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Digital Model of Blood Circulation Analysis System

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Abstract. Digital signal processing is one of the most powerful technologies, developed by achievements in science and electronics engineering. Achievements of this technology significantly influenced communications, medicine technique, radiolocation and other. Digital signal processors are usually used for effective solution of digital signal processing problems class. Today digital signal processors are widely used practically in all fields, in which information processing in real-time is needed. Creation of diagnostic medicine systems is one of perspective fields using digital signal processors. The aim of this work was to create digital mathematical model of blood circulation analysis system using digital signal processing instead of analogical nodes of device. In first stage – work algorithm of blood circulation analysis system and mathematical model of blood circulation analysis system in Matlab–Simulink environment was created. In second stage – mathematical model was tested experimentally. Mathematically imitated Doppler signal was sent to tissue and was reflected. The signal was processed in digitally, blood flow direction was marked and blood speed was evaluated. Experimentation was done with real signals that were recorded while investigating patients in eye clinics. Gained results confirmed adequacy of created mathematical model to real analogical blood circulation analysis system (Lizi *et al.*, 2003).

Keywords: ultrasound, digital signal processing, ophthalmology, Doppler, eye vascular system, blood flow, digital spectral analysis.

1. Introduction

Working principals of continuous wave's blood circulation analysis system (Paunksnis *et al.*, 2003a, 2003b; Marven and Ewers, 1993). There are two types of blood circulation analysis system – continuous wave (CW) and pulsed wave (PW). Ultrasonic transducer is made of two piezoelements in one frame in CW device (Fig. 1). Transmitting piezoele-

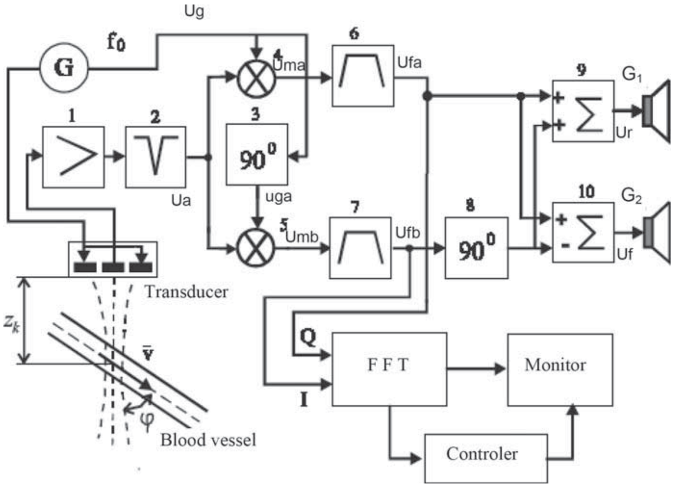

Fig. 1. Functional scheme of CW blood flow analysis system.

ment generates acoustic waves and recieving piezoelement receives reflected waves. Input signal carry diagnostic information about analyzed tissues and blood flow.

Generator (G) produces continuous stable oscillations of high frequency. They are made for transducer excitation and are passed to mixer (Fig. 1, 3–5) for frequency detection. Transducer produces harmonic oscillations, described as

$$u_0 = A_0 \cdot \sin(\omega_0 \cdot t). \tag{1}$$

Echo signal, reflected from the tissues and blood-vessel can be expressed as

$$u = A_0 \cdot \sin(\omega_0 \cdot t) + A_f \cdot \sin\big[(\omega_0 + \omega_f) \cdot t\big] + A_r \cdot \sin\big[(\omega_0 + \omega_r) \cdot t\big], \tag{2}$$

here ω_0, A_0 – main frequency of the generator and amplitude of signal that is reflected from the still tissues. ω_f, ω_r – Doppler frequencies, that are produced by blood particles moving towards and forward from transducer. A_f, A_r – amplitudes of appropriate signal, that are proportional to amount of moving blood particles. Blood particles are moving not in the same speed and spectrum of received signal (Fig. 2) is rather complicated. It is seen that frequency of reflected waves depends on moving direction of blood particles. Central frequency of echo signal is obtained by reflecting waves from surface tissues and from construction of transducer. So, the amplitude of this component in spectrum is the biggest.

Primary amplifier (1) intensifies received signal for about 20 db. Signal is filtered with special narrow band barrier filter (2). The filter represses and does not pass signals which frequencies are equal or close to supporting frequency. Band width of filter does not exceed ± 250 Hz when supporting frequency is about few MHz. Filter does not pass signals from stationary and slow moving tissues, blood-vessel lining, heart valves and etc.

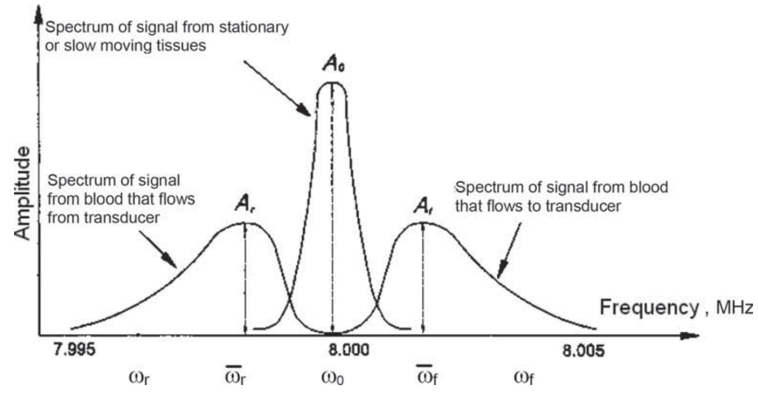

Fig. 2. Spectrum of received signal.

Demodulator (Fig. 1, 3–7) detects Doppler signal of low frequency. Special quadratic detector is used, that has two input channels and two outputs, also two mixers for receiving signals. Direction is detected according to whether frequency of input signal is bigger or lower than supporting frequency. Signal u_a that is amplified and filtered in receiver is sent to common input. Supporting frequency signals of the same amplitude, one of whom is turned at a 90° angle, are sent to others:

$$u_{ga} = A_g \cdot \sin(\omega_0 \cdot t), \tag{3}$$

$$u_{gb} = A_g \cdot \cos(\omega_0 \cdot t). \tag{4}$$

Signals (3) and (4) are multiplied in the mixers and signals in the outputs are gained:

$$u_{ma} = u_a \cdot u_{ga}, \tag{5}$$

$$u_{mb} = u_a \cdot u_{gb}. \tag{6}$$

Elaborating expressions (5), (6) it is seen that a lot of signals appear because of multiplication of signals and their frequencies are: $\omega = 0$ – continuous component of output voltage, ω_f – Doppler frequency from particles moving to transducer, ω_r – Doppler frequency from particles moving from the transducer, $2 * \omega_0$ – double supporting frequency, $2 * \omega_0 + \omega_f$ – sum of frequencies, $2 * \omega_0 + \omega_r$ – difference of frequencies. Broadband filter (Fig. 1, 6–7) is needed for eliminating unwanted harmonics. Also it passes only a signal of Doppler frequency, which is carrying information about speed of blood. If amplitude of supporting signals (3) and (4) is $A = 1$, then we can get such expressions of signal in filter outputs:

$$u_{fa} = 0.5 \cdot A_f \cdot \cos(\omega_f \cdot t) + 0.5 \cdot A_r \cdot \cos(\omega_r \cdot t), \tag{7}$$

$$u_{fb} = 0.5 \cdot A_f \cdot \sin(\omega_f \cdot t) - 0.5 \cdot A_r \cdot \sin(\omega_r \cdot t). \tag{8}$$

Blood particles are moving with different speed, so there exists spectrum of moving speeds of blood particles. Consequently in expressions (7), (8) there is received not one frequency (Doppler) but spectrum of frequencies. Signal (7), (8) is sometimes called quadratic because of components in itself, whereof phase differs in 90°. Components of Doppler signal are not yet separated from different blood flow direction. For distinguish direction there is needed further signal processing, which is realizable with phase shifter and adder in the device. Phase shifter turns into its both inputs phases of sending signals in angles φ_1 and φ_2 so, that difference of these angles is fixed and equal to 90° in all range of frequencies:

$$\varphi_1 - \varphi_2 = 90^\circ. \tag{9}$$

Signal gathers such an expression in output of phase shifter when evaluating phase turn according to (9):

$$u'_f = 0.5 \cdot A_f \cdot \sin(\omega_f \cdot t) + 0.5 \cdot A_r \cdot \sin(\omega_r \cdot t), \tag{10}$$

$$u'_r = 0.5 \cdot A_f \cdot \sin(\omega_f \cdot t) - 0.5 \cdot A_r \cdot \sin(\omega_r \cdot t). \tag{11}$$

Two adders perform summing of signals in the device (Figs. 1, 9 and 10) one whereof sums and other one subtracts signals given in its inputs. Gained signals in outputs of adders:

$$u_f(t) = u'_f + u'_r = A_f \cdot \sin(\omega_f \cdot t), \tag{12}$$

$$u_r(t) = u'_f - u'_r = A_r \cdot \sin(\omega_r \cdot t). \tag{13}$$

These signals are intensified by amplifiers of low frequency and transferred to loudspeakers. It is seen from expressions (12), (13) that there are separate Doppler signals that define blood flow direction. Loudspeaker G_1 works when blood flows to the transducer, G_2 – from the transducer.

Quadratic signal is given to spectrum analyzer, in which calculation of signal spectrum is done. Complex signal is applied to input of spectrum analyzer. The signal is gained from sum of 1st channel's signal Q and 2nd channel's signal multiplied by complex efficient j:

$$X(t) = Q(t) + j \cdot I(t). \tag{14}$$

As it is seen from previous formulas, we can calculate speed of blood flow and distinguish blood flow direction. For this we must also know angle between acoustic ray generated by transducer and axis of blood-vessel. Frequency dependence on angle and blood flow direction:

$$F = \frac{2 \cdot f_0}{c} \cdot V \cdot \cos\varphi, \tag{15}$$

here f_0 – main frequency of probe signal, c – spread velocity of ultrasonic waves through the human tissues, V – average velocity of blood flow, ϕ – angle between of blood flow vector and ultrasonic transducer (vector of ultrasonic signal spread). Incorrect evaluation of angle ϕ may cause big inaccuracies while computing average velocity of blood flow. Two experimental signals were recorded to media files format (*wav*) and saved in computer. First signal obtained from *a. carotis*. In this case probe was placed by angle of 45° when recording. Second signal obtained from *a. ophthalmica.* In this case probe was placed by angle 0° when recording. Velocity of blood flow of *a. carotis* is about 104 cm/s and velocity of *a. ophthalmica* range about 30 cm/s. These signals were used for testing of created model. Creating model in such a way there were used only signals recorded to computer files. That is why, there was no need to measure probe angle of blood vessel before every experimental investigation of model. When creation of model will be done, there will be evaluated probe angle of blood flow, depth of blood vessel and other factors that influence calculation accuracy of average velocity of blood flow.

Flowing blood particles in blood vessel are moving in different speed that means there exists spectrum of blood speeds. Because of this reason Doppler signal will be made of various frequentative components. Spectral analysis of Doppler signal gives extra valuable information about character and dynamics of blood flow.

Discrete Fourier transform (DFT) is used for spectrum calculation (Haykin and Van Veen, 1999; Diniz, 2002). DFT can be realized by software or equipment. In this case, spectrum is calculated for discreet signal of particular finite term. Assumption is made that analyzed signal is periodic and its period is equal to term of realization. Discrete spectrum of the signal is calculated:

$$S(f_k) = \frac{1}{N}\sum_{n=0}^{N-1} u(n)\cdot W_N^{kn} = B(k) + j\cdot C(k)$$

and

$$W_N^{kn} = \mathrm{e}^{-j\frac{2\pi k}{N}} = \cos\left(\frac{2\cdot\pi}{N}\cdot k\right) - j\cdot\sin\left(\frac{2\pi}{N}\cdot k\right), \tag{16}$$

here W_N^{kn} – weighted multiplier; N – number of readings of analyzed signal; $S(f_k)$ – complex amplitude of kth harmonic of spectrum; $u(n)$ – nth reading of realization of input signal. Number of calculated spectrum components is equal to number of readings N. Complex signal (14) is given to input of spectrum analyzer. Its real and imaginary parts are made of components of quadratic signal which is got in output of detector (Sugata *et al.*, 1992). Sequence of complex digitalized signal:

$$u(n) = u'_f(n) + j\cdot u'_r(n), \tag{17}$$

or

$$\begin{aligned} u(n) = {} & \left(0.5\cdot A_f\cdot\cos\frac{2\pi}{N_f}\cdot n + 0.5\cdot A_r\cdot\cos\frac{2\pi}{N_f}\cdot n\right) \\ & + j\cdot\left(0.5\cdot A_f\cdot\sin\frac{2\pi}{N_f}\cdot n + 0.5\cdot A_r\cdot\sin\frac{2\pi}{N_f}\cdot n\right), \end{aligned} \tag{18}$$

here $N_f = N_r = N$ – number of discretization points. Putting (18) to (15), there are calculated real and imaginary components *B(k)*and *C(k)* of amplitude spectrum of the signal. Also powers of spectrum density are calculated:

$$A^2(k) = B^2(k) + C^2(k). \tag{19}$$

Fast Fourier transform algorithm is used to fasten calculation. It uses symmetry and periodicity characteristics of sine and cosine.

Let's analyze work of real ultrasound Doppler system. Ray of transducer is directed to blood-vessel. Frequency changes proportionally to speed *v(t)* of moving blood particles because of acoustic waves Doppler effect ultrasound waves that are reflected from moving blood particles. Receiver of echo signal distinguish Doppler signal, which frequency is equal to difference of frequencies of sent and received waves. This difference is called Doppler frequency. Speed of blood flow is not stable in the blood-vessel and so spectrum of Doppler frequencies is measured. Time function of such spectrum is called Doppler ultrasound sonogram (Janulevičienė *et al.*, 2002; Šebeliauskienė *et al.*, 2001; Yamamoto *et al.*, 2004; Hwang *et al.*, 2004). Sonogram is 3 dimensional (3D) dynamic image that reflects blood flow in blood-vessel.

Calculated components of signal spectrum are symmetrical in respect of middle ($k = N/2$). The latter match position of base line in monitor. Lower components match frequencies f_f and higher – f_r. Then components $1, 2, 3, \dots, N/2$ are gained because of blood particles moving to the transducer and components $(N/2+1), (N/2+2), \dots, N$ – because of blood particles moving from the transducer. Such position of calculated data is convenient for imaging in monitor. Base line match continuous voltage which frequency is $f = 0$. Quasi-3D image is obtained in the monitor (see Fig. 3).

Abscissa axis is time in sonogram so we can decide about blood flow change from sonogram during cycle of action of the heart. Spectrum is on ordinate axis, it is calculated from Doppler signal. This is instantaneous spectrum which term of calculation must be such that during it blood flow change would be slight. Doppler frequency is proportional to speed of blood so ordinate axis might be calibrated in speed units – m/s. Third coordinate of sonogram is brightness of monitor points that structure the sonogram. Brightness of point is proportional to amplitude of adequate component of Doppler signal spectrum. Amplitude of signal is proportional to amount of blood flow particles that move

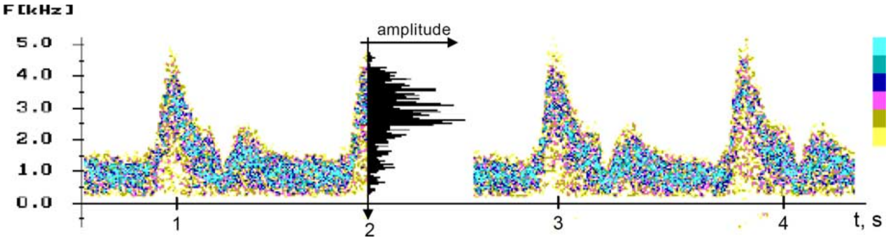

Fig. 3. Example of sonogram image.

in the same speed. In such a way, Doppler sonogram gives information about character of blood flow, absolute values of blood speed and its change during the action of the heart.

2. Materials and Methods

We designed mathematical model of continuous waves (CW) system. There is made structural scheme of CW system (see Fig. 4) and according to it there is created mathematical model of diagnostic device in Matlab–Simulink environment. This model was tested with simulated Doppler signal. Mathematical model consists of: FM modulator (1), main generator (2), model of simulated Doppler signal (3), quadratic demodulator (4), phase shifter in 90° (5), adder of backward and forward flow (6), band filter (7).

Doppler effect in mathematical way can be compared to frequentative modulation so there was used model of frequentative modulation with deviation of 8 kHz during design of Doppler signal. Imitational signal – is a signal that imitates dependence of speed of blood over time

During testing of mathematical model, input signal (imitator of Doppler effect) is made of imitational signal (Fig. 5), which central frequency is 8 MHz and frequentative modulator's with 1 V/kHz deviation. Modulating signal – is array in which values of signal are recorded. Initial period of discretization is 0.0005 s. On purpose to get proper modulating signal its discretization period must concur with discretization period (5e–9s) of modulator. This means that frequency of discretrization must be raised 10,000 times and gained signal must be filtered with low frequency filter.

Frequentative modulator is realized as function

$$\sin\left(\left(u_2 \cdot 10^3 + 8 \cdot 10^6\right) \cdot 2 \cdot \pi \cdot u_1\right), \tag{20}$$

there $u[1]$ – vector of time reading and $u[2]$ – vector of frequency's shift. Harmonic signal of 8 MHz is in the output of supporting generator. Then we get signal in the output of modulator that imitates signal reflected from blood flow. Supporting generator and frequentative modulator are synchronized from systemic clock.

Quadratic demodulator (Fig. 7) is used for detection of Doppler shift of frequency. Frequency of signal discretization is very high in the output of quadratic demodulator. Frequency of signal discretization must be reduced and filtered with band filter.

Matlab/Simulink environment has integrated tools for calculation of filters – *FDAtool*. This program was used to define coefficients of FIR filter and to insert generated code

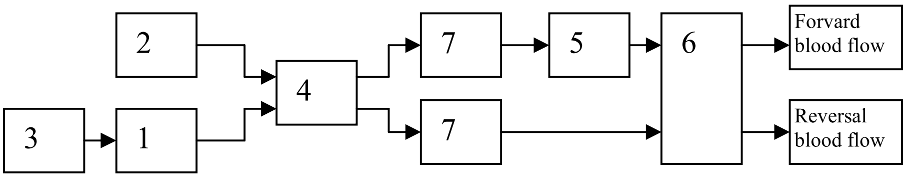

Fig. 4. Block scheme of CW system model in Matlab–Simulink environment.

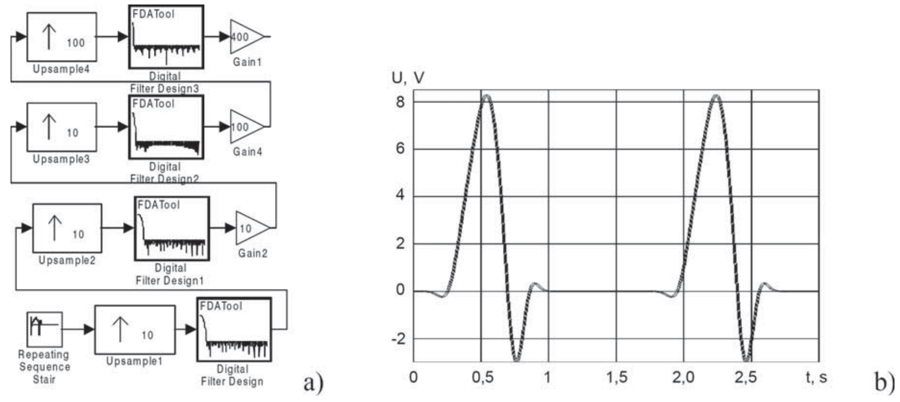

Fig. 5. Fragment of model of CW system: model of simulated testing signal (a) and testing signal it self (b).

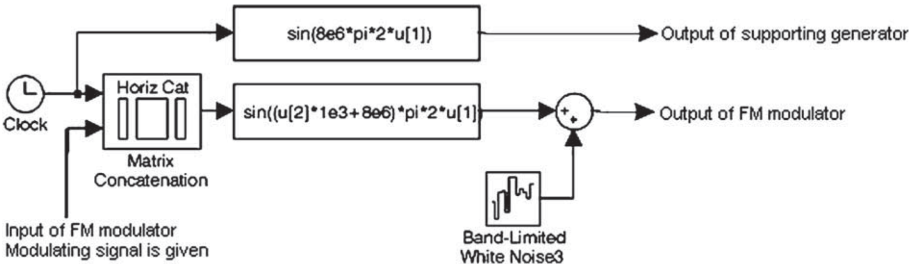

Fig. 6. Fragment of model of CW system: frequentative modulator and supporting generator.

into *Simulink*. If we want to differentiate signals of alteration of positive and negative frequency we need to turn phase of one signal in 90° over all range of frequencies. Hilbert transformation is ideal for this:

$$H_{\mathrm{Hilbert}}(\mathrm{e}^{t\pi 2fe}) = \begin{pmatrix} i, & -\frac{1}{2} \leqslant f \leqslant 0 \\ -i, & 0 \leqslant f < \frac{1}{2} \end{pmatrix}. \tag{21}$$

Ideal Hilbert transformation turns phase of the signal in angle of $+90^\circ$ for such range of frequencies: $-\frac{1}{2} \leqslant f < 0$, and 90° $0 \leqslant f < \frac{1}{2}$, here f – frequency of discretization.

Base mathematical expression of Hilbert transformation $\hat{f}(t)$ of function $f(t)$:

$$\frac{1}{\pi} \cdot P \cdot \int_{-\infty}^{\infty} \frac{f(t)}{t-\tau} \cdot \mathrm{d}\tau, \tag{22}$$

here t and τ are time, P – constant that is calculated by cauchy method. Using Hilbert transformation phase of the signal is turned gradually over all range of frequencies from 50 Hz to 9900 Hz. Summing signals that are filtered and which phases are turned we can differentiate negative and positive signals of alteration of frequencies (Fig. 9). Modeled

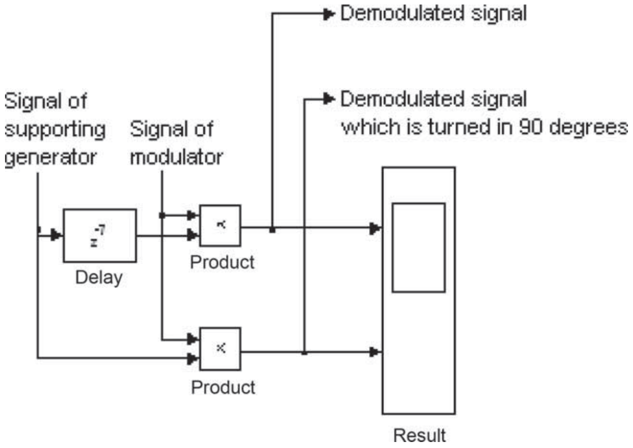

Fig. 7. Fragment of model of CW system: model of quadratic demodulator.

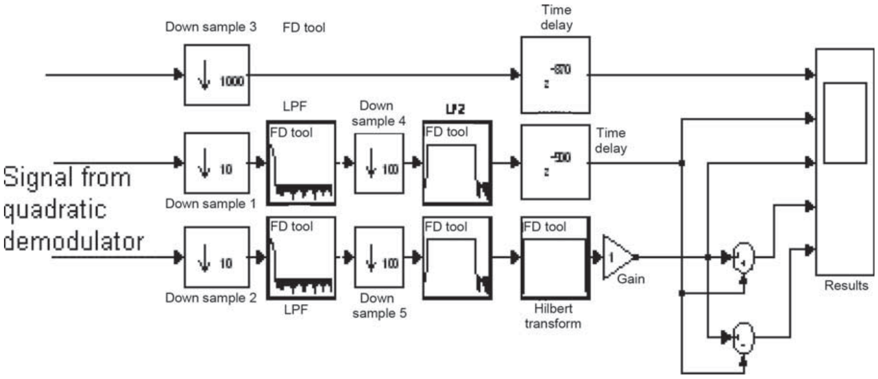

Fig. 8. Part of CW system model: digital filters, Hilbert transformation, adders of the outputs.

Doppler signal is saved in WAV file. Processing of Doppler signal in diagnostic device is spread into stages:

- Modulating signal 44.100 MHz of frequency of discretization is created.
- Modelating modulator and demodulator is 44.100 MHz of frequency of discretization.
- Frequency of discretization of demodulated signal is reduced to 44.1 kHz and filtered.
- Hilbert transformation and distinguishing direct and reverse Doppler signal is done.
- Frequentative analysis of entered and modificated signal is done.
- Hemodynamic parameters that evaluate blood circulatory system are calculated.

Results of signal processing during all these stages are saved in *.wav files. Special block from *Simulink* environment is used for writing from *Matlab* to *.wav files. Modelated files *.wav of Doppler signal can be read with *WaveLab* software.

Analysis of work of mathematical model of CW system in Matlab/Simulink environ-

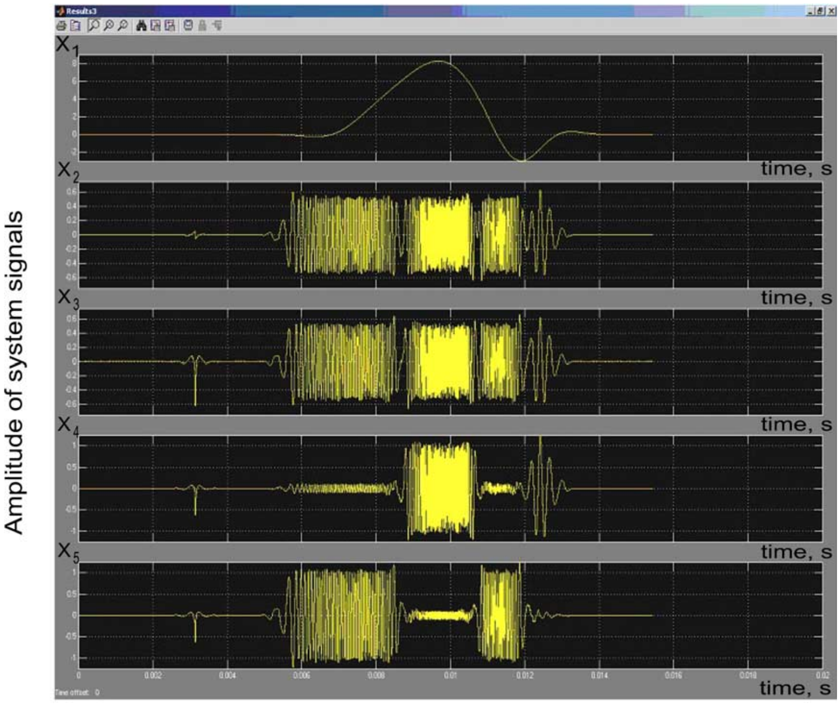

Fig. 9. Distinguished signals of direct and reverse blood flow when processing imitational modeled signal.

ment is done using real signals that are carrying Doppler information. This experiment is done in these stages:

- Diagnostic signal during analysis of patient is saved in *.wav file from real investigative device of circulatory system of CW Doppler in Eye clinics in Kaunas. Signal is recorded from the output of quadratic detector;
- Signal is given to linear input of computer and then digital signal processing is done. This means that signal is filtered, Hilbert transformation is done, direct and reverse Doppler signal is distinguished. Distinguished signals are saved in *.wav file with *WaveLab* program. Recorded signal is given in Fig. 10.

Work algorithm of mathematical model processing real Doppler signals:

- Doppler signal is read from the wav file;
- signal from wav file is read by blocks so discrete sequences of signal must be in series sequence and block *unbufer* is used;
- right and left channel of the signal is distinguished;
- signal is filtered with band FIR filter. Parameters of the filter: 82th order, band of passed frequencies – from 200 Hz to 8 kHz, algorithm FIR, frequency of discretization is 44.1 kHz;
- Hilbert transformation of the signal is done. Frequency of discretization is 44.1 kHz, band of frequencies of phase turning is from 100 Hz to 22 kHz, algorithm FIR, line of the filter – 500;

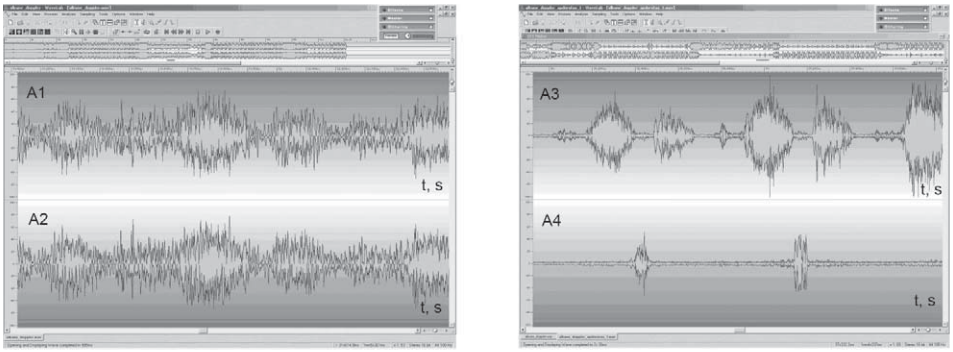

Fig. 10. Signal after quadratic detector (a), direct and reverse Doppler signal are distinguished (b).

- other channel is delayed because Hilbert transformation delays signal. Since 500 coefficients are used for calculation of Hilbert transformation, delay is 500 readings too;
- signal is summed and subtracted so that direct and reverse Doppler signal are distinguished;
- processed signal is saved in wav file;
- frequentative analysis of the signal is done;
- according to results of spectral analysis, hemodynamic parameters are calculated.

Direct and reverse signals are distinguished when digital processing of Doppler signal is done. It shows in Fig. 10a. When signal is in one channel it disappears in another. Comparing spectral analysis of processed signal with input signal it is seen that signal was filtered correctly, this means that high frequencies filtered beside 8 kHz and low – beside 200 Hz. We can conclude that digital model of signal processing works properly. Using calculation methodology of Doppler signal spectrum we can calculate not only spectrum of signal but we can also distinguish direction of moving blood, find *max*, *min* and *medium* speed of blood flow, index of pulsation, frequency of heart beat, other parameters.

Converting of quadratic signal into complex is needed for detection of blood flow direction. Wherefore in first step we sum signal of first channel with signal of second channel multiplied by complex multiplier j. Fourier transformation with 128 component point was used for analysis of spectrum. Discretization frequency of analog digital transducer of processor's systemic plate of Texas Instruments digital signals is 48 kHz and max frequency of blood flow signal that was obtained in real way was about 6 kHz. Frequency of discretization we reduced 6 times because Fourier transformation is calculated from $-F_s/2$ to $F_s/2$ Hz, where F_s is frequency of discretization. This means that spectrum will be calculated from -8 kHz to $+8$ kHz in range of frequencies.

Signal is filtered and normalized when Fourier transformation is done. Selector was used for proper imaging of modeling results in computer screen. Matrix of spectrum points is rearranged with its help so that the points of direct movement data in quasi-3D graph would be showed above medium line of graph. Reverse direction – vice versa. Later

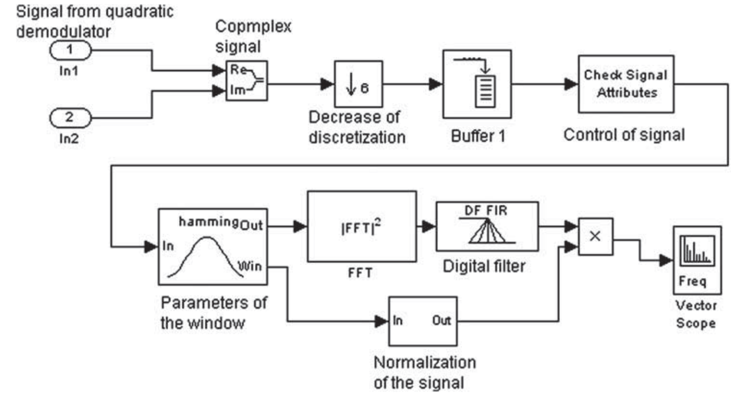

Fig. 11. Functional scheme of model of calculation of circulatory system's spectrum.

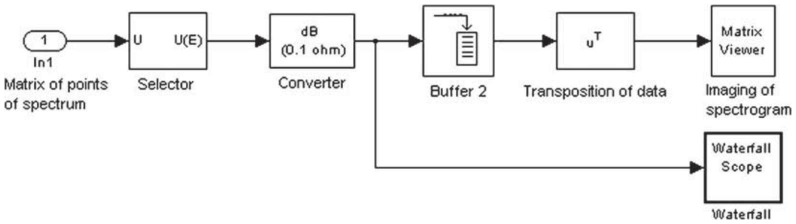

Fig. 12. Functional scheme of imaging of circulatory system's spectrum.

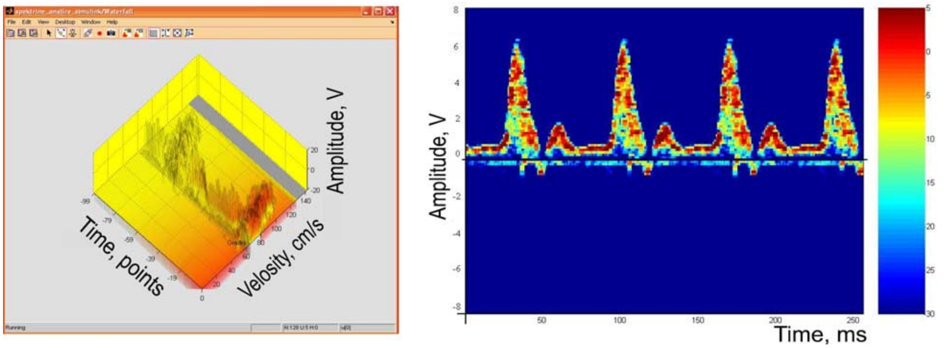

Fig. 13. Imaging way of 3D circulatory system's spectral analysis (a) and imaging way of quasi-3D circulatory system's spectral analysis.

powers of spectral density are calculated and the data are ready for imaging of circulatory system's parameters.

Investigating work of created mathematical model while processing imitational and real Doppler signals, it was seen that created model obeys properly and precisely all functions that are intended. There for next creation stage of digital blood circulation analysis system – transfer of mathematical model to real device of digital information processing – processor of digital signals of Texas Instruments (Orge *et al.*, 2002; Fujioka *et al.*, 2006).

3. Conclusions

1. Created digital model of blood circulation analysis obeys properly and precisely all functions that are intended to it. Also digital processing of diagnostic information has big advantage against analogical devices (Grigaitis *et al.*, 2007) – simple change of algorithms of information processing, bigger precision of calculation, compact, lower price and etc.
2. Realizing this model with signal processors we can simply change analogical parts of low frequency of Doppler device. Theoretically, we can change chains of high frequency (quadratic demodulator; Dzemyda and Sakalauskas, 2009) also, but in this case extra device is needed – high-speed transducers of analogical radio signals, high-speed memory buffers and etc.
3. Processing analogical signals with digital algorithms can improve precision of Doppler system, makes opportunity to create and realize new hemodynamic parameters (Treigys *et al.*, 2008), gives flexibility of connection with peripheral devices. Disadvantage – high price of digital signal processors of major power.
4. Putting over first stage of mathematical model creation of diagnostic system we can begin next – realizations of digital blood circulatory system using creation stage of processors of digital signals.

References

Diniz, P. (2002). *Digital Signal Processing: System Analysis and Design*. Cambridge University Press, Cambridge.

Dzemyda, G., Sakalauskas, L. (2009). Optimization and knowledge-based technologies. *Informatica*, 20(2), 165–172.

Fujioka, S., Karashima, K., Nakagawa, H., Saito, Y., Nishikawa, N. (2006). Classification of ophthalmic artery flow in patients with occlusive carotid artery disease. *Japanese Journal of Ophthalmology*, 50(3), 224–228.

Grigaitis, G., Bartkute, V., Sakalauskas, L. (2007). An optimization of system for automatic recognition of ischemic stroke areas in computed tomography images. *Informatica*, 18(4), 603–614.

Haykin, S., Van Veen, B. (1999). *Signals and Systems*. Wiley, New York.

Hwang, J., Chen, S., Chiu, S., Wu, S. (2004). Embolic cilioretinal artery occlusion due to carotid artery dissection. *American Journal of Ophthalmology*, 138(3), 496–498.

Janulevičienė, I., Kuzmienė, L., Cimbalas, A., Paunksnis, A., Barzdžiukas, V. (2002). Color Doppler imaging of retrobulbar hemodynamics in normal tension glaucoma patients and normal controls. *Ultragarsas*, 4(45), 39–42.

Lizi, F.L., Felepa, E.J., Alam, S.K., Deng, C.X. (2003). Ultrasonic spectrum analysis for tissue evaluation. *Pattern Recognition Letters*, 24, 637–658.

Marven, C., Ewers, G. (1993). *A Simple Approach to Digital Signal Processing*. Texas Instruments.

Orge, F., Harris, A., Kagemann, L., Kopecky, K., Sheets, C.W., Rechtman, E., Zalish, M. (2002). The first technique for non-invasive measurements of volumetric ophthalmic artery blood flow in humans. *British Journal of Ophthalmology*, 86, 1216–1219.

Paunksnis, A., Kurapkienė, S., Mačiulis, A., Paunksnienė, M.L. (2003a). Evaluation of ultrasound attenuation characteristics of human cataract. *Informatica*, 14(4), 529–540.

Paunksnis, A., Kurapkienė, S., Mačiulis, A., Raitelaitienė, R., Jurkonis, R., Lukoševičius, A. (2003b). Estimation of ultrasound attenuation coefficient of human cataract. *Ultragarsas*, 1(46), 37–40.

Šebeliauskienė, D., Paunksnis, A., Barzdžiukas, V. (2001). Color Doppler investigation of ophthalmic artery in patients with malignant intraocular tumors. *Ultragarsas*, 1(38), 38–41.

Sugata, Y., Murakaami, K., Masayasu, I., Yamamoto, Y. (1992). An application of ultrasonic tissue characterization to the diagnosis of cataract. *Acta Ophthalmologica*, 70(204), 35–39.

Treigys, P., Saltenis, V., Dzemyda, G., Barzdziukas, V., Paunksnis, A. (2008). Automated optic nerve disc parameterization. *Informatica*, 19(3), 403–420.

Yamamoto, T., Mori, K., Yasuhara, T., Tei, M., Yokoi, N., Kinoshita, S., Kamei, M. (2004). Ophthalmic artery blood flow in patients with internal carotid artery occlusion. *Ophthalmol.*, 88(4), 505–508.

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Skaitmeninis kraujotakos tyrimo prietaiso modelis

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Skaitmeninis signalų apdorojimas – viena iš galingiausių šiuolaikinių technologijų, turinčių didžiulę įtaką mokslo ir elektronikos inžinerijos pasiekimams. Pasiekimai šioje srityje įtakoja naujų galimybių ir savybių medicinos prietaisų atsiradimą. Sparčiai vystantis technologijoms šiuolaikiniai skaitmeninių signalų procesoriai sėkmingai atlieka analoginių elektroninių mazgų funkcijas, dažniausiai papildydamos jas naujomis galimybėmis.

Šio darbo tikslas buvo sukurti skaitmeninį kraujotakos tyrimo prietaiso modelį ir eksperimentiškai patikrinti jo veikimo teisingumą. Skaitmeninis modelis buvo kuriamas Matlab–Simulink aplinkoje. Sudarant skaitmeninį modelį buvo sukurti ir ištirti skaitmeniniai kraujotakos sistemos tyrimo prietaiso mazgai: ultragarsinių žadinimo impulsų generatorius, specialių charakteristikų juostiniai ir režekciniai filtrai, ultragarsinių signalų maišiklis, kraujo srauto tekėjimo krypties detektorius, kraujo srauto dalelių greičių pasiskirstymo analizatorius.

Eksperimentiškai skaitmeninis modelis buvo patikrintas dviem būdais. Pradžioje buvo sumodeliuotas diagnostinį kraujotakos tyrimo sistemos įėjimo signalo savybes atitinkantis ultragarsinio signalo modelis ir ištirtas atskirų sukurto modelio dalių darbas apdorojant šį signalą. Antrame etape Kauno Akių klinikoje į Wav laikmeną buvo įrašyti realūs garsiniai kraujotakos tyrimų signalai ir juos apdorojus sukurtame skaitmeniniame modelyje dar kartą buvo įsitikinta siūlomo modelio adekvatumu realiai diagnostinei sistemai. Šiuo metu vykdomas trečias skaitmeninio modelio kūrimo etapas – visos diagnostinės sistemos funkcijų realizacija skaitmeniniame signalų procesoriuje. Buvo pasirinktas Texas Instruments skaitmeninių signalų procesorius ir jam derinti tiekiama programinė ir aparatinė įranga.