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Application of Hilbert's transformation in ophthalmic measurements

Measurement of the thickness of the layers is a mandatory stage of diagnosis before surgery in ophthalmology. Features of the structural structure of the eye can create significant settlements of ultrasonic energy. This scattering transforms the reliable detection of the reflected echo pulse, which limits the possibility of ultrasonic measurement of the thickness of the layers of the eye.

Introduction

Due to the complex multilayered structure of the eyeball, it is necessary to measure the thickness of each of its tissue layers. To solve this problem, an ultrasonic diagnostic method is used, the essence of which is that an ultrasonic probing signal with a frequency of approximately (8... 12) MHz is sent to the diagnostic object (human eye), after reflection from the layer boundary the signal is returned. Knowing the value of the speed of the ultrasonic wave in the layer of the eye c , you can measure the passage time τ and calculate the thickness h (by formula 1.1):

$$h = \frac{c\tau}{2} \quad (1.1)$$

To determine the size of the layers, use the ultrasonic method of A-scanning (amplitude scan).

In the A-scan, one sound signal is sent from the sensor. Echoes that return to the transducer are converted into a series of spikes with a height proportional to the strength of the reflected signal.

The gain or input sensitivity of the A-scan changes the size of the resulting spikes. Proper balance is necessary when choosing the gain because weak signals or smaller damage are more noticeable when the gain is high but also increases the noise, thereby reducing the resolution.

The acoustic path is the path of the ultrasonic wave from the radiating transducer to the transducer receiver. One of the main features of the scan is the value of the parameters of the acoustic path, which is how the ultrasonic wave will behave when passing through different biological layers.

The echo-pulse ultrasound method involves determining the delay time required for the propagation of ultrasound of the probing radio pulse signal through the eye. The delay time is related to the thickness of the eye layer. As a rule, the values of the signal passage time are evaluated by the time position of the bypass probing and bottom ultrasonic signals, which are determined using amplitude detectors. The disadvantage of this method of measuring the delay time is the presence of error, which is associated with the final duration of the radio pulse signal and the rate of increase/decrease of its envelope. As a result of random factors, the measured value of the delay time may have an error.

Known methods of processing signals of ultrasonic measurements are based on the application of amplitude characteristics of signals.

Main part

A new precision method for measuring τ was proposed. Its essence is to form an acoustic probing signal, introducing it into the layers of the eye, receiving the signal after its propagation in the eye, determining the phase characteristics of the probing and reflected signals, calculating the thickness of the object by signal delay time and known signal propagation rate. that a phase-pulsed radio pulse signal is used to generate the acoustic probing signal, and the signal propagation delay is measured as the difference between the time positions of the FH jumps of the probing and reflected signals. FH is realized using Hilbert's transformation.

A Hilbert transform is a linear integral transformation that matches a function to another function in the same domain. GHG makes it possible to separate the amplitude and phase characteristics, as well as to determine the phase characteristics of ultrasonic ophthalmic signals and evaluate their integral changes not only throughout the study interval but also locally and within one period of the carrier signal. These data are necessary for the implementation of the proposed method, which is based on the analysis of FH.

For a given valid signal $u(t)$ is determined and matched complex-valued signal of the form:

$$z(t) = u(t) + iu_n(t) \quad (2.1)$$

Where $u_n(t)$ is the Hilbert transformation of the signal $u(t)$.

The formation of the Hilbert image was realized thanks to the auxiliary function which works as follows:

The fast Fourier transform of the input sequence is calculated, preserving the result in the vector x . A vector h is created, the elements of $h(i)$ which have the values:

- 1 for $i = 1, (n / 2) + 1$;
- 2 for $i = 2, 3, \dots, (n / 2)$;
- 0 for $i = (n / 2) + 2, \dots, n$;

The element-by-element product x and h is calculated. The inverse fast Fourier transform of the sequence obtained previously is calculated and the first n elements of the result are returned.



Fig.1 – Hilbert signal image

Known methods of processing signals of ultrasonic measurements are based on the application of amplitude characteristics of signals. The most commonly used bypass signal, or its certain instantaneous values, such as those for which there is an intersection of signals of a certain level. Such processing methods are relatively easy to implement, but at the same time a significant part of the measurement information contained in the phase characteristic of the signals is lost, and, as a result, the accuracy of thickness measurement is reduced. This decrease becomes more noticeable with a decrease in the signal-to-noise ratio (s/w) of the analyzed signal, which occurs, for example, during ultrasonic measurement of the layers of the eye with significant attenuation.

An important property of Hilbert transformation is that in the presence of $x(t), t \in (-\infty, \infty)$ this transformation allows you to unambiguously define the functions at all points of the interval of existence. Thus, Hilbert transformation allows you to assess and analyze current changes and even in the middle of the cycles of periodic signals, and therefore allows you to get the necessary statistical material and analyze the probabilistic nature of phase signal characteristic and amplitude signal characteristic.

The accuracy of measurement of this method is most influenced by the sampling frequency of the ADC, physical and mechanical properties of the eye, the features of the analyzed FH signal, mechanical and natural factors and the ratio of s/w.

The practical implementation of this method involves additional research aimed at analyzing the characteristics of the propagation of phase-locked signals in the electroacoustic pathways of ultrasonic thickness gauges.

Conclusion

In this work, ultrasound diagnostics in ophthalmology was analyzed. A new method in ophthalmic ultrasound measurements has been proposed, which is based on the analysis of the phase characteristics of the ultrasonic signal.

The methodology of ultrasonic signal processing is established and analyzed. A mathematical explanation of the new method.

It is established that in order to significantly reduce the methodological error, it is necessary to coordinate the signal periods and sampling. The ratio of the observation time and the sampling period must be an integer.

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