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Mutual Conversion between B-mode Image and Acoustic Impedance Image

B モード像と音響インピーダンス像の相互変換

Tan Wei Chean[1‡], Naohiro Hozumi[1], Sachiko Yoshida[1] and Kazuto Kobayashi[2]
([1]Toyohashi Univ. of Technology; [2]Honda Electronics Co., Ltd)
陳偉健 [1‡]，穂積直裕 [1]，吉田祥子 [1]，小林和人 [2]([1]豊橋技術科学大学, [2]本多電子株式会社)

1. Introduction

In order to study the acoustic properties of a B-mode image, we have proposed two ways of analysis methods to do so. First method is the conversion of acoustic impedance image into B-mode image (Z to B). Acoustic impedance image contains acoustic characteristics of the measured target. Hence, by using our proposed calculation processes, an acoustic impedance image can be converted into calculated B-mode image. Second method is the direct conversion of B-mode image into acoustic impedance image (B to Z). In this case, B to Z analysis uses the inverse version of our proposed calculation theory which is used in Z to B analysis. By using B to Z analysis, measured acoustic impedance image is unnecessary because acoustic characteristics could be calculated directly from a measured B-mode image.

2. Interpretation of acoustic impedance image into B-mode image (Z to B)

Fig. 1 represents a methodology to interpret an acoustic impedance image into a B-mode image with the use of Time Domain Reflectometry (TDR) algorithm. It is assumed that the ultrasonic wave is put in from the left of the acoustic impedance image, and the pixels of the image will be considered as the components of transmission line. By using the TDR theory represented by equations (1) to equation (3), series of acoustic impedance along one line of the image would be converted into one line of a B-mode image.

$$Z_{xN-1}(\omega) = Z_N \frac{e^{\gamma_N \Delta\ell} + \Gamma_N(\omega) e^{-\gamma_N \Delta\ell}}{e^{\gamma_N \Delta\ell} - \Gamma_N(\omega) e^{-\gamma_N \Delta\ell}} \quad (1)$$

$$\Gamma_N(\omega) = \frac{Z_{xN} - Z_N}{Z_{xN} + Z_N} \quad (2)$$

$$\gamma_N(\omega) = \alpha_N + j\beta_N \quad (3)$$

Z_{xN-1}, Γ_N are impedance and reflection coefficient respectively. γ_N is propagation constant, which is made up of attenuation constant α_N and phase constant β_N .Although scatter, refraction and attenuation through the propagation of ultrasound are all ignored, it would not significantly affect the understanding of B-mode image, because in many practical cases amplitude compensation along the depth is performed in order to retain uniform image intensity along the depth. Using the TDR algorithm, impulse responses of transmission line model induced by the propagation of ultrasonic wave are calculated and Fourier transformed (**Fig. 2**). By doing this way, transmission line model is simplified and internal multiple reflection can also be taken into account in frequency domain. Finally, inverse Fourier transform is performed to reproduce an impulse response in time domain, which basically corresponds to one line of the B-mode image.

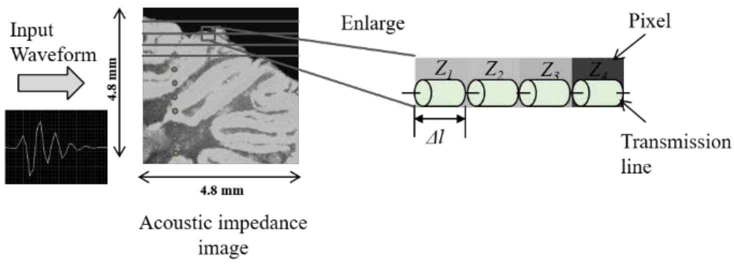


Fig. 1 Transmission line model.

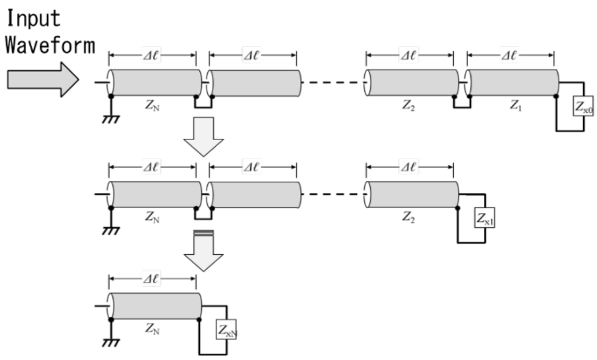
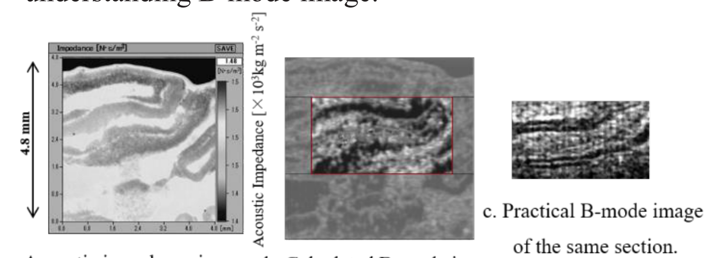


Fig. 2 TDR calculation algorithm.

As an experiment rat cerebellar tissue was used as specimen and its acoustic impedance image was attained by measuring it with acoustic impedance microscope (**Fig. 3a**). Subsequently, the acoustic impedance image was interpreted into calculated B-mode image (**Fig. 3b**). From **Fig. 3**, it can be seen that calculated B-mode image (**Fig. 3b**) shows some similarities, in comparison with **Fig. 3c**, which represents practically acquired B-mode image of the corresponding tissue before being subjected to cross-sectional acoustic impedance observation. Hence, we believe that this calculation method has the potential to be used as a tool in understanding B-mode image.



a. Acoustic impedance image. b. Calculated B-mode image. c. Practical B-mode image of the same section.

Fig. 3 Calculation result of acoustic impedance image and its comparison with practically acquired B-mode image.

3. Interpretation of B-mode image into acoustic impedance image (B to Z)

The theoretical background is similar to the method stated in **2**, however, the direction of calculation algorithm is opposite, as shown in **Fig. 4**. B-mode image is composed of RF waveform $s_{tgt}(t)$ from the target. At first, the RF waveform is subjected to Fourier transform in order to be represented as below.

$$S_{tgt}(\omega) = \frac{Z_{xN} - Z_N}{Z_{xN} + Z_N} S_0(\omega) \qquad N = 0,1,2,..., N \tag{4}$$

$S_0(\omega)$ is input waveform. Next, perform deconvolution to $S_{tgt}(\omega)$ with $S_0(\omega)$ and impulse response from Z_0 to Z_{xN} will be attained.

$$\Gamma_0(\omega) = \frac{S_{tgt}(\omega)}{S_0(\omega)} = \frac{Z_{xN} - Z_N}{Z_{xN} + Z_N} \qquad N = 0,1,2,..., N \tag{5}$$

Subsequently, inverse Fourier tranform is performed to equation above to extract the equation below.

$$g_0(t) = \frac{Z_{N+1} - Z_N}{Z_{N+1} + Z_N} \qquad N = 0,1,2,..., N \tag{6}$$

Here, only the first term of the above equation that is

$$g_0(t_0) = \frac{Z_1 - Z_0}{Z_1 + Z_0} \tag{7}$$

does not contain multiple reflection from other components of the tansmission line model. Hence we use this first term to calculate the acoustic impedance of the first component of transmission line.

$$Z_1 = \frac{1 + g_0(t_0)}{1 - g_0(t_0)} Z_0 \tag{8}$$

Repeating the steps, all the acoustic impedance components along the transmission line can be calculated and reflected into B-mode image.

As an experiment, human cheek skin was observed as a B-mode image (**Fig. 5a**). It was subsequently interpreted into acoustic impedance image as shown in **Fig. 5b**. As can be seen, calculated acoustic impedance image shows the structure of skin which includes stratum corneum, epidermis and dermis. However, the calculated acoustic impedance of the skin is yet to be further discussed because scatter and attenuation through the acoustic beam propagation were out of consideration. In addition, although the beam was highly focused, the incidence was assumed to be completely vertical to the tissue surface. Nevertheless, we believe that this method has a strong potential to be a strong tool in understanding B-mode image in the future. It is also believed to be useful in the assesment of comestic effects to skin.

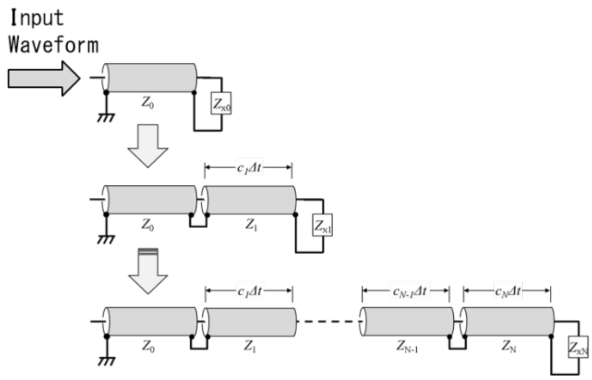
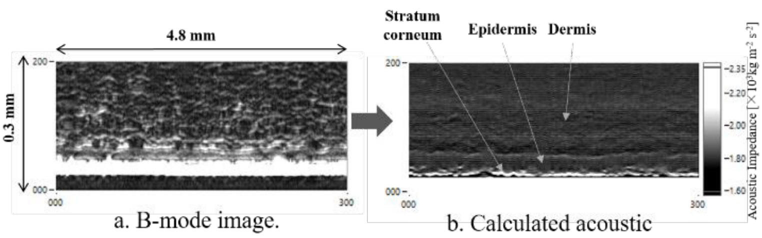


Fig. 4 Inverse TDR calculation algorithm.



a. B-mode image. b. Calculated acoustic impedance image.

Fig. 5 Calculation result of cheek skin B-mode image.

4. Conclusion

Mutual conversion between cross-sectional acoustic impedance image and B-mode image of corresponding tissue structure was discussed. Theories similar to time domain reflectometery were employed by assuming no significant scatter and attenuation are taking place through the propagation. In addition, although the ultrasonic beam in the experiment was focused, the incidence was assumed to be vertical to the surface of the tissue. In spite of these unclear factors, an experimental result by using cerebellar tissue showed a good agreement between cross-sectional acoustic impedance profile and interpreted B-mode image. Interpretation from a B-mode echograph of human skin showed a clear acoustic impedance distribution, although cross-sectional profile by acoustic microscope was not available. Some improvements may be required in order to retain precision in terms of estimated acoustic impedance.