Using an ontological approach for improvement of the Interval model in the problem of the recurrent laryngeal nerve identification during thyroid surgery

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Abstract

The problem of constructing a mathematical model of the electrophysiological properties of the tissues of a patient's surgical wound around the thyroid gland is discussed in this article. This problem occurs during surgery on the thyroid gland. The technology and means of identification of the reverse laryngeal nerve in the process of surgical intervention are briefly considered. It is shown that the model of distribution of electrophysiological characteristics of woven surgical wounds increases efficiency of detection of recurrent laryngeal nerve. The model is constructed in a differential form on the basis of trial irritation of surgical wound tissues pulsed current with an root mean square (RMS) of current strength value of up to 2 mA. However, this model requires customization for a specific patient, which reduces the effectiveness of the technology of detection of recurrent laryngeal nerve. It is proposed to classify all types of pathologies in the thyroid gland and to develop an ontological model that will serve as a model for managing the selection processes of previously developed difference equations for operated patients. This approach makes it possible to increase the efficiency of existing technology.

Keywords:

interval model, ontological approach, model identification, recurrent laryngeal nerve, thyroid surgery

1. Introduction

Surgical interventions on various human organs often require classification and recognition of surgical wound tissue types. Most often, the surgeon has to identify nerve tissue on the background of muscle and connective tissue in order to avoid damage. Nerve tissue damage can be fatal to the functioning of other human organs. One such tissue is the Recurrent laryngeal nerve (RLN). Its detection and localization is carried out during surgery on the neck or during the removal of thyroid tumors [1]. The means of monitoring the process of this operation are various neuromonitors, which monitor the passage of signals through the RLN and in case of signal disappearance signal to the surgeon about the presence of damage [2]. However, this approach is ineffective because it states the fact of damage. This may be beneficial to health insurance, but is not entirely beneficial to the patient [3].

All these neuromonitors work on the principle of stimulation of tissues by pulsed current at different frequencies and processing of the signal-reaction to stimulation by means of spectral analysis methods, or simple check of conductivity of electric current by nervous tissues [2,3]. Such approaches are not sufficient to establish the location of nerve tissue. During surgery on organs close to critical nerve tissues, such as RLN, the surgeon must have an idea of the location of these tissues on the surgical wound to avoid potential damage. Therefore, it is important not only to establish the fact that the signal passes through the nervous tissue, but also to classify areas of this tissue, to model and predict the possible location of this tissue and thus avoid damage. Such detection methods, tools and information technologies are RLN described in a number of works, in particular in [4].

However, tissue classification to some extent makes it possible to detect the location of the RLN, but does not help the surgeon to predict the distance from the site of surgery to the nerve tissue. The technology for solving this problem is given in [5]. The technology is based on mathematical models, which represent the surface of the surgical site as an object with distributed parameters. Different electrophysiological properties of tissues are observed at each point of surgical wound irritation by alternating or pulsed current. After a series of AC stimuli, you can identify this model - as an object with distributed parameters. Then such a mathematical model will be suitable for predicting the electrophysiological properties of tissues at any point of the surgical wound.

Similar studies are given in [4,5]. In the vast majority, the response to stimulation by alternating or pulsed current is estimated by the amplitude of the information signal [5]. However, it is not possible to measure this amplitude accurately, but with some error. In this case, for each AC stimulus determine the guaranteed interval of the information signal - the response to the stimulus. Next, build an interval model for the spatial distribution of tissue characteristics in the form of a difference equation. Then such a model can be used to identify and predict areas where the RLN is located [5].

It should be noted that such models are built in the form of an algebraic equation, or difference [5]. The use of algebraic equations in this case causes certain difficulties, which are associated with the difficulty of adjusting the electrophysiological properties of the tissues of a particular patient. Therefore, their use in the specified technology of detection of RLN is limited. Recently, the technology of detecting the location of RLN during surgery on the thyroid gland uses interval difference equations. Adjusting them to a specific patient is easier, because in the process of surgery it is enough to choose one of the previously built models for operated patients and adjust the difference scheme for the current patient. For that surgeon it is enough to make some irritations of tissues of a surgical wound pulsed current strength value of up to 2 mA. However, and in this case the situation is difficult. Often such models are inaccurate, and accordingly the technology itself becomes inefficient.

Preliminary observations of patients in the course of a number of thyroid surgeries have shown that the electrophysiological properties of the tissues of the surgical wound of patients largely depend on the pathology of the thyroid gland. Therefore, it was decided to improve the existing technology through the use of an ontological model that contains all the acquired knowledge about the pathologies of patients who have been operated on to remove a thyroid tumor.

2. Features of the interval model and identification method

Consider the features of the construction of the above model in the form of an interval difference equation.

Suppose you performed a series of tissue irritations on a surgical wound with current strength of up to 2 mA. Also, let the results of those stimuli received the characteristics of the information signal in the interval form. Then the results of these stimuli are presented as follows:

$$[z_{i,j}] = [z_{i,j}^{-}, z_{i,j}^{+}], i = 1,\ldots,I, j = 1,\ldots,J, [z_0(i,j)] \in [z_{i,j}^{-}; z_{i,j}^{+}], \quad (1)$$

where $[z_0(i,j)]$ is the value of the signal which obtained after processing the data of the reaction to surgical wound stimulation $i = 1,\ldots,I, j = 1,\ldots,J$; $z_{i,j}^{-}, z_{i,j}^{+}$ are the min and max values of the corridor for the amplitude signal; $i = 1,\ldots,I, j = 1,\ldots,J$ are a discrete coordinate of the spatial distribution of tissue characteristics of the surgical wound;

In expression (1) takes into account the main errors of technical or other tools.

A model for RLN identification is considered as a discrete equation, that is, the main difference equation in such form [1, 5]:

$$[\hat{v}_{i+1,j+1}] = [\hat{v}_{i+1,j+1}^{-}; \hat{v}_{i+1,j+1}^{+}] = \vec{f}^{T}([\hat{v}_{0,0}], \ldots, [\hat{v}_{0,j}], \ldots, [\hat{v}_{0,j}], \ldots, [\hat{v}_{i,j}]) \cdot \hat{\vec{g}},$$
$$i = d+1,\ldots,I, j = d+1,\ldots,J, \quad (2)$$

where $\vec{g}$is a vector of unknown parameters of discrete difference equation; $d$is order of difference equation; $\vec{f}^{T}(\bullet)$is a vector of is a vector of special functions, can be linear, that define the structure of discrete equation; $\hat{v}_{i,j}$ is a predicted value of main amplitude in the mark with specified discrete coordinates i, j. Further, the mathematical model (2) will be called an interval difference equation (IDE).

Based on the conditions (1) of guaranteeing the accuracy of the mathematical model within the accuracy of the main experiment, the IDE (2) will be configured according to the specified criterion [4, 5]:

$$[\hat{v}_{i,j}^{-}; \hat{v}_{i,j}^{+}] \subset [z_{i,j}^{-}; z_{i,j}^{+}], \forall i = 1, \ldots, I, \forall j = 1, \ldots, J. \quad (3)$$

By substituting in the formula (3), the other recurrent formula (2) instead of the interval evaluations $[\hat{v}_{i,j}^{-}; \hat{v}_{i,j}^{+}]$, we obtain the interval system of non-linear algebraic equations (ISNAE) with the defined values of the interval:

$$\begin{cases} [\hat{v}_{0,0}^{-}; \hat{v}_{0,0}^{+}] \subseteq [z_{0,0}^{-}; z_{0,0}^{+}]; \\ \vdots \\ [\hat{v}_{d,d}^{-}; \hat{v}_{d,d}^{+}] \subseteq [z_{d,d}^{-}; z_{d,d}^{+}]; \\ z_{d+1,d+1}^{-} \le \vec{f}^{T}([\hat{v}_{0,0}], \ldots, [\hat{v}_{0,j}], \ldots, [\hat{v}_{i,0}] \ldots \\ \ldots, [\hat{v}_{d,d}], \vec{u}_0, \ldots \vec{u}_k) \cdot \hat{\vec{g}} \le z_{d+1,d+1}^{-}; \\ \vdots \\ z_{I,J}^{-} \le \vec{f}^{T}([\hat{v}_{0,0}], \ldots, [\hat{v}_{0,j}], \ldots, [\hat{v}_{i,0}] \ldots \\ \ldots, [\hat{v}_{I,J-1}], \vec{u}_0, \ldots \vec{u}_k) \cdot \hat{\vec{g}} \le z_{I,J}^{-}; \\ i = d+1 \ldots I, \quad j = d+1 \ldots J, \quad k = 0 \ldots K. \end{cases} \quad (4)$$

In contrast to the linear case [6] nonlinear parameters represented in such system. The method based on the behavioral model of artificial bee colony [6,7] is used for its identification.

The application of this model identification method involves the execution of activity phases of all types of bees in the colony: employed bees, scout bees and onlooker bees [8].

Thus, using the parametric and structural identification [4,5] we obtain the interval of the mathematical model which is dispensation of the max amplitude (or amplitude of the spectral component) of the information signal on the surface of the surgical wound.

For example, take the model built in [5]. In Table 1 represented the part of data obtained during of diseases of the thyroid gland surgery.

Table 1

Fragment of the Set of Values of the Amplitude of the Spectral Components

№	Coordinates			Interval values
	i	j		$[z_{i,j}]$
1	0	0		[0,58;0,92]
2	0	1		[0,45;0,54]
3	0	2		[0,39;0,44]
…	…	…		…
24	4	3		[0,025;0,034]
25	4	4		[0,016;0,025]

Such a structure of the model for Recurrent laryngeal nerve identification was obtained on the last iteration of method implementation:

$$\begin{gathered} [\hat{v}_{i,j}^{-}; \hat{v}_{i,j}^{+}] = -0.0161 + 0.503 \cdot [\hat{v}_{i,j-2}^{-}; \hat{v}_{i,j-2}^{+}] \\ +0.2145 \cdot [\hat{v}_{i-1,j}^{-}; \hat{v}_{i-1,j}^{+}] + 0.7969 \cdot [\hat{v}_{i,j-1}^{-}; \hat{v}_{i,j-1}^{+}] \cdot [\hat{v}_{i,j-1}^{-}; \hat{v}_{i,j-1}^{+}] \\ +0.6344 \cdot [\hat{v}_{i-1,j-1}^{-}; \hat{v}_{i-1,j-1}^{+}] \cdot \\ \cdot [\hat{v}_{i,j-1}^{-}; \hat{v}_{i,j-1}^{+}] \cdot [\hat{v}_{i,j-1}^{-}; \hat{v}_{i,j-1}^{+}], \\ i=1\ldots4, j=2\ldots4, \end{gathered} \quad (5)$$

where $[\hat{v}_{i,j}^{-}; \hat{v}_{i,j}^{+}] \subset [z_{i,j}^{-}; z_{i,j}^{+}] = [z_{i,j} - z_{i,j}0{,}02; z_{i,j} + z_{i,j}0{,}02]$ and {i=0, j=0,…,4} ∨ {i=0,…,4, j=0,1} are the initial conditions.

As you can see, to customize this model for a particular patient, you need to set 14 points for the initial conditions. This means that in the process of surgery, the surgeon must make at least 14 irritations of the tissues of the surgical wound at certain points. However, if you create a repository of models that were built during the operated patients and use it for subsequent patients, it is possible to significantly reduce the time of the operation at the preparatory stage, when the surgeon identifies RLN.

3. Using an ontological approach for improvement of the interval model in the problem of the recurrent laryngeal nerve identification during thyroid surgery

The paper proposes an ontological approach to present the concepts, methods and means of mathematical modeling on the basis of interval data, namely the declarative and procedural parts, mathematical knowledge is separated. The declarative part of ontology consists of the information needed to build the model, the information derived from the mathematical model and the corresponding mathematical expressions that represent the model. The procedural part consists of detailed parts of the mathematical model, appropriate methods and algorithms for their implementation, procedures for initializing.

The ontology of a mathematical model consists of an operating class, the subclasses of which are various operations that occur during the implementation of the model, and also contain the conditions for the implementation of each of the operations. This ontological description also consists of a class of results, which stores the results of the solution of the model, as well as the results of experiments.

The procedural part of the approach consists of a mechanism of construction based on methods of data relationship analysis, which analyzes equations in the ontological interpretation of mathematical models and translates them into expressions that can be interpreted in other external software environments [9].

Based on the analysis of the structure of mathematical models based on interval data, the modeling process and the features of experiments, the mathematical model in terms of ontological approach can be formalized using the following structures:

$$Mm = \langle Ma, Mi, Mo, Par, M\,r, M\,c, Mmt\rangle, \quad (6)$$

where Ma is the subject area within which the mathematical model is built or used; Mi - descriptions of the mathematical model;Mo - the set of objects of use of the model; $Attr$ - set of parameters; Mr is a set that describes the result of building object models; Mc - set of characteristics of the experiments; Mmt - set of methods for identifying model parameters.

$$Ma = \langle IdMa, NmMa\rangle, \quad (7)$$

where $IdMa$ - subject area identifier; $NmMa$ - subject area.

$$Mi = \langle IdMi, NmMi, IdMa\rangle, \quad (8)$$

where $IdMi$ - equation identifier; $NmMi$ - formalized description of the equations of the mathematical model;

$$Mo = \langle IdMo, NmMo, IdMa, IdMi\rangle, \quad (9)$$

where $IdMo$ - is the object identifier; $NmMo$ is the information that describes the structure of the model's use object.

$$Par = \langle IdPar, PT, PV, IdMa, IdMi, IdMo\rangle, \quad (10)$$

where $IdPar$ - parameter identifier; PT - parameter type; TV - values of model parameters;

$$M\,r = \langle IdM\,r, R\,Nm, IdMa, IdMi, IdMo\rangle, \quad (11)$$

where $IdMr$ - result identifier; RNm - statements that describe the result.

$$Mc = \langle IdMc, MA, Dsc, IdMa, NA, IdMo, IdMi, IdPar\rangle \quad (12)$$

$$SuMth = \langle IdMmt, IdMc\rangle, \quad (13)$$

where $SuMth$ - method of identification of model parameters; $IdMc$ - identifier of features that affect the conditions of the experiments; MA - main characteristics; NA - alternative characteristics, Dsc - a statement that describes the conditions of use of the mathematical model.

$$Mmt = \langle IdMmt, IdMth, IdMo, IdMa, IdMi, IdPar\rangle \quad (14)$$

$$Mth = \langle IdMth, NmMth, Ac\rangle, \quad (15)$$

where $IdMth$ - is the method identifier; $NmMth$ - method of identification of model parameters; Ac - is the set of statements that defines the method.

Figure 1 shows an example of the implementation of the ontological approach for the tasks of visualization of the RLN in the process of complex surgery on the thyroid gland, the features of the implementation of some described in detail in [5,10].

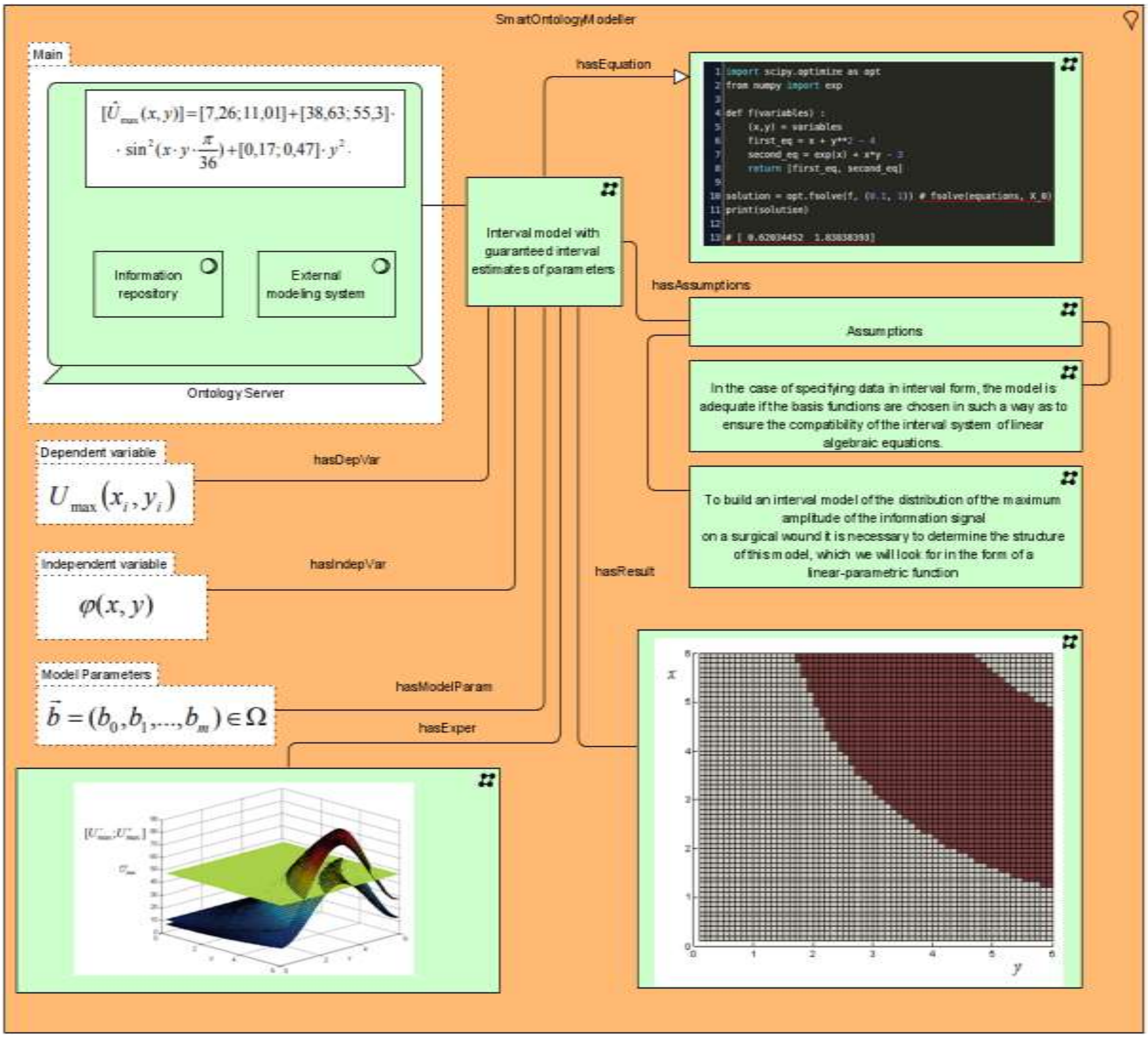

Figure 1: An example of the implementation of the ontology of the interval model for the task of visualization of the inverse RLN during surgery on the thyroid gland in the environment SmartOntologyModeller

4. Conclusion

Methods, means and information technology for predicting the placement of nerve tissues during surgery on the neck or removal of a tumor on the thyroid gland are considered. The technology is based on the construction of an interval difference operator, which describes a surgical wound with its electrophysiological properties as an object with distributed parameters.

Application of the ontological approach in the above-mentioned RLN identification technology. Provides significant time savings for thyroid surgery. Because, instead of completely building an interval model in the form of a difference equation, the surgeon enters the results of the patient's examinations before the operation (history).

Then, using the ontological model and the repository of interval models for the operated patients, the most adequate model is selected. If necessary, the surgeon can make additional adjustments to the model. However, this will not require a large number of irritations in the area of surgery.

It should be noted that the proposed ontology approach is currently being tested during surgery on the thyroid gland. Additional results can be published after the completion of the tests, ie if there is a sufficient sample of statistics.

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