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INTELLIGENT MILLIMETRE-WAVE SYSTEM FOR MEDICAL DIAGNOSTICS

This paper reports results of the research work on development of intelligent millimeter-wave system for medical diagnostics. In particular there are considered measuring and control subsystems. Measuring subsystem processes signals and data in frequency, time and spatial domain. Control subsystem operates managing over scanning and measuring process by control and test signals for measurer switching, start and stop scanning, receive and transmit a data from millimeter-wave sensor and table manipulation.

Keywords - biomedical application, medical diagnostic, intelligent system, millimeter-wave system.

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ІНТЕЛЕКТУАЛЬНА СИСТЕМА МІЛІМЕТРОВОГО ДІАПАЗОНУ ДЛЯ МЕДИЧНОЇ ДІАГНОСТИКИ

У статті представлено результати розробки інтелектуальної системи міліметрового діапазону для медичної діагностики. Зокрема, розглянуто підсистеми вимірювання та керування. Підсистема вимірювання виконує обробку сигналу та даних у частотній, часовій та просторовій областях. Підсистема керування виконує керування над процесом сканування та процесом вимірювання за допомогою сигналів керування та тестових сигналів для вмикання вимірювача, старту та зупинки сканування, прийому та передачі даних від сенсора міліметрового діапазону та маніпуляцій столу.

Ключові слова – біомедичні застосування, медична діагностика, інтелектуальна система,система міліметрового діапазону.

Introduction

The development of modern techniques for noninvasive diagnostic sets requirements to ensure complete diagnostic safety, efficiency, comprehensiveness while maintaining high reliability of quantitative results. One of the promising directions for creating such devices is based on the idea of using information properties of the extra low millimeter-wave radiation from the human body or other biological objects. The main difficulty in registration of such radiation is associated with exceptionally low power electromagnetic field generated by the body and the absence lack of opportunities for effective their reception by the radiation sensitive receivers.

Intelligent millimeter-wave system for medical diagnostics investigates properties of biological objects in millimeter range both in active and passive mode of scanning. Using these data it is possible to provide a medical diagnostics. Effectiveness of medical diagnostics is provided by intelligent millimeter-wave system with combination of measuring process, scanning process, computational process, control and visualization.

It has been proposed an original intelligent millimeter-wave system for medical diagnostics as result of analytic review of instrumentation and techniques for medical diagnostics. Proposed intelligent system consists of measuring subsystem, scanning subsystem, control subsystem, hardware-software signal and data processing subsystem and visualization subsystem.

MEASURING SUBSYSTEM

Any measurement is analog-to- digital conversion - set of measured values are replaced with a selectable digital equivalent. The procedure of converting the continuous physical counts in its digital sampling values is called quantization (level or time), and accompanied by the appearance of quantization errors are divided into methodological (depending on the chosen method of quantization, measurement conversion), and instrumental caused by a resolution of the final practical circuits and circuit elements of real gauges. It has been used as basic theory a correlation properties of the scattered electromagnetic fields [1].

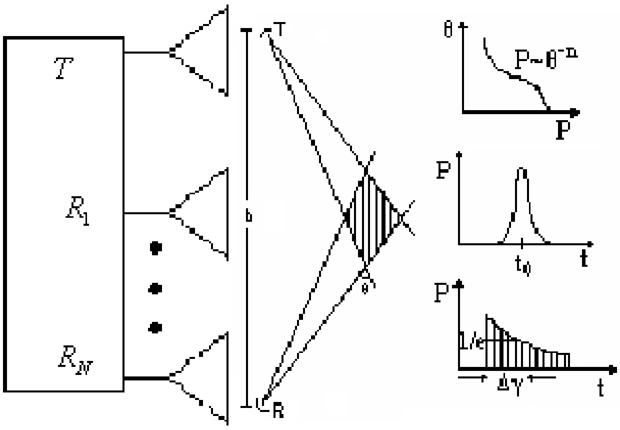

Figure. 1. Measuring Subsystem

Proposed measuring subsystem (Fig. 1) operates remote sensing of biological object localization and properties in human body. It consists of transmitter T and N receivers R. Number of relievers provide a required resolution and precision. It has been used spatial, time and frequency correlation of measured data from biological object. The spatial correlation allows precise localization of biological object. The frequency correlation allows to defined pathology or physiology state of the localized biological object. The time correlation provides dynamic registration of biological object.

The scattered field resulting from an integral of elementary scattering elements is given by:

$$E_s = \frac{K_s^2}{4\pi R}\int_V E_1(r) f_\varepsilon(r) e^{-iKr} d^3 r, \tag{1}$$

It is defined the function *f(z)* as a delay function. This has dimension field strength such that the scattering cross section as a function of distance *z* along the direction of propagation (z is measured along the direction of *K*) is obtained by squaring the *f(z)* function. From Equation 1, we have:

$$E_s(K) \sim \int f(z) e^{-iKr} d^3 z, \tag{2}$$

where $K = \omega / c$.

If we are dealing with a scattering medium that can only be determined in statistical terms such as the turbulence field of biological objects, the delay function *f(z)* should be replaced by the auto correlation function *R(Δz)*. This relationship between the measured quantity *E(K) ~ E(F)* and the parameters describing the scattering arena is obtained by evaluating the auto correlation function also in the frequency domain:

$$\begin{aligned} R(\Delta K) &= E^*(K) E(K+\Delta K) \sim \\ &\sim \int R_\sigma(\Delta z) e^{-iK\Delta z} d\Delta z, \end{aligned} \tag{3}$$

Note that this simple equation does not include the ambiguity phase term e^{-iKz}, where K – is the wavenumber associated with frequency F and z is the distance to the scattering arena. There also is $e^{-iK\Delta z}$ phase term. The influence of this is negligible if either the carrier frequency F or the scattering object is randomized slightly.

We characterize the scattering arena in terms of a 4 dimensional wavenumber spectrum, 3 in space and one in time, *A(K,ω)* . The power spectrum *Φ(K,ω)* is obtained by computing $A(K,\omega)A^*(K,\omega)$.

When dealing with stochastic biophysical processes such as self radiation turbulence by cell exchange phenomena, we shall use a simple expression for the wavenumber spectrum (the Fourier transform of the spatial autocorrelation function of the scattering cross-section):

$$\Phi(K,\omega) \sim K^{-n}, \tag{4}$$

if we are dealing with inertial sub range turbulence n = 11/3.

We shall now seek methods that enable us to measure the spatial wavenumber spectrum. First, let us consider the functions in time domain bearing in mind that the spatial function *f(z) = f(cτ)* , where c is the phase velocity of the electromagnetic wave and *τ* the time.

Using wide-beam antenna so that the multipath transmission is governed by the scattering mechanism rather than by the beam geometry, we first seek an expression relating path length *l* and the position in space of the scattering element, i.e., we require an expression relating *l* and the scattering angle *θ* (figure 1). If *d* is the length of the chord between *T* and *R*. Simple geometric calculations give the required results:

$$\theta = 2\left|(l/d)^2 - 1\right|^{1/2}, \tag{5}$$

If we transmit a short radio pulse, the power that reaches the receiver has traveled through a wide variety of different paths. By substituting for *θ* in the expression for the angular power spectrum ($P \sim \theta^n$), we get the spectrum relating power and path length. Expressing this spectrum in terms of the path length *Δl*, which is in excess of the minimum path length l_0 (i.e., writing $l = l_0 + \Delta l$), we find that the power spectrum referred to *τ* is given by:

$$\frac{P(\tau)}{P(0)} = \left(1 + \frac{8c\tau}{\theta^2}\right)^{-n/2}, \tag{6}$$

Where we have transferred from space *l* to time *τ* by *l=cτ*

The 10 dB width of this delay function *P(τ)*,which is derived from the spatial wavenumber spectrum of the form $\Phi(K) \sim K^n$ is then:

$$\Delta\tau_{1/10} = \frac{\theta^2 d}{8c}\left(10^{1/n} - 1\right), \tag{7}$$

Hence, the width of the temporal autocorrelation function *R(Δτ)* resulting from a K^{-n} wavenumber spectrum is given in equation 7.

Now let us consider the correlation properties ill the frequency domain *R(ΔF)*, from which we can estimate the size distribution *Φ(2π/L)* of the scattering arena. In order to obtain a simple first order estimate of the bandwidth from which we call characterize the scattering arena, we write:

$$\Delta F = \frac{1}{\Delta\tau} = \frac{8c}{\theta^2 d}\left(10^{1/n} - 1\right)^{-1}, \tag{8}$$

The manipulation in the frequency domain *R(ΔF)* obtained by multiplying *V(F)* with *V*(F+ΔF)* enables us to couple to scales in the scattering arena of *ΔL=2π/ΔK=c/ΔF* rather then scales *l=c/F*. This technique is often referred to as *ΔK* principles or frequency interferometry.

The spatial field-strength correlation function is the Fourier transform of the angular power spectrum of the wave reaching the receiving antennas. При определении угла прихода специфической рассеянной волны с помощью угла места α (относительно центральной линии через T и R) и угла азимута β (относительно большой круговой плоскости, которая проходит через T и R) получаем спектр $\Phi(K) \sim K^{-n}$, который дает увеличение углового спектра формы:

$$P(\alpha,\beta) \sim \left(\beta^2+\alpha^2\right)^{-n/2}, \tag{9}$$

The horizontal correlation offield strength is thus obtained by a Fourier transformation or *P* with respect to β, whereas vertical correlation is obtained from $P(\alpha)$ relationship.

Simple approximate expression can be obtained if we approximate $P(\alpha)$ and $P(\beta)$ by a *sin(x)/x* function, thus giving us a simple expression for the Fourier transform. This is a procedure well known in antenna theory. From antenna theory we know that if *L* is the width of the illuminating field strength distribution, the width or the resulting angular power spectrum (beam width) is given by:

$$\theta_{1/2} = 0{,}88\,\lambda/L, \tag{10}$$

where λ – the radio wavelength.

From such considerations, we can obtain approximate expressions for the horizontal and vertical correlation distances:

$$L_H = \frac{0{,}44\lambda}{\theta\left(4^{1/n}-1\right)^{1/2}}, \tag{11}$$

$$L_V = \frac{0{,}44\lambda}{\theta\left(2^{1/n}-1\right)}, \tag{12}$$

CONTROL SUBSYSTEM

It has been investigated a possibility to improve a scanning process and a measuring process by the control subsystem for higher effective millimeter-wave medical diagnostics. Control subsystem operates managing over scanning and measuring process by means control and check signal for measurer switching, scanning start and stop, receive and transmit a data from millimeter-wave sensor, table manipulation.

There were investigated main operations of control subsystem: orientations of table with object, forming positioning control impulses, start and stop operation of the scanning subsystem. Second, there were investigated following main operations of the measuring subsystem: receiving a radiation from biological object by the detector unit, start and stop operation of the detector units, forming a signal of start and stop operation of the detector unit, transmitting data to the data processing unit. The detector unit registers radiation from biological object or/and test generator. There is used a synchronizer for correct work of scanner subsystem with measuring subsystem. For example, the detector control impulses should be synchronized with the positioning control impulses. If the detector control impulses are longer than the positioning control impulses, it causes the incorrect imaging. Investigation of the synchronizing algorithms has proved ability of control system to improve the efficiency of millimeter-wave medical diagnostics system.

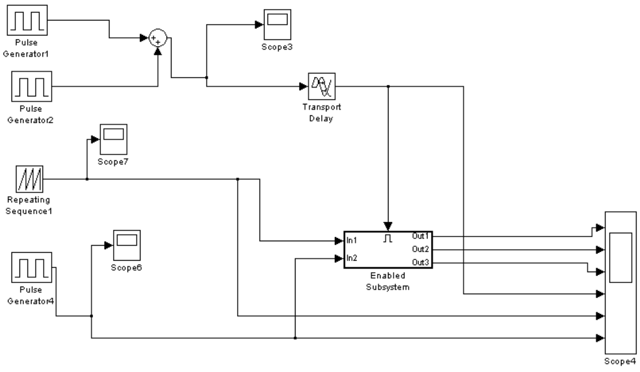

Figure. 2. Control subsystem

The main characteristics of the control signal are level, waveform, and phase and squareness ratio. Subsystems detection and scanning respond to signals a certain level, the suppression of the signal in the transmission channel, change its shape or length of major fronts and bust leads to failures of subsystems. Figure 2 shows the control signal (s) and its distortion in the form of (b) and squareness (c).

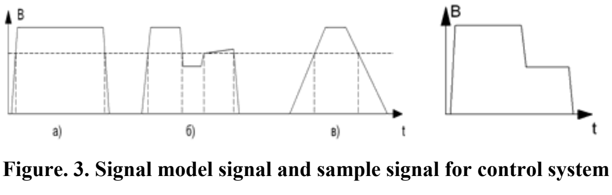

Figure. 3. Signal model signal and sample signal for control system

Phase signal has the greatest impact on the performance of the complex. The delays, which make channels, can lead to significant errors when removing the signal. The presented model has the ability to build different signal control system and study their impact on the initial data. Control signals are building by using generators Pulse

Generator 1 та Pulse Generator 2. This generator is meander generators are configured to generate a signal. The role of the scanning subsystems generator plays Pulse Generator 4 generates the meander. Generator, which simulates the signal from the detector, is Repeating Sequence 1 generates the saw signal. Oscillator frequency varies twice. Control signals and the signal from the detectors and scanners input the synchronization module (Enabled Subsystem). If synchronization pulses will have a certain form, frequency and phase, the synchronization module will be carried out product operation signal scanning and detection. The block output have to produce a picture as shown on figure 4. In case control signals will have shape distortion the output signal will not required.

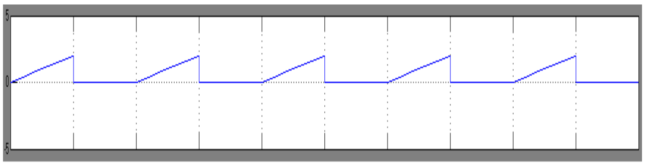

Figure. 4. Sample signal for control system

CONCLUSION

The investigation of intelligent millimeter-wave system allows determining the medical and engineering requirement for intelligent medical diagnostics in comparison with ordinary medical diagnostics.

The study of visual models of biological objects of the clinical diagnostics suggested the use of millimeter-wave radiation, which increases the information content of the dynamic models through the micro - and nanolocalizing normal and pathological areas to allow for more efficient functional and structural diagnostics of the human body at the cellular and molecular levels.

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