Methods and Tools for Electrophysiological Monitoring of Recurrent Laryngeal Nerve Monitoring During Surgery on Neck Organs

Mykola Dyvak[1], Volodymyr Tymets[1], Andriy Dyvak[2], Oksana Huhul[1],

1. Faculty of Computer Information Technologies, Ternopil National Economic University, UKRAINE, Ternopil, 8 Chekhova str., e-mail: mdy@tneu.edu.ua, volodymyrtymets@gmail.com, oksansggg@i.ua

2. Department of Surgery with Urology №1 by L.Ya. Kovalchuk, I. Horbachevsky Ternopil State Medical University, UKRAINE, Ternopil, 1 Maidan Voli, e-mail: dyvak_anmy@tdmu.edu.ua

Abstract – **Methods and tools for electrophysiological monitoring and identification of recurrent laryngeal nerve (RLN) are considered in the paper. The method of identification and tools for stimulation of surgical wound tissues during surgery on neck organs are represented. Improved information technology of RLN identification and results of its application are shown**.

Keywords– **neck organs surgery, recurrent laryngeal nerve, single-board computer, multi-functional electro-stimulator.**

I. Introduction

Recurrent laryngeal nerve (RLN) monitoring is very important procedure during the neck surgery. For this purpose, special neuro monitors are used. They work based on the principle of surgical wound tissues stimulation and estimation of results of such stimulation [1-5]. The main problem that arises during this process is the proper choice of stimulation methods. In [1] and [4], the latest results of researches related to RLN neuro-monitoring are represented.

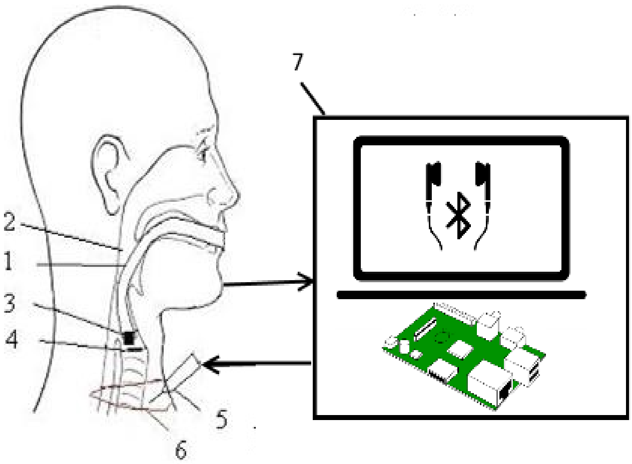
Other electrophysiological method of RLN stimulation and monitoring requires the alternating current with fixed frequency [7]. The methods and mathematical models for solving this problem are considered in [6-7].

The main problem of the mentioned methods is a high risk of RLN damage. This risk is mainly caused by the accuracy of output information signal (result of surgery wound tissues stimulation) processing. Methods of spectral analysis of this signal [7] give an opportunity to select the main spectral component and to classify the surgery wound tissues. Methods of RLN location visualisation based on building the model of distribution of amplitude of the information signal on the surgery wound allow to detect the high-risky area [7]. The combination of these method in one information technology of processing of signal (reaction on the surgery wound tissues stimulation) is an important task. The paper is dedicated to this task.

The method of RLN monitoring is based on the task of its stimulation as the first sub-task. Other aspect of the task is the processing of reaction on RLN stimulation. After the processing, a conclusion about the RLN location in the surgery area is made.

II. Task Statement

Let's consider the functionality principles of existing hardware solution for RLN identification. The scheme of the device is shown in Fig.1 [7].



1 is respiratory tube, 2 is larynx, 3 is sound sensor, 4 are vocal cords, 5 is probe, 6 is surgical wound, 7 is multifunctional block for RLN stimulation and visualize of RLN

Fig. 1. Scheme of device and method for RLN identification

In respiratory tube 1 that inserted into larynx 2, the sound sensor 3 implemented and positioned above vocal cords 4.

Probe 5 connected to alternator. It performs the function of a current generator controlled by the single-board computer 7. Surgical wound tissues are stimulated by the alternating current with the fixed frequency via probe. As a result, vocal cords 4 are stretched.

Flow of air that passes through patient's larynx, is modulated by stretched vocal cords. The result is registered by voice sensor 3. Obtained signal is amplified and is processed by single-board computer 7.

For processing of obtained signal, special software is installed on a single-board computer. The main functions of the software are:

- segmentation of information signal based on analysis of its amplitude;

- analysis of amplitude spectrum using Fourier-transform;
- calculation of a spectral component with a maximal amplitude (let’s call it “the main spectral component” further);
- classification of tissues of surgical environment at the points of stimulation using threshold method.

Software for changing the frequency of RLN stimulation is written in programming language Node.js. Node was created by Ryan Dahl. Now Node.js is a trademark of Joyent, Inc. and is used with its permission and maintained by the Node.js Foundation [8-9]. Node is open-source platform and located on Github.

Block of processing and displaying information is developed based on single-board computer Raspberry Pi 3 [10].

Raspberry Pi 3 was selected because of two upgrades made to it. The first one is a next generation Quad Core Broadcom BCM2837 64-bit ARMv8 processor making the processor speed increased from 900 MHz in the Pi 2 to up to 1.2GHz in the Pi 3.
The second one is addition of the built-in BCM43143 Wi-fi chip. There is also Bluetooth Low Energy (BLE) module implemented on the board.

At the same time, such an approach does not ensure a significant decrease in the RLN damage risk. For detection of high-risky area of surgery, it is expedient to build a mathematical model for RLN identification.

For these purposes, we use the properties of surgical wound tissues which are characterized by a different reaction on the stimulation by alternating current with a fixed frequency. In Fig. 2, the fragments of amplified information signal obtained from the sound sensor and fragments of their spectral characteristics are shown.

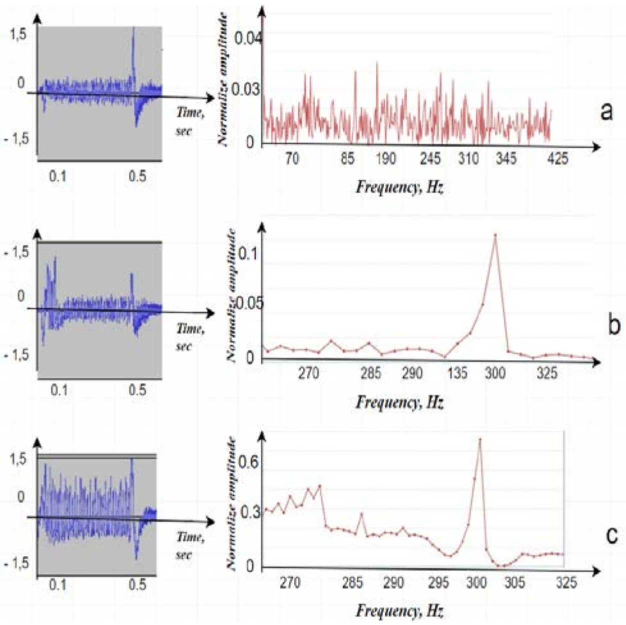


Fig. 2. Result of stimulation of RLN by alternating current with frequency of 300 Hz.

We can see the result of stimulation of the muscle tissue at a distance of more than 1 cm from RLN, with a specific blurred spectrum, without a clearly distinguished main spectral component in Fig. 2 a). Fig. 2 b) reflects the result of stimulation of the muscle tissue at a distance of not more than 3 mm, with a specific distinguished main spectral component with a small amplitude value. Finally, the result of RLN stimulation with a specific main spectral component with a sufficiently high normalized amplitude (6 times higher than in the previous case) is illustrated in Fig. 2 c).

The described properties give a possibility to develop the method, mathematical model and to improve the RLN identification technology in general.

III. Mathematical model for RLN identification

Let’s represent obtained set of stimulated points in such form:

$$[z_{i,j}] = [z^-_{i,j}, z^+_{i,j}], i = 1, \dots, I, j = 1, \dots, J, \quad (1)$$

where $[z_{i,j}]$ is an interval estimation of the normalized amplitude of main spectral component; *i*, *j* are indices of discrete increments of coordinate values on *X* and *Y* axes relatively to some initially given point. Interval estimation of the amplitude $[z_{i,j}]$ is caused by the fact that different values of main spectral component amplitude $z_{i,j}$ may be obtained for equal values of *i* and *j*. In addition, there is some error of detecting the point with coordinates *i*, *j*.

A mathematical model for RLN identification is considered as a discrete difference model (DDM), that is, the difference scheme in such form [1, 7]:

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

where $\vec{f}^T(\bullet)$ is a vector of unknown basis functions that define the structure of DDM; $\hat{v}_{i,j}$ is a predicted value of main spectral component amplitude in the point with discrete specified spatial coordinates *i*, *j*; $\vec{g}$ is a vector of unknown parameters of DDM; d is order of DDM. Further, the model (2) will be called an interval discrete difference model (IDDM).
To identify this model, the results of measurement of the main spectral component amplitude in the points of stimulation are used.

Based on the requirements of ensuring the accuracy of the model within the accuracy of the experiment, the setting of IDDM (2) will be realized using such criterion [2]:

$$[\hat{v}^-_{i,j}; \hat{v}^+_{i,j}] \subset [\hat{z}^-_{i,j}; \hat{z}^+_{i,j}], \forall_i = 1, \dots, \forall_j = 1, \dots, J. \quad (3)$$

By substituting in the expression (3), the recurrent expression (2) instead of the interval estimations $[\hat{v}^-_{i,j}; \hat{v}^+_{i,j}]$, together with the defined initial interval values, we obtain the interval system of non-linear algebraic equations (ISNAE) [12]:

$$\begin{cases} [\hat{v}_{0,0}^{-}; \hat{v}_{0,0}^{+}] \subseteq [\hat{z}_{0,0}^{-}; \hat{z}_{0,0}^{+}]; \\ \vdots \\ [\hat{v}_{i-2,j-2}^{-}; \hat{v}_{i-2,j-2}^{+}] \subseteq [\hat{z}_{i-2,j-2}^{-}; \hat{z}_{i-2,j-2}^{+}]; \\ [\hat{v}_{i-1,j-1}] = \vec{f}^{T}([\hat{v}_{0,0}], \dots, [\hat{v}_{i-2,j-2}], \\ \vec{u}_{o}) * \vec{\hat{g}}\,; \\ z_{i,j}^{-} \leq \vec{f}^{T}([\hat{v}_{0,0}], \dots, [\hat{v}_{i-1,j-1}], \vec{u}_{i,j}, \dots, \vec{u}_{i,j}) * \\ \vec{\hat{g}} \leq z_{i,j}^{+} \\ z_{i+1,j}^{-} \leq \vec{f}^{T}([\hat{v}_{0,0}], \dots, [\hat{v}_{i-1,j-1}], \vec{u}_{i,j}, \dots, \vec{u}_{i,j}) * \\ \vec{\hat{g}} \leq z_{i+1,j}^{+} \\ i = 2, \dots I, j = 2 \end{cases}$$

The solution of the obtained system is a vector of unknown parameters of IDDM $\hat{g}$. Methods of solving of this system are described in the papers [11-12].

The obtained model in the form of IDDM (2) is graphically represented in Fig. 3.

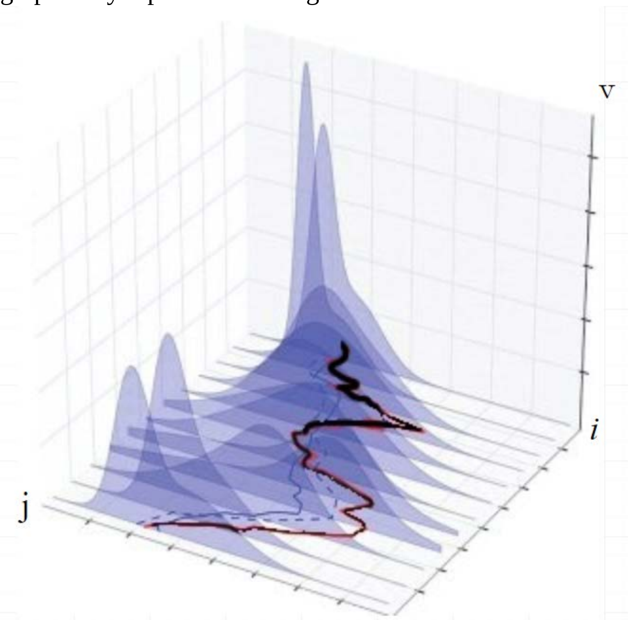


Fig. 3. Visualization of RLN location using IDDM (2).

As we see in Fig. 3, the distribution of values of amplitude of the main spectral component of signals as the reaction on RLN stimulation and surgical wound tissues stimulation is marked with grey color. The RLN location is marked by black colored line on the plane.

IV. Methods and tools of elecrtophysiological momitoring RLN

For RLN location identification in the surgery area during surgery on neck organs, we improved the information technology. This technology consists of 4 main steps, a detailed description of which is given below. The scheme of the information technology is shown in Fig. 4.

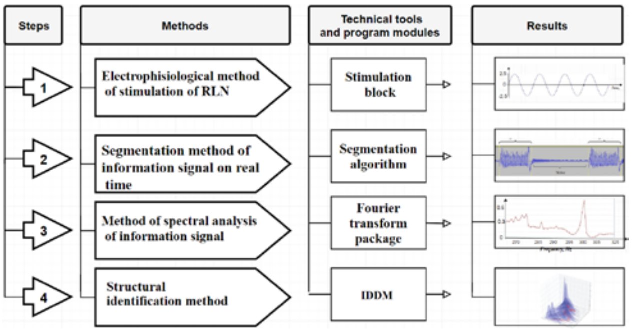


Fig.4. Scheme of information technology for information signal (as a result of stimulation of surgical wound of tissues) processing.

Step 1. Obtaining of information signal (as result of stimulation of surgery wound tissues).

At this step, the multifunctional block for surgical wound tissues stimulation is used. The result of stimulation is recorded by the sound sensor. The obtained information signal is digitized and processed by the single-board computer Raspberry Pi 3. The stimulation results are processed in a real-time mode. Also, they may be stored on the external data storages.

Step 2. Segmentation of information signal.

This step is needed to highlight the patient reaction on tissues stimulation from sound signal taken during inhale or exhale.

In Fig. 4, the information signal is displayed and the segmentation principle is visually represented. As we can see from the Fig. 2, there are two segments. Each of them is result of the stimulation of RLN. The intervals between the segments represent delay of a patient's breath. These intervals are not informative for tissue classification method and named as the noise.

Unlike existing method of segmentation "synchronization with the appearance of the current of stimulation", main approach of automatic segmentation is based on the principle of threshold choice of an informative segment.

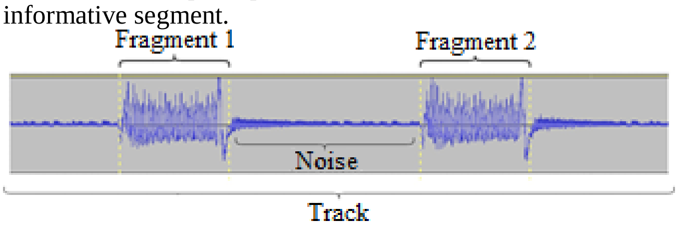


Fig. 5 Illustration of the information signal segmentation.

Because information signal is represented in digital form, for determining of segment beginning to estimate the energy threshold of current, *n* countdowns are proposed:

$$E = \sum_{i=1}^{n} u_i^2, \tag{4}$$

where u_i is i-th countdown of information signal.

If this energy exceeds the threshold, then, this is the beginning of the segment:

$$E \geq E_{tr}, \text{ then, } u_{start} = u_n. \tag{5}$$

If the energy of n counts is less than the threshold, then, this is the end of the segment:

$$E \leq E_{tr}, \text{then}, u_{stop} = u_n. \quad (6)$$

So, the resulting segment consists of a set of countdowns:

$$U = \{u_i \in [u_{start}; u_{stop}]\}, \quad (7)$$

where $[u_{start}; u_{stop}]$ is interval of countdowns of determined signal.

Step 3. Selecting of the main spectral component.

After segmentation of information signal recorded by sound sensor, it is necessary to select the main spectral component of the information signal. At first, the Fourier transform is used for this.

As it is shown in Fig. 2, the amplitude of the main spectral component depends on the distance from the stimulation point to the RLN. Therefore, the amplitude of the selected spectral component is in inverse proportion to this distance.

The obtained at this stage data array is represented in the form (1).

Step 4. Modeling of distribution of the main spectral component amplitudes.

A mathematical model for RLN identification is considered as an interval discrete dynamic model that is, the difference scheme in form (2). For its identification, the method of structural and parametric identification based on the behavioral model of artificial bee colony [13-14] is used. Behavioral model of artificial bee colony imitates the foraging behavior of the honeybee colony [13].

The application of this IDDM structural identification method involves the implementation of activity phases of all types of bees in the colony: onlooker bees, employed bees and scout bees. Let's consider all stages of implementation of IDDM structural identification method in more details. The result, at this stage, is the model that graphically represented in Fig. 3. Probable RLN location is illustrated by black line.

The test examples with sample of over 1500 stimulation points for different patients showed that using presented technology allow to decrease the RLN damage risk from 20% to 14%. So, the proposed methods and tools for electrophysiological RLN monitoring have a good perspective of development and application.

VI. Conclusion

The proposed methods and tools for electrophysiological RLN monitoring and identification are realized using single-board computer Raspberry Pi 3. Applying of this methods for previously obtained sample of signals (reaction on stimulation of surgical wound tissue) showed good results. In particular, it was shown that for sample of over 1500 stimulation points for different patients using this technology, the risk of RLN damage is decreased from 20% to 14%.

Acknowledgment

This research was supported by National Grant of Ministry of Education and Science of Ukraine “Mathematical tools and software for classification of tissues in surgical wound during surgery on the neck organs” (0117U000410).

References

[1] Abstract book of First World Congress of Neural Monitoring in Thyroid and Parathyroid Surgery, Krakow, Poland, 2015, 161 pp.

[2] M.C.D. Poveda, G. Dionigi, A. Sitges-Serra, M. Barczynski, P. Angelos, H. Dralle, E. Phelan and G. Randolph. “Intraoperative Monitoring of the Recurrent Laryngeal Nerve during Thyroidectomy: A Standardized Approach (Part 2)”. *World Journal of Endocrine Surgery*, vol. 4, no. 1, pp. 33-40, 2012.

[3] V.K. Dhillon and R.P. Tufano. “The pros and cons to real-time nerve monitoring during recurrent laryngeal nerve dissection: an analysis of the data from a series of thyroidectomy patients”. *Gland Surgery*, vol. 6, no. 6, pp. 608-610, 2017.

[4] H.Y. Kim, X. Liu, C.W. Wu, Y.J. Chai and G. Dionigi. “Future Directions of Neural Monitoring in Thyroid Surgery”. *Journal of Endocrine Surgery*, vol. 17, no. 3, pp. 96-103, 2017.

[5] W.E. Davis, J.L. Rea, J. Templer. “Recurrent laryngeal nerve localization using a microlaryngeal electrode”. *Otolaryngology – Head and Neck Surgery*, vol, 87, no. 3, pp. 330-333, 1979.

[6] M. Dyvak, O. Kozak, A. Pukas. “Interval model for identification of laryngeal nerves”. *Przegląd Elektrotechniczny*, vol. 86, no. 1, pp. 139-140, 2010.

[7] M. Dyvak, N. Kasatkina, A. Pukas, N. Padletska. “Spectral analysis the information signal in the task of identification the recurrent laryngeal nerve in thyroid surgery”. *Przegląd Elektrotechniczny*, vol. 89, no. 6, pp. 275- 277, 2013.

[8] M. Cantelon, M. Harter, T.J. Holowaychuk and N. Rajlich. “Node.js in Action. Shelter Island,” NY: Manning Publications, 2013, 416 pp.

[9] P. Teixeira. “Professional Node.js: Building Javascript Based Scalable Software,” Indianapolis, IN: John Wiley & Sons, Inc., 2012, 408 pp.

[10] Bush, Steve (25 May 2011). "Dongle computer lets kids discover programming on a TV,". Electronics Weekly. Retrieved 11 July 2011..

[11] I. Voytyuk, M. Dyvak, V. Spilchuck, “Research of quality characteristics of models structure in kind of interval difference operator,” *11th International Conference The Experience of Designing and Application of CAD Systems in Microelectronics (CADSM)*, pp. 87-87, 2011.

[12] M. Dyvak, N. Porplytsya, Y. Maslyak, M. Shynkaryk “Method of Parametric Identification for Interval Discrete Dynamic Models and the Computational Scheme of Its Implementation,” *Advances in Intelligent Systems and Computing II: Selected Papers from the International Conference on Computer Science and Information Technologies, CSIT 2017*, pp.101- 112, 2018.

[13] D. Karaboga, B. Gorkemli, C. Ozturk, N. Karaboga, “A comprehensive survey: artificial bee colony (ABC) algorithm and applications,” *Artificial Intelligence Review*, vol. 42, no.1, pp. 21-57, 2014.

[14] D. Karaboga, “An idea based on honey bee swarm for numerical optimization,” *Technical Report TR06*, Computer Engineering Department, Engineering Faculty, Erciyes University, Turkey, 2005.