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Visualization and Virtual Diagnosis of the Cardiovascular System Current State by the Results of Its Non-Invasive Monitoring.

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ABSTRACT

The article presents the results of clinical trials efficiency and effectiveness of the original information system that implements geometric method for constructing and visualizing multidimensional virtual image of the patient's condition ($A_N(t)$), is used to solve the problem of recognition of its nosology of disease based on a study of two-dimensional topology of the mutual arrangement of the image of the current state cardiovascular system (CVS) patient $A_2(t)$ regarding the two-dimensional images of the reference classes B_{2i},diagnoses, as well as mutual arrangement B_{2i} relative to each other.

Keywords: cardiovascular system, visualization, diagnostics, noninvasive monitoring.

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INTRODUCTION

The concept of mathematical modeling of cardiac problems in medical decisions on the results of non-invasive monitoring of its condition is based on the fact that computer-assisted diagnosis is considered as an informational support of the cardiologist during its analysis of cardiographic information and diagnosis [1, 2, 3]. In this case it is that mathematical modeling is used for visualization of the current status and cardio case history of cardiovascular system (CVS) patients [4, 5]. This information resource will allow avoiding gross errors in interpreting the results of analysis of cardiac information and make convenient perception of diagnosis. In addition, it becomes possible to carry out non-invasive heart conditions' diagnosis to a new level.

METHODOLOGY

The given approach, proposed by the team, to solving the problem of automation procedures for determining the current state of the patient is based on the CVS recognition problem of pre-built multi-dimensional virtual image ($A_N(t)$) by comparing it with a set of standard multidimensional images diagnoses B_i. Wherein each of the B_i is a set of numerical values of a set of characteristics taken from the recommendations of the European Society of Hypertension (ESH) and the European Society of Cardiology (ESC), 2013) [6].

The basis of the development of an information system for recognition problem ($A_N(t)$) to develop a managed care solutions is geometric method of formation, visualization and interactive analysis of the results of conformity assessment ($A_N(t)$) to a particular B_i. The theoretical basis for solving the mentioned problems is the theory of fuzzy sets.

It should be noted that the basic procedures to solve this problem are:

1. The formation in N-dimensional feature space of virtual three-dimensional models of various forms of the disease - B_i as M - loci, where M - number of diseases; i = 1; 2; 3 ... and multidimensional virtual image that characterizes the current state of the CVS of the given patient $A_N(t)$ [4].

2. The formation of two-dimensional images of the current state ($A_2(t)$) and two-dimensional images of classes of states B_{2i} representing the projection $A_N(t)$ and B_i { X', Y' } on the plane coinciding with the plane of the multicolored monitor screen [5].

3. The analysis of mutual arrangement topology $A_2(t)$ regarding B_{2i} and B_{2i} mutual arrangement relative to each other. [4]

For example, in Fig. 1a, and graphically illustrates one of the possible relative positions $A_2(t)$ of the two-dimensional models of virtual forms of the disease on the plane $\{X'; Y'\}$. Fig. 1b illustrates one of the possible relative positions of the two-dimensional models $A_2(t)$ of virtual forms of the disease on a multicolored monitor screen displaying the plane.

In general, all data processing protocols implemented in solving the problem of generation of managed care solutions, are combined into a single algorithm based on the original method of visualization and recognition of pre-built multi-dimensional virtual image ($A_N(t)$) state CVS patient [4].

The automated system, proposed by a research team, of generating a control medical decision implements the solution in two situations:

- Generation of managed care solutions of a corresponding disease in establishing the fact of $A_2(t)$ belonging to only one of B_{2i};

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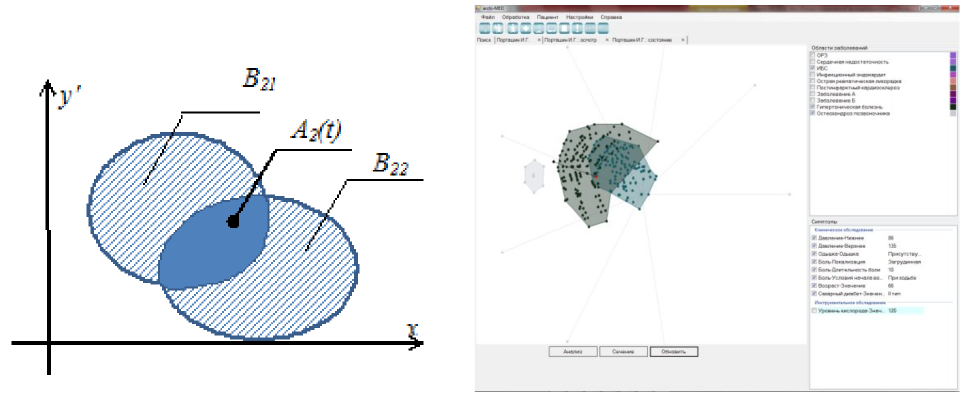
- Generation of managed care solutions of a corresponding disease in establishing the fact of belonging $A_2(t)$ simultaneously to two or more B_{2i}.



(a) (b)

Figure 1: Topology of the relative position of the two-dimensional image of the two states and two-dimensional models of virtual forms of the disease: a - on a plane $\{X';Y'\}$; b - multicolor screen monitor that displays the plane $\{X';Y'\}$

The performance and efficiency of the developed automated systems for the generation of managed care solutions was carried out in the course of its clinical trials on the basis municipal fiscal health facility MFHF "City Hospital № 2 of Belgorod." Effectiveness of the mentioned information system was conducted on the basis of assessment of the compliance program generated results diagnoses electronic reference diagnosis (RD). At the same time the diagnoses put by a cardiologist were taken as the reference diagnoses were considered, in relation to the same group of patients [7].

MAIN PART

During the clinical trials database information system study was recorded information on the two diseases (coronary heart disease and hypertension). A control group of patients consisted of patients with spinal osteochondrosis without pathology of the CVS. The list of data provided by the clinic staff is illustrated in Table 1 and Table 2.

In clinical trials, there were conducted 200 experiments. The selection of samples was taken at random. The quality indicators of the electronic diagnoses generation were used: the diagnostic sensitivity (DS); diagnostic efficiency of electronic diagnostics (DE).

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Table 1: Data of symptoms and their parameters given by cardiologist description

.	The name of the symptom	Symptom's parameters
	Age	1) not defined
		2) 0-17 years
		3) 18-44 years
		4) 45-64 years
		5) 65-74 years
		6) 75-84 years
		7) >85 years
	Diabetes mellitus	1) not defined
		2) I type
		3) II type
		4) no
	Hypertension	1) not defined
		2 Optimum blood pressure (BP) - SBP (systolic blood pressure) <120 and DBP (diastolic blood pressure) <80 mmHg
		3)) Normal blood pressure - SBP 120-129 and DBP 80-84 mmHg
		4 High normal blood pressure SBP 130-139 and DBP 85-89 mmHg
		5) the first degree of hypertension - SBP 140-159 and DBP 90-99
		6) Secondary hypertension - SBP and DBP 160-179 100-109
		7)) third degree AG - GARDEN> 180 and DBP> 110
		8) Isolated systolic hypertension - SBP ≥ 140 and DBP <90
	Availability of pain	1) not defined
		2) there is no painful sensations
		3) There is a pain
	Duration of pain without the use of painkillers	1) not defined or painful sensations arise
		2) upto 15 minutes
		3) 15 and more minutes
	Localization of pain	1) not defined or painful sensations arise
		2) chest pain
		3) abdominal pain
		4) pharyngalgias
		5) pain in the arm
		6) pain in the scapula
		7) lower jaw pain
		8) pain in other parts of the body
		9) At the same time: the sternum; in the hand; in the scapula
		10) At the same time: the sternum; in the hand
	Dyspnea	1) not defined
		2) yes
		3) no
	Electrical axis of the heart	1) not defined
		2) normal position (от 0° до +90°)
		3) The deviation to the right (from +91 ° to +180 °)
		4) A sharp deviation to the right (from +181 ° to +269 °)
		5) The deviation to the left (from +270 ° to +329 °)
		6) Tolerance of normal position (from +330 ° to +359 °)
	nonspecific repolarization changes	1) not defined
		2) not observed
		3) Yes (without location)
		4) Yes, in the apical inferolateral wall
	…	…
5	Hyperkalemia	1) not defined
		2) no
		3) Light (5.5-6.5 mEq / L)
		4) Moderate (6.5-8.0 meq / l)
		5) Heavy (9-11 mEq / L)

These figures are calculated on the basis of the results of clinical trials, illustrated in Table 2.

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Table 2 Results of clinical tests

Surveyed patients	electronic diagnostic results				total
	n_{c1}	n_{c2}	n_{c3}	n_{c0}	
$n_{\omega 1}$	TP1	LP12	LP 13	LP 14	TP1+ LP 12+ LP 13+ LP 14
$n_{\omega 2}$	LP21	TP2	LP 23	LP 24	LP 21+TP2+ LP 23+ LP 24
$n_{\omega 3}$	LP31	LP 32	TP3	LP 34	LP 31+ LP 32+TP3+ LP 34
$n_{\omega 0}$	LP01	LP 02	LP 03	TP04	LP 01+ LP 02+ LP 03+TP04
total	TP1+LP21+P31+LP01	TP2+ LP 12+ LP 32+ LP 02	TP3+ LP 13+ LP 23+ LP 03	TP04+ LP 14+ LP 24+ LP 34	[illegible]

wherein
- R - number of the class studied the disease;
- nωr - the number of patients in the test sample, in which the cardiologist diagnosed the disease class ωr;
- $n_{\omega 0}$ - the number of patients in the test sample, in which the cardiologist diagnosed that they have no diseases studied;
- n_{cr} - the number of patients in the test sample, in which the information system has diagnosed the disease class ωr;
- n_{c0}- the number of patients in the test sample, in which the information system has diagnosed that they have no diseases studied;
- TPr - true positive result of electronic diagnostics, equal to the number of patients in the test sample, in which the diagnosis of the disease class ωr was put cardiologist and generated program;
- FPij - false positive diagnosis of e equal to the number of patients in the test sample, in which the cardiologist diagnosed the disease under study lack ωi, and the program has generated erroneous decision Grading CVS to Class disease ω_j, i≠j.

Illustrated in Table 2, the results of clinical trials have been used to quantify the quality of the generation of electronic diagnoses, payment of which was carried out in accordance with the relations:

$$\begin{cases} DSr = T\,\mathrm{Pr}/n_{\omega_r}\,; \\ DE = (TP1 + TP2 + TP3 + TP0)/\Sigma. \end{cases} \qquad (1)$$

It was assumed that the class ω1 include patients of the experimental sample with a diagnosis of "the presence of coronary artery disease," the class ω2 include patients of the experimental sample with a diagnosis of "the presence of arterial hypertension," the class ω3 include patients of the experimental sample with a diagnosis of "the presence of spinal osteochondrosis" and to the class of ω0 - patients of the experimental sample with a diagnosis of "healthy."

Table 3 illustrates the results of experimental verification of the effectiveness of electronic diagnostics, calculated based on the data illustrated in Table 2.

Table 3: The results of experimental verification of the effectiveness of electronic diagnostics

Surveyed patients	electronic diagnostic results				Total
	n_{c1}	n_{c2}	n_{c3}	n_{c0}	
$n_{\omega 1}$	47	3	2	3	55
$n_{\omega 2}$	4	43	4	2	53
$n_{\omega 3}$	1	5	43	3	52
$n_{\omega 0}$	1	3	1	35	40
Total	53	54	50	43	200

In accordance with relation (1) and the data illustrated in Table. 3 were calculated quality generation electronic diagnoses:

$$DS1 = \frac{47}{55} = 0{,}855;\ DS2 = \frac{43}{53} = 0{,}811;\ DS3 = \frac{43}{52} = 0{,}827;$$

$$DS0 = \frac{35}{40} = 0{,}875;\ DE = \frac{168}{200} = 0{,}84$$

Analysis calculated quantitative estimates of DS and DE suggests that a group of authors developed an automated system generating a control medical decisions based on the geometric method of pattern recognition [7, 8, 9], is quite effective.

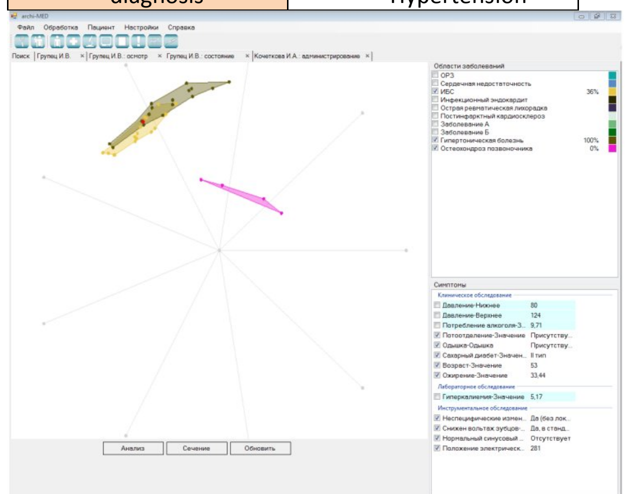
For example, in Fig. 2 illustrates a structure of information and procedures to support the generation of electronic diagnosis of one of the patients included in the statistical sample. According to the patient information system has generated a correct diagnosis.

a

Symptom	1
Voltage Deflection reduce-value	Yes in standard derivation
Hyperkalemia-value	5,17
Electrical axis of the heart-Value	281
Normal sinus rhythm value	none
Loss of consciousness-value	0
Dyspnea Dyspnea	present
Sweating- Value	present
Pain -localization	0
Pain-duration	0
Pain the starting conditions	0
Pressure-Lower	80
Pressure-top	124
Alcohol consumption-value	9,71
Obesity-value	33,44
Diabetes mellitus-value	II type
Age-value	53

b

CAD	36
Hypertensive heart disease	100
Osteochondrosis (no CVD)	0
diagnosis	Hypertension



c

Figure 2: Type and structure of informational support of procedure generation electronic diagnosis of one of the patients included in the statistical sample: a - input parameters; b - topology relative position of the two-dimensional models of virtual forms of the disease multicolor screen monitor; c - in – Imprint

Also it was assessed the reliability of the results of clinical trials of automated systems for the generation of managed care solutions using the f-Fisher criterion [10]. At the same time to determine the degree of homogeneity of indistinguishability experimental and reference samples as reference samples was taken results diagnoses cardiologist by disease: "the presence of coronary heart disease"; "The presence of arterial hypertension"; "The presence of spinal osteochondrosis," as well as the diagnosis of "healthy." As used in the experimental sample corresponding electronic diagnoses system information generated in the process of clinical testing.

According to the results of clinical trials in accordance with the known method [9] were calculated f-Fisher criteria for each of the diseases (F_{D1} - "coronary heart disease" - F_{D2} "disease Hypertension" - F_{D3} "disease osteochondrosis" - "Healthy"):

$$F_{D1} = \frac{\sigma^2_{131}}{\sigma^2_{231}} = 1{,}11\ ;\ F_{D2} = \frac{\sigma^2_{132}}{\sigma^2_{232}} = 1{,}15;\ F_{D3} = \frac{\sigma^2_{133}}{\sigma^2_{233}} = 1{,}14\ .$$

Then the tables Fischer [10] were determined tabulated values of this criterion F_{table} = 1.6 for each of the diseases considered for the chosen significance level of p ≤ 0,05 and degrees of freedom k = n-1 = 199.

Comparative analysis of the calculated values of f-Fisher's exact test for each of the diseases (F_{D1} F_{D2} F_{D3}) with tabulated values (F_{table}) suggests that generated by an automated system control medical decisions are correct.

Finally, it was concluded that implementation of the proposed approach to solving the problem of automation procedures generate electronic diagnosis of the current state of the CVS patient will enable technology-based "tele-cardiology" quickly monitor and analyze the flow patterns of disease, improve the accuracy of diagnosis of diseases, and in some cases to solve the problem prognostic

CONCLUSION

Overall, the analysis of clinical trial results showed the following:

- Proposed automated system for assessing the current state of the CVS patient, based on the solution of the problem of recognition pre-built multi-dimensional virtual image ($A_N(t)$) of this condition by comparing it with a set of standard classes of multidimensional images diagnoses Bi, is workable;
- Generated by an automated system control medical decisions for each of the diseases(F_{D1} F_{D2} F_{D3}) are valid for a given sample size, the number of degrees of freedom k = n-1 = 199. and the chosen level of significance p ≤ 0,05
- Implementation of the proposed approach to the problem of automating the assessment of the current state of the CVS patient will quickly monitor and analyze the flow patterns of disease, improve the accuracy of diagnosis of diseases, and in some cases to solve prognostic problems.

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