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[1]**V. M. Sineglazov,**
[2]**Ju. V. Smirnova**

INTELLIGENCE DIAGNOSTICS OF HEART DISEASE BASED ON NEURAL NETWORKS ENSEMBLE USE

[1,2]Aviation Computer-Integrated Complexes Department, Faculty of Air Navigation Electronics and Telecommunications, National Aviation University, Kyiv, Ukraine
E-mails: [1]svm@nau.edu.ua ORCID 0000-0002-3297-9060, [2]ironylp18@gmail.com

Abstract**—***The problem of constructing an intelligent system for diagnosing heart valve disease is considered. It is shown that the diagnosis is established on the basis of the results of a standard examination, which includes anamnesis, laboratory data, electrocardiogram, echocardiography and Doppler examination. The use of hybrid neural networks of ensemble topology is substantiated for solving the problem. In order to show that the appropriate neural networks for composing an ensemble can be effectively selected from a set of available neural networks, an algorithm for structural-parametric synthesis of hybrid neural networks of ensemble topology is proposed. As for training component neural networks it is used Bagging approach. Accuracy and diversity were used as criteria. The structure of the diagnostic system for recognition of valvular heart disease is presented. The results of research of the developed software are presented. As for training component neural networks, the Baging approach is used. The structure of the diagnostic system for recognition of valvular heart disease is presented. The results of the study of the developed software are presented.*

Index Terms—heart disease; neural networks ensemble; disease; electrocardiogram; echocardiography; Doppler examination.

I. INTRODUCTION

Currently, the main modern direction of science and technology is the development and use of methods and systems of artificial intelligence. The main developers of this approach are two countries: the United States and China. It should be noted that Ukraine ranks first in the field of artificial intelligence in Eastern Europe. This is primarily due to the significant increase in the number of Ukrainian companies working in this field, the opening of specialties in this field and the development of training courses. Artificial intelligence technologies will help improve the development of the economy, the labor market, government institutions and society at large. Their use will reduce costs and increase production efficiency, quality of goods and services.

Artificial intelligence technologies will help improve the development of the economy, the labor market, government institutions and society in general. Their use will reduce costs and increase production efficiency, quality of goods and services.

It is very important for Ukraine to continue basic and applied research in the field of artificial intelligence, because in the future achievements in this field will be one of the integral components of economic prosperity of any state.

One of the main directions in the field of artificial intelligence is the development of intelligent diagnostic medical systems, in particular the diagnosis of heart disease.

Among the causes of mortality and disability, valvular heart disease is one of the leading. The frequency of failure of one or more heart valves in chronic forms of the disease is 350-400 cases per 100 thousand population.

Heart disease is an organic lesion of the heart valves, its partitions, large vessels and myocardium, which leads to dysfunction of the heart, stagnation of blood in the veins, tissues and organs. There are congenital and acquired heart defects.

Acquired heart defects are anomalies and defects of the heart valves, its openings or partitions between the chambers, the vessels extending from it, which lead to a violation of intracardiac and systemic hemodynamics and, as a result, to the development of acute or chronic circulatory failure.

More than 70% of deaths occur in Ukraine due to cardiovascular diseases: heart attacks, strokes, heart failure, coronary heart disease.

Thus, the issues of timely diagnosis, and in turn, the selection of appropriate treatment are of great medical and social importance, and the development of a diagnostic system capable of detecting the disease as accurately as possible becomes one of the important tasks worldwide.

The dysfunction or abnormality of one or more of the heart's four valves (the mitral valve and aortic valve on the left side, and the tricuspid valve and pulmonic valve on the right side) is called valvular heart disease [1]. In a normally functioning heart, the four valves keep blood flowing in one direction and only at the right time. These valves act as gates that swing open to allow blood to flow through and then tightly shut until the next cycle begins [1].

There are a number of types of valvular heart disease, including; valvular stenosis, valvular regurgitation, atresia of one of the valves and mitral valve prolapse [1].

The majority of these cases involve disorders of the aortic valve and the mitral valve. Deaths due to pulmonic and tricuspid valve disorders are rare.

Mitral valve insufficiency (mitral regurgitation) is a heart disease characterized by incomplete closure of its valves during left ventricular systole, leading to reverse blood flow (regurgitation) from the left ventricle to the left atrium.

Mitral insufficiency is divided into five stages.

Insufficiency of the aortic valves (aortic insufficiency) – the absence of complete closure of the leaflets of the semilunar valves of the aorta in diastole and the occurrence of reverse blood flow (regurgitation) from the aorta to the cavity of the left ventricle.

Diagnosis is based on the results of a *standard examination.*

A. Required Research

1) Anamnesis (medical history) and physical examination findings. Physical examination may reveal a murmur, evidence of heart enlargement and fluids within the lungs.

2) Laboratory data – complete blood count (ESR, leukocytes, hemoglobin), biochemistry and serology (proteins and protein fractions, C-reactive protein, fibrinogen, antistreptococcal and complement binding antibody titers).

3) Electrocardiogram (myocardial hypertrophy, rhythm and conduction disturbances). An electrocardiogram may reveal arrhythmias and chamber enlargement.

4) Echocardiography and Doppler study Echocardiography and a Doppler ultrasound are the most widely used methods, and are very useful in assessment of presence and severity of valve disease. Doppler heart sounds (DHS) are one of the most important sounds produced by blood flow, valves motion and vibration of the other cardiovascular components [3]. However, the factors such as calcified disease or obesity often result in a diagnostically unsatisfactory Doppler techniques assessment and, therefore, it is sometimes necessary to assess the spectrogram of the Doppler shift signals to elucidate the degree of the disease [3]. In addition to Doppler techniques, the techniques that are more complex have also been developed (Laplace Transform and Principal Components Analysis). The DHS waveform patterns from heart valves are rich in detail and highly non-stationary. After the data pre-processing has been realized, the feature extraction process was carried out.

Many studies have been implemented to classify Doppler signals in the pattern recognition field [4], [5].

5) Magnetic resonance imaging (MRI). Magnetic resonance imaging can provide clear three-dimensional images of the heart and its valves.

6) Consultation with a cardiac surgeon.

B. Additional research

- immunological blood tests (B- and T-lymphocytes, CEC, NST-test);
- daily ECG monitoring;
- coagulogram;
- catheterization of the heart cavities;
- coronary angiography.

II. Problem Statement

Recent advances in artificial intelligence have led to the emergence of expert systems for medical applications. Moreover, over the past few decades, computing tools have been developed to improve physicians' experience and ability to make decisions about their patients. Given the need for such an expert system, in this study we propose a method of effective diagnosis of heart disease.

It is necessary to diagnose heart disease according to the results of a standard examination. As mentioned above, to solve this problem, we will use an intelligent diagnostic system built on the basis of the use of artificial neural networks (ANN).

Development and application of ANN on the basis of advanced technologies is one of the priority areas of science and technology in all industrialized countries. A neural network is a distributed parallel processor consisting of elementary blocks of information processing that accumulate experimental knowledge and provide it for further processing.

The use of neural networks (NN) as part of an intelligent diagnostic system (ISD) involves solving the problem of structural-parametric synthesis, as a result of which it is necessary to determine the network structure (topology, number of layers, number of neurons in each layer, type of activation function) and the value of weight coefficients , thresholds. In order to simplify the task, taking into account the list of mandatory studies, we will divide the entire task into two subtasks:

1) processing of ECG video images (myocardial hypertrophy, rhythm and conduction disturbances), echocardiography and Doppler examination, magnetic resonance tomograms of the chest organs in three projections in order to highlight the essential signs that determine the presence of heart disease;

2) determination of the diagnosis based on the selected signs, anamnesis, laboratory data, consultation with a cardiac surgeon and additional studies.

The solution of the first subtask allows you to determine:

- signs of hypertrophy (the presence of teeth of different types) based on computer processing of the ECG;
- type, shape, stage of the defect and its prognosis, discordance in the movement of the anterior and posterior leaflets, an increase in the speed of movement of the anterior leaflet, signs of its fibrosis based on computer processing of echocardiography;
- a direct sign of a defect-turbulent systolic blood flow in the cavity of the left atrium; based on computer processing of Doppler echocardiography.

To solve the first subproblem, it is advisable to use convolutional neural networks, which are considered in detail in the author's work [6].

The second subtask is the classification task. To solve it, it is proposed to use an ensemble approach, when neural network ensembles are used as a classifier.

Neural network ensemble is a learning paradigm where a collection of a finite number of neural networks is trained for the same task [7]. The characteristic feature of an ensemble is redundancy; each predictor could perform the task on its own, but better generalization performance is obtained from the combination. It originates from Hansen and Salamon's work [8], which shows that the generalization ability of a neural network system canbe significantly improved through ensembling a number of neural networks, i.e., training many neural networks and then combining their predictions. Since this technology behaves remarkably well, recently it has become a very hot topic in both neural networks and machine learning communities [9], and has already been successfully applied to diversified areas such as face recognition [10], [11], optical character recognition [12] – [14], scientific image analysis [15], medical diagnosis [16], [17], seismic signals classification [18], etc. In general, a neural network ensemble is constructed in two steps, i.e., training a number of component neural networks and then combining the component predictions.

As for training component neural networks, the most prevailing approaches are Bagging and Boosting.

As for training component neural networks, known algorithms are usually divided into two classes: algorithms that for new classifiers change the distribution of training examples, based on the accuracy of previous models (busting), and those in which new members of the ensemble learn independently of others (beging). Bagging is proposed by Breiman [19] based on bootstrap sampling [20].

Bagging has proved to be a popular technique, applicable to many problems. Domingos [21] gives a Bayesian account, and investigates that Bagging succeeds because it shifts the prior distribution of the combined estimator to a more appropriate region of the model space.

The creation of an ensemble approach [22] is often divided into two steps: (1) generate individual members, and (2) appropriately combine individual members' outputs to constitute a new output. The basic method for forming ensemble-based methods is to train each member model using random parameters. In the neural network context, these methods include techniques for training with different network topologies, different initial weights, different learning parameters, and learning different portions of the training set [23]. Moreover, methods for creating ensembles focus on creating classifiers that disagree on their decisions. In general terms, these methods alter the training process in an attempt to produce classifiers that will generate different classifications.

Ensemble-based techniques can increase the productivity of generalization by combining several separate neural networks that are trained to perform a single task.

The general structure of the parallel ensemble of neural networks is shown in Fig. 1. An ensemble in which input data enters simultaneously to all networks that form a hybrid neural network is called parallel. The main element in creating such an association is the "amalgamation layer", which is responsible for aggregating the performance of various components of the ensemble.

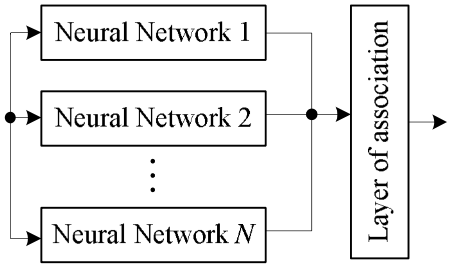

Fig. 1. The general structure of a parallel ensemble of neural networks

III. STRUCTURAL-PARAMETRIC SYNTHESIS ALGORITHM OF THE NEAR NETWORK ENSEMBLE

An ensemble of neural networks is a group of topologies united in a single structure, which may differ in architecture, learning algorithm, learning criteria and types of forming neurons [24] – [26]. In another variant, the term is understood as an ensemble "combined model", the output of which is a functional combination of outputs of individual models [27].

Input data can be divided into specific groups for processing by different ANN or fed to all networks at the same time.

Forming ensembles of ANN, it is necessary to optimize two criteria – quality training of separate ANN and their optimum Association.

A necessary and sufficient prerequisite for building aт ANN ensemble that has greater accuracy in solving the classification (prediction) problem than each individual module is to include ANNs that meet the criteria of accuracy and diversity in its composition. As the diversity of the ensemble decreases with increasing accuracy of the members of the ensemble, the task of creating an effective ensemble is reduced to finding a compromise.

In most ensemble methods, diversity and accuracy are achieved by manipulating training sample data. One of the problems with these approaches is that they tend to build oversized ensembles. This requires a large amount of memory to store the trained modules (classifiers). To overcome this problem, we use the Pruning procedure, which provides the optimum choice of a subset of individual modules (classifiers) from an already built ensemble in terms of accuracy, variety, and memory costs.

Let $D = \{d_1, ..., d_N\}$ be the set of N data points where $d_i = \{(x_i, y_i) \mid i \in [1, N]\}$ is a pair of introductory features and a label representing the ith data point, $C = \{c_1, ..., c_M\}$ set of M-modules, where $c_i(x_j)$ gives the prediction of the ith module at the jth data point, $V = \{v^{(1)}, ..., v^{(N)} | v^{(i)} = [v^{(i)}_1, ..., v^{(i)}_L], i \in [1, N]\}$ set of vectors, where $v^{(i)}_j$ is the number of predictions for the jth label of the ith data point of the ensemble with a majority vote (majority vote), and L the number of source labels.

Required based on the accuracy and variety of classifiers $C = \{c_1, ..., c_M\}$ select members to form an ensemble, having a test dataset and considering that the networks are pre-trained on bootstrap samples.

The main idea behind bootstrap is to repeatedly extract repeated samples from the empirical distribution by the Monte–Carlo statistical method: we take the finite set of n terms of the original sample $x_1, x_2, ..., x_{n-1}, x_n$, where at each step of n consecutive iterations using a random number generator evenly spaced $[1, n]$, an "arbitrary" element is draw nx_k, which again "returns" to the original sample (ie can be retrieved).

Therefore, the preliminary stage in the construction of the ensemble is the creation of basic classifiers, which must be independent.

These classifiers are trained on independent datasets.

The algorithm of structural-parametric synthesis of the NN ensemble is presented in the work of the author [6].

It should be noted that a dynamically averaged network (DAN) (see Fig. 1) is determined via

$$f_{AOI} = \sum_{i=n}^{n} w_i f_i(x),$$

where $c(f_i(x)) = \begin{cases} f_i(x), \text{if } f_i(x) \geq 0.5, \\ 1 - f_i(x), \quad \text{else,} \end{cases}$ – weighted average (WA) network outputs. The weight vector is calculated each time the original ensemble is evaluated to obtain the best solution for the particular case, rather than selecting the weights statically.

III. RESULTS OF THE EXPERIMENT

The datasets used in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://doi.org/10.5281/zenodo.5279448.

As one of the options for constructing a neural network of ensemble topology for solving the problem of diagnosing valvular heart diseases, a hybrid neural network was studied, consisting of a multilayer perceptron, a radial-basic neural network, and an Elman recurrent network.

The efficiency of any machine learning model is determined using measures such as True Positive Rate, False Positive Rate, True Negative Rate and False Negative Rate. The sensitivity and specificity measures are commonly used to explain clinical diagnostic test, and to estimate how good and consistent was the diagnostic test. The sensitivity metrics is the truepositive rate or positive class accuracy, while specificity is referred to as true negative rate or negative class accuracy. However, there is often a trade-off between the four performance measure metrics in "real world" applications. We obtained 94% classification accuracy from experiments performed on a data set containing 150 samples. Our system also received 100% sensitivity and 95% specificity.

IV. CONCLUSIONS

A study was conducted, as a result of which the structure of the automated system of construction of neural networks of ensemble type was developed, which allows to increase the efficiency and accuracy of diagnosis of heart valve diseases, to reduce the time of diagnosis.

In this paper, the existing algorithms of structural-parametric synthesis are investigated and, as a result, the algorithm of structural-parametric synthesis of the ensemble of neural networks is developed to solve the classification problem, which allows to increase the accuracy of networks.

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Sineglazov Victor. orcid.org/0000-0002-3297-9060. Doctor of Engineering Sciences. Professor. Head of the Department.
Aviation Computer-Integrated Complexes Department, Faculty of Air Navigation Electronics and Telecommunications, National Aviation University, Kyiv, Ukraine.
Education: Kyiv Polytechnic Institute, Kyiv, Ukraine, (1973).
Research area: Air Navigation, Air Traffic Control, Identification of Complex Systems, Wind/Solar power plant.
Publications: more than 660 papers.
E-mail: svm@nau.edu.ua

Smirnova Julija. Master.
Aviation Computer-Integrated Complexes Department, National Aviation University, Kyiv, Ukraine.
Research interests: artificial neural networks.
Publications: 1.
E-mail: ironylp18@gmail.com

В. М. Синєглазов, Ю. В. Смірнова. Інтелектуальна діагностика захворювання серця на основі використання ансамблю нейронних мереж

Розглянуто проблему побудови інтелектуальної системи діагностики ураження клапанів серця. Показано, що діагноз встановлюється на підставі результатів стандартного обстеження, яке включає анамнез, лабораторні дані, електрокардіограму, ехокардіограму та допплерівське дослідження. Для вирішення поставленого завдання обґрунтовано використання гібридних нейронних мереж ансамблевої топології. Запропоновано алгоритм структурно-параметричного синтезу гібридних нейронних мереж ансамблевої топології. Як критерії були використані точність та різноманітність. Наведено структуру діагностичної системи розпізнавання клапанних захворювань серця. Наведено результати досліджень розробленого програмного забезпечення. Що ж до навчання компонентних нейронних мереж, то використовується підхід Бегінгу. Подано структуру діагностичної системи для розпізнавання клапанних вад серця. Наведено результати дослідження розробленого програмного забезпечення.

Ключові слова: хвороба серця; ансамбль нейронних мереж; захворювання; електрокардіограма; ехокардіографія; Допплерівське дослідження.

Синєглазов Віктор Михайлович. orcid.org/0000-0002-3297-9060.
Доктор технічних наук. Професор. Завідувач кафедрою.
Кафедра авіаційних комп’ютерно-інтегрованих комплексів, Факультет аеронавігації електроніки і телекомунікацій, Національний авіаційний університет, Київ, Україна.
Освіта: Київський політехнічний інститут, Київ, Україна, (1973).
Напрям наукової діяльності: аеронавігація, управління повітряним рухом, ідентифікація складних систем,

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E-mail: svm@nau.edu.ua

Смірнова Юлія Василівна. Магістр.
Кафедра авіаційних комп'ютерно-інтегрованих комплексів, Національний авіаційний університет, Київ, Україна.
Напрям наукової діяльності: штучні нейронні мережі.
Кількість публікацій: 1.
E-mail: ironylp18@gmail.com

В. М. Синеглазов, Ю. В. Смирнова. Интеллектуальная диагностика заболеваний сердца на основе использования ансамбля нейронных сетей

Рассмотрена проблема построения интеллектуальной системы диагностики поражения клапанов сердца. Показано, что диагноз устанавливается на основании результатов стандартного обследования, которое включает анамнез, лабораторные данные, электрокардиограмму, эхокардиограмму и допплеровское исследование. Для решения поставленной задачи обосновано использование гибридных нейронных сетей ансамблевой топологии. Предложен алгоритм структурно-параметрического синтеза гибридных нейронных сетей ансамблевой топологии. В качестве критериев были использованы точность и разнообразие. Приведена структура диагностической системы распознавания клапанных заболеваний сердца. Представлены результаты исследований разработанного программного обеспечения. Что касается обучения компонентных нейронных сетей, то используется подход Бэгинга. Представлена структура диагностической системы для распознавания клапанных пороков сердца. Представлены результаты исследования разработанного программного обеспечения.
Ключевые слова: болезнь сердца; ансамбль нейронных сетей; болезнь; электрокардиограмма; эхокардиография; Допплеровское исследование.

Синеглазов Виктор Михайлович. orcid.org/0000-0002-3297-9060.
Доктор технических наук. Профессор. Заведующий кафедрой.
Кафедра авиационных компьютерно-интегрированных комплексов, Факультет аэронавигации электроники и телекоммуникаций, Национальный авиационный университет, Киев, Украина.
Образование: Киевский политехнический институт, Киев, Украина, (1973).
Направление научной деятельности: аэронавигация, управление воздушным движением, идентификация сложных систем, ветроэнергетические установки.
Количество публикаций: более 660 научных работ.
E-mail: svm@nau.edu.ua

Смирнова Юлия Васильевна. Магистр.
Кафедра авиационных компьютерно-интегрированных комплексов, Национальный авиационный университет, Киев, Украина.
Направление научной деятельности: искусственные нейронные сети.
Количество публикаций: 1.
E-mail: ironylp18@gmail.com