Indicators of the Course Remote Procedures Correction according to IoMT the Patient State Assessments in Restorative Medicine

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Abstract

The process of modeling recovery procedures implemented remotely in a 5G network for IoMT and wireless Wi-Fi devices is considered. Reactions to the dynamics of the state vector of Markov chains, as a consequence of deviations in the parameters of the patient state, were studied. An algorithm that establishes a connection between statistical parameters and the facts of hidden failures of measurements has been studied, and definitions have been formed that are suitable for the formation of productive AI rules for the classification of hidden failures. The suitability of the proposed AI tools: the input and output vector of the state, their relative increments, and the assessment of the weight coefficient between the two steps to be information signals of changes in the patient's state was quantitatively investigated. It has been demonstrated that the ratio of the relative changes of the output vector to the relative changes of the input vector is the most sensitive and can serve as a signal indicator of the need for changes in procedures.

Keywords 1

Markov chains, AI tools, classification definitions, relative gains, signal indicators, procedure changes.

1. Introduction

The automation of remote recovery processes, which is a necessary prerequisite for the spread of 5G networks and wireless devices used in health care, is becoming a need of the hour [1]. Examples of the architecture of a successful structure of modules suitable for inclusion in automated control systems (ACS) demonstrate the successful use of single-board Wi-Fi controllers for monitoring and data collection [2 4]. It is also predicted that their use in the Internet of Medical Things (IoMT) will spread [5 6]. In addition, the prevalence of such gadgets as notebooks, doctors' books, nurses' smartphones, sensor instruments for patient monitoring, and other medical technologies contribute to their widespread use [7 8].

At the same time, adaptation of auxiliary elements for long-term monitoring, formation of sequence, and adjustment of the course of procedures as part of a wireless sensor network to restore and maintain activity creates a new set of problems [9]. The first group is the comfort of use. The second is the inability of the sensors themselves to work for a long time without supervision for bio-medical non-invasive research [10]. The third is the unpreparedness of information technologies and ACS for home support of the patient, which provides correction without the direct presence of a doctor [11]. Under these conditions, the search for tools and mechanisms, algorithmic and software for the implementation of methods regulated by the Ministry of Health under the conditions of using socio-economically available equipment, which will ensure their effective implementation, becomes relevant.

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2. Analysis of recent publications and identification of unsolved problems

One of the works that studied the necessity of implementing monitoring and the technical capabilities of socially accessible remote medicine suggests the use of GSM modules as a distribution and replacement or addition in rural and hard-to-reach areas of Internet networks [12]. However, the limitation of the number of control parameters with means of infrared heartbeat measurement does not cover all the needs of remote monitoring and recovery. The low cost of devices with functions of an extended list of sensors, a single-board controller of the Arduino Uno series, and a GSM module will help to provide a suitable home base for an effective monitoring system [12]. However, its potential capabilities will still require the development of intellectualized algorithms for the formation of recommendations and quick remote doctor's prescriptions.

Work [13] considers the problem of the efficiency of wireless local networks as a problem of the access method. Carrier-Aware Multiple Access with Collision Avoidance (CSMA/CA) is a promising efficient sharing of the common medium between active stations. On the basis of the predicted determination of the probability of network elements being in one of the possible states, the distribution of the environment and transition diagrams are controlled with the involvement of the generated solutions of the system of differential equations [13].

The synthesis of the properties of Markov chains and the task of improving the model due to the combined use of artificial neural networks with the properties of express estimation of synaptic weights has not exhausted its potential properties [14]. The formation of a structure suitable for recurrent reconfiguration using calibration is formed together with the analytical determination of the coefficients of synaptic weights and recurrent reconfiguration [14]. However, today there are no known examples of such a complex neural network application that provides improvement and correction input vector of Markov chain models.

The work [15] offers evaluations of the functioning and security of critical infrastructure and the model of functioning of the cyber-physical system by calculating metric criteria. The proposed analytical approach summarizes the results of the expert evaluation of the system in VPR-metrics and the results of the statistical processing of information about the operation of the system presented in the parametric space of the Markov model. Reducing the required amount of empirical way of choosing the required amount to obtain objective estimates of the system under study [15]. Also, taking into account the configuration scheme and architecture of the security subsystem of the studied system, the completeness, compactness, and ease of interpretation of the evaluation results are evaluated when calculating the metric [15]. However, the question of the analysis of the accuracy of the estimates and the correction of the structure and stability of the Markov model remained out of consideration.

As shown in the paper [16], the need for intelligent data analysis involves normalization, and the reduction of the sensitivity of the analysis model by artificial intelligence tools to fluctuations in the values of the features in the data set is a factor in increasing the stability of the assessment of the adequacy of the model under study. However, the last statement without specifying the conditions and circumstances is debatable and subject to further investigation. In addition, the performance of diagnostic and monitoring tasks cannot deviate from the methods regulated by the Ministry of Health. The proposal of using a two-stage method of normalization of numerical sets of medical data, based on the possibility of considering both the interdependencies of each observation from the set and their absolute values, is obviously able to increase the accuracy of the classifier for decision trees and additional trees [16]. However, the lack of estimates of the accuracy of indirect measurement will determine the possibilities of complete metrological evaluations and conclusions.

The combined combination of 5G network and Wi-Fi devices with recovery devices used in medical technologies opens up innovative opportunities for patients, especially the transition from local clinics to rehabilitation in their own homes with the support of family and special doctors and an automated system [17]. Markov chain tools have been improved as a solution to collective description problems. It is shown that the square of the ratio of the output to the input vector is determined by the ratio of the next to the previous probability of the states of the process for an arbitrary step of Markov chains. However, the establishment of the fact of such influence did not determine the causes and connections with the patient's condition and the actual indicators of the condition for certain groups of diseases and obviously requires further research. During modeling, it was established that the change in parameters is observed within 80% of changes in relation to the average value [17]. In addition, it is shown that due to the coordinated application of the recurrent network, opportunities have been created to improve the modeling algorithms of the structure of the model of recovery procedures for post-stroke patients.

A development and addition to the above-mentioned works on modeling by means of regression analysis of a small data set is the work [18], which critically examines the tasks that arise in many industries. Their analysis of problems in cases where there is insufficient chronological data for effective intellectual analysis is particularly important for medicine. Furthermore, the practice of using polar opposite existing tools, which are either very simple, which can lead to erroneous predictions, or complex, which leads to unnecessary overfitting. In contrast, the authors of [18] consider and propose tools for universal intragroup methods for combining data augmentation and elements of ensemble learning, which increases forecast accuracy. Of course, examples of non-linear computational intelligence tools that are studied for different algorithmic implementations of the proposed method using both machine learning algorithms and artificial neural networks work on two short data sets from different fields of medicine. However, the accuracy of predictive solutions requires an increase in the training time of each of the algorithms due to both a significant increase in the sample size and the need for time to generate a doubled amount of input data [18]. The latter complicates the application of the achieved results.

Despite the fact that Markov chains are a powerful tool for evaluating the performance of computer networks and have been used in telecommunications research for more than 100 years, they do not stop demonstrating their new properties and new results [19]. Examples of their application to the assessment of the modern Internet and adaptability when working in network structures successfully implement the description of complex stochastic models of transmitted flows. The demonstrated features of two Markov models of an almost self-similar process, when modeling Internet traffic, reveal the practical correspondence of the obtained results with the data of a known generator of self-similar traffic [19]. The work [20] discusses the problems of successful document circulation, the passage of flows, and business documentation and tools, the use of which in medical practice significantly accelerates and improves the process and leads to the development of the service. Methods of effective use of databases, bank data, and document-oriented storage allow you to make records, make changes to them, perform data searches, and process them. The client application manages the records, automates the processes of interaction between the staff and the patient, and provides for the integration of records and genomic data to achieve better prevention, diagnosis, prognosis, and treatment [20]. In its essence, the global architectural scheme of a specific medical automated system is implemented. The necessary completion of such a system could be the generated genomic data and a list of the body's responses to medicinal actions and prescriptions.

Another problem that arises during the formation of a mathematical model and needs to be solved is the need to estimate the methodological and instrumental error [21]. Its comprehensive examination, as the magnitude of multifactorial influence, is a solution that ensures the informational completeness of the data of direct and indirect measurements [21]. The estimation of tolerances and representation in the form of a quantitative interval for problems of estimating the parameters of radio electronic circuits and by the method of ellipsoidal estimation is presented in the work [22]. However, despite the advantages of parallelization [22], they cannot be implemented due to problems of discontinuities due to quantization. No less important is the problem of determining sensor failures, which is caused by their aging and structural changes in semiconductors, as a result of which changes in characteristics occur and noise is generated [23]. The search and selection of modern methods for early detection of such malfunctions together with the use of differential processing schemes partially solves this problem. However, its solution requires duplication, which increases the cost of the system as a whole [23].

In this regard, as shown in [24], the problem of structuring and assessing the reliability of the hardware part used for processing experimental data during model formation requires duplication, for the formation of several samples and timely identification of hidden failures.

An equally important role in the reliability problems can be played by the created mathematical models of the development of functional quality indicators combined in the metric, in the conditions of asynchronous or synchronous changes in the spatial location relative to the base station of the end devices in the 5G-IoT system [25].

Thus, for the further development of the potential possibilities of modeling methods, there are unsolved problems that need to be solved for the further formation of intellectualized algorithms and the formation of recommendations for fast remote doctor's prescriptions. In addition, the range of combined problems that also require their solution includes the problem of accuracy estimates and accounting and structure correction, control, and ensuring the stability of the Markov model. In particular, their solution must take into account the methods recommended by the Ministry of Health and data from the analysis of the condition of the equipment and hidden failures.

3. Purpose and objectives of the research

The purpose of the study is to improve the processing data algorithms based on the dynamics components control of the vector input from the list and according to the methods recommended by the Ministry of Health, by forming evaluation samples and accounting for the accuracy, stability of the Markov model, and correction of the operating modes of the equipment with insufficient accuracy and hidden failures.

To achieve the goal, the following tasks were formulated:

- to establish a connection between the components of the input vector and the dynamic properties of monitoring parameters, which are regulated by the Ministry of Health for a group of diseases and are measured directly or indirectly by continuous monitoring devices;
- build an algorithm and establish a connection between statistical parameters and the facts of hidden failures of duplicated or control measurements;
- to investigate the suitability of the initial state vector for two consecutive steps, which is defined and ordered by the system time and the evaluation of the weight coefficient between the two steps, to be information signals of changes in the patient state.

4. Improvement of algorithms for preparation of the input vector components based on control of dynamics according to the list recommended by the Ministry of Health. Accuracy and stability in failure conditions

4.1. Algorithms for preparation of components of the input vector based on dynamics control according to the list recommended by the Ministry of Health

Let's assume that for recovery in the post-treatment period (after a certain disease) a list of n indicators and a range of values are specified for the safe conduct of m procedures according to the methodology of the Ministry of Health. Under these conditions, let's also assume that the initial vector of states $\bar{R}$ is set by a special doctor treating the disease and approved by a family doctor. The list of procedures together with the probability of their suctioning is written in n steps, which tells the number of parameters. As shown in [17], the output state vector $\bar{L}$ for two consecutive steps, which is defined and ordered by the system time *Δt* and the estimation of the weight coefficient *δ(t)* between the two steps, is calculated as follows:

$$\bar{L} = \left(\bar{R}^T \|p\|\right)^T \tag{1}$$

and

$$\delta(t)\Big|_{max} \leq 1 + \frac{P(t+\Delta t)^2}{4\left[P(t)\right]^2} \tag{2}$$

A comparative analysis of the dynamics of the values of the modules of the input and output vectors and the range of values of the weight coefficient, especially as an indicator of changes in its upper limit, shows that their deviations, as expected, exceed the limits of permissible errors. The generalized scheme of the post-infarction and post-stroke recovery device was considered [1, 17], which is presented in fig. 1.

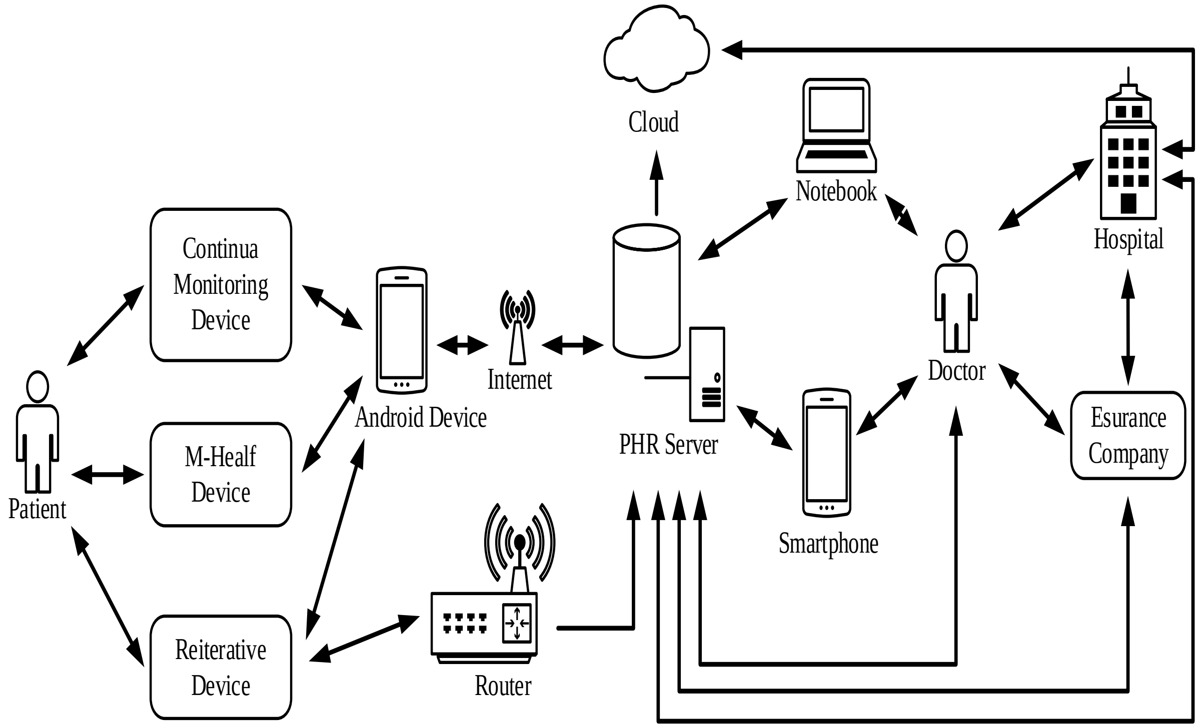

Figure 1: Block schema of the structure of remote rehabilitative ACS, which is integrated into the system of the family doctor [17].

The process of simulating the operation of such a generalized scheme shows that it is not suitable for accounting for the influence of state and well-being parameters, therefore, for further application, it was accepted that it needs clarification. In this regard, it was considered as the main hypothesis that the factor of discrepancies is the lack of accounting for the differential impact of data to the considered as the patient indicators of state on the values of the initial state input vector $\bar{R}$. As an additional hypothesis, the method of expert analysis of special and family doctors was adopted for continuous step-by-step verification, as well as verification every five or ten steps giving samples with clarification of the forecast trends of the output vector and weight coefficient. The review of the process of attracting input information of the results of the measurement of the parameters that determine the state was presented as the process of the structure of the function belonging to a fuzzy expert assessment. Thus, in the range of permissible changes of the parameter (from the lower to the upper boundary), which is measured quantitatively, quantitative assessments of various experts were formed. On the basis of statistical processing, mathematical expectations of the membership function are formed, which, in accordance with the values of the state parameters, determines the sequence and probability of the need to apply the procedure. The independence of such processes and incoherence of actions does not ensure an orderly transfer of data. The data of the mobile electrocardiograph, tonometer, pulse oximeter and paramedical indicators for the comprehensive assessment of the patient's readiness for procedures with physical loads differ both in terms of the values of the limits and in the type of presentation (quantitative and qualitative). In this regard, they need to be brought to a defined quantitative unified range [0,1]. On the basis of what has been said on a formal example, for the i-th component of the input vector $\bar{R}$ as a function of the corresponding i-th component of the vector of patient parameters $\bar{X}$, we present:

$$\tilde{x}_i = \frac{X_i - X_{i\min}}{\left| X_{i\max} - X_{i\min} \right|}, \qquad i = \overline{1, n} \tag{3}$$

Under the conditions of the accumulated data obtained according to the regulated methods of the Ministry of Health in the form of connected sets:

$$R_{ij} = f_j(X_i) \tag{4}$$

then their transformation taking into account the new variables (3), after statistical processing, allows you to find the mathematical expectation m_{ij} and the mean square deviation to construct the normal distribution law, and calculate the value of the probability that it will become the so-and-so i – th component of the input vector:

$$\begin{aligned} & m_{ij}\left[R_{ij}\right] = f_j\left(\tilde{x}_{ij}\right), \\ & p_{ij} = \int_0^1 \frac{1}{\sigma_{ij}\sqrt{2\pi}} e^{-\frac{\left(\tilde{x}-m_{ij}\right)^2}{2\sigma_{ij}^2}} d\tilde{x}; \end{aligned} \tag{5}$$

Obtaining the value of the components constructed in this way requires combining them with qualitative indicators. Suppose qualitative components are represented by experts using the apparatus of fuzzy sets by membership functions:

$$\mu_{ij}\left(\tilde{x}_{ij}\right) = f_j\left(\tilde{x}_{ij}\right)$$

Their processing according to the algorithm (5) reduces all components of the input vector to a defined quantitative unified range [0,1] with a defined mathematical expectation, mean squared deviation. Under the assumption of a normal distribution, according to the algorithm (5), the probability of applying each of the procedures is found. The latter allows finding the sum of the components of the input vector to normalize them and ensure the requirement that their sum is equal to one.

4.2. Relationship between statistical parameters and control of hidden failure facts by means of duplicate or control measurements

An automated system was considered, in which the division into continuous monitoring modules and periodic control modules was applied [1]. A five-point measurement scheme was used to ensure the advantages of the principle of system separation and the justification of lossless compression. It ensured the determination of four first-order derivatives, two second-order derivatives, and one third-order derivative at four points. In the fifth point, the predicted value is calculated and compared with the measured value. For further application and expansion of the possibilities of establishing a connection between statistical parameters and control of the facts of hidden failures and i- that component of the vector of patient parameters of the j-th dimension of channel c, we will present:

$$\tilde{x}_{ij}^c = \tilde{x}_{ij-1}^c + \sum_{j=1}^{K} \frac{\Delta t^k}{k!} \frac{d^k \tilde{x}_{ij}^c}{dt^k}\Bigg|_{t_{j-1}}, \quad j = \overline{1,m} \tag{6}$$

The use of internal memory and definition (6) allows you to calculate the deviation between readings measured at one system time by different channels:

$$\Delta\tilde{x}_{ij}^{c+1} = \left(\tilde{x}_{ij}^{c+1} - \tilde{x}_{ij}^c\right) \tag{7}$$

Under these designations and conditions, the comparison of deviations with the error, which is calculated according to the class of accuracy and the amount of the forecast error, allows the formation of productive rules.

Definition 1. If two samples of five values measured by two channels are not statistically different, and the relative difference at the fifth point is less than the accuracy class of measurement device, then such measurement channels for which the relative difference at the fifth point is less than the accuracy class have been five measurements done in normal mode.

Definition 2. If two samples of five values measured by two channels are statistically different, and the relative difference at the fifth point is greater than the accuracy class, then the measurement channel for which the relative difference at the fifth point is greater operates in the hidden failure mode.

4.3. Suitability of the output vector of the state and the estimation of the coefficient of weights to be information signals

A new feature, the weight coefficient δ(t), which was introduced in [17] and its evaluation in two steps, serves as an upper limit and estimates the growth limitation. Of course, its properties are not obvious and therefore subject to investigation. The main idea of such a numerical experiment is to simulate the effect of changes in the patient's condition indicators on the values of the initial vector $\bar{R}$. It was expected that the simultaneous changes of successive steps' output state vector and the weight coefficient δ(t) estimation between two steps would demonstrate stable repetitive properties. Representation of the corresponding i-th component of the vector of patient parameters, j-th measurement of channel c according to (6) allows to present the initial data and results of the experiment in Table 1.

Table 1
Parameters determining the patient's condition

j	$\tilde{x}_{1j}$, mmHg Art.	$\tilde{x}_{2j}$, mmHg Art.	$\tilde{x}_{3j}$, beats/min	$\tilde{x}_{4j}$,%	$\tilde{x}_{5j}$, degree. C	$\tilde{x}_{6j}$	$\tilde{x}_{7j}$
1	125	68	63	95	36,7	0,87	0,91
2	128	69	60	96	36,6	0,89	0,94
3	124	67	60	95	36,6	0,89	0,93
4	123	65	59	94	36,5	0,86	0,92
5	123	65	59	94	36,5	0,85	0,92

Column 1 shows the measurement number of the parameters that determine the patient state, and columns two through six show the upper and lower pressure, pulse, oxygen concentration, and temperature, respectively. The seventh represents the sensation itself, and the eighth represents muscle fatigue as felt by the patient.

Table 2
Markov network parameters

j	$\lvert\bar{R}_j\rvert$	$\Delta\lvert R_{1j}\rvert/\lvert\bar{R}_{1j}\rvert$	$\delta(t_j)$
1	0,621879	-0,02594	1,23438
2	0,631526	-0,01083	1,227412
3	0,638384	-8,6E-05	0,120325
4	0,643063	0,007243	1,220166
5	0,657342	0,029609	1,208286

Calculations of the input values of the vector $\bar{R}$ were carried out for each j-th dimension presented in tables 2 and 3. The second table used the parameters of the dimensions of table 1. The latter allows monitoring the influence of state parameters on the input vector and relative changes. As can be seen from the analysis data of Table 2, the state parameters have a slight effect on the input vector and the estimation of the weight coefficient, but they significantly affect the relative changes of the input vector, showing a jump of several orders of magnitude.

It should be noted that the output vector also changes relatively monotonously depending on changes in the patient's condition. However, the ratio of the relative change of the output vector (tab. 3, column 3) and the ratio of the relative changes of the output to the relative changes of the input changes (column 4) by two and three orders of magnitude.

Thus, as a result of modeling, it was established that the ratio of relative changes of the output vector to relative changes of the input is the most sensitive and can serve as a signal indicator of changes.

Table 3

Markov network parameters

j	$\lvert\bar{L}_j\rvert$	$\Delta\lvert\bar{L}_{1j}\rvert / \lvert\bar{L}_{1j}\rvert$	$\Delta\lvert\bar{L}_{1j}\rvert\lvert\bar{R}_{1j}\rvert / \Delta\lvert\bar{R}_j\rvert\lvert\bar{L}_{1j}\rvert$
1	0,602139	-9,2329E-05	0,00356
2	0,602321	0,0002099	-0,01939
3	0,603039	0,0014022	-16,2175
4	0,603474	0,00212456	0,293343
5	0,6	-0,00364434	-0,12308

5. Modeling and discussion of the results

Modeling of the process of choosing the sequence of procedures, demonstrated the properties of the analysis tools of the components of the input $\bar{R}$ and output $\bar{L}$ vector (1) and the estimation of the weight coefficient *δ(t)* between the two steps (2).

Due to the Euclidean norm and the statistical data processing algorithm (5), the quantitative and qualitative data were reduced to a single range [0,1] and the relationship between the static and dynamic properties of the monitoring parameters (6) and their deviation according to the duplicated measurement (7) was established. The obtained results became the basis for forming of definitions as the basis of productive rules of intellectual analysis and failure fixation. In addition, the proposed modeling and its analysis in two consecutive steps, ordered by system time, leads to the conclusion that the ratio of relative changes of the output vector to relative changes of the input is the most sensitive and can serve as a signal indicator of the need for changes in procedures.

The implementation of research results in the work algorithms of post-treatment recovery modules requires taking into account the patient's reaction and opinion and ensuring the comfort of use. Such a requirement will need to expand further research taking into account the socio-psychological aspects of the perception of the nature of patient interaction and the course of the process. It is obvious that the above, together with preparation for the required level of knowledge of information technologies for home support of the patient, to ensure the correction of procedures without the direct presence of a doctor, is an equally important task.

6. Conclusions

1. The synchronous and duplicated measurements of the parameters of the patient's conditions can be the basis of the information support of the algorithm of dynamic correction rehabilitative procedures, which are regulated by the standard of the Ministry of Health for a group of diseases. The algorithm of measurement of the deviation output state vector and of estimation of the weight coefficient between the two steps should be needed to ensure for study of it as the reason in dynamic changes the input vector.

2. The connection and determination of correspondence between statistical parameters and facts of hidden failures of duplicated or control measurements establish a comparison of the relations of three features: accuracy class, statistical discrepancy of samples and absolute difference of two synchronous measurements.

3 The highest sensitivity between the output vector of the state for two consecutive steps, which is determined and ordered by system time and weight coefficient estimation, is demonstrated by the ratio of relative changes of the output vector to relative changes of the input, which is the most sensitive among them and can serve as a signal indicator of changes. The changes in the modulus and sign of the value of the ratio of the relative changes of the output vector to the relative changes of the input vector can be used to physically correct an actuated signal in the automated control system for initialization start of correction during of rehabilitative procedure.

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