Chapter 14

Non-Invasive Active Acousto-Thermometer

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ABSTRACT

The problem of detecting and identifying the heat transfer processes in living tissues using a noninvasive ultrasound technique is discussed. An optimal method, which is optimal in terms of maximum of likelihood, is proposed to detect the temperature variations within internal layers of the living tissue. The properties of signals returned from different tissues are examined. The ultrasound velocity for different temperatures and the salt composition of a specimen under study is estimated. Results of the algorithm simulation are given.

INTRODUCTION

Remote monitoring of the temperature in different types of a medium is a topical issue both in engineering, biology, and medicine (Dmitriev, 1987). Specifically, when treating cancer diseases through hyperthermia, in diagnosing internal inflammatory processes, etc. the application of contact methods results in the hazardous injury of vitals (Pasechnik, 1991). Therefore the immediate goal of to-day us to develop special technical tools that would provide the non-invasive monitoring of the temperature in the living organism areas under study.

To obtain some reliable information on the internal layers of living tissues, technical facilities are needed to radiate, receive and extract information from echo signals. To this end both active (Sytnik, 2002) and passive (Pasechnik, 1991) systems can be employed. The operation of passive systems is based upon the reception and processing of object self-radiations.

However, the passive accoustothermometry techniques allow making an integral estimate of the temperature along the observation beam. Yet if the temperature profile is to be restored, it is necessary to scan an area under study from different points and to solve a set of integral equations. As a results, one cannot obtain on-line information. At the same time the accuracy of measurements is largely depth-

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dependent. As shown in (Anosov, 1995), an acceptable accuracy is attained at a depth of no more than 3 to 5 cm, which, in many instances, is insufficient. Moreover, bone and fatty tissues can lead to dramatic distortion of a temperature spatial profile. To obtain reasonable accuracies signal storing should take quite a long time, which is found to be comparable to the typical period of time during which the thermodynamic processes occur in living tissues.

The above shortenings can be avoided if one falls back upon an idea of determining the degree to which the local areas of the living tissue are heated. This idea is based upon the measurement of the temporal or phase delay of an ultrasound signal as it passes through a heated region (Dmitriev, 1987),(Sytnik, 2002). In the general case the delay is governed by the rate at which the ultrasound propagates in tissues. This rate, in its turn, is dependent upon the tissue temperature and the blood salt composition. If the aforementioned composition is considered to show no dramatic change on being heated, then the phase shift between the signal that has passed through the tissues prior to and after heating will result from the temperature gradient. In other words, the power of the ultrasound signal transmitted into a human organism should be brought up to a level so that a signal returned from the remotest point of a signal propagation path could not only exceed the self-radiation of tissues and the receiver noise more than once, but also keep the tissues from being appreciably heated. In this instance, the typical targets are the boundaries of transition between fatty, muscular, bone and tumor-affected tissue, blood vessel walls, etc. The variation in the position of these targets along the same path upon heating will enable the temperature gradient profile to be restored.

PHYSICAL PRINCIPLES OF THE PROPOSED TECHNIQUE

A plot of the sound wave velocity as a function of temperature *c(T)* for homogeneous media (say, water) and for different sounding signal frequencies using the data drawn from the reference (Hutte,1934), is presented on Figure 1.

As far as medical applications are concerned, hyperthermia in particular, the temperature interval between 39^0 and 45^0 C is of certain interest. The experimental studies indicated that the derivative of sound velocity with respect to $dc\,/\,dT^0C$ over this particular temperature interval is insignificant (Figure 2), and for the carrier frequency of sounding signal $f = 0,88 f = 0,88$ MHz yields an increment of a complete returned-signal phase $\Delta\Psi$ on the order of 0,1 of phase degree (or $1,8*10^{-3}$ rad) by a temperature degree according to the Celsius scale.

In terms of obtaining a high accuracy of measurement and ensuring the simplicity of hardware realization it would be more expedient to estimate the sound velocity from the variations in the phase difference between a reference coherent signal and the signals echoed from typical inter-layer inhomogeneities rather than the echo-signal delay time. Specifically, upon recording the time interval within which the echo signal are being sampled and comparing the phase difference between the fluctuations in these samples one can easily notice the variations in signal propagation on those propagation paths where both a rise in temperature and a relevant change in the sound propagation are observed to occur. As the sounding signal frequency increases, the requirements for the equipment sensitivity tend to be less stringent. This tendency is clearly apparent from the experimental data (see Figure 3), where the curves are given as $f = 1,76$ MHz and $f = 3,0$ MHz.

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