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The prototype of ultrasonic imaging system–attachment for diagnosis of human eye tumours

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Abstract

The most important problem in ophthalmology is early-stage diagnosis of malignant tumours of the eye in order to prevent metastasis of cancer and to save the human life. This problem required the development of prototype of ultrasonic imaging system-attachment for conventional non-invasive ultrasonic diagnostic equipment.

The performed experimental study shows that the developed data acquisition system is suitable to acquire, synchronise and digitize with a higher sample rate and amplitude resolution (not less than 200 MHz and 12 bits), also to store the ultrasonic diagnostic signals, which are received from conventional ophthalmological scanners. These stored raw ultrasonic signals can be further processed using advanced digital signal processing algorithms, independently from the basic features installed into a conventional medical diagnostic equipment. The experimental research has revealed the tasks of improvement of the developed system, like reduction of the own noise level of the preamplifier, optimization of the time varying gain law, selection of cut-off frequencies of the band-pass filters and necessity to acquire the signals reflected from the internal structure of eye.

Keywords: ultrasonic imaging, eye tumours, phantom, ophthalmology.

Introduction

Ultrasonic medical imaging devices use high-frequency (7.5…40 MHz) ultrasound waves for non-invasive examination of many different parts of human body. Ultrasonic imaging has reached a considerable level of technical maturity with the advent of computer-based scanners, new transducer technology (multi-element phased arrays of different configurations, CMUT's), novel pulse sequencing (like code sequences), unique image and signal processing using more advanced techniques and etc. The industry of medical imaging has used this real-time technology for both early detection of health problems and general diagnostics procedures [1-4].

Ophthalmologic ultrasonography offers the real-time and effective non-invasive examination of ocular tissues and pathologies even in the presence of optical opacities. The most important problem in ophthalmology is diagnosis of human eye tumours in dealing with cancer prevention and early-stage diagnostics. This problem required the development of non-invasive system for intraocular tumour diagnosis, its tissue characterization and parameterization which will consist of the innovative device-attachment, conventional non-invasive ultrasonic diagnostic equipment, innovative digital ophthalmoscope and sophisticated software [5].

Description of the hardware

Ultrasonic scanners are the most important part of the ophtalmological diagnostic equipment which is gradually improved and have been successfully applied in a clinical practise. Implementation of embedded computers and digital circuitry inside the architecture of modern ultrasonic imaging systems introduce the possibility of extensive user control of an operation mode during pulse-echo experiments. The ophthalmological diagnostic equipment recently proposed in the market uses conventional methods, like detected (envelope) imaging of A-scan, B-scan, 3D scan and etc. Such imaging does not give the possibility for user to apply sophisticated data processing (analysis in the time-frequency domain, spatial filtering, reliable tumour profile visualization and etc.). Hence, innovations in this area are implemented with notably delays. This makes a gap in the market and provides possibility to create an innovative ultrasonic system-attachment for acquisition and processing of raw ultrasonic radiofrequency (RF) signals in order to perform differentiation of intraocular tumours [5-8].

However, in order to get as much as possible valuable information about the tumours and their structure it is necessary to create the methods and instruments for extraction of qualitative new and valuable information from ultrasonic RF signals. To develop the more advanced ultrasonic imaging system the limitations of the existing in the market ultrasonic diagnostic system have been analysed. To our knowledge, the commercially available ultrasonic equipment evaluated during literature review has some limitations from the viewpoint of the investigation of human eye tissues [5]. RF signal is not accessible to the user for further processing and analysis using more advanced analysis techniques like the time – frequency filtering, phase imaging and etc. [5, 9]. A small number of colour scale values usually is being visualized – typically 256 levels of the amplitude (48 dB). Also, usually the sampling frequency doesn't exceed 100 MHz. According to the analysis of similar digitization systems used for medical investigation [10], the sampling frequency of 200 MHz and analog-digital converter (ADC) with 12 bits of resolution (4096 levels, 72 dB) could be used. The proposed structure of the ultrasonic imaging system-attachment for diagnosis of eye tumours is presented in Fig.1.

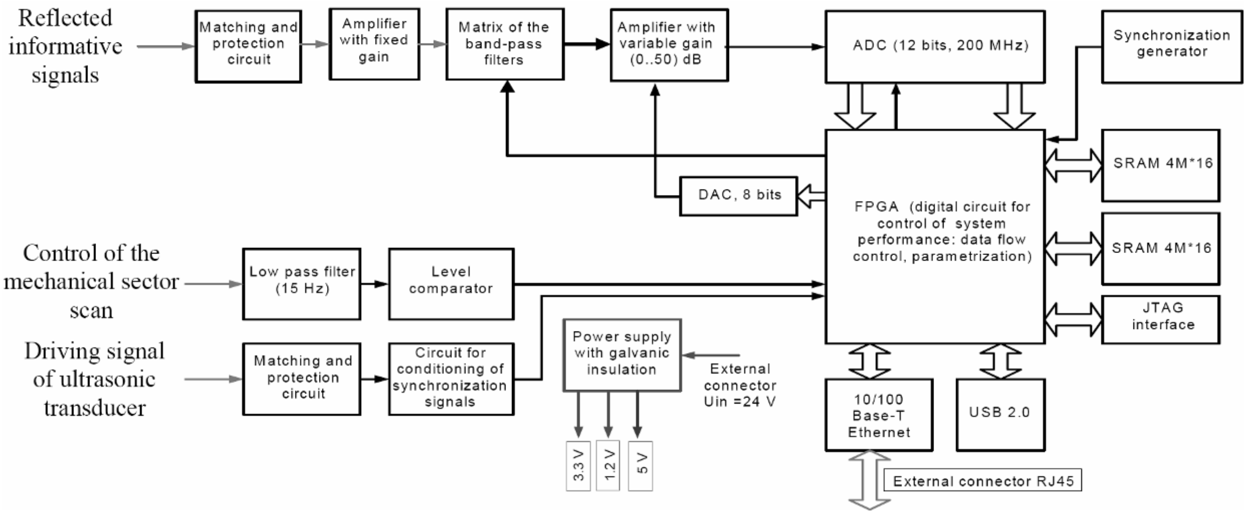


Fig.1. **Block diagram of the proposed ultrasonic system for radio frequency signal capturing and processing.**

The images of the developed portable ultrasonic diagnostic system are presented in Fig. 2. The overall diagnostic system consists of the conventional ophthalmological scanner, the ultrasonic probe (array of transducers), the splitter to acquire raw signals, the preamplifier for initial amplification and the main data acquisition unit for digitization and storage. The embedded computer has USB 2.0 and 10/100 Base-T interfaces for data exchange with an external personal computer. The external computer with an appropriate installed software is used to display the A-scan and B-scan images, also to visualize the processed data using the denoted signal processing algorithm.

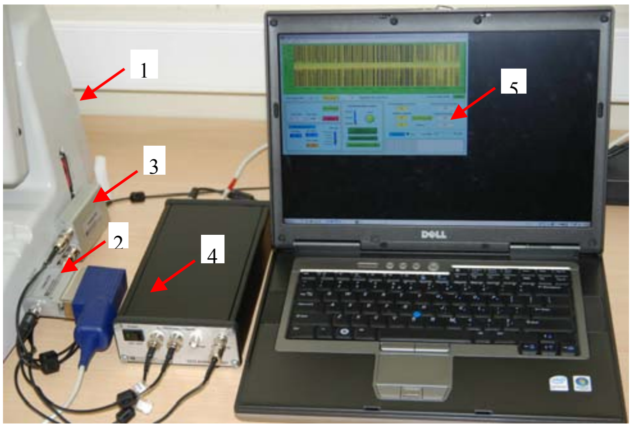


Fig.2. **Images of the developed ultrasonic system: 1 – conventional ultrasonic ophthalmological scanner, 2 – connector of the ultrasonic probe / splitter, 3 – low noise preamplifier, 4 - data acquisition system, 5 – personal computer.**

The portable data acquisition system includes the ARM9 family-based embedded computer (32 bits), programmed for acquisition of a whole B-scan frame (116 measurement positions, 348 signals), time interleaved analog-digital converter (12 bits and 200 MHz sampling frequency), preamplifier (40 dB), amplifier with the time varying gain (up to 80 dB), user selectable matrix of the band-pass filters in the frequency band 5..40 MHz (16 possible configurations) and FPGA chip for control of synchronous sampling of reflected ultrasonic signals.

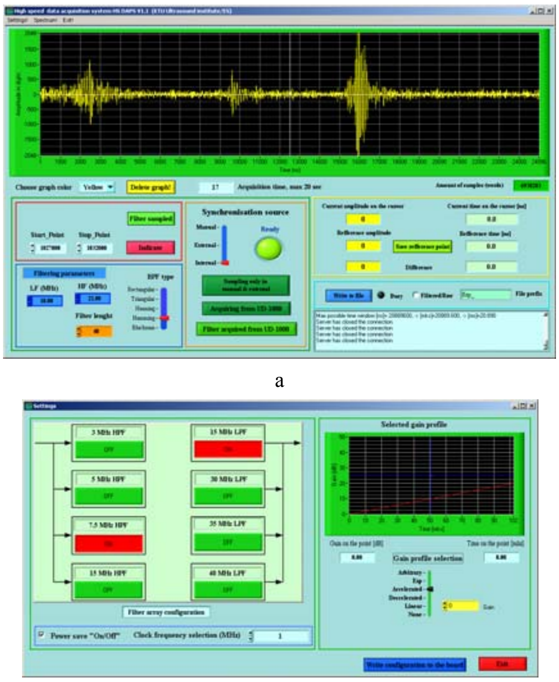
The synchronization scheme is designed to acquire 384 segments of the signal (A-scans) with the accumulation of appropriate flag of stable synchro-signal detection in order to reconstruct the B-scan image. The user interface windows for set-up of the system parameters, like operating mode, selection of the filter, adjustment of the gain and storing of the digitized ultrasonic signals is presented in Fig.3.

Investigation of the phantom

The experimental verification of the developed ultrasonic data acquisition, processing and visualization system was performed. The purpose of such investigations was to estimate the reliability, the performance and the spatial resolution in the case of a specially prepared phantom made of appropriate reflectors.

The principle of a human eye investigation using an ultrasonic technique is presented in Fig.4 a. The typical axial length *D* of eye is between 22.0 and 24.5 mm. Tumours were groupedinto four categories based on a thickness *d*: small (the tumour thickness <3 mm and basal diameter<10 mm), medium (tumour thickness between 3 and 5 mm and basal diameter≤15 mm), large (the tumour thickness between 5 and 10 mm and basal diameter≤20 mm) and extra-large (tumour thickness ≥10 mm or basal diameter>20 mm) [11].

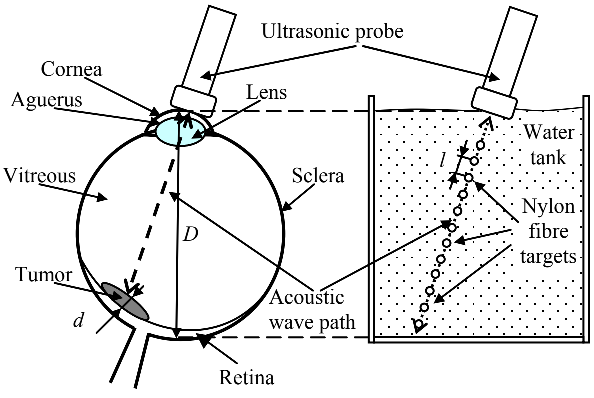
The basic informative ultrasonic signals are assumed to be those that are reflected from the area between 20 mm in depth and further down to the surface of the retina.


a

b

Fig.3. **The user interface for set-up of system parameters: a – the main window of ultrasonic data acquisition system control; b – window for set-up of system parameters (filtering and gain settings).**

In order to evaluate the axial resolution of the developed system the appropriate phantom was used. It is made of nylon fibres having diameter of 0.1 mm. The fibres were stretched in parallel segments and along 35 mm in depth away from the surface of the probe, the spatial distance between each segment was 1 mm (Fig.4,b). The phantom was placed in a water-filled tank.

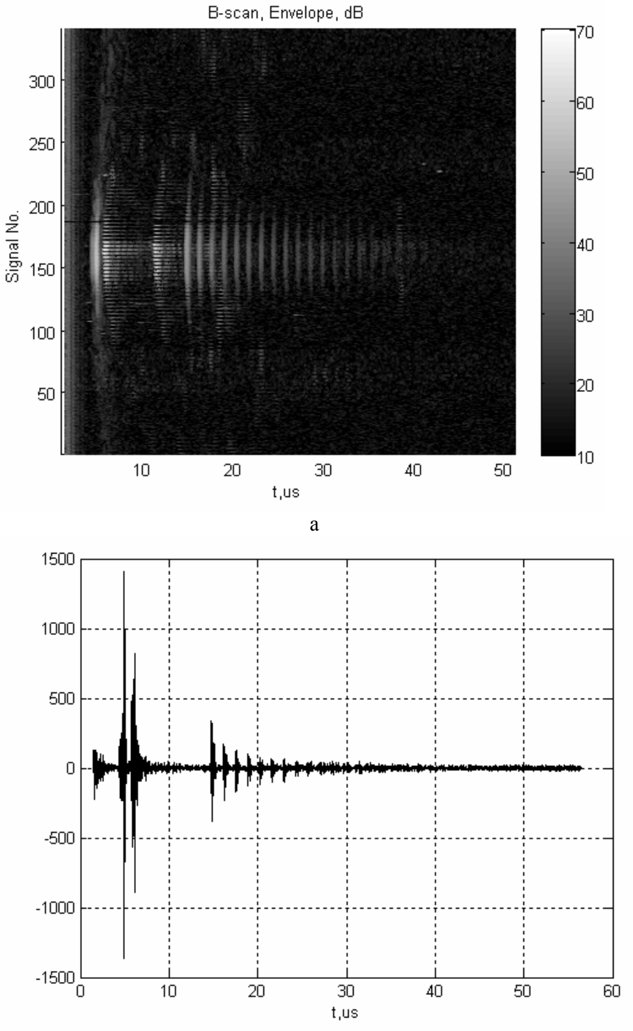


a b

Fig.4. **The principle of human eye investigation using ultrasonic technique (a) and experimental set-up for evaluation of the ultrasonic system resolution using phantom (b).**

The acoustic properties of water (ultrasound velocity c≈1500 m/s) are close to the acoustic properties of the human eye. The typical ultrasound velocities in structures of the eye are the following: cornea – 1640 m/s, aqueous – 1532 m/s, normal lens – 1640 m/s, cataractous lens – 1629 m/s and vitreous – 1532 m/s [12]

The ultrasonic transducer was excited by a pulse having the central frequency of 10 MHz. The reflected signals from the segments of the nylon fibres were amplified in the preamplifier (40 dB) and transferred to the main data acquisition unit. The selected value of the total gain of the system was 62 dB. The operations of filtering (in the frequency band 7.5-15 MHz) and digitization (using sampling frequency of 200 MHz) were performed. Further, the signals were stored in a memory of the data acquisition unit, transferred to an external computer for processing and visualization in forms of A-scan and B-scan. The B-scan image reconstructed from the ultrasonic signals reflected from the nylon fibre targets and the corresponding waveform (A-scan) of the signal No.155 are presented in Fig.5.

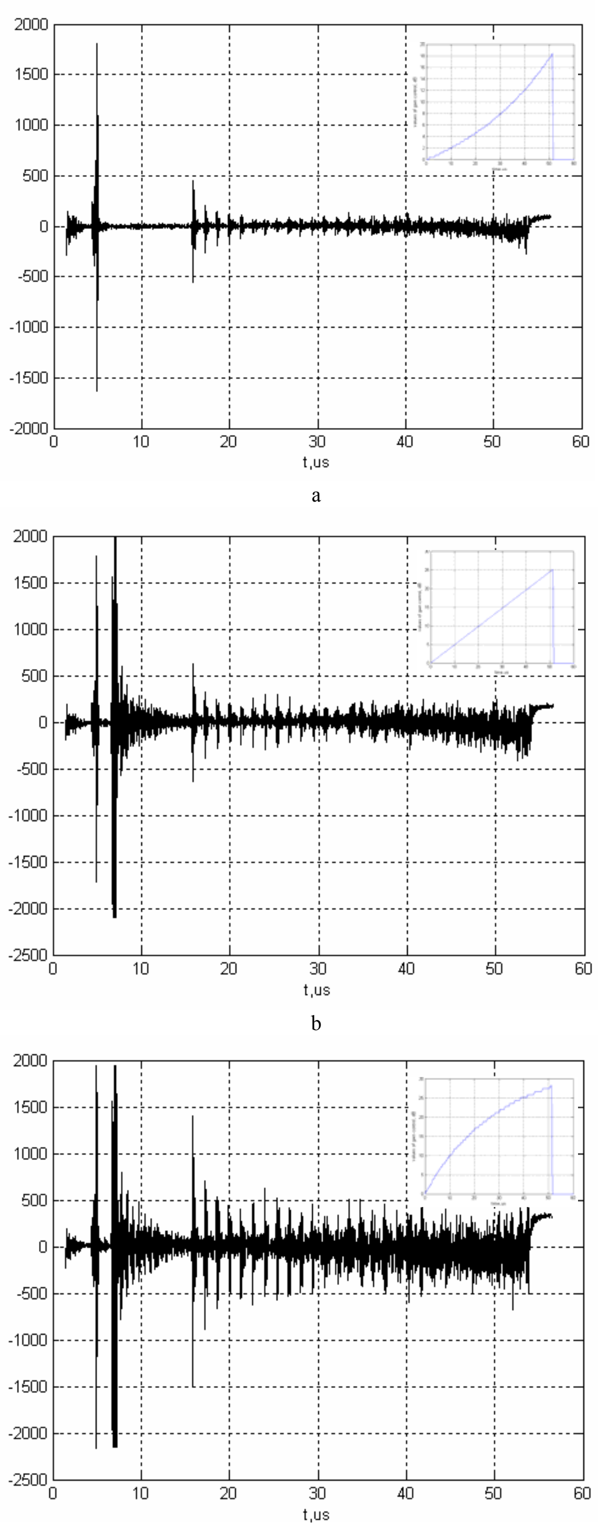


a

b

Fig.5. **The B-scan image of the nylon fibre targets (a) and corresponding waveform (A-scan) of the signal No.155 (b).**

For these images, the delay time of signal propagation which is equal to 50 µs corresponds to the propagation depth of 37.5 mm in water. The amplitudes and the signal to noise ratio (S/N) of reflected informative signals (Fig.5) are not sufficient for a further analysis, therefore the appropriate time-varying gain should be applied. The A-scans obtained in cases of different profiles of time-varying gain are presented in Fig.6.



a

b

c

Fig.6. **The registered ultrasonic signals in cases of different time varying gain profile: a – exponential 0-18 dB; b – linear 0-25 dB; c – logarithmic 0-28 dB, the amplitudes of the signals are denoted in arbitrary units.**

As it can be seen from the obtained A-scans, by selecting of the appropriate time – varying gain profile, the particular segments of the reflected signal may be extracted. Therefore, it is necessary to estimate the necessary profile of gain control and the segment of interest in the case of human eye investigation.

On the other hand, simultaneously with informative signals the native noises of electrical circuitry of the preamplifier are also amplified, impairing the signal to noise ratio of the whole system. The reliable solution is selection of analog components of the preamplifier possessing as low noise level as available in the supply market, simultaneously well known techniques of noise reduction should be used also.

Conclusions

The performed experimental study shows that the developed data acquisition system is suitable to acquire, to digitize with a higher sample rate (not less than 200 MHz) and more precise amplitude resolution (not less than 12 bits), also to store the ultrasonic diagnostic signals which are received from the conventional ophthalmological scanners.

These stored raw ultrasonic signals can be further processed using advanced digital signal processing algorithms, independently from the basic features installed into a conventional medical diagnostic equipment. Experimental research has revealed the tasks of improvement of the developed system, like reduction of the noise level of the preamplifier, optimization of the time varying gain profile, selection of cut-off frequencies of the band-pass filters and necessity to acquire the signals reflected from the internal structure of the eye.

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Žmogaus akies auglių diagnostinės ultragarsinės vizualizavimo sistemos priedo prototipas

Reziumė

Akies audiniams išsamiai apibūdinti ir piktybiniams navikams diagnozuoti šiuo metu plačiai taikomos įvairios ultragarsinės diagnostikos sistemos. Šiame darbe nagrinėjama inovatyvi ultragarsinė akių diagnostikos sistema, įgalinanti išplėsti įprastos ultragarsinės diagnostikos sistemos galimybes. Sukurtosios sistemos pranašumas – galimybė gauti išsamesnę informaciją apie akies piktybinių auglių pobūdį ir pasiskirstymą. Aprašytųjų šios sistemos eksperimentinių tyrimų tikslas buvo nustatyti galimybes skaitmenizuoti, apdoroti, įrašyti ir išsaugoti įprastinėmis ultragarsinės diagnostikos sistemomis fiksuojamus ultragarsinius signalus, kurie toliau būtų apdorojami specialiais skaitmeniniais signalų apdorojimo algoritmais, siekiant padidinti registravimo dinaminį diapazoną ir atkuriamų vaizdų skiriamąją gebą.

Eksperimentiniais tyrimais nustatyta, kad sukurtoji sistema užtikrina 200 MHz diskretizavimo dažnį ir 12 bitų amplitudės kvantavimą, kas įgalina fiksuoti aukštesnio nei 10 MHz centrinio dažnio ultragarsiniais keitikliais priimamus informatyvius signalus.

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