醫工學會誌：第5卷，第1號，1984
J. of KOSOMBE:Vol. 5, No. 1

特 別 講 演
84—1—02

Basic Aspects of Signal Processing in Ultrasonic Imaging*

Masao Saito

1. Introduction

The ultrasonic echo imaging is now widely used in clinical applications. The technology up to present has been based on a simple idea that a pulse transmitted from the surface of the body is reflected back by the irregularities inside of the body, as in the case of flaw detection in steel industry. Imaging devices based on such a simple idea are already on the market and finding wide applications.

The structure of the biological object, however, is far more complex than the steel plate, and various random phenomena are observed. The development of the technology, on the other hand, seems to have come to the stage where more thorough and detailed investigations have to be made on the properties of the reflected signal as well as the matching of the display with the human visual characteristics, so that the knowledge is utilized to improve the design of the imaging devices.

The actual signal processing in ultrasonic imaging can roughly be divided into two aspects. One is rather superficial, where the image is merely modified to look better to the human observer. Examples of such processings are deconvolution, histogram modification, interpolation and edge enhancement. The other is to improve the signal based on the propagation and reflection characteristics of ultrasound in tissues, such as randomness, frequency-dependent attenuation and reflection. The latter is the more basic approach, but often encounters a difficulty in the implementation. Both of the two approaches should be taken into consideration in the design of actual devices.

The discussion in this presentation starts with the basic aspects and proceeds to the practical aspects. The views described will be utilized, not only in the improvement of the existing echo-imaging devices, but also in the future development of what are called tissue-characterization devices.

2. Attenuation and Phase

As is well-known, as the first step of approxiamation, the attenuation constant of the ultrasound in the propagation through biological medium is proportional to the frequency. This is the greatest frequency dependence in the ultrasonic echo, and various kinds of amplitude equalizing circuits are equipped.

It is also well-known that a frequency dependent attenuation is always accompanied by a phase characteristic, which together

Professor of Medical Engineering, Institute of Medical Electronics, Faculty of Medicine, University of Tokyo, Japan

* 대한의용생체공학회 1984년도 춘계 학술대회에서 강연한 내용을 발췌한 것임.

produce a waveform distortion. The waveform distortion is the first basic data that has to be at hand, when any elaborate signal processing is to be considered.

In the minimum-phase system, the phase characteristic is obtained from the attenuation through an integral expression. There may be an arguement as to whether or not the ultrasound propagation in a medium is of the minimum phase. It may be convinced however, from the equivalent circuit for the plane wave propagation, for example, that the propagation can be considered as minimum phase, except for the term representing a uniform delay. There are of course some exceptions, such as in the case of multipath propagation in focusing, where the propagation is not minimum phase. There are several mathematical problems in the calculation of the wave-form distortion based on above idea. They can, however, be overcome. Observing the results, it is seen that the waveform distortion is more remarkable for wide-band signals, less than 2 in terms of Q.

3. Signal Equalization

In the past, equalization of the signal has been made only in terms of amplitude. With the knowledge about the waveform distortion at hand, however, the waveform itself can be equalized to restore the original pulse as faithfully as possible, and to improve the longitudinal resolution. In order to take the effect of the noise into consideration, constrained deconvolution or Wiener filter may be used. There will not be produced a great difference by the choice of the processing method.

It is easy to show that, unless the signalto-noise ratio is unusually low, the waveform equalization can imporve the resolution by several times.

4. Properties of Reflection

Irregularities in the biological object usually consist of clearly defined discontinuities and randomly distributed small discontinuities. An example of the former is the boundary between two different kinds of tissues and an example of the latter is the granular structure of the liver.

In correspondence to above situation, the ultrasonic echo consists of a large pulse from clear disocninuity and noise-like waves from random small discontinuties. Those two components require separate processings since the clearly-defined boundaries should be observed as clearly as possible, but the randomly distributed irregularities have only statistical meanings. Thus, there must be a means to separate the two components, which will be discussed by another author. It should be pointed out, however, that a standard waveform is needed in the separation of large reflections from the whole received signal, and the standard waveform must be calculated based on the knowledge of the attenuation and phase characteristics.

After separating the two components, the large reflections should be used to define the macrostructure as clearly as possible, and the random component should be used only to define the statistical properties of the tissue.

5. Macrostructure

Assume that the received echos consist only of the large reflections from clearly-defined boudaries of tissues. Still there is produced a waveform distortion in the course of the propagation of the pulse through the medium, and even if a very sharp pulse is transmitted, the received pulse is of a broader waveform.

Mathematically, the problem can be stated as follows, simplifying the situation to the one-dimensional case. Given an unknown one-dimensional layered structure and measuring the transfer function between the transmitted and reflected waves, determine the unknown structure.

This problem is a typical one in the field of distributed network theory and has been answered from various kinds of approaches. With the complete knowledge of the trasnfer function, the structure can uniquely be determined if the medium is lossless. It is a puzzling phenomenon, however, that the structure cannot uniquely be determined if the medium is lossy, even if one assumes that the attenuation is proportional to the frequency. One might argue whether or not the image on CRT screen is a reality. This is what is called in mathematics an improperly (ill-) posed problem, and the answer has to be sought within a reasonble range of approximation.

There are of course many algorithms that can determine the layered structure within a limited range, such as two-layered or three-layered structures. In such a case as heart wall, the medium inside of the structure can be assumed as loss-less, which somewhat simplifies the computation. It is true, on the other hand, that a fine layered structure makes the idnetification more difficult and produces a slow-varying frequency dependence, which is difficult to separate from the original frequency characteristics.

6. Microstructure

The microstructure at cellular level, for example, produces random, noise-like reflections from homogeneous medium. The microstructure near the boundary also produces reflections, and the reflection coefficient from a boundary usually exhibits a frequency-dependence. A large number of small reflections, together with the distribution of transmitted and received fields and the geometry of transducer, produce complicated frequency-dependence and unnecessary fluctuations.

The efforts in signal processing are directed toward elimination of unnecessary fluctuations by some means of averaging and toward utilization of the statistical properties of the random echos to extract some useful parameters of the tissue.

Assuming that the statistical properties of the random microstructure remain unchanged for a certain range, one can extract some tissue parameters by statistical processings. Typical example is the local attenuation constant. Tbe method of center-frequency shift is one of the methods, which is mathematically clear. In actual application of the method, however, various kinds of sophistications are needed, and it may be wise to utilize the whole range of the spectrum to extract the center frequency or to approximate the attenuation characteristics.

7. Practical Considerations

Whenever a sophisticated signal prcessing is to be considered in ultrasonic imaging, one is confronted with the difficulty of digitizing and storing the echo waveforms at carrier level. At the present stage of cost and complexity, the signal processing has to be considered at video level, where one or more frames of images can be digitized and stored. The processing at carrier level can only be considered along a single scanning line.

Thus, what can practically be performed in the imaging device will be the deconvolution or equalization along the depth at carrier level to improve the longitudinal resolution, deconvolution at video level along horizontal direction to improve the lateral resolution, and some processings after storing the image, such as histogram conversion and interpolation to improve the outlook of the images.

Although they look trivial to theorist, they are important in providing help to the human observer who must extract qualitative obrsevations from the image. There are many small techniques to be considered in maintaining the quality of the image after storing the data and restoring the image. Examples are sampling circuit, detection scheme and averaging filters. Human visual characteristics should also be taken into consideration. It is sometimes useful to emphasize the portion of the image according to the properties of the echo, such as motion, randomness, etc.

8. Conclusion

The technology of ultrasonic echo imaging has come to the stage where more sophisticated image processings are required both from basic and practical approaches. There are still many rooms that small or essential improvements can be made from technology.

There are expected to emerge various kinds of other ultrasonic imagings based on transmission or scattering. The elaboration of echo imaging technology, however, will continue for some years, and will pave the way toward those newly emerging ultrasonic technologies.