Principles of Biomedical Ultrasound and Photoacoustics
hw03: Photoacoustic Depth Profiling and SO2 Measurement

Due on Tuesday, Dec 12, 2017

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1 Part I

1.1 Repeat Fig.1 in reference paper

In the reference paper, they had simulated an acoustic wave of forward and backward wave. In this problem, we need to reproduce this fig. Figure 1 shows the result.

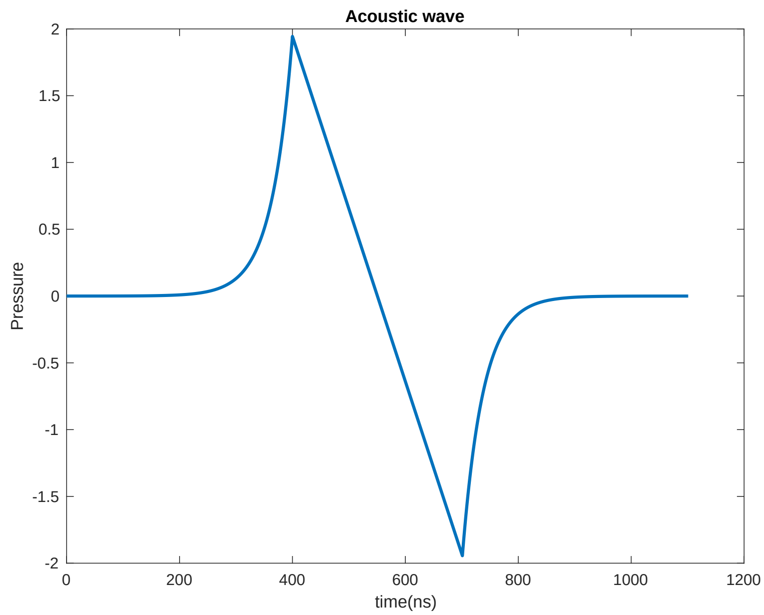

Figure 1: Acoustic Wave

Because the part between positive and negative wave is implicit, I only use a straight line connecting the two peak points by dynamically solving a linear equation and make the space between them 300 ns.

1.2 Repeat Fig.2 in reference paper

Now add a gaussian noise to our signal which the ratio of standard deviation of the noise to the peak of the simulated photoacoustic signal is 5%. Figure 2 shows the noisy signal and Figure 3 shows the exponential decay of siganl.

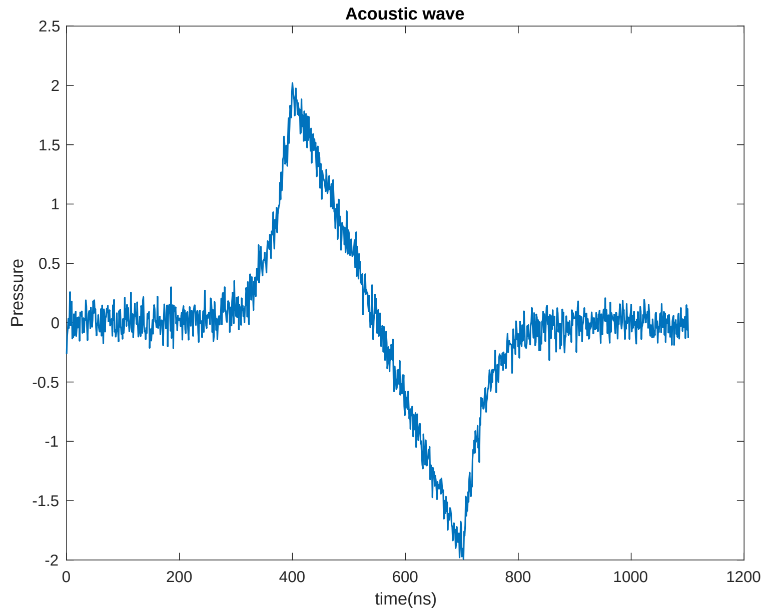

Figure 2: Acoustic Wave with noise

In the reference paper, there is a equation for curve fitting this decay from author's experimental result.

$$p(z) = 9.5 \exp^{-185z}$$

Because the parameters I used is different, I adjust the amplitude from 9.5 to 1.94 as shown in Equation 1.

$$p(z) = 1.94 \exp^{-185z} \tag{1}$$

Now Figure 3 show the noisy decay and curve of Equation 1.

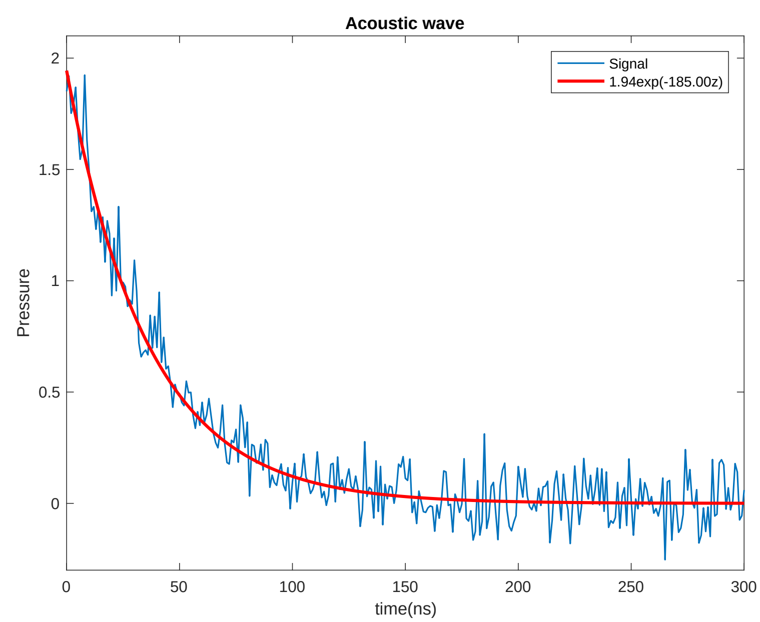

Figure 3: Acoustic Wave with noise

In this figure, we can find that Equation 1 is fitting well.

1.3 Curve fitting for absorbtion coefficient

Now from Figure 3, we apply curve fitting and get our estimated μ_a of noisy signal. Figure 4 shows the estimated curve and noisy signal.

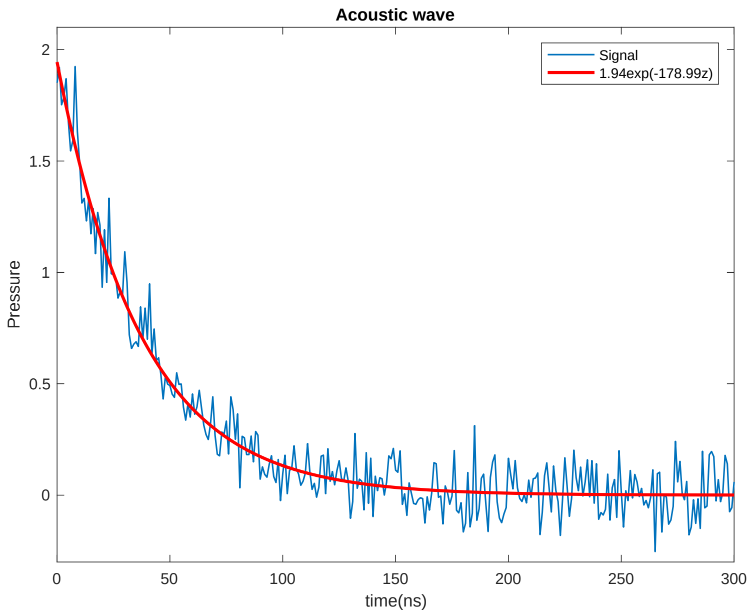

Figure 4: Curve fitting for absorbtion coefficient

From my experimental result, the range of estimated μ_a is from 178 to 182 and the real μ_a I used is 180. As a result, the curve fits the signal pretty well I think.

1.4 Peak value vs absorbtion coefficient

Theoretically, the peak of signal will proportional to μ_a which is $\mu_a \times \Gamma \times H_0 = 0.0108\mu_a$ in my case. So in this part, we need to plot the peak value of different absorbtion coefficient from 10 to 180. Figure 5 shows the result.

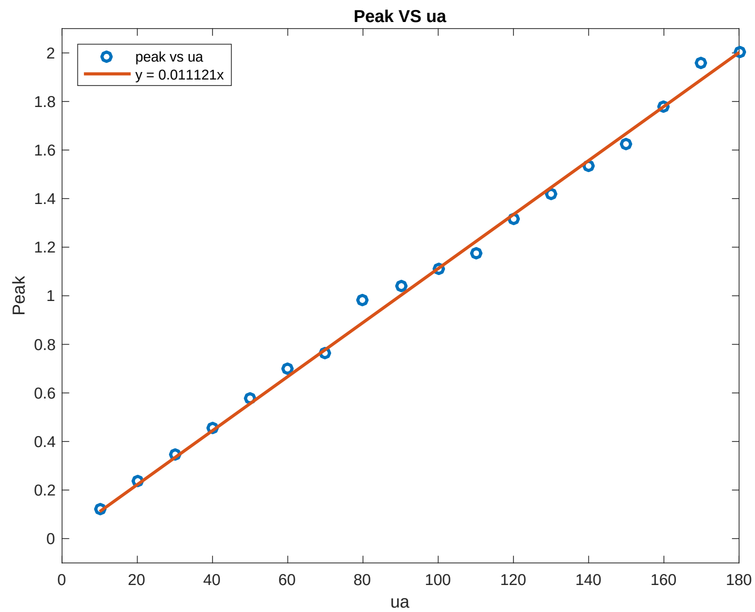

Figure 5: peak vs absorbtion coefficient

For better visualization, I also plot the curve fitting result for peak and μ_a and the slope is 0.011 which is very close to theoretical value 0.0108. So the peak value of noisy signal is still propotional to μ_a.

1.5 μ_a (estimated) vs μ_a (real)

Similar to Section 1.4, now for each μ_a we need to use curve fitting to estimate absorbtion coefficient for them. Figure 6 shows the result.

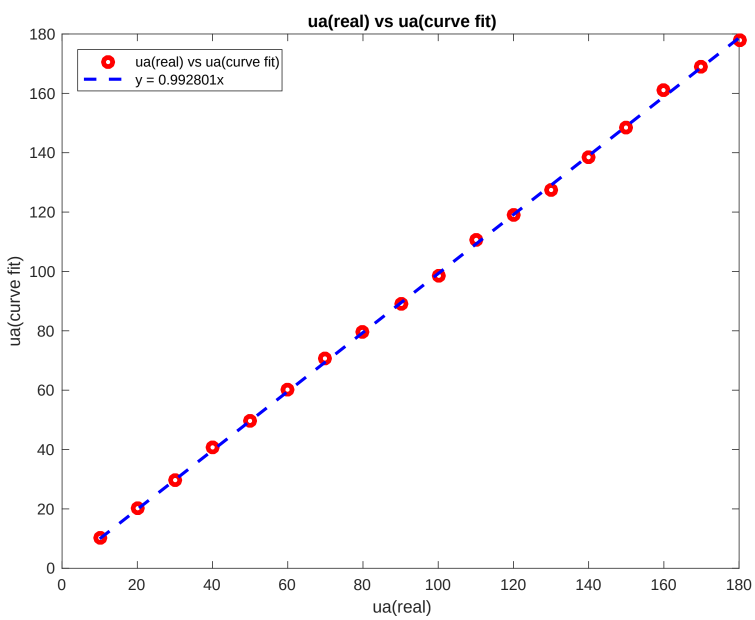

Figure 6: μ_a (estimated) vs μ_a (real)

For better visualization, I use curve fitting for μ_a (estimated) vs μ_a (real) in Figure 6 and the slope is about 1. As a result, our estimated μ_a is really close to real one.

1.6 Repeat 4 and 5 with transducer impulse response

Now we repeat 4 and 5 but considering transducer impulse response. Assume the impulse responses of the transducer used are Gaussian pulse centered at 5 MHz, 10 MHz, 25 MHz, and 50 MHz, respectively, with -6 dB fractional bandwidth of 60%

1.6.1 Peak value vs absorbtion coefficient

Figure 7 show the result of Peak value vs absorbtion coefficient.

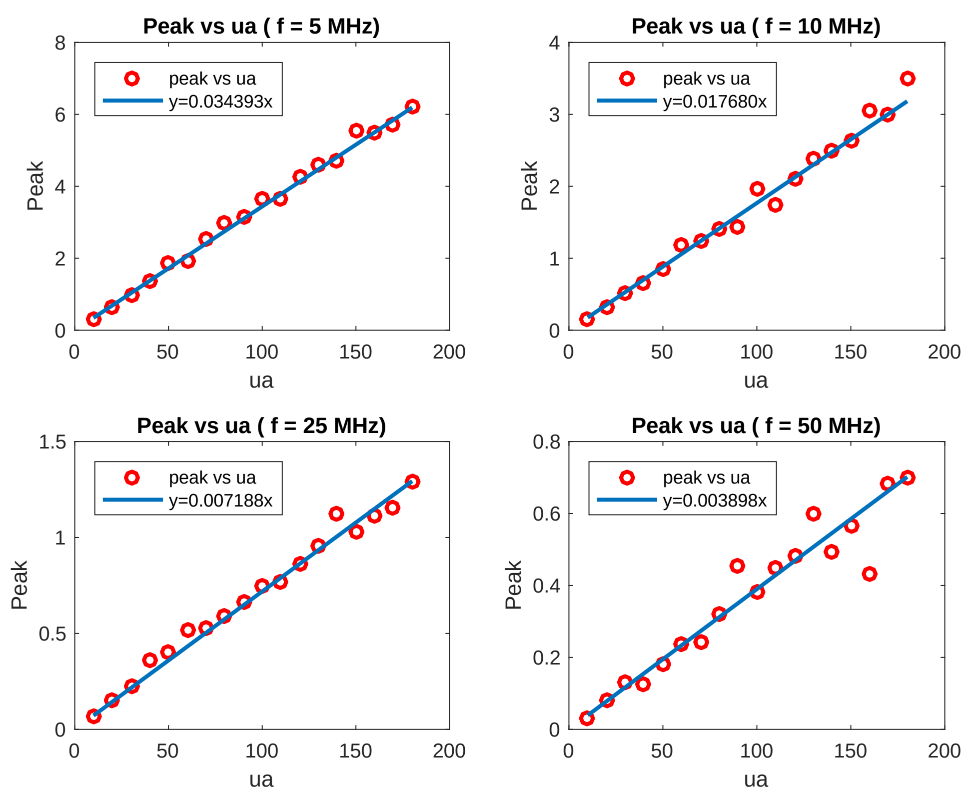

Figure 7: Peak value vs absorbtion coefficient

In Figure 7, the scalar of between peal and μ_a is not 0.011. However, we can find that their relation is still proportional from the four sub figures. And when center frequecny of transducer become larger, the figure become more noisy

1.6.2 μ_a (estimated) vs μ_a (real)

Figure 8 show the result.

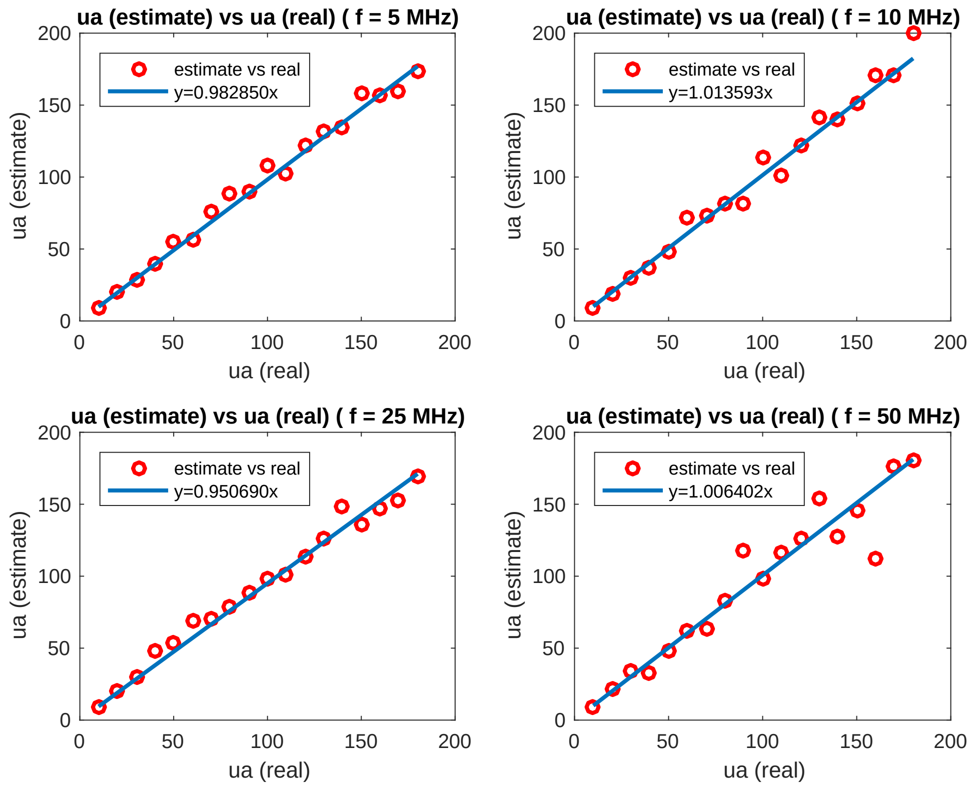

Figure 8: μ_a (estimated) vs μ_a (real)

In Figure 8, we can find that the estimated μ_a is still close to real μ_a and the slope is about 1, but when transducer center frequency gets larger, the points become much noisier.

2 Part II

Now in the section, we will use the same methodology in Part I for simulating blood sample.

2.1 Estimate SO2 level with peaks of different λ

In this problem, we need to estimate SO2 level with simulated peaks of several λ (= 578, 584, 590, and 596 nm). In class materials, SO2 level can be derived by solving a linear system:

$$k \times \begin{bmatrix} \varepsilon_{HbO2}(\lambda_1) & \varepsilon_{Hb}(\lambda_1) \\ \varepsilon_{HbO2}(\lambda_2) & \varepsilon_{Hb}(\lambda_2) \\ \varepsilon_{HbO2}(\lambda_3) & \varepsilon_{Hb}(\lambda_3) \\ \varepsilon_{HbO2}(\lambda_4) & \varepsilon_{Hb}(\lambda_4) \end{bmatrix} [gg] \tag{2}$$