Initial parameters choice optimization for plane wave propagation model fitting

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Context

Throughout this project we try and estimate multiple parameters of an unknown material according to plane wave propagating through it. We try and find the attenuation, thickness of the material as well as the speed of sound as it travels through it.

Set-up

We have got two transducers :

- One Emitter that emits an ultrasonic impulse signal
- One receiver that receives the signal

Two sessions of measurement have been done, one without any object (cf figure 1) and one with an object (cf figure 2). The two resulting signals are our input data

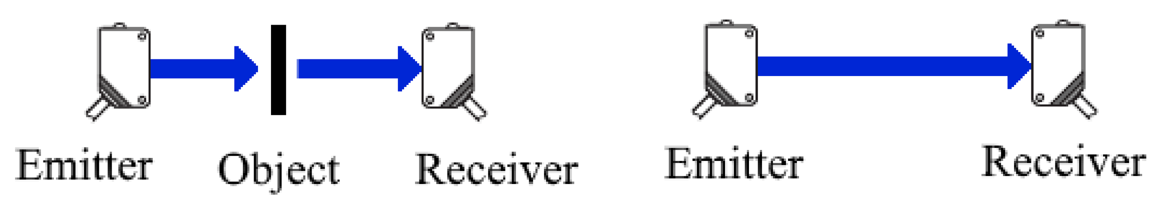

Figure 1, Experimental set-up

Methods

Under the assumption of plane wave propagation, in transmission with one multiple reflection, the final wave propagation model and transfer function can be expressed as :

$$Hexp = \frac{fft(in)}{fft(out)} = A\frac{e^{-\frac{i\omega DM}{VM}} + (1-A)e^{-\frac{3i\omega DM}{VM}}}{e^{-i\omega\frac{DM}{Vw}}}$$

Where A is the attenuation of the material, VM is the speed of sound in the material,

DM is the material thickness and VW is the speed of sound in water (1500m/s). By fitting this model to our two signals, we can estimate the optimal values for the three parameters D_M, V_M and A.

We focus our attention on the part of the Hexp signal that can be fitted with our model.

In order to fit our model to the data, we choose to use the lsqnonlin function from Matlab. We will see that the initial values play a very important role in the convergence of the model towards the input model, and therefore have chosen to display the converging nature of our model according to the initial parameters.

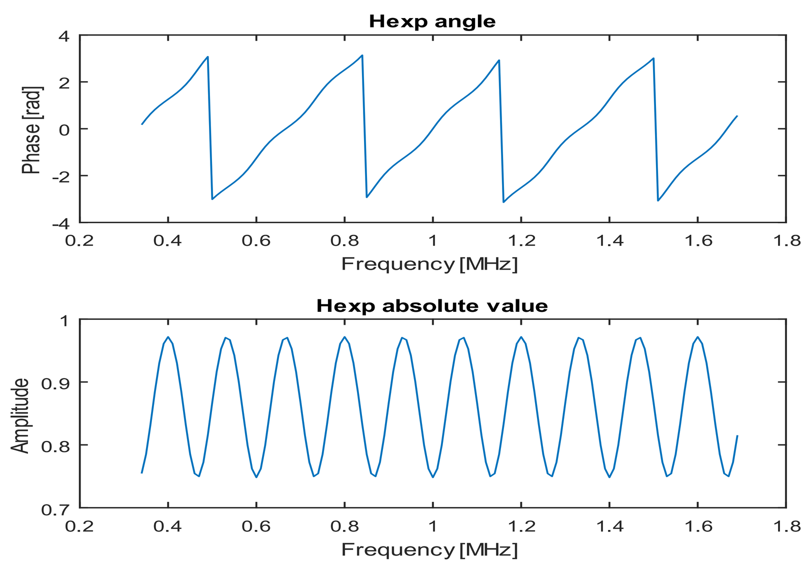

Figure 2. Amplitude and angle vs frequency of the relevant Hexp signal part.

Results

The initial values chosen were the following : A = 0,5, DM = 0,01 and VM = 3000m/s. Fitting our model resulted in the convergence of our values towards the values of the input data, as can be seen in Figure 3 and Figure 4. The values for A, DM and VM found during this experiment were the following : VM = 2700m/s, A = 0,86 and DM = 1cm. This identifies the material as being Perspex [1].

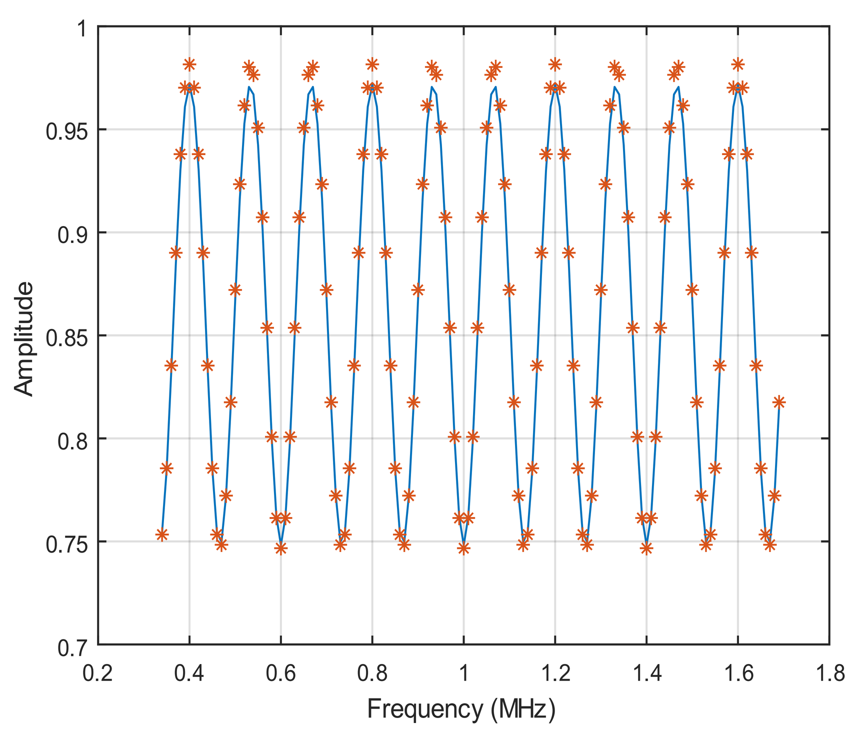

Figure 3. Amplitude vs Frequency of the fitted model (red) and input data (blue)

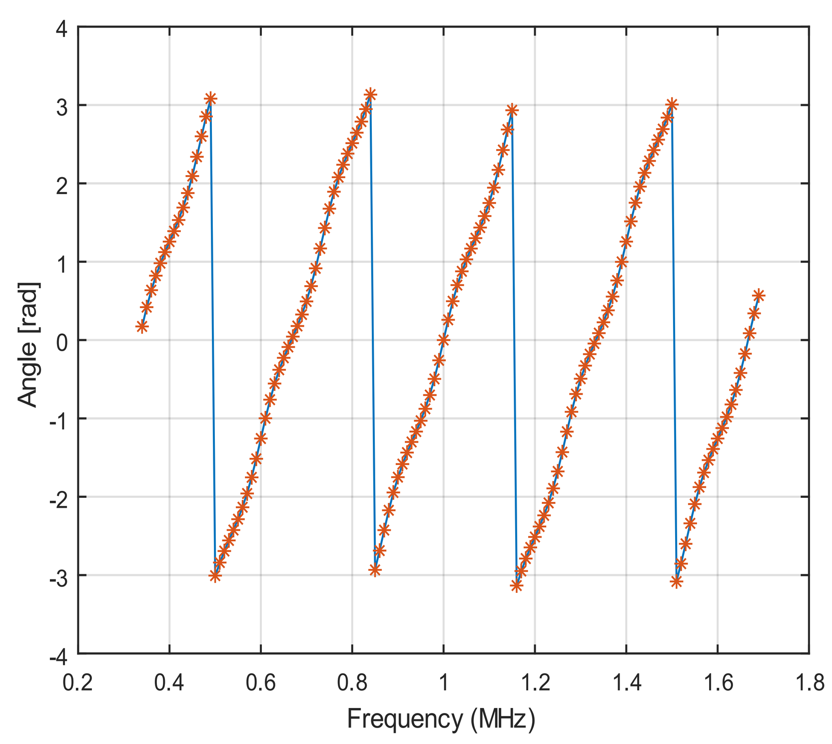

Figure 4. Angle vs Frequency of the fitted model (red) and input data (blue)

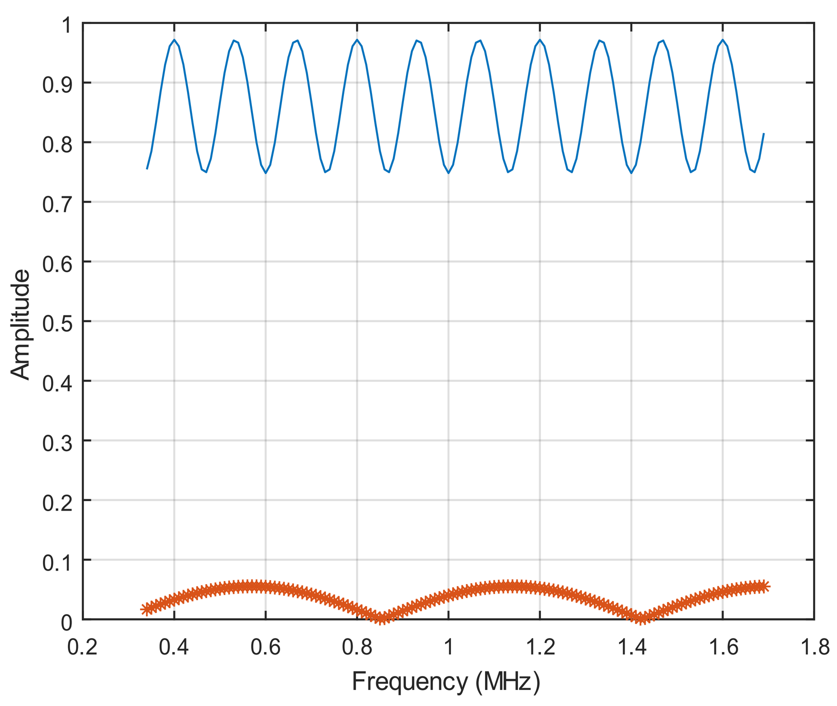

Figure 5. Amplitude vs Frequency of the badly-fitted model (red) and input data (blue)

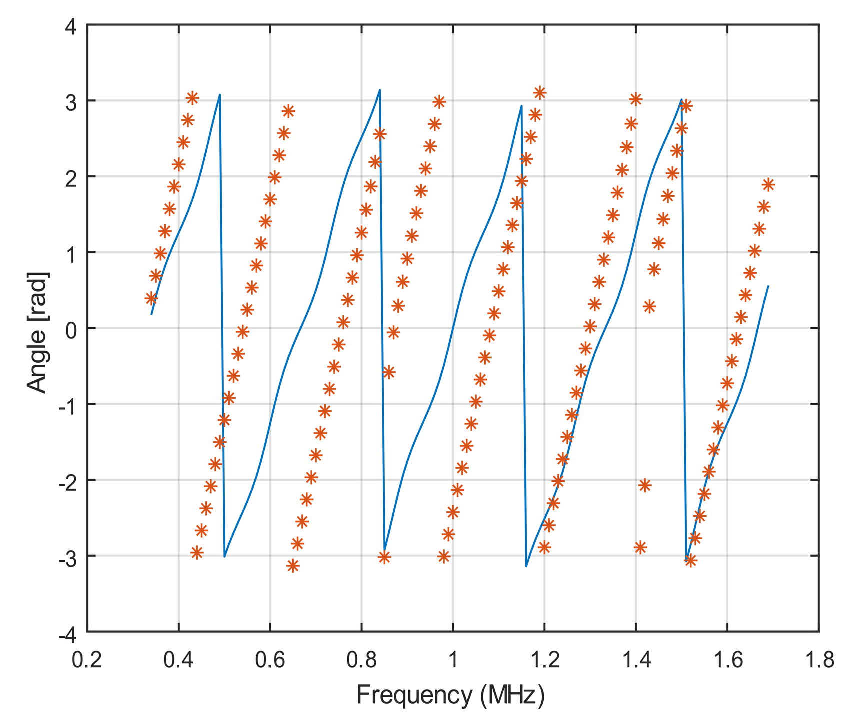

Figure 6. Angle vs Frequency of the badly-fitted model (red) and input data (blue)

Modifying the initial values led to some experiments not converging to the expected results, sometimes outputting completely inaccurate values. The change from VM = 3000m/s to VM = 10000m/s resulted in the prediction of VM = 10881m/s, A = 0,02 and DM = 0,009m, as well as badly-fitted models that can be seen in Figures 5 and 6.

In order to emphasize the importance of correctly choosing the initial parameters in a plane wave propagation model fitting, we have defined ranges for each parameters and displayed a heat-map of the convergence of our model according to the chosen initial parameters, which is visible in Fig. 7, 8 and 9.

The ranges for each parameter were the following :

$$VM = [2000; 3500], A = [0; 1], DM = [0; 500]$$

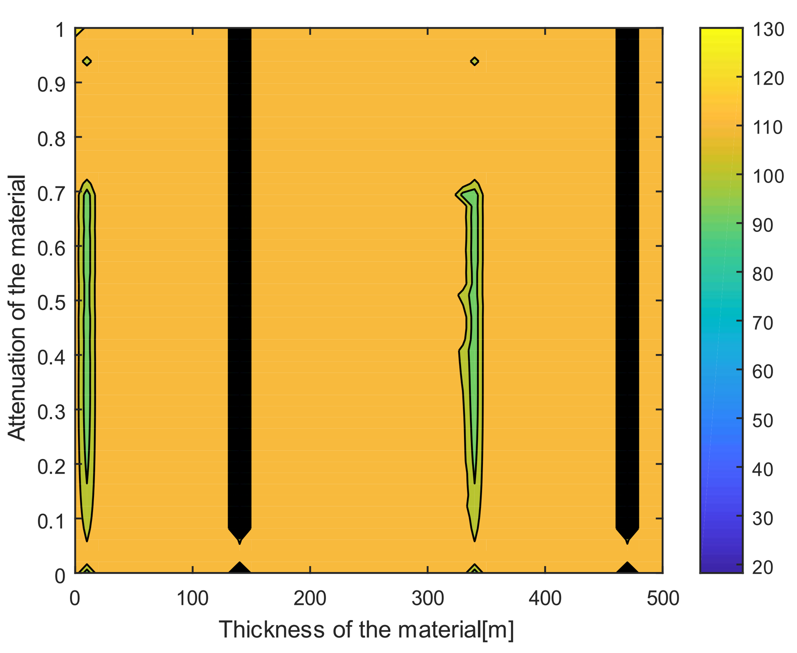

Figure 7. Error rate between the fitted model and input data depending on ranges for A and DM.

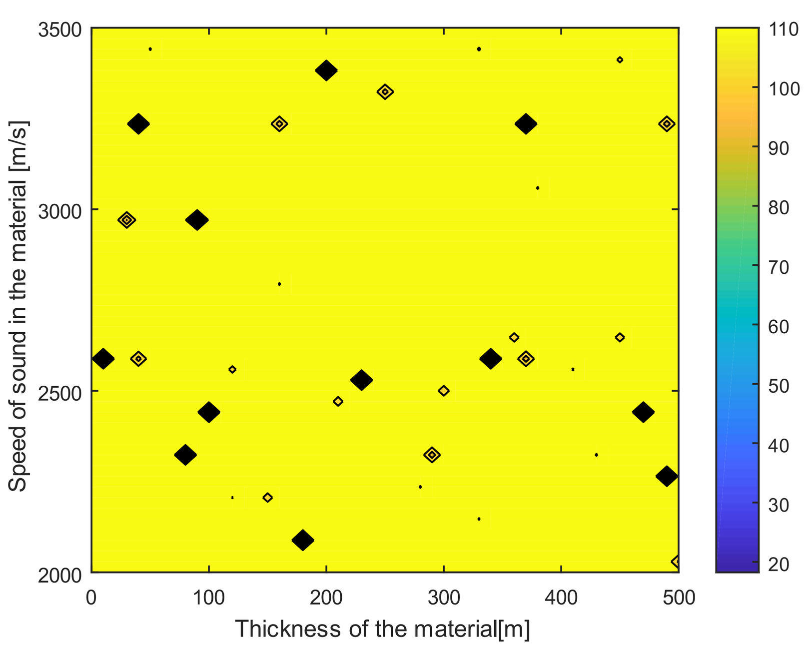

Figure 8. Error rate between the fitted model and input data depending on ranges for VM and DM.

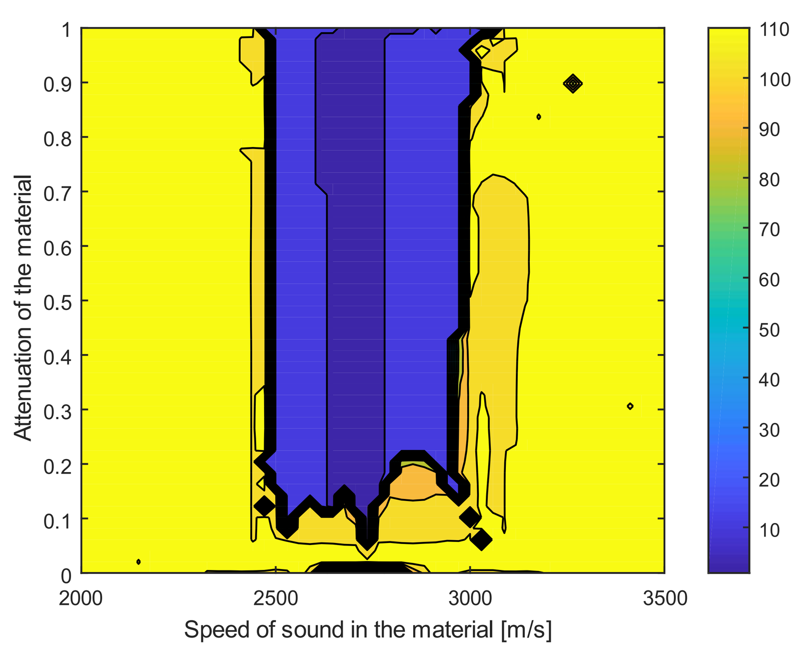

Figure 9. Error rate between the fitted model and input data depending on ranges for A and VM.

The error rate that allow us to identify the convergence of our model as calculated according to the residual of the lsqnonlin fitting. The higher the residual, the furthest away is the model from the data. An optimal result is for the residual to be null.

Conclusion and discussion

As seen through this experience, the choice of the initials conditions is of utmost importance. The three sought parameters can be inaccurate or totally wrong. This exercise introduced us to the MATLAB lsqnonlin function, as well as how to correctly use it to optimize our results and initial conditions.

References

[1] R. Longo, Q. Grimal, P. Laugier, S. Vanlanduit, P. Guillaume, Simultaneous determination of acoustic velocity and density of a cortical bone slab: ultrasonic model-based approach-correspondence, IEEE Trans. Ultrason. Ferroelectr. Freq. Control 57 (2010) 496–500