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Adaptive Information Technology for Recurrent Laryngeal Nerve Identification Based on Electrophysical Method of Its Stimulation

***Abstract**. The paper represents an informational technology for recurrent laryngeal nerve (RLN) monitoring among the tissues of a surgical wound. The technique for applying the electrophysiological method for surgery wound tissue stimulation is described in detail as well as an assessment of the reaction on this stimulation. The main principles for adapting the parameters of this method to the specific patient are outlined. To estimate the reaction on the stimulation and define the distance from the stimulation point to its closest placement point, the spectral analysis of the informational signal is used. The approbation results of the applied technique during the thyroid surgery are described*

Streszczenie.** Artykuł przedstawia technologię informacyjną do monitorowania nerwu krtaniowego wśród tkanek rany chirurgicznej. Opisano technikę stosowania elektrofizjologicznej metody chirurgicznej stymulacji tkanki rany, a także ocenę reakcji na tę stymulację. Przedstawiono główne zasady dostosowania parametrów tej metody do konkretnego pacjenta. Aby oszacować reakcję na stymulację w celu wykrycia RLN i określenia odległości od punktu stymulacji do jego najbliższego punktu umieszczenia, stosuje się analizę spektralną sygnału informacyjnego. Opisano wyniki zatwierdzenia zastosowanej techniki podczas operacji tarczycy. **Adaptacyjna metoda a identyfikacji laryngologicznego nerwu bazująca na elektrofizycznej stymulacji

Keywords: neck organs surgery, recurrent laryngeal nerve, informational technology, multi-functional electro-stimulator.
Słowa kluczowe: operacja narządów szyi, nawracający nerw krtaniowy, technologia informacyjna, wielofunkcyjny elektrostymulator.

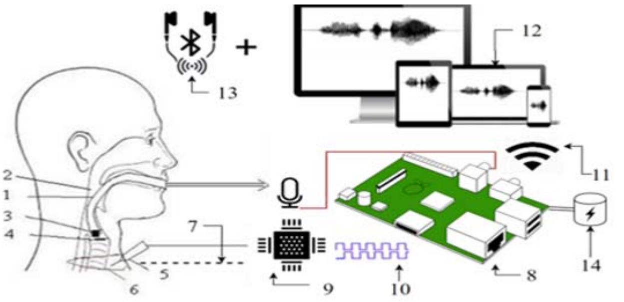
Introduction

Nowadays, the number of people with different forms of thyroid disease is significantly growing. It is caused by the Chornobyl accident and environmental impairment [1]. Usually, severe forms of thyroid disease are cured by the surgery. It evokes a significant risk of the RLN tissue damage, which results in severe forms of respiratory diseases and in some cases even in the voice loss. [2-4]. By analyzing the current technologies for detecting RLN location [5-7], we can state that practically all of them focus on RLN monitoring instead of its location. Such approach can result in RLN damage and increases the surgery duration. That's why the current task is to develop a technology not only for RLN monitoring bur for detecting its location among the surgery wound tissues. This technology includes electrophysiological methods and tools for surgery wound tissues stimulation as well as the methods and techniques for processing the informational signal - reaction on the wound stimulation. All of these methods are described in this work. In contrast to the previous technologies, this one includes both the methods and tools and can be adapted to a specific patient. The authors of the research have approbated the proposed technology. The general results of this approbation are also described in this work.

Task statement

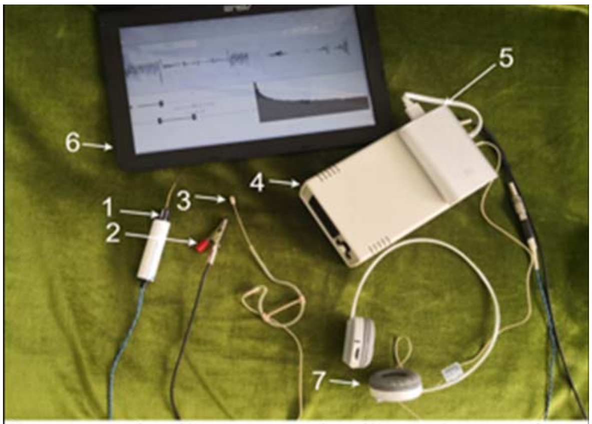
The works of the authors [8-10] include the structural schemes of the system which describe the ways of technology implementation as well as its technical means. The generalized structural-functional scheme is represented on the fig.1.

We refer to the research [8] when describing the main hardware parts and their functional interaction. "In respiratory tube 1 that inserted into larynx 2, the sound sensor 3 implemented and positioned above vocal cords 4. The active probe 5 is connected to the generator of rectangular impulses 9 controlled by the single board computer 8. Surgical wound tissues are stimulated by the current with rectangular impulses via active probe. As a result, vocal cords 4 are stretched.



1) respiratory tube; 2) larynx; 3) sound sensor; 4) voice; 5) active probe; 6) surgical wound; 7) passive probe; 8) single-board computer Raspberry Pi; 9) rectangular pulses generator; 10) rectangular pulses generated by Raspberry Pi; 11) communication channel between devices (Wi-Fi) 12) visual information unit of the surgeon (tablet, phone, personal copier, laptop); 13) audio surgeon unit (Bluetooth or radio headphones); 14) power supply.

Fig.1. Functional scheme of RLN identification process, among the tissues of the surgery wound [8]



1) active probe; 2) passive probe; 3) sound sensor that is installed in the endotracheal tube); 4) head unit; 5) power supply unit; 6) visual surgeon unit (tablet, telephone); 7) audio surgeon unit (headphones).

Fig.2. Representation of the hardware part of the RLN identification device

Air flow 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 processed by the single board computer. The results of stimulation and signal processing are represented with the help of visualization blocks 12 and audio signal for the surgeon 13".

Figure 2 provides the scheme of the developed device for RLN detection on the surgery wound.

The developed device is based on the single-board computer Raspberry Pi and analogical device for stimulating the surgery wound tissues with the alternating or impulse current with the preset frequency and the operating current. Also, the hardware part includes the audio and video control device that informs the surgent or the assistant about the type of the stimulated tissue.

The multiple application of this device has also shown its main functional deficiencies. First of all, the technology requires improvement in determining the optimal parameters of the electrophysiological method of the surgery wound tissues stimulation. Secondly, these parameters can be different for each patient. That is why it is required to provide the setup of adaptive parameters. Thirdly, the dependency of informational signal characteristics on the tissue needs additional research.

Adaptive setting of the electrophysilogical method

First of all, let's review the possibility of improving the current technology for RLN detection. As we can see on the fig.3, in comparison with the famous technology [9], a current one includes the adaptive setup of the electrophysiological method and also consists of 5 steps.

A. *Obtaining of information signal (as result of stimulation of surgery wound tissues)*

The first stage within this informational technology is receiving the informational signal. The informational signal is the sound signal that passes through the patient's larynx. This signal emerges because of the surgery wound tissue stimulation. Stimulation reduces the vocal cords to one degree or another.

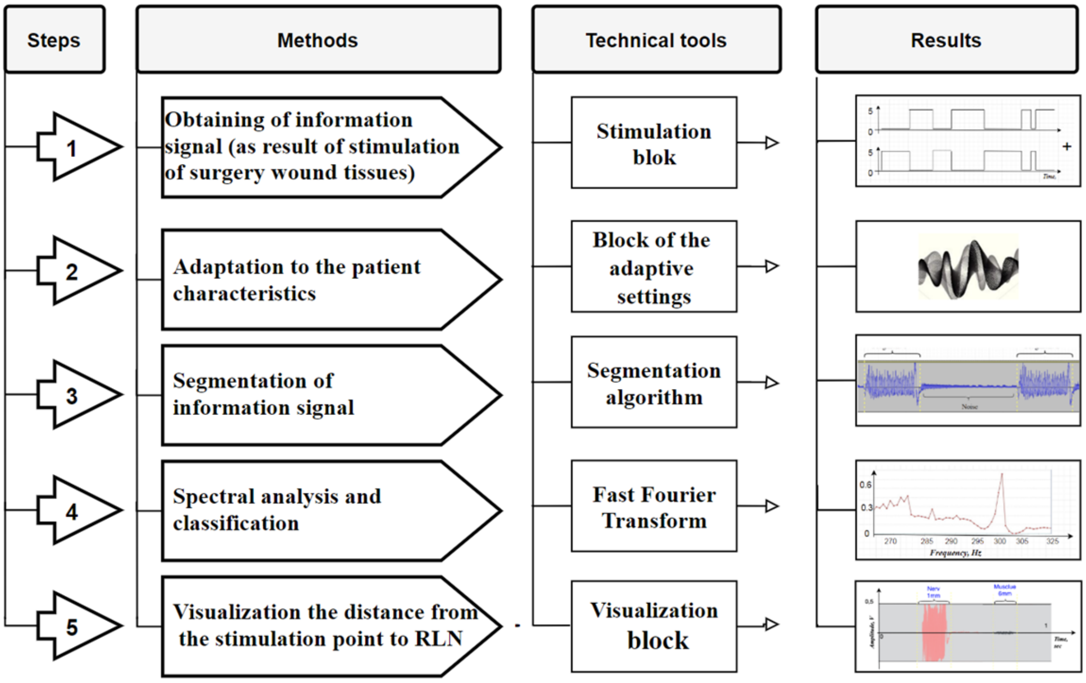


Fig.3 Scheme of information technology of the process of identification of the RLN in the surgery wound

Multiple studies of the nerve tissue structure and the electrical signals transmission has shown that the stimulation of the sensitive tissues should be executed by the current with rectangular impulses with frequency from 50Hz to 1kHz [10]. It's obvious that the tissue stimulation for different patients can result in different reaction. That's why the process of impulse current characteristics management (such as amplitude, frequency, and pulse duty cycle) should be automated and adaptively set depending on the reaction on the stimulation. The basis of this setup is an obtained informational signal and its characteristics.

B. *Adaptation to the patient characteristics*

As the parameters of the obtained informational signal depend on the impulse current parameters of tissue stimulation, on this stage, the adaptive stimulation signal setup is applied to achieve a desired reaction - a stimulation result. On this stage we also receive other characteristics of the patient's surgical wound tissue. As the physical characteristics of the thyroid and the surgery wound tissue are different for each patient, the reaction to the stimulation can also differ. This thesis is proved by the research. By applying the impulse current in range from 0,5 mA to 1,7 mA, we can get the stable reaction for the tissue of each patient. It's important to mention that the range of the current value is safe for any patient and their tissues.

First, we set up the operating current for surgery wound tissue stimulation. For automatic operating current regulation, the system with the inverse connection and software management was used. It was created with the single-board computer. First, the sensor processes the sound signal during patient breathing, then it is segmented and the biggest amplitude value is determined for each segment of the sound signal.

$$u_{dmax} = \max_{i=1,\dots N} u_i \qquad (1)$$

The value u_{dmax} shows the lowest limit of the scale for representing the informational signal. N - is the general amount of discrete of the segmented informational signal for several inhales and exhales of the patient.

Then, the largest pulse duty cycle of the impulse sequence is programmatically set to provide the operating current value of 0,5 mA. After this the RLN stimulation starts. The obtained informational signal is segmented and its maximum amplitude is determined:

(2) $$u_{RLNmax} = \max_{i=1,\dots N} u_i$$

During the research, it was established that for an effective visual perception of RLN stimulation, the amplitude of the informational signal during RLN stimulation should be several times higher than the amplitude of the informational signal during the inhale and exhale of the patient without stimulating the surgery wound tissue. This multiplicity coefficient is marked as r. If the condition is not fulfilled

(3) $$u_{RLNmax} \leq r * u_{dmax}$$

then we need to decrease the pulse duty cycle to provide the higher operating current value that on the previous level and after that repeat the RLN stimulation.

This procedure is conducted several times until the conditions are met. (3).

When the mentioned algorithm is implemented, the optimal operating stimulation current and the value of the highest scale of the informational signal are defined. A block diagram of the described algorithm is shown on the figure below.

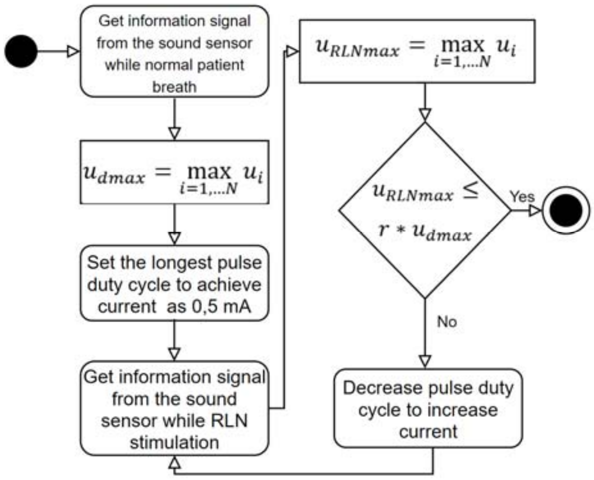


Fig.4. Flowchart of the adaptive adjustment of the current of stimulation of RLN to the patient characteristics

Now we need to obtain other characteristics of the patient surgery wound tissue. As known, the bigger the distance from the stimulation point, the less distinct is the main spectral element of the obtained informational signal [11]. In case of RLN stimulation, the informational signal contains the spectral element with the high amplitude. The main energy is concentrated around the frequencies of this main spectral element. Based on this fact, we will do the series of the simulations in different distances from RLN with the goal to get the set of the informational signals $m = 1,\dots,M$. Then, with the help of Fourier Transform, we define the spectrum of each informational signal $U_m(2\pi f)$ and evaluate the energy in area $f_{\text{Д}} \pm 5Hz$ of the main spectral elements:

(4) $$E_m = \frac{1}{2\pi f_{\text{Д}}} * \int_{-2\pi f_{\text{Д}}}^{2\pi f_{\text{Д}}} U_m^2(2\pi f)\, df$$

where $U_m^2(2\pi f\ \ )$ - energy spectrum of the information signal.

To simplify the process of determining the amplitude spectrum $U_m(k)$ of the informational signal, the following equation can be used:

(5) $$E_m = \sum_{k=1}^{n_\delta} U_m^2(k)$$

where n_δ – is the amount of discretes in the area of the main spectral element.

Obviously, it's impossible to exactly define the distance from the stimulation point to RLN during the surgery. That's why we will define it on the interval $d_m \in [d_m^-, d_m^+]$, де d_m^-, d_m^+ - where is the evaluation of the smallest and biggest distance from the stimulation point to RLN.

In such a way, the following table can be created.

Table 1. Interval data for building the dependency between the interval values of the distance and the energy of informational signal.

Distance interval from the stimulation point to RLN	Energy of the informational signal in the main spectral element
$[d_m^-, d_m^+]$	E_m

Then, based on this data, the mathematical dependency between the interval distance value and the energy of the informational signal in the main spectral element is built. The function is the base of this dependency

(6) $$d = b_0 + b_1 * \varphi_1(E) + \dots + b_j * \varphi_j(E)$$

where $\varphi_1(E), \dots, \varphi_j(E)$ - some basic functions, such as polynomial. To build the mentioned dependency, we use the interval analysis based on the data from the table 1[12]. As a result, we get the interval dependency:

(7) $$[d^-, d^+] = [b_0^-; b_0^+] + [b_1^-; b_1^+] * \varphi_1(E) + \dots + [b_j^-; b_j^+] * \varphi_j(E) .$$

C. Segmentation of information signal

This step is conducted after the fixation of the sound signal by the sensor. Segmentation sets aside the sound signal (which is the result of surgery wound stimulation by the electric current) on the audio signal background that emerges because of air transmission in the patient's larynx. (as a result of inhale and exhale). The figure 4 depicts the audio signal during the patient's breathing. The interval marked as “NOISE” indicates the shortness of breath between the inhale and the exhale. The reaction on the stimulation should be fixed on the fragments marked on the fig.4 as FRAGMENT 1 or FRAGMENT2 (during the inhale and the exhale).

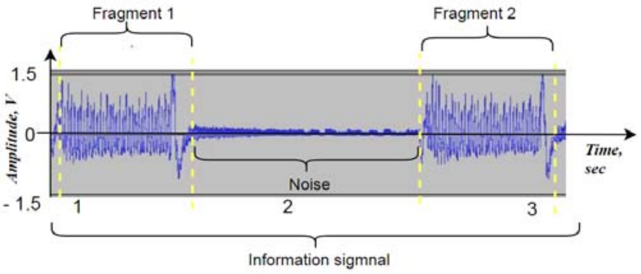


Fig.5. Illustration of the information signal segmentation.

In order to reveal these fragments, the following algorithm is used.

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

(8) $$E = \sum_{i=1}^{n} u_i^2$$

where u_i is i-th countdown of information signal.

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

(9) $E \geq E_{tr}$ then, $u_{start} = u_n$

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

(10) $E \leq E_{tr}$ then, $u_{stop} = u_n$

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

(11) $E \geq E_{tr}$ then, $u_{start} = u_n$

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

It's also important to define the threshold energy value for segmentation. This threshold is defined in the process of adaptive signal parameters setup.

D. *Spectral analysis and classification*

Segments of the informational signal which duration depends on the duration of the stimulation, are set for the spectral analysis in the single-board computer. For this, Fourier translation is used. The process of the spectral analysis is applied in the Node JS [13 -14 environment with the help of fourier-transform package.[15].The requirements of real time functioning put the additional limitations on this procedure. Specifically, the technique of the discrete signal thinning is applied without losing its spectral characteristics.

As mentioned above, informational signals - results of the surgery wound tissues stimulation have different spectrums. For example, during RLN stimulation, spectrum has the main spectral element with high amplitude. If the muscle tissues are stimulated at the distance of more than 2 cm from the nerve, the reaction has a slightly “vague” spectrum, which means without the main element. In such a way, the classification of the tissues and the distance from RLN to the stimulation point can be done with the help of interval dependence, built during the adoption of surgery wound tissue characteristics to a certain patient. The algorithm of the classification is represented below.

First, based on the spectrum analysis, we define the energy of the main spectral element:

(12) $$E = \frac{1}{2\pi f_{д}} * \int_{-2\pi f_{д}}^{2\pi f_{д}} U^2 (2\pi f)\, df$$

where $U^2 (2\pi f \ \ )$ - energetic spectrum of the informational. Or the following formula can be applied to show the amplitude spectrum $U \ \ (k)$ of the informational signal:

(13) $$E = \sum_{k=1}^{n_\delta} U^2 (k)$$

That is why when substituting the obtained value into the formula, we get the values interval for the distance $[d^- , d^+]$ stimulation point to RLN. This value allows the surgeon to take a decision.

E. *Visualization the distance from the stimulation point to RLN*

During the last stage, the surgeon has to get information about the tissue type and the distance from the stimulation point to RLN. The examples of these visualizations are shown on the figure 5.

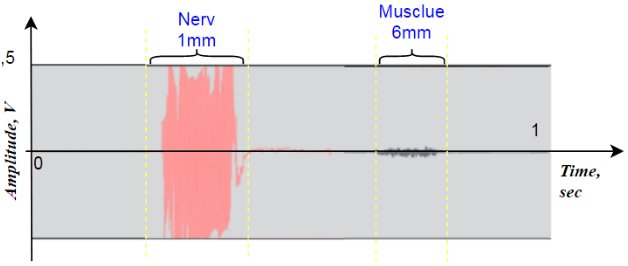


Fig.6. Visualisation of the surgery wound tissues stimulatuon results electrophysiological stimulation

As we can see from the figure, there is a type of the tissue above each fragment of the patient exhale it belongs to and the distance from RLN. Also, the fragments are highlighted with different color.

Subsystem for electrophysical method of RLN stimulation

Now let's review some aspects of the practical adoption of electrophysical methods for providing the reaction on the surgery wound tissue stimulation. The nerve tissues resistance depends on their thickness. Moreover, the method of signal transmission in these issues is significantly different from current transmission in conductor (electron motion at selected voltage difference) The picture 2 illustrates the method of charge propagation in the nerve tissues, including RLN [8].

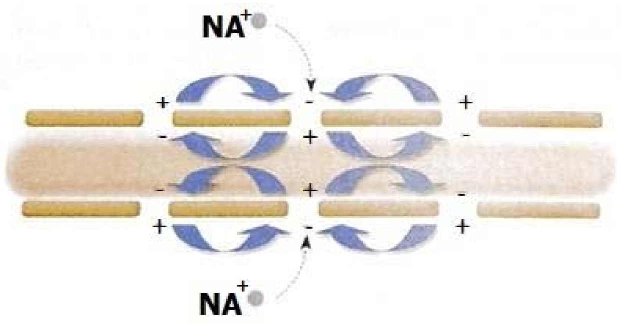


Fig.7. The block for stimulating surgery wound tissues is one of the most complicated technical solutions [8]

During the stimulation it is necessary to provide the relevant reaction on the surgery wound. It is important to avoid the nerve fiber damage because of the current intensity and provide the traction of muscles, that stretch vocal cords.

Based on the famous methods of tissue stimulation in existing Continuous Intraoperative Neural Monitoring (CIONM) [5 - 6], the new method of RLN stimulation with rectangular impulses was developed. It forms the rectangular impulses with regular duration and frequency from 10 Hz to 450 Hz, with the regulated operated current from 0,5 to 1.7 mA.

To create the method of RLN stimulation with the help of rectangular impulses, the stimulation block was developed. It includes the hardware and software part. The hardware is created in the form of analogous schema for single board computer Raspberry Pi. It's created on the base of scheme INA132 [16]. Its scheme is shown below:

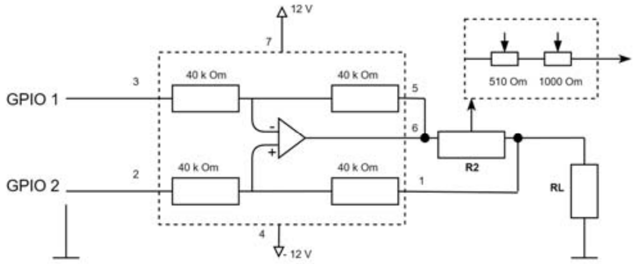


Fig.8. Scheme of electrostimulator of surgery wound tissue

This analogous scheme is connected to the one of the outputs of GPIO Raspberry PI with the voltage 5V. The rectangular impulses the frequency and form of which are set in Raspberry Pi are taken from 2 other outputs (3V). Obtained impulses are transformed in a way to receive the one with negative and positive voltage. The analogous scheme is a current generator for obtaining the operating current when the surgery wound tissue conductivity is different for each patient. On the output of the analogous scheme there are 2 outputs for active and passive probes. The process of forming two-polar impulse current is provided on the fig.9.

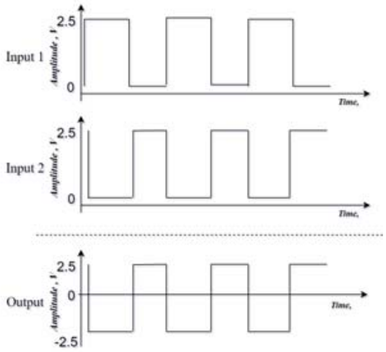


Fig.9. Schematic representation of rectangular pulse generation processes

To provide the programmable control of the analogous current, the special software was developed in the single board computer. To create the programmable module of the rectangular impulses generation, the programming language Java Script and the platform Node js were chosen.

This module is called a Rectangular generator. Its main task is to transmit power for 2 outputs GPIO in Raspberry Pi. When 1 pin is turned on, another one is turned off. The package “on- off” was used to process the output data. The power is transmitted from 1 to 0 in a certain amount of time. However, these time intervals are small - several milliseconds. To provide this, the library “sleep” was used[17]. Below you can see the code for this module implementation:

```
 do {
if(step === 6) {
  step = 1;
  out2.writeSync(1);
}
if(step === 2) {
  out1.writeSync(1)
}
if(step === 3) {
  out1.writeSync(0)
}
if(step === 5) {
   out2.writeSync(0)
 }
times[step] - 1 && sleep.usleep(times[step -1]);
step ++;
} while (true);
```

Results of work (oscillogram) subsystem for electrophysical stimulation of RLN on oscilloscope is shown on figure 10.

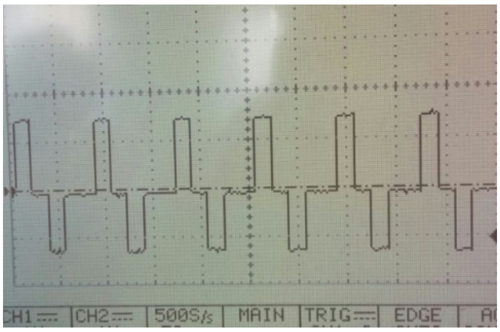


Fig.10. Results of work subsystem for electrophysical stimulation of RLN on oscilloscope.

Subsystem for RLN identification in surgery wound

The processing of an informational signal received during the surgery wound stimulation is another important task during RLN identification. This process includes both the processing of an informational signal and visualization of these results. These processes are carried out by the subsystem for RLN identification in surgery wood.

The developed device is based on the single-board computer Raspberry Pi. It’s not assigned for the visualization of the complex graphic processes. For this reason, a decision to divide the informational signal processing and its visualization between the Raspberry PI itself and the visualization device. We have used a mobile device (mobile phone or tablet) as a block of visualization. It also has specialized software installed. The communication between the visualization block and RLN detection device is done via Wi-Fi. The software for visualization was developed with Java Script programming language.

Because of these reasons, the diagram of the programming system components was developed. It allows to introduce the system in the form of 3 main components with the specific task for each.

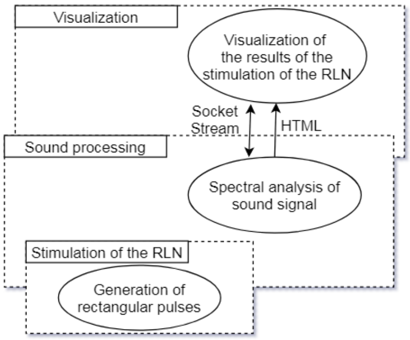


Fig.11. Component diagram

The component used for software management of the surgery wound tissue is described in the previous chapter. The component of sound signal processing is responsible for the implementation of the methods for RLN detection in the surgery wound area. The component of the visualization is responsible for the visual presentation of the sound signal processing results.

The fig.12 provides the software architecture - the element of the technology described above

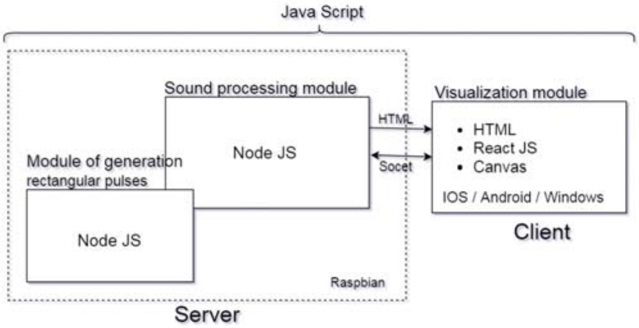


Fig.12. Software architecture of the device for RLN monitoring.

The architecture consists of two main parts: client and server. Server is created on the single-board computer Raspberry Pi. The module of the rectangular impulses generation is responsible for generating impulses. The module of the sound signal processing is designed for recording the sounds of the patient breathing obtained as a result of RLN stimulation. Also, the module functionality includes the communication with the client based on the Socket IO technology [18].

The software of the sound signal processing module is developed with the Node js platform and Java Script programming language. It includes such programming submodules as sound handler, sound decoder, and spectral analyzer. The code sample of the spectral analyzer module is provided below:

```
const fft = (wave) => {
        let waveLength = wave.length;
        let index = nearestPow2(waveLength);
        while (!(index <= wave.length)) {
                waveLength = waveLength - 2;
                index = nearestPow2(waveLength);
        }
        const cutedWave = wave.slice(0, index);
        const spectrum = fjs.Transform.toSpectrum(cutedWave, {
          method: 'fft',
        } );
        return { wave: values(cutedWave), spectrum };};
```

The client is the video control device (phone, tablet, or notebook), which is any device that can work with modern browsers. Such approach allows to significantly increase the number of visualizations. That is why the surgeon will have an opportunity to use his or her own smartphone together with the developed by us device. The client side of the software is the web application developed with HTML, JavaScript, and Canvas [19]. Such approach allows to use this software on any device. The client application was developed with React.js platform [20]. To visualize the obtained results, the module visualizer was created. It's developed with the AudioContext technology and Canvas. The code sample for visualizing the results of surgery wound tissues stimulation is provided below:

```
const drawWave = function(dataArray, canvasCtx, width, height, styles) {
  canvasCtx.fillStyle = styles.fillStyle;
  canvasCtx.fillRect(0, 0, width, height);
  canvasCtx.lineWidth = styles.lineWidth;
  canvasCtx.strokeStyle = styles.strokeStyle;
  canvasCtx.beginPath();
  const bufferLength = dataArray.length;
  const sliceWidth = width * 1.0 / bufferLength;
  let x = 0;
  for(let i = 0; i < bufferLength; i++) {
    const v = dataArray[i] / 128.0; // byte / 2 || 255 / 2
    const y = v * height / 2;
    if(i === 0) {
      canvasCtx.moveTo(x, y);
    } else {
      canvasCtx.lineTo(x, y);
    }
    x += sliceWidth;
  }
  canvasCtx.lineTo(width, height / 2);
  canvasCtx.stroke();
```

The result of code execution by the video control device is shown on the figure 13.

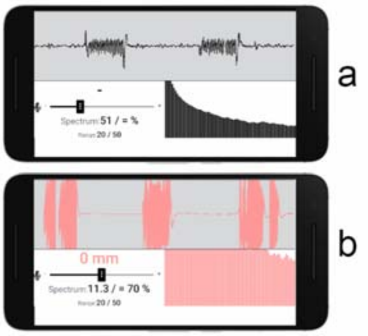


Fig.13. Visualization of the sound signal form during the muscle tissue and RLN stimulation.

As we can see, the result is represented in the form of an informational signal, the relation of the signal energy in the area of main spectral elements to the energy in the same range for the background signal that represents the sound during patient exhale or inhale, and the calculated distance from the stimulation point to RLN

Approbation

The developed technology was tested during the neck surgery for over 50 patients. The part of the results of informational signal processing is shown in the table 2.

Table 2. Characteristics of the information signal during the surgery wound stimulation with rectangular impulses and without stimulation.

Num-ber of stimu-lation point	The value of energy of the MSC of information signal with stimulationn	The value of energy of the MSC of information signal without stimulation	Freq-uency of impulses	Value of the current strength in the stimula-tion point
1	0.460824	0.088201	250 Hz	0.4-1.4
2	0.546805	0.088654	250 Hz	0.4-1.4
3	0.522948	0.035728	250 Hz	0.4-1.4
4	0.174416	0.09957	250 Hz	0.4-1.4
5	0.288416	0.078975	250 Hz	0.4-1.4
6	0.216996	0.067639	200 Hz	0.4-1.4
7	0.453883	0.098776	200 Hz	0.4-1.4
8	0.286874	0.065289	200 Hz	0.4-1.4
9	0.368341	0.064551	200 Hz	0.4-1.4
10	0.368405	0.058569	200 Hz	0.4-1.4

The value of energy in the area of the main spectral component with stimulation is significantly higher than the value of energy without tissue stimulation.

Then we have conducted series of experiments to evaluate the correlation of the mentioned energy during RLN stimulation and muscle tissue at different distances to RLN. The results of the experiments for 1 patient are presented in the table 3. As we can see the value of energy in the area of the MSC of the informational signal and a distance between a stimulation point and this component. Obtained results state that the suggested technology not only gives opportunity to classify the tissues of surgery wound but also to monitor the distance from the stimulation point, which significantly decreases the risk of RLN injury.

Table 3. Characteristics of the information signal during the surgery wound stimulation with rectangular impulses and without stimulation

Num-ber of stimu-lation point	The value of energy of the MSC information signal without stimulation	Distance from the stimulation point to RLN	The value of energy of the MSC amplitude of information signal with stimulation	Diffe-rence in per-cents
1	0,0546483	6 mm	0,0582346	6 %
2	0,0546483	6 mm	0,0580420	5 %
3	0,0546483	2 mm	0,0926326	33 %
4	0,0546483	2 mm	0,0875852	37 %
5	0,0546483	2 mm	0,1162751	53 %
6	0,0546483	0 mm	0,2861518	69 %
7	0,0546483	0 mm	0,3556029	84 %
8	0,0546483	0 mm	0,3742160	85 %
9	0,3444083	0 mm	0,3444083	84 %

In order to approve or refute the research conclusion the series of experiments with over 40 different patients were conducted. The averaged results are made for different types of stimulation in the fig. 14.

In order to approve or refute the research conclusion the series of experiments with over 40 different patients were conducted. The averaged results are made for different types of stimulation in the fig. 6.. The only difference between the value of energy in the area of the MSC of informational signal for different patients is easily eliminated with adaptive setting of electrophysiological method.

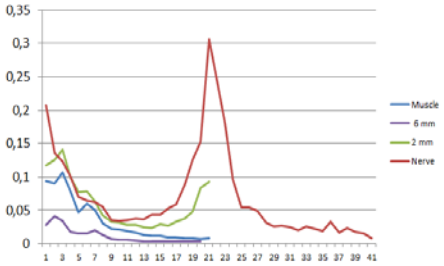


Fig.14. The average results for different cases of patients surgical wound stimulation

Conclusion

The informational technology for RLN detection with the help of adaptive setup of parameters of electrophysiological method was studied. The detailed description of the hardware and software for electrophysical principle of RLN stimulation is provided. The main characteristics of this type of stimulation are experimentally defined. Frequency was adapted to range from 50 Hz to 1kHz and the electric current on the level from 0.5 mA to 1.7 mA. The software for RLN identification in the surgery area is described. The visualization processes of this procedure are outlined. This approach allows not only to classify the tissues of the surgery wound on the neck organs, but also develop the system of automated control of dangerous (because of the high probability of RLN injury) areas of surgery.

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REFERENCES

[1] Guda, B. B., & Kovalenko, A. E. (2019). Clinico-morphological characteristic of papillary thyroidal carcinomas in patients, born before and after of the Chornobyl AES disaster. Klinicheskaia Khirurgiia, 86(4), 29-33.
[2] Abstract book of First World Congress of Neural Monitoring in Thyroid and Parathyroid Surgery, Krakow, Poland, 2015, 161 pp.
[3] Hoon Yub Kim , Xiaoli Liu, Che-Wei Wu, Young Jun Chai , Gianlorenzo Dionigi - Future Directions of Neural Monitoring in Thyroid Surgery - J Endocr Surg. 2017 Sep;17 :96-103
[4] 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.
[5] 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.
[6] Gianlorenzo Dionigi,corresponding Che-Wei Wu, Ralph P. Tufano, Antonio Giacomo Rizzo, Angkoon Anuwong, Hui Sun, Paolo Carcoforo, Cancellieri Antonin - Monitored transoral endoscopic thyroidectomy via long monopolar stimulation probeo, - J Vis Surg. 2018; 4: 24
[7] Hoon Yub Kim,1 Young Jun Chai, Marcin Barczynski, Özer Makay, Che-Wei Wu, Antonio Giacomo Rizzo, Vincenzo Bartolo, Hui Sun, Gianlorenzo Dionigi, - Neural Monitoring Society (KINMoS) Technical Instructions for Continuous Intraoperative Neural Monitoring in Thyroid Surgery - J Endocr Surg. 2018 Mar;18 61-78
[8] Porplytsya, N., Dyvak, M. "Interval difference operator for the task of identification recurrent laryngeal nerve", Proceedings of the 16th International Conference on Computational Problems of Electrical Engineering (CPEE'2015), 2015, pp. 156-158.
[9] M. Dyvak, A. Dyvak, V. Tymets and M. Cegielski, "Information Technology for Electrophysiological Approach of Recurrent Laryngeal Nerve Identification During Surgery on Neck Organs," 19th International Conference Computational Problems of Electrical Engineering, Banska Stiavnica, 2018, pp. 1-4.
[10] M. Dyvak, V. Tymets, V. Brych, A. Dyvak and V. Shidlovsky, "Tools for the recurrent laryngeal nerve stimulation in the tasks of its monitoring," 2018 XIV-th International Conference on Perspective Technologies and Methods in MEMS Design (MEMSTECH), Lviv, 2018, pp. 215-218.
[11] M. Dyvak, A. Pukas and M. Komar, "Methods and tools for reducing the risk of damage the reverse laryngeal nerve during the surgical operation on a thyroid," *Proceedings of the 6th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems*, Prague, 2011, pp. 604-607
[12] 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.
[13] David Wilson. "Mastering Node.js: Best practices to Server-side Development" Independently published, 2019, 135 pp.
[14] Moaml Mohmmed "Learn node.js in one day: Learn the fundamentals of Node.js, and deploy and test Node.js applications on the web," Independently published, 2019, 97 pp.
[15] Fourier Transform Access mode https://www.npmjs.com/package/fourier-transform
[16] INA132 Access mode - https://www.ti.com/lit/ds/symlink/ina132.pdf
[17] Node Sleep Access mode https://github.com/erikdubbelboer/node-sleep -
[18] Socket.IO Tutorial: JavaScript library for real-time web applications, Kindle Edition, January 6, 2020, 77p
[19] Canvas Api – Access mode - https://developer.mozilla.org/uk/docs/Web/API/Canvas_API
[20] React in Action 1st Edition, Mark Tielens Thomas, Manning Publications; 1st edition (July 8, 2018), . 360 p.
[21] AudioContext Access mode https://developer.mozilla.org/ru/docs/Web/API/AudioContext