1J3-1

Reduction of Low-Frequency Noise in Cross-Sectional Ultrasound Property Micro Imaging by Frequency-Resolved Spatial Averaging.

周波数分解空間平均処理による超音波物性量顕微断層像の低周波ノイズ除去

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1. Introduction

Ultrasound microscopy is suitable for non-destructive and non-staining observation of thin biological tissues such as human skin and cultured cells[1]. By performing analysis to the dataset obtained from the scanning area, not only 2D but also 3D observation can be performed.

In the acoustic impedance microscope proposed in this study, a focused pulsed ultrasound is transmitted from the back of the polymeric substrate to a specimen, and a cross-sectional acoustic impedance distribution in the depth direction can be obtained. Since the acoustic impedance interpretation process is similar to integration along time axis, low-frequency noise that exists in the signal will cause an accumulation of error as the calculation goes deeper [2].This type of noise is considered to be a random noise and can be reduced by taking the spatial average of the waveforms along adjacent scanning points, however, this treatment may reduce the spatial resolution in the lateral and axial direction. Therefore, taking into account that the wideband pulse contains variety of frequencies, the authors proposed an analysis method based on the fact that the beam width depends on frequency. In other words, we decompose each waveform into its corresponding spectrum and take the spatial averages only on the low-frequency parts while maintaining the high-frequency components in the spectrum. Human cheek skin will be used as the target of observation.

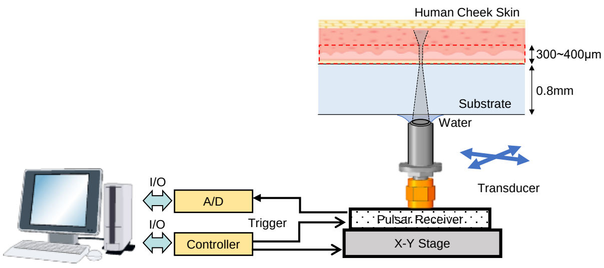

Fig. 1 The ultrasound microscope system.

2. Measurement system

Fig. 1 shows the system of ultrasonic microscope. A focused pulsed ultrasound wave with a center frequency of 80 MHz was transmitted from the transducer with the aperture of 2.4 mm and focal length of 4 mm. The measurement target was a human cheek skin that is in contact with the 0.8 mm polystyrene substrate.

3. Measurement method and signal processing

3.1 Acoustic impedance conversion

Echo waveforms were acquired by scanning the transducer along x-y directions. The reflection signals were normalized by the reference signal that comes badk from the interface between the substrate and water (inverse convolution process).

The signal was converted into sequential acoustic impedance in the direction of skin depth that is corresponding to the time axis, by referring the acoustic impedance of the substrate.

This process requires a normalized spectrum over a wide frequency range that includes DC and very low frequency components. However, errors due to low-frequency spuriousness generated in the normalization process propagate backward on the time axis and accumulate.We attempted its reduction.

3.2 Concept of noise reduction

A focused pulsed ultrasound contains a wide range of frequency components. The spatial spreading of the beam depends on the frequency, as illustrated in **Fig. 2**. Since the beam of low-frequency components is widely spreading, the signals obtained from adjacent scanning points are almost the same. On the other hand, as the beam spot of high-frequency components is highly localized, different response may come back from the adjacent scanning point.

For low-frequency components where the wavelength is very long compared to the spacing between scanning points, the signals from adjacent scanning points are almost the same. Therefore, spatial averaging in this range will not significantly affect the morphology of the image.

On the other hand, high-frequency components with wavelengths shorter than the spacing between scanning points show different responses at different scanning points. Spatial averaging over the entire frequency band can reduce random noise, but at the same time it reduces the spatial resolution of the image.As explained in **Fig. 3**, the signal strength of low-frequency component is highly suppressed due to the frequency characteristics of the transducer and the measurement circuit.

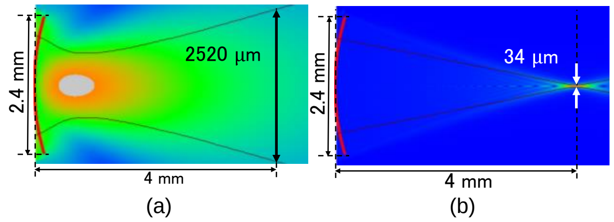

Fig. 2 Frequency dependence of sound field and beam width.((a). 1 MHz , (b). 80 MHz)

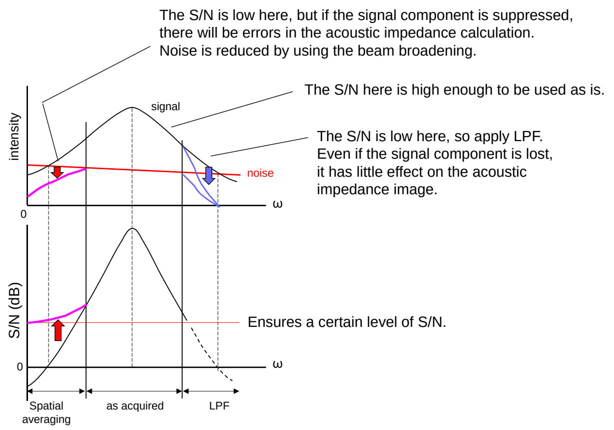

Fig. 3. Illustration of the noise reduction process

Due to the superimposition of noise in this range, the signal-to-noise ratio is significantly reduced in the low-frequency components. However, in this frequency band, noise reduction by spatial averaging without reducing spatial resolution is possible, as described above.

The signal-to-noise ratio decreases in the extremely high frequency range, but a low-pass filter (LPF) can reduce the noise without giving significant influences to the signal to be analyzed, as its spectrum intensity is very low as well in this frequency range.

The noise reduction method based on the above is shown in **Fig. 4**.To suppress low frequency noise, the signal is Fourier transformed.For low-frequency components with large beam spread, spatial averaging is performed with signals from adjacent scanning points in a range that matches the beam spread characteristics at each frequency.The spread function gets narrower as frequency gets higher, in order to retain spatial resolution.All the frequency components after the above processing are synthesized into one spectrum, and inverse Fourier transformed to reconstruct the signal in time domai As a result, the signal of which only low frequency components have been stabilized by the spatial averaging is reproduced.

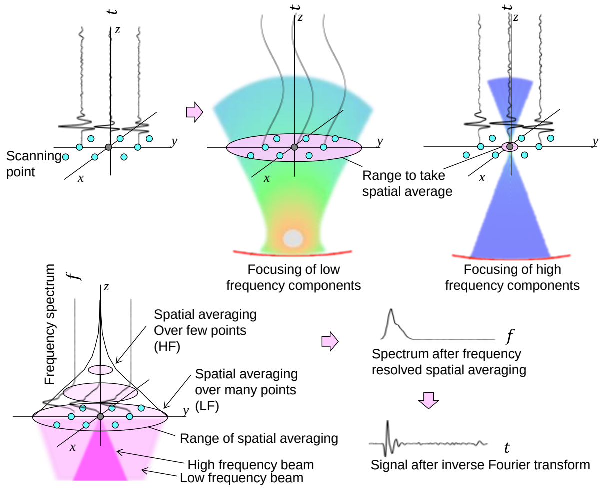

Fig. 4 Frequency-resolved spatial averaging method

4. Results

Fig. 5 shows the acoustic impedance profile of human cheek skin. (b)is the result of frequency-resolved spatial averaging of the signal in (a). The accumulated error, which had become larger toward the rear, was reduced, and the internal structure of the skin became clearer due to the stabilization of the acoustic impedance distribution.

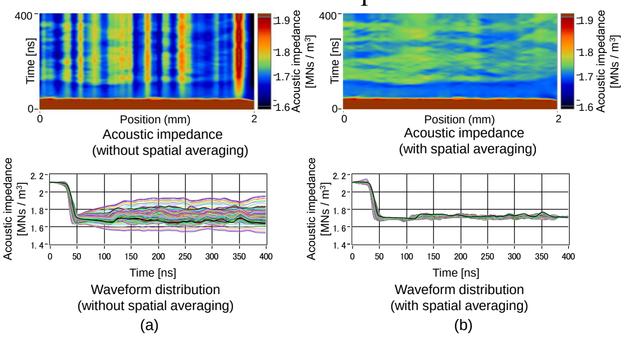

Fig. 5 The improvement in cross-sectional acoustic impedance image of human cheek skin after low-frequency reduction by spatial averaging

5. Summary

A frequency-decomposed spatial averaging process was used to take advantage of the fact that the beam of focused pulsed ultrasound spreads significantly in the low-frequency component.This allowed to sharpen the cross-sectional acoustic impedance image of the skin and obtain good results.

References

[1] Naohiro Hozumi et al.,Ultrasonics, Volume 99, November 2019.

[2] Edo Bagus Prastika et al.,Japan Society of Applied Physics, Volume 59, Number SK, July 2020.