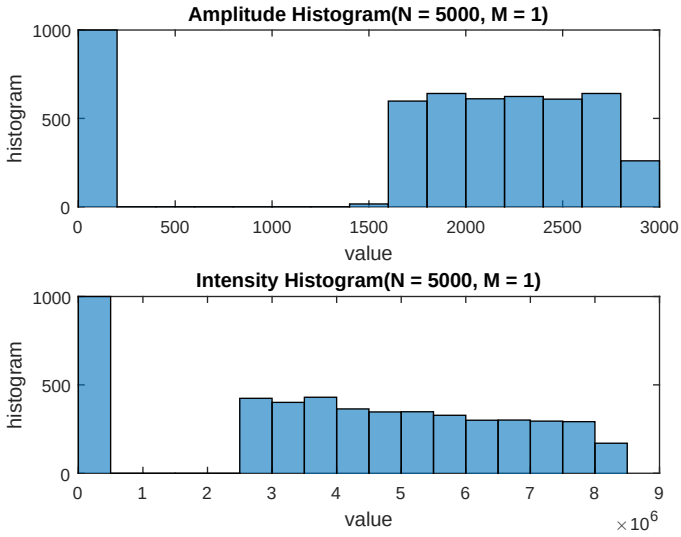

Figure 24: Histogram of amplitude (top) and intensity (bottom) of array (N = 5000, M = 1, phase[0, π])

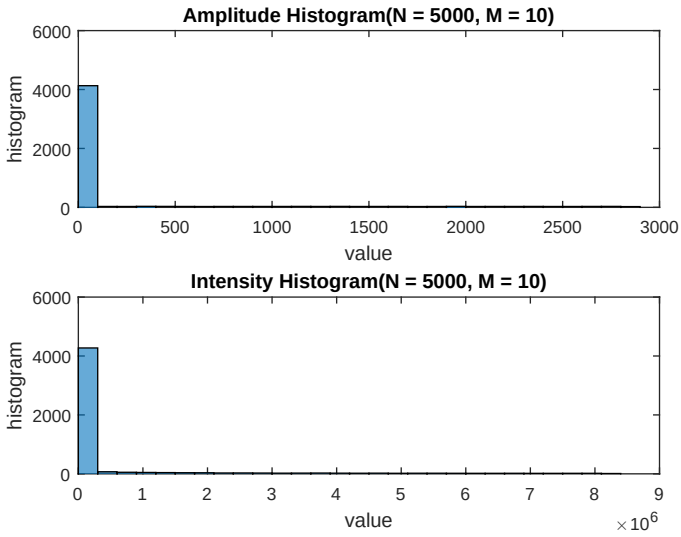

Figure 25: Histogram of amplitude (top) and intensity (bottom) of array (N = 5000, M = 10, phase[0, π])

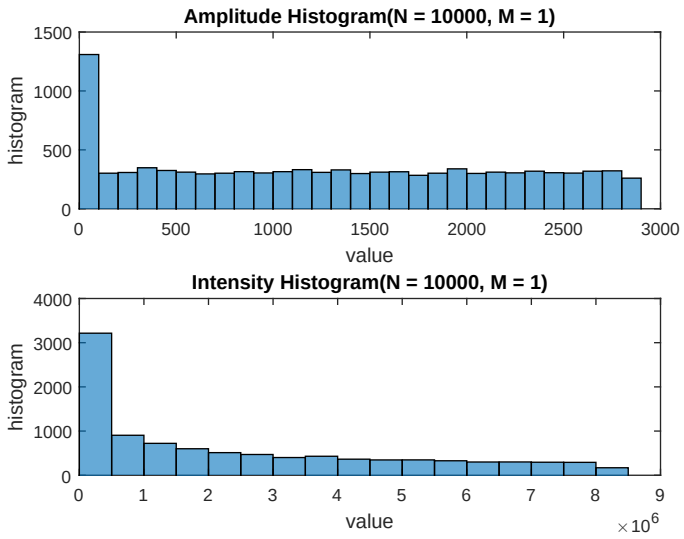

Figure 26: Histogram of amplitude (top) and intensity (bottom) of array (N = 10000, M = 1, phase[0, π])

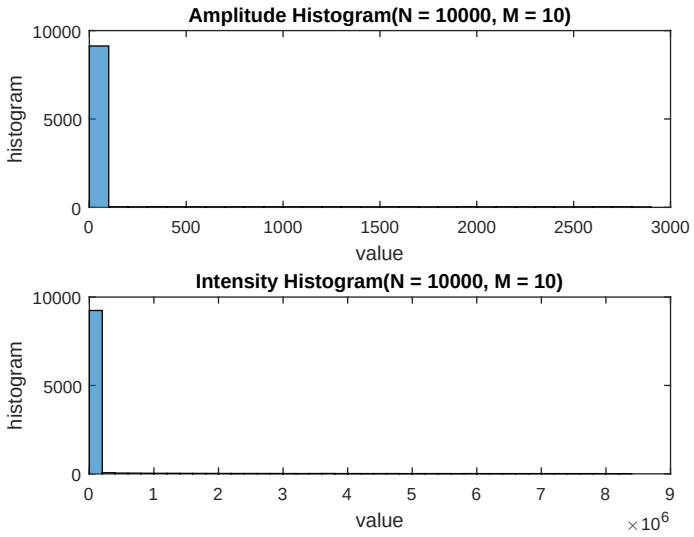

Figure 27: Histogram of amplitude (top) and intensity (bottom) of array (N = 10000, M = 10, phase[0, π])

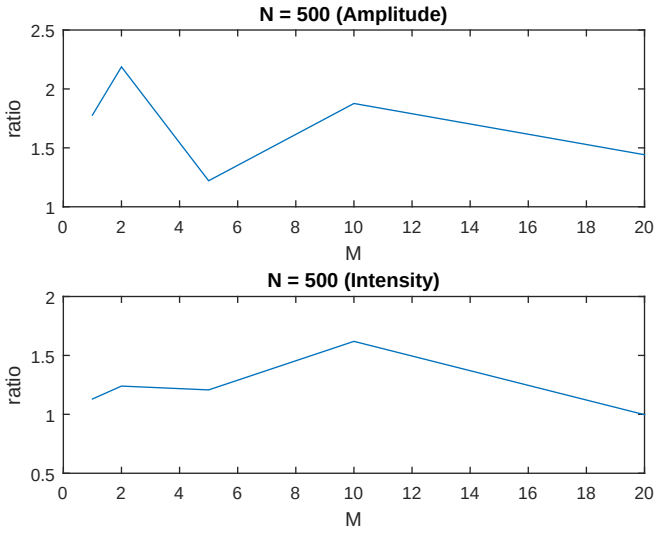

Figure 28: Ratio of mean and standard deviation (N = 500, phase[0, π])

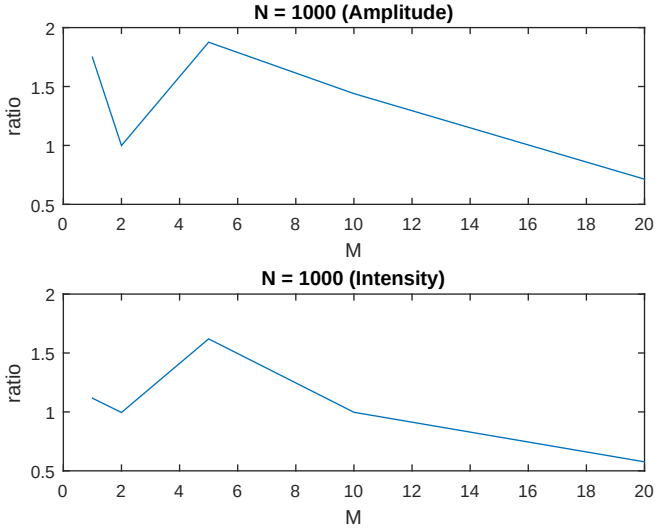

Figure 29: Ratio of mean and standard deviation (N = 1000, phase[0, π])

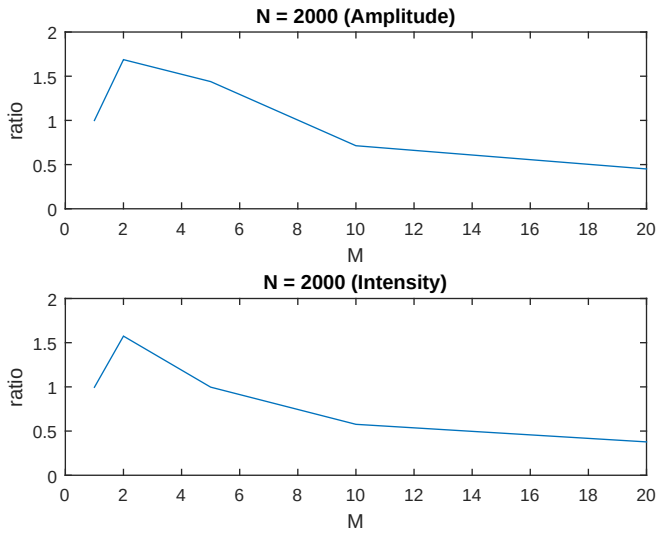

Figure 30: Ratio of mean and standard deviation (N = 2000, phase[0, π])

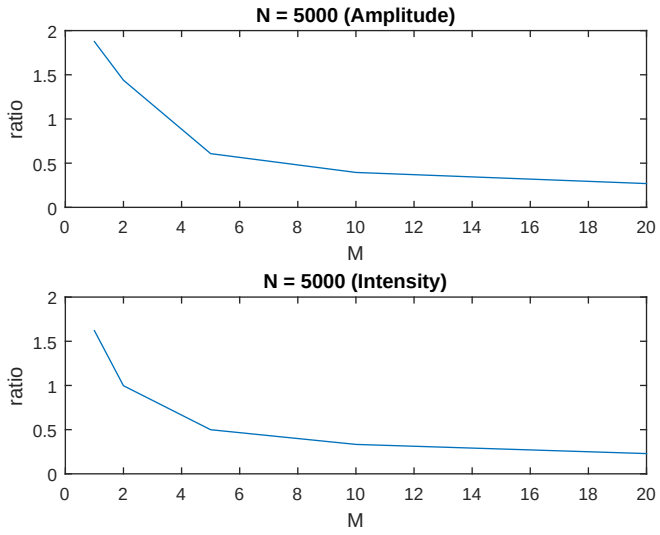

Figure 31: Ratio of mean and standard deviation (N = 5000, phase[0, π])

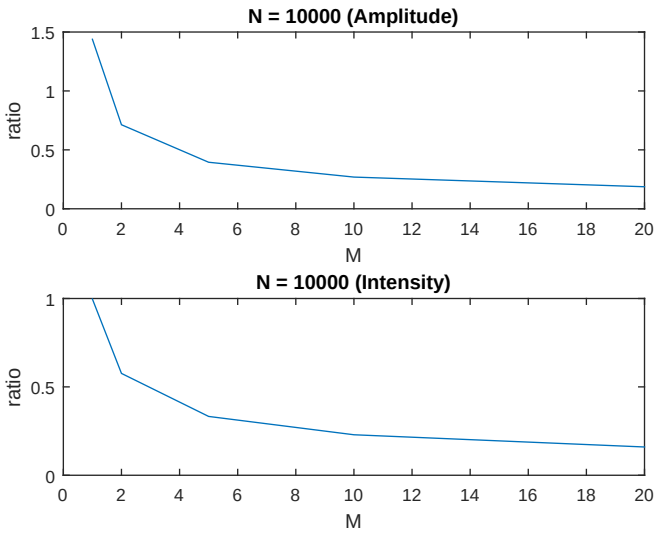

Figure 32: Ratio of mean and standard deviation (N = 10000, phase[0, π])

2.d Smooth amplitude and intensity

Now we will use a moving average filter [0.5, 0.5] to smooth the amplitude and intensity, which is a post-processing. Figure 33 show the ratio as a function of M for different N.

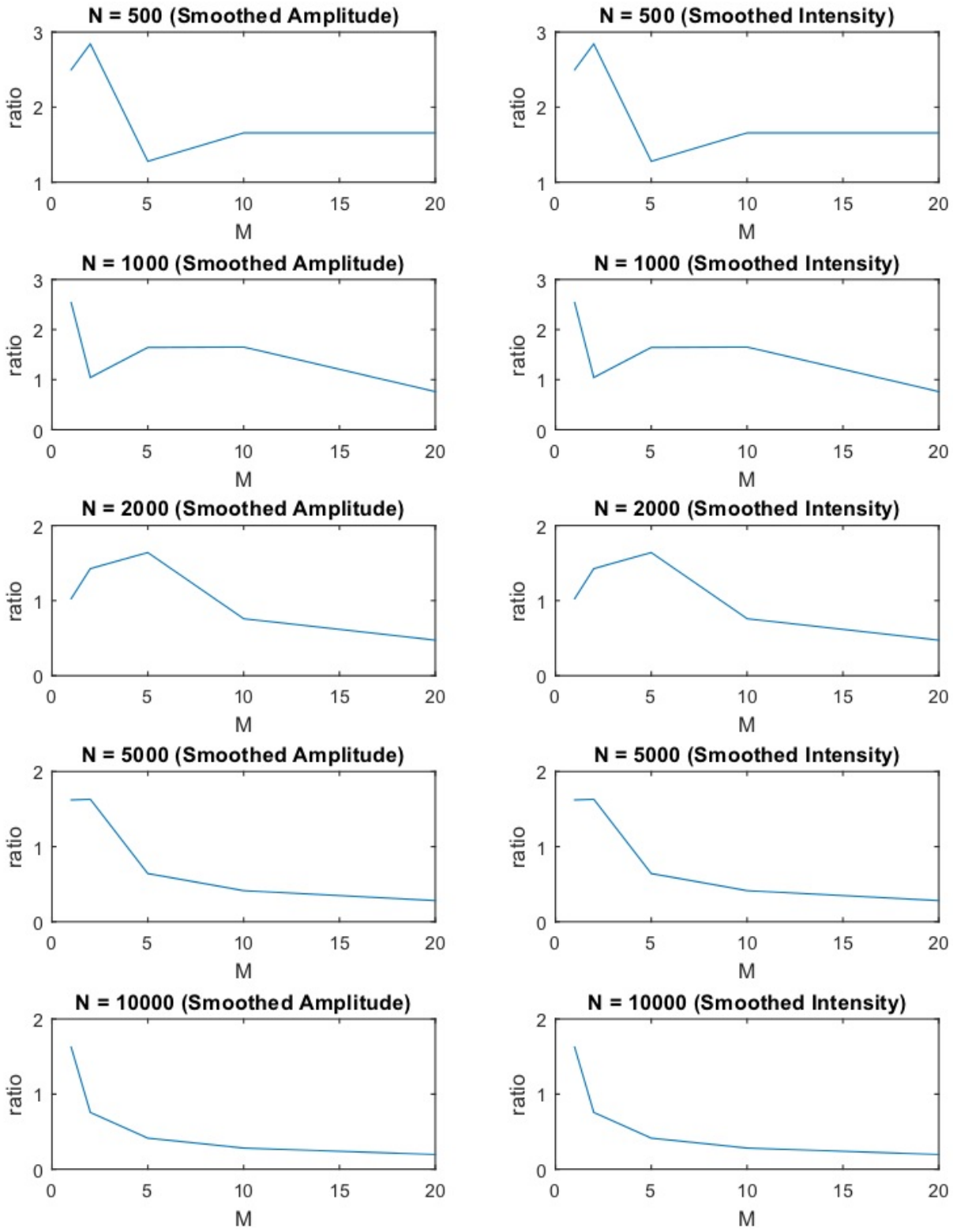

Figure 33: Ratio as function of M with smoothed amplitude and intensity

2.e Smooth new array

Now we will try to use the same filter to smooth new array obtained from (b), which is a pre-processing. Figure 34 show the ratio as a function of M for different N.

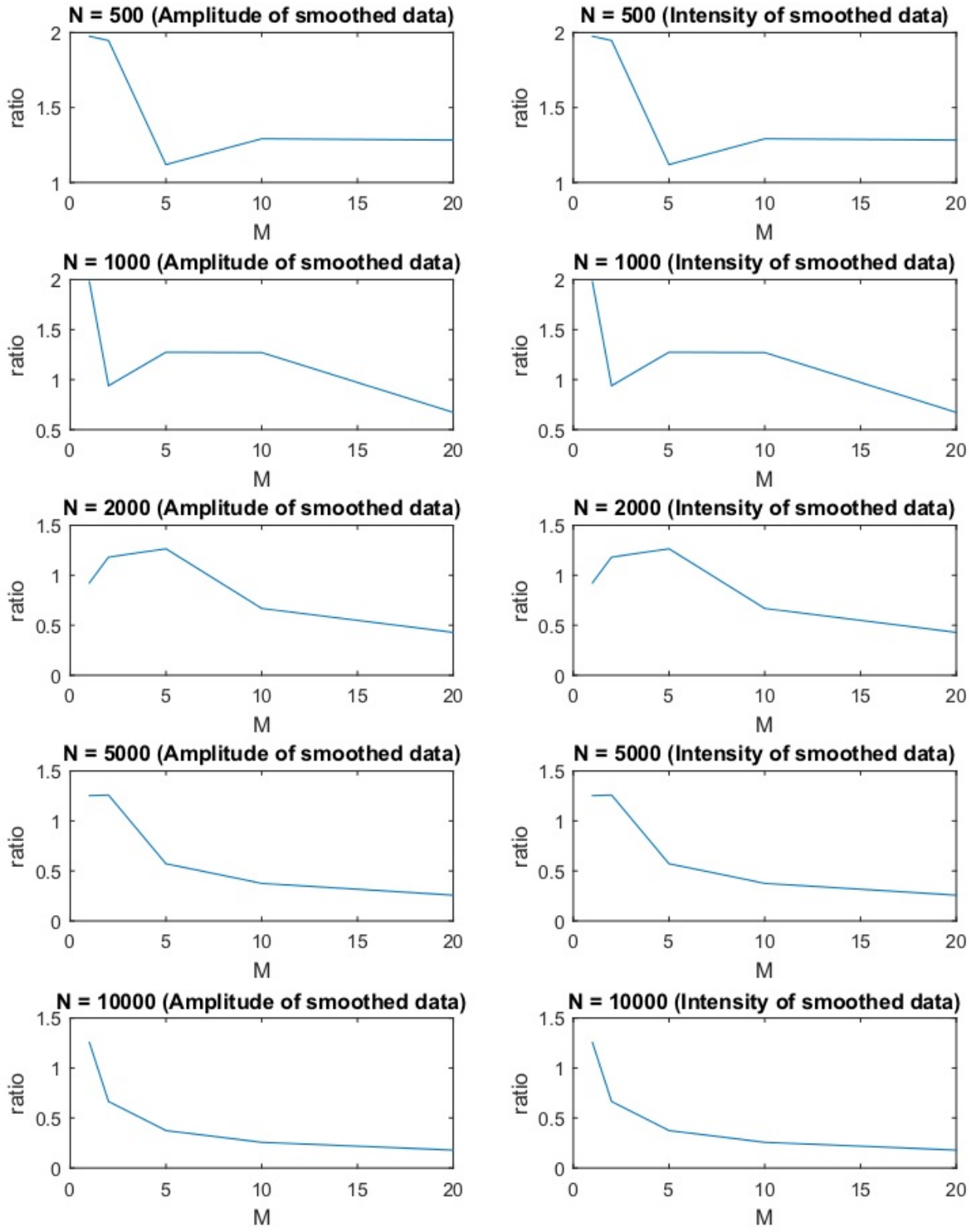

Figure 34: Ratio as function of M with smoothed data array

3 Part II

In this part, we will use Matlab tool **Field2** to simulate phantom scattering.

3.a Ratio of two area

Now we should calculate the ratio of mean to the standard deviation for amplitude and intensity. To divide the image into two part, I manually crop 2 area from the image which one is lighter and the other is darker. The ratio is summarized as Table 1:

	Experimental Ratio	Theoretical Ratio
Amplitude (higher scattering inclusion)	1.6517	
Intensity (higher scattering inclusion)	0.8688	
Amplitude (speckle background)	1.7776	
Intensity (speckle background)	0.8742	

Table 1: Ratio for lighter/darker area

3.b Contrast of two area

For the two area, we will calculate their contrast by following formula:

$$contrast = |I_1 - I_2|$$

where I_1 and I_2 are mean value in dB. Table 2 show the result.

	Experimental Contrast	Theoretical Contrast
Amplitude	16.9036	20
Intensity	33.8073	40

Table 2: Contrast of amplitude/intensity

Because the contrast of intensity is $20 * \log(amplitude^2) = 2 * 20log(amplitude)$, so the value should be double than amplitude.

3.c Reduce the contrast

Reduce contrast value until we cannot tell which part is lighter or darker in image. Figure [35, 36, 37, 38] show result of contrast [20, 10, 7, 5], respectively.

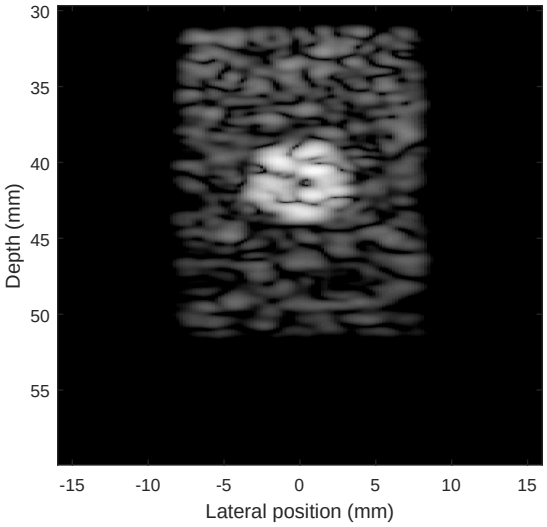

Figure 35: Contrast = 20

When contrast = 20 (Figure 35), the border of lighter and darker area is clear to tell.

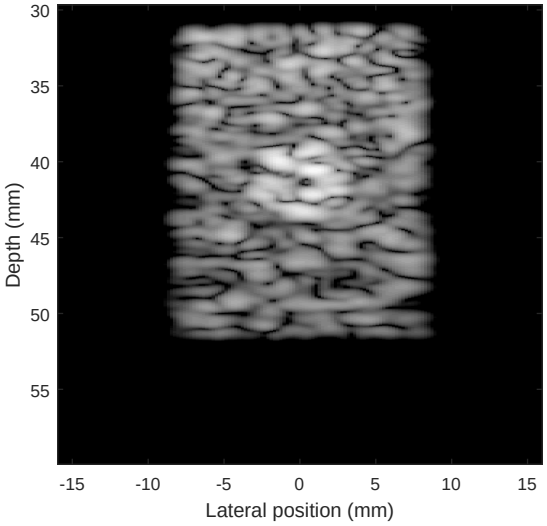

Figure 36: Contrast = 10

When contrast = 10 (Figure 36), the intensity of two area is close but we can see the border clearly.

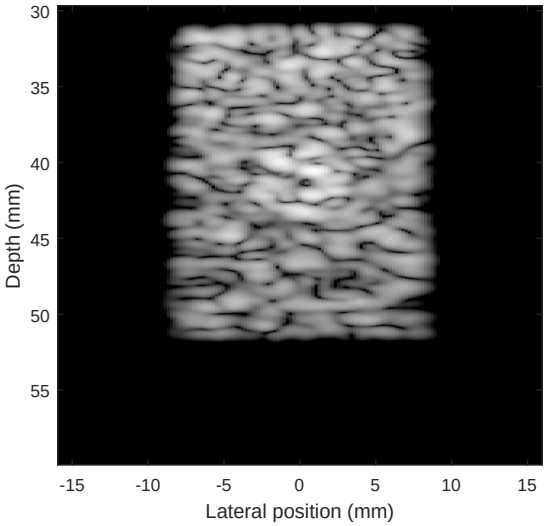

Figure 37: Contrast = 7

When contrast = 7 (Figure 37), the intensity of two area is very close and border is very unclear.

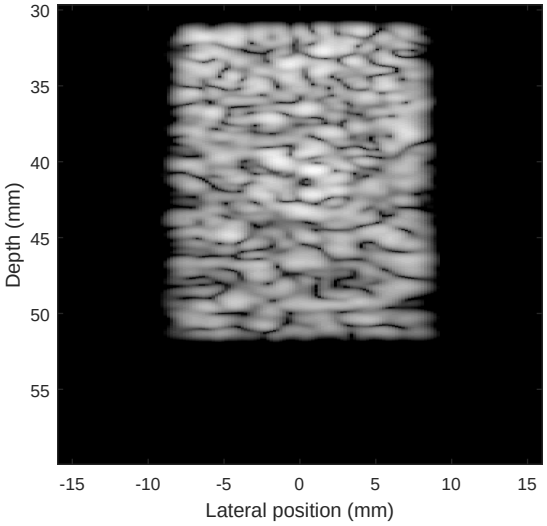

Figure 38: Contrast = 5

When contrast = 5 (Figure 38), the border totally disappear.
As a result, I think the **minimum detectable contrast is 7 dB**.