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The Acoustic Impedance Interpretation of Human Skin Structure by Using Time and Frequency Domain Deconvolution

Edo Bagus Prastika[1†], Atsushi Imori[1], Tomohiro Kawashima[1], Yoshinobu Murakami[1], Sachiko Yoshida[1], Naohiro Hozumi[1], Ryo Nagaoka[2], Kazuto Kobayashi[3]
([1]Grad. School Eng. Toyohashi University of Technology; [2]Grad. School of Science and Research, University of Toyama [3]R & D Division, Honda Electronics Co., Ltd)

1. Introduction

The process of interpreting the acoustic properties of human skin structure based on its reflection intensity is an important part of ultrasound assessment[1-4]. The deconvolution process, which is done in order to estimate the reflection coefficient that comes only from the target without the interference of any other components, is the most challenging and difficult part. There are two kinds of signals that are applied for the calculation. First is the signal reflected from the boundary between the substrate and the skin (target signal), and the second is the signal reflected from boundary between the substrate and the water (reference signal)[1]. Normally, the reflection coefficient at the boundary between the substrate and the skin is obtained by deconvolving these two signals only in the frequency domain. However, improper division in frequency domain often introduces some artifacts to the result of the deconvolved signal, especially when the intensity of the reference signal is small. A constant with small value can also be subjected to the reference signal as a tuning parameter, so the impact of the artifacts is not really significant before transforming the output signal back to the time domain[1]. Nevertheless, since this way of calculation relies on the tuning value, two conditions often occur for the low-frequency components of the reconstructed signal, it is either the missing of necessary frequency components or creation of unnecessary ones, which makes this kind of calculation is unpredictable. In order to deal with this problem, a new method of deconvolution in both time and frequency domain is proposed in this paper. The essential low-frequency components are obtained from the time domain calculation, which is then combined with the high-frequency components from the conventional frequency domain method. As a result, a human skin data was observed by using the proposed method, and a better interpretation of human skin structure based on its value of acoustic impedance was successfully obtained, compared to the result when the calculation is performed only in the frequency domain.

E. B. Prastika : e189202@edu.tut.ac.jp
N. Hozumi : hozumi@ee.tut.ac.jp

2. System Setup

Fig. 1 shows the setup of the system used in the experiment. A transducer with the focal frequency of 80 MHz transmits a focused ultrasound wave from the rear side of the substrate. The transducer type is a transceiver, which means that the reflection waveform is also received by the same transducer.

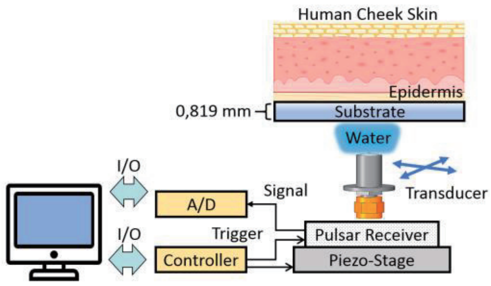

Fig. 1 System Setup

On the other side of the substrate is where the human face skin is attached. A distilled water is used as a coupling medium between the transducer and the substrate, and between the outer part of the skin and the substrate. The piezoelectric stage moves the transducer to scan the object along *x* and *y*-axis with the area size of 2 x 2 mm^2, containing 300 x 150 x 200 data points (*x*, *y*, and *z* resolution) with a sampling time of 125 ps.

3. Signal Processing

3.1. Preparation

Fig. 2 illustrates the concept of the proposed time-frequency deconvolution method. Firstly, both target and reference signal is deconvolved in the frequency domain by using the conventional method. The output is then convolved by the second-order differential of a Gaussian function and transformed back into the time domain. The envelope of the signal is then obtained from the real part of the analytical signal by making use of Hilbert Transform, and the peak location of each envelope is detected. Secondly, some impulses signal are generated by shifting the reference signal around the location of where the peaks are detected, and by using the least square algorithm, the most appropriate combination of intensities of these impulse signal is calculated. This is defined as time domain deconvolution. As the number of the assumed impulses is limited, the output of this process is poor in resolution in high frequency components.

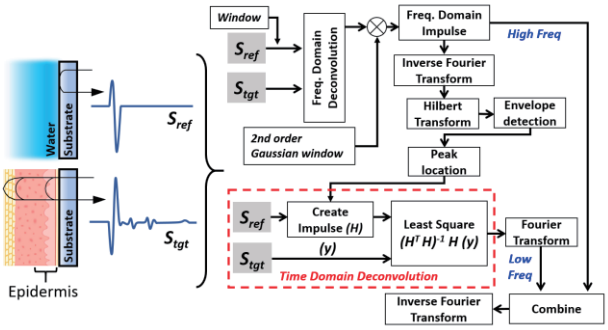

Fig. 2. The stream of the signal processing

The calculated signal is then transformed into the frequency domain and by using a specified threshold value, its low frequency components are taken and combined with the high frequency components from the conventional frequency domain deconvolution. The output is then transferred back into the time domain.

3. Result and Discussion

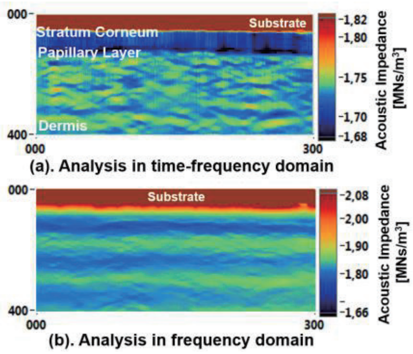

Fig. 3 Acoustic impedance distribution of human skin

Fig.3 (a) and **Fig.3 (b)** show the result between the proposed time-frequency domain deconvolution method and the conventional frequency domain deconvolution, respectively, after being applied to observe the human skin structure. Each reflection coefficient along the beam direction is converted into the distribution of acoustic impedance by using the TDR algorithm method[1,2,3].

As shown by **Fig.3 (a)**, the detail and some layers on the skin structure especially on the dermis area can clearly be seen by using the proposed time-frequency domain method. It also shows that the area between the Stratum Corneum and Papillary layer has a lower value of acoustic impedance, compared to the dermis area. This has a good agreement with the fact that area below the papillary layer is filled with cells such as keratinocytes, while the dermis area which has a higher acoustic impedance value consists of elastin and collagen, which harder in terms of structure. The conventional method, shown by **Fig.3 (b)**, is unable to distinguish the difference between these structures since the result mostly contains high frequency components, so neither the detail nor the difference between each layer is clearly seen.

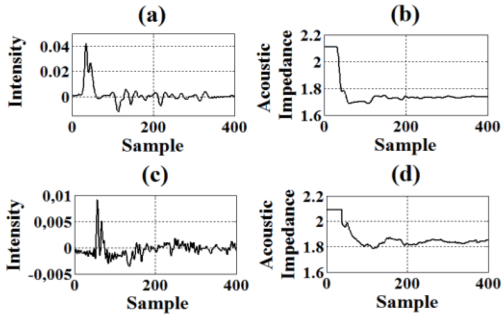

Fig.4 (a). Time-dependent reflection coefficient by the proposed time-frequency domain deconvolution. (b). Acoustic impedance profile by the proposed time-frequency domain deconvolution. (c). Time-dependent reflection coefficient by the full frequency domain deconvolution. (d). Acoustic impedance profile by the full frequency domain deconvolution.

The proposed time-frequency domain method provides a good profile in both the deconvolved signal and the acoustic impedance distribution, as shown in **Fig.4 (a)** and **Fig.4 (b)**. **Fig.4 (c)** shows the time-dependent reflection coefficient along the beam by the full frequency domain deconvolution. A strong reflection comes back from the interface between the substrate and the stratum corneum. The waveform is slightly disturbed by low frequency components. Although this disturbance is not clear, it gives a strong influence onto the acoustic impedance profile as shown in **Fig.4 (d)**.

4. Conclusion

A new deconvolution method which is performed in both time and frequency domain is proposed. The low and high frequency components are obtained from the result of calculation in the time and frequency domain, respectively. As a result, a clear view of the skin structure is obtained by using the proposed method, compared to the result when the calculation is performed only in the frequency domain.

References

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