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Improvement of Technical Capabilities and Innovative Features of Ultrasound Devices

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Abstract. As a means of medical visualization, diagnostic devices based on the principle of propagation of ultrasound signals in the environment have found wide application due to their informativeness and minimal extraneous effects. Ultrasound diagnostic tools are constantly being improved according to developing technology and increasing demands. In the article, the technical and diagnostic capabilities of ultrasound diagnostic tools were reviewed, important factors affecting the improvement of the diagnostic characteristics of modern computerized ultrasound medical diagnostic devices were determined.

Keywords: Ultrasound, Doppler effect, Computerized ultrasound medical diagnostic devices, Diagnostic complex, Information.

1 Introduction

Ultrasound diagnostics has been successfully used in world clinical practice for many decades. Currently, according to the opinion of leading specialists of Western countries, computerized ultrasound medical diagnostic devices have found wider application and make up approximately 25% of medical diagnostic equipment in the world market, and this indicator is expected to increase to 50% in the coming decades.

Neurology, neurosurgery, angiology, psychiatry, traumatology and resuscitation are of special relevance and social importance among the fields of application of ultrasound diagnostic methods in health care [1, 2].

The development of computer and information technologies and their application in ultrasound medical devices allow to significantly increase the quality and objectivity of diagnostic studies of the brain structure, arteries and veins, as well as external organs [5].
The relevance of these studies is constantly increasing in recent years.

2 Physical And Technical Bases Of Ultrasound Diagnostics

The basis of the construction of modern ultrasound diagnostic systems is based on the principle of echolocation of ultrasound signals, which allows receiving information about organs and biological structures through the radiation of directed acoustic signals and the reception of echo signals reflected from the biological inhomogeneous acoustic environment [3, 4, 6]. At this time, the irradiated narrow-band ultrasound waves are used to estimate the duration of ultrasound passage through certain tissues and organs of the human body. Relatively simple guidance is used to determine the dimensions of the organ, to obtain various visual indicators and indices characterizing its condition.
A wide range of medical research related to the diagnosis of cardiovascular diseases is provided by ultrasound doppler devices with the application of sensors of various purposes [9-11]. The basis of the construction of such devices is the Doppler effect. The essence of the Doppler effect is that the frequency of the echo signal emitted by moving biological tissues differs from the frequency emitted by the ultrasound sensor [7, 8]. This allows to determine the speed and direction of blood circulation in the vessels by measuring the Doppler shift of the frequency, as well as to determine the symptoms of various diseases by means of spectral analysis methods.

3 Diagnostic Features of Various Ultrasound Devices

Doctors evaluate ultrasound diagnostic complexes according to the known classification of technical levels of the devices, based on the functional characteristics of their implemented diagnostic modes, a number of accepted parameters reflecting the quality of the device, as well as their knowledge and application experience.
Modern ultrasound diagnostic devices use operating modes that reflect the following basic types of diagnostic information:

- two-dimensional white-black image of the applied object (B-mode);
- time-gated bright echogram (M-mode);
- blood flow velocity analysis: D-mode (PW and CW);
- location and shape of vessels (PD-mode);
- spatial distribution of cell movement speed, description of movement direction, energy of emergency or echo signals (TD-mode).

Also, combined modes are used, for example, B+M, B+D (duplex mode), B+D+CFM (triplex mode). In more modern technical complexes, modes have been added that allow describing the spatial location and shape of various structures and organs. In addition, the mode of three-dimensional images is applied, which allows you to obtain a two-dimensional acoustic section of an arbitrary location, an accurate report of objects of any shape under study, volumetric images of objects observed from different angles.

Doctors see two-dimensional and three-dimensional image acquisition and real-time processing as promising directions for the development of ultrasound diagnostics. The following advantages of such methods of information description can be mentioned:

- significant improvement of information capabilities for the purpose of researching the location, form and condition of various structures and bodies;
- more accurate calculation of the volumes of studied objects of any shape;
- reducing the volume (measures) of physical intervention during surgical operations.

Evaluation characteristics of the image quality that a diagnostic device will provide for physicians include resolution (length and width), sensitivity, dynamic range, contrast resolution, frame rate, and absence of artifacts.

At present, the following methods of speed measurement in biological tissues have been applied:

The "spectral doppler" method is divided into two modifications: "continuous doppler" (CW) and "pulse-wave doppler" (PW mode). In CW mode, sinusoidal signals with long duration are radiated and received. In PW mode, a burst of pulses is emitted and received [2]. Both modes are applicable to speed measurement of frequency shift spectral analysis. Both modes basically diagnose the state of the object being studied, the doctor selects the point where the blood flow velocity is measured, is connected to the W mode and switches to the CW or PW mode. At this time, the spectrum of the Doppler shift of the frequency changing over time or the average and maximum speed of blood flow, as well as their change over time, are displayed on the screen of the monitor [9, 10]. In CW mode, it is necessary for the doctor to correctly select the speed range and accurately focus the sensor. In the PW mode, the estimation of the spectrum of velocities can be ambiguous, which manifests itself in the form of erroneous representations of the spectrum. Cancellation of this effect is achieved by manipulation of the repetition rate and selection of the range of speeds. In the technical implementation of the "spectral doppler" method, spectral analysis methods are applied to speed up calculations.

4 Prospects for The Construction of Computerized Ultrasound Devices

Most of the computerized ultrasound medical diagnostic devices currently used in healthcare facilities are foreign-made devices. The world's leading manufacturers of medical equipment offer a wide selection of ultrasound devices that perform a large number of diagnostic functions, but the price of the most modern devices of a given class approaches 500,000 US dollars, which is unaffordable for most healthcare institutions. On the other hand, the scale of the modern diagnostic problems of a number of diseases requires the use and development of the technical base of the country's healthcare institutions.

A modern portable echoencephalo-dopplerograph provides diagnosis of diseases and diseases of the brain, veins, arteries and veins of the head, as well as upper and lower limbs by echo-impulse and ultrasound doppler location methods. This device combines four informative diagnostic methods:

1. Echoencephalography with calculation and printing of data on the width of the ventricle, M-echo distances of the cerebral cortex.
2. Echography with mathematical processing of amplitude parameters of M-echo pulses.
3. Ultrasound dopplerography with registration of flow speed and direction on the carotid, eye and spinal arteries.
4. Transcranial dopplerography, which provides an analysis of the circulation of blood flow through the internal arteries and veins of the skull.

Further development of the model line of diagnostic devices is aimed at improving the diagnostic capabilities of ultrasound devices with the use of real-time two-dimensional and three-dimensional visualization of the structure of the human brain and cerebral vessels.

This makes it possible to compare the topographic relationships of the structures located near the carotid artery, to diagnose bifurcation anomalies together with the precise assessment of thrombi and stenoses, to determine the developing stages of atherosclerotic narrowing of the carotid arteries with minor symptoms.

Most of the modes under consideration can be implemented based on modern computing technologies only with the application of the fastest microprocessors, which mainly creates the need to organize parallel processing of signal information with a large flow and to build microprocessor configurations.

The design of such very complex complexes initially requires computer modeling, and the requirements for the construction of a concrete simulation model are mainly determined by the selected and developed methods of signal processing.

The development of the new generation of ultrasound diagnostic devices is provided on the basis of a deeper development of the new principles of the trunk-module architecture. This allows creating a wide range of specialized and multifunctional devices from a limited number of unified modules in accordance with the above-mentioned requirements and their diagnostic capabilities. The computing power has been increased due to the organization of parallel processing of the multi-channel flow of signal information. It confirms the prospects for the introduction of specialized signal processing processors, which provide the possibility of enhancement. Individually, such capabilities are provided by commercially available TMS320C62xx series from TexasInstruments, TigerSHARC series from AnalogDevices, and PMIS digital signal processors from Altera's STRATIX series. Increasing the productivity of the architecture and software capabilities of the new element base enables the realization of relatively inexpensive, compact and competitive ultrasound diagnostic complexes. These complexes provide unique opportunities for obtaining valuable diagnostic information with two-dimensional and three-dimensional visualization of the studied objects in real time.

At this time, the complex and demanding issues of designing new generation diagnostic complexes are related to the development and technical implementation of effective algorithms of signal information processing. The initial processing system of alarm information should provide the solution of the following issues in real time:

- formation of the directional diagram of the phased antenna lattice and realization of the multi-beam reception mode;
- linear and adaptive planar matching in the multibeam reception space;
- correlation analysis in multi-beam reception space for measurement of Doppler signal from moving structures;
- spectral (energy and frequency) analysis in the multibeam reception space due to formed dipolar signals;
- analysis and classification of contours and surfaces, color coding and construction of isometric projections and sections.

Taking into account the fast pace of technology development and the dynamics of the development of market issues, the tools for building simulation models of diagnostic complexes should be quite universal, allowing for prompt inclusion of changes in the methodological and technological basis of building simulation models. Also, the imitation model of the complex should be brought to full natural modeling and mock-up.

MATLAB and Simulink standard software complexes running on widely used Windows and UNIX computer platforms are selected as the basic building tools of the integration environment, which allow creating simulation models of the designed systems. In such an environment, the creative team gets the opportunity to design a complex computing complex at all stages and debug it on various hardware and software platforms, up to the construction of a working model of the designed product, with minimal effort.

The main stages of development are as follows:

- the research and development phase of the concept, methods and algorithms;
- systematic design stage, including the selection of components, development of the system structure, main nodes, communication interfaces, and technical solutions;
- mock-up, testing and implementation of hardware and software solutions.

In the research and development phase of the concept, methods and algorithms implemented in the designed computing complex, the standard tool of MATLAB mathematical modeling with the addition of specialized application programs is used:

- Signal Processing Toolbox is designed for verification of signal processing and algorithms,
- Communication Toolbox is designed for designing and analyzing communication systems,
- The Filter Design Toolbox is designed for designing complex digital filters and implementing them in floating-point mathematics.
- Wavelet Toolbox is designed for analysis, compression and impulse decomposition of signals and images.

Software tools of the Simulink system are used at the stage of systematic design. Simulink is an interactive tool for modeling and analyzing dynamic systems that allows you to write the structure of the designed system, model its state during operation, evaluate its performance, and detect errors or bottlenecks in the design. Simulink, on the one hand, organically enters the concept of mathematical modeling of complex algorithms implemented in the MATLAB system, and on the other hand, it allows to verify the main architectural concepts of the project. That is, it allows you to use the hierarchical structure of the system, discretization tools, Stateflow event modeling tools, DSP Blockset library models of the main nodes of digital signal processing, and Fixed-Point Blockset nodes that perform specified point operations.

In addition to the verification and specification of architectural and software solutions, there is an opportunity to implement local technical solutions in the form of new library modules. Real-Time Workshop moves to the final stage of complex design using a full-featured software-hardware complex in a real-time environment.

5 Conclusions

The technology of designing a new generation of ultrasound devices with unique diagnostic capabilities will allow to meet the growing needs of doctors in the near future, and will provide a qualitatively new level of diagnosis and prevention of cerebrovascular diseases.

The following are important factors affecting the improvement of the diagnostic properties of modern computerized ultrasound medical diagnostic devices:

- Application of modern ultrasonic sensors;
- Application of modern methods of digital signal processing, acquisition of two-dimensional and three-dimensional images of the studied object in real time;
- Implementation of parallel microprocessor processing methods;
- Application of modern design technologies of diagnostic complexes;
- Cooperation and collaboration of medical and technological institutes.

Improving the functional capabilities of ultrasound diagnostic devices can involve various methods and solutions aimed at enhancing imaging quality, increasing diagnostic accuracy, expanding clinical applications, and improving user experience.

Advanced Imaging Technologies: Integrating advanced imaging technologies such as contrast-enhanced ultrasound (CEUS), elastography, shear wave imaging, and three-dimensional (3D) or four-dimensional (4D) imaging can enhance diagnostic capabilities by providing additional information about tissue characteristics, vascularity, and structural abnormalities.

Higher Frequency Transducers: Utilizing higher frequency transducers allows for improved resolution and better visualization of superficial structures. Conversely, lower frequency transducers penetrate deeper into tissues, enabling better visualization of deeper structures. Offering a range of transducer frequencies increases the versatility of ultrasound devices.

Multi-frequency Transducers: Implementing transducers capable of emitting multiple frequencies can optimize imaging for different clinical scenarios. For example, a transducer capable of switching between high and low frequencies can provide both detailed superficial imaging and deeper penetration when needed.

Software Enhancements: Continuous software updates and improvements can add new features, enhance image processing algorithms, and optimize user interfaces. Software upgrades can also address specific clinical needs, such as improved fetal imaging, cardiac imaging, or vascular imaging.

Artificial Intelligence (AI) Integration: Integrating AI algorithms into ultrasound devices can automate image analysis, improve diagnostic accuracy, and assist in real-time decision-making. AI-based image processing techniques can enhance image quality, reduce artifacts, and provide quantitative measurements.

Ergonomic Design: Designing ultrasound devices with user comfort and ergonomics in mind can reduce operator fatigue, improve scanning efficiency, and enhance user experience. Features such as adjustable monitor positions, intuitive control panels, and lightweight transducers contribute to improved usability.

Wireless Connectivity and Data Sharing: Incorporating wireless connectivity features enables seamless data transfer, image sharing, and remote consultations. Cloud-based platforms can facilitate collaboration among healthcare professionals and support telemedicine applications.

Portable and Point-of-Care Solutions: Developing portable and point-of-care ultrasound devices enhances accessibility to imaging in various clinical settings, including emergency departments, intensive care units, and ambulatory care settings. Compact, handheld devices offer flexibility and convenience for bedside examinations.

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