CEUR-WS.org/Vol-3200/paper26.pdf

Information Technology for Identification of Electric Stimulating Effects Parameters

Volodymyr Fedorchenko, Igor Prasol and Olha Yeroshenko

Kharkiv National University of Radio Electronics, Nauky Ave. 14, Kharkiv, 61166, Ukraine

Abstract

A wide range of modern therapeutic devices based on various physical principles, widely used in medicine, cosmetology, sports. Among them, electric massage devices occupy a worthy place, alternative to classic manual massage. Therapeutic electromassage procedures are popular, convenient and beneficial for the recovery of the body. They are widely used in the treatment of chronic diseases of the circulatory system, musculoskeletal system, internal organs, etc. The restoration of damaged muscles is especially effective, provided that the parameters of stimulating effects are chosen correctly. Therefore, in this work, it is proposed to use an information method for studying the neuromuscular system based on electromyography.

The parameters of the stimulating effect do not always optimally correspond to a specific patient or a selected area of the body, which leads to insufficient effectiveness of therapeutic procedures, prolongation of rehabilitation. Elimination of shortcomings is possible due to the adjustment of the parameters of electrical stimuli depending on the data of myographic studies of a particular patient.

Based on the data obtained by EMG, specific parameters of stimulating effects (electrical impulses) are selected, such as amplitude, frequency, duty cycle, etc., which makes it possible to implement a technical device for carrying out rehabilitation procedures. Therefore, an electromassage apparatus is proposed, built on the basis of a modern microcontroller, which allows, on the basis of EMG data, to change stimulating impulses of exposure in a fairly wide range, thereby realizing an individual approach to each patient and increasing the efficiency of therapeutic procedures.

Keywords

Biomedical parameters, electromyostimulator, total electromyography, electromyogram, neuromuscular system, musculoskeletal system, time-frequency analysis

1. Introduction

In the modern world, the number of factors negatively affecting human health is becoming more and more.The human body ceases to have time to heal itself.All this requires a search for new combinations of recovery methods., when medical devices are used in conjunction with drug methods, implementing various types of electrotherapy.

The effectiveness of the use of electrotherapy devices is largely based on the use of methods and means of diagnostic support, which would give objective information about the patient's condition, contributing to the successful solution of the problem localization of zones of influence for electrostimulation, correct setting and achievement of treatment goals.

In order to improve the quality and speed of treatment, system development required, in which

III International Scientific And Practical Conference "Information Security And Information Technologies", September 13–19, 2021, Odesa, Ukraine
EMAIL: volodymyr.fedorchenko@nure.ua (A. 1); igor.prasol@nure.ua (A. 2); olha.yeroshenko@nure.ua(A. 3)
ORCID: 0000-0001-7359-1460 (A. 1); 0000-0003-2537-7376 (A. 2); 0000-0001-6221-7158 (A. 3)
© 2021 Copyright for this paper by its authors. Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0).
CEUR Workshop Proceedings (CEUR-WS.org)

automation will be provided, allowingprovide the most effective treatment result.

The ultimate goal of creating an automated electrotherapy system is to develop modeling methodsand research of control systems and devices percutaneous electroneurostimulation, characterized by adaptation to changes in biological objects.

The novelty is the development of a methodology for analyzing the functions of electrostimulating devices, which makes it possible to minimize negative effects during the stimulation procedure.

2. Electrostimulation

Electrical stimulation in this approach causes minimal changes in the treated area of the skinand nearby tissues, which allows to increase the efficiency of the treatment process.

Skeletal muscle electrical stimulation, which are the basis of the musculoskeletal system, gives a positive healing, preventive and training effects.

During electrical stimulation of the neuromuscular system, a rational choice of modes is importantand a combination of tonic and kinetic contractions, which significantly affect the increase in mass, development of strength, increased excitability and muscle performance [1, 2].

Electrical stimulation is successfully combined with traditional drug therapy. To enhance metabolic and trophic processes, muscle tissue stimulation is performed using targeted stimulation and contraction of a specific muscle group.

An important property of neuromuscular structures when irritated by electric currents, the dependence of excitability on the rate of change in the amplitude of the stimulating signal [1].

Depending on the signal amplitude and the excitation threshold of the neuromuscular structure, the following electrostimulation modes are distinguished: subthreshold, threshold and suprathreshold(fig. 1) [3-5].

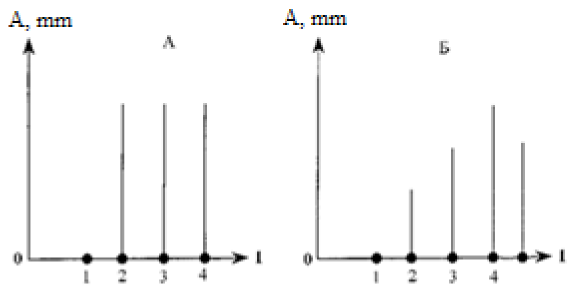

Figure 1: Dependence of the signal amplitude and the excitation threshold of the neuromuscular structure(a) - muscle fiber, б) – muscle, 1) subthreshold stimulus, 2) threshold stimulus, 3) submaximal suprathreshold stimulus, 4) maximum suprathreshold stimulus)

The dependence of the amplitude of muscle contraction on the strength of the stimulus occurs according to the law of power relations:

- Each excitatory tissue has its own functional reserve.
- Each excitatory tissue has its own functional boundary.

With the help of electrical stimulation, you can temporarily change the muscle composition. In all cases, the strength of the electrical stimulation current depends on its density per unit area of the electrodes, resistance value on the electrode-skin section, excitability of those muscles, which are subject to stimulation and individual characteristics of the human body. The most important factor that determines the shape of muscle contraction is the frequency of irritation. Single muscle contractions are possible only with a low frequency of irritation. At a high frequency of stimulation, the muscle contracts tetanically. For human skeletal muscles, the optimum frequency of stimulation is different. The optimum frequency of irritation also changes when the state of the body changes (fitness, time of day, previous load, etc.). Pulse electric current used in electrostimulation has a wide variety of characteristics (frequency, shape, pulse duration, character of the current, the ratio of the periods of stimulation and pauses, etc.), which leads to a great variety of options for conducting electrical stimulation of the locomotor system. Optimal electrical stimulation is only possible if, when the repetition rate and shape of stimulating signals correspond to the physiological properties of neuromuscular structures.

3. Characteristics of muscle contraction

The strength and speed of contraction are important characteristics of a muscle. The equations expressing these characteristics were empirically obtained by A. Hill and subsequently confirmed by the kinetic theory of muscle contraction (Deshcherevsky's model).

Hill's equation, which relates the strength and speed of muscle contraction, has the following form [6-8]:

$$(P+a)(v+b) = (P_0+a)b = a(v_{max}+b), \quad (1)$$

where v – muscle shortening rate; P – muscle force or load applied to it; v_{max} - maximum speed of muscle shortening; P_0 - strength developed by a muscle in isometric contraction mode; a, b - constants.

The total power developed by the muscle is determined by the formula:

$$N_{gen} = (P+a)v = b(P_0-P). \quad (2)$$

The muscle efficiency remains constant (about 40%) in the range of strength values from 0,2 P_0 to 0,8 P_0. In the process of muscle contraction, a certain amount of heat is released. This value is called heat production.

Heat production depends only on the change in muscle length and does not depend on the load. Constants a and b have constant values for a given muscle. Constant a has the dimension of force, a and b - velocity. Constant b is highly temperature dependent. The constant a is in the range of values from 0,25 P_0 to 0,4 P_0. Based on these data, the maximum rate of contraction for a given muscle is estimated. [7-13]:

$$v_{max} = b \bullet (P_0 / a). \quad (3)$$

Muscle strength depends on the morphological properties and physiological state of the muscle:

- The original muscle length (resting length). The more the muscle is stretched at rest, the stronger the contraction (Frank-Starling law).
- Muscle diameter or cross section. Allocate two diameters:

  - anatomical diameter - muscle cross section.

  - physiological diameter - the perpendicular section of each muscle fiber. The larger the physiological section, the more strength the muscle has.

There are two types of muscle strength:

- Absolute strength - the ratio of maximum strength to physiological diameter.
- Relative strength - the ratio of maximum strength to anatomical diameter.

The greatest work and power is achieved at medium loads [4-6].

4. Electromyographic signal processing method

For a qualitative and quantitative assessment of the state of the human neuromuscular system using electromyogram (EMG) the information method of time-frequency analysis based on spectrograms can be used (fig. 2, fig. 3) [6-12].

This method is implemented on the basis of the fast windowed Fourier transform. In this case, the signal is divided into time intervals ("windows") of short duration, within which it can be considered stationary. Time intervals are called quasi-stationary segments, and the approach to processing is analysis over short intervals [13-30]. The original signal on the selected segment is multiplied by the window function and undergoes a fast Fourier transform in accordance with the expression:

$$STFT = \int [x(t) \cdot \omega^* (t - \tau)] \cdot e^{-2jft\pi} dt, \quad (4)$$

where x(t) – original signal, ω(t) – window function, k_τ – time shift amount, k – the ordinal number of the window shift, f – frequency, t – time, $\omega^*(t)$ – complex conjugate window function [13-14].

Next, we obtain a portion of the spectrogram for the analyzed window by squaring the real part (amplitude) of the windowed Fourier transform:

$$X(t) = | STFT(\tau_k, f)|^2. \quad (5)$$

To conduct a quantitative analysis of EMG signals, it is necessary to calculate the following parameters of the time-frequency representation of the total EMG: lower and upper cutoff frequency, median frequency, effective spectrum width and a number of others [13-41].

The average signal amplitude is also calculated by the formula:

$$A_{\text{cp}} = \frac{1}{N} \sum |A\,[i]|, \quad (6)$$

where A [i] - amplitude of the i-th sample of the registered signal, N – signal counts.

The lower and upper cutoff frequencies determine the effective spectrum width, i.e., the frequency range in which at least 90% of the signal power is concentrated [17-20]. The median is the frequency dividing the area under the energy spectral density curve into two equal parts [16].

Determination of frequency parameters is performed automatically based on the results of calculating the spectrogram of the EMG signal. For this, the value of the EMG signal energy in each cell of the spectrogram is calculated:

$$E[i,j] = A[i,j]^2, \qquad (7)$$

where A[i, j] - the amplitude of the electromyogram in the i-th row and j-th column.

Next, we determine the median frequency f_m. For this, a column with a serial number j is allocated, which corresponds to the spectral energy density of the signal at the j-th moment of time.

Signal energy concentrated in effective spectrum width $E_{эфф}[j]$ is more than 90%, calculated by the formula:

$$E_{эфф}[j] = 0{,}95 \sum_{k=1}^{F} E[k,j]. \qquad (8)$$

Lower cutoff frequency f_{Hj} is determined from the condition: the difference between the sum of the elements of the column with indices from f_{Hj} to f_{m_j} and the value $\frac{1}{2}E_{эфф}[j]$ minimal modulo.

Upper cutoff frequency f_{Bj} is determined from the condition: the difference between the sum of the elements of the column with indices from f_{m_j} to f_{Bj} and the value $\frac{1}{2}E_{эфф}[j]$ minimal modulo.

These processing parameters make it possible to fully assess the frequency content of the EMG signal.

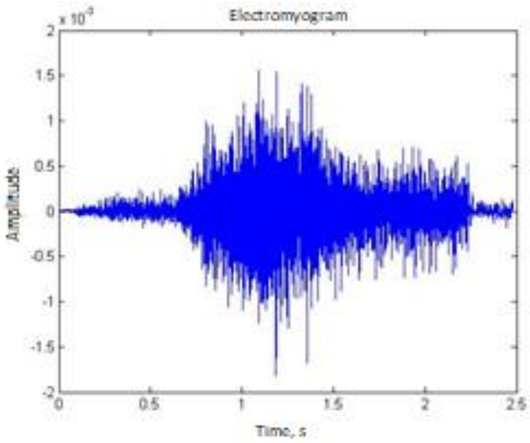

Figure 2: Electromyogramof the muscle *m. biceps brachii*

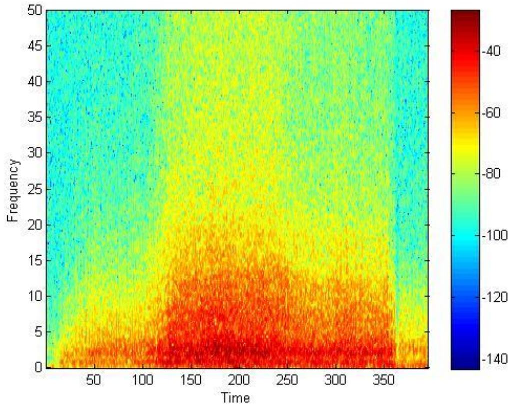

Figure 3: Corresponding spectrogramof the muscle *m. biceps brachii*

Let us represent the parameters of the EMG signal in the form of a certain finite set

$$A_m = \{a_i\}(i = \overline{1,m}), \qquad (9)$$

where A - the designation of this set; m – cardinality multitudes; a_i – elements of the set.

The elements of the set can be amplitudes, frequencies of the spectrum components, phase shifts, etc.

Let us represent the parameters of stimulating influences also in the form of a finite set

$$B_n = \{b_i\}(i = \overline{1,n}), \qquad (10)$$

where B - the designation of this set; n – cardinality multitudes; b_i – elements of the set.

The elements of the set can be the amplitude and frequency of stimuli, the type of modulation, modulation parameters, time intervals, etc.

Thus, the task is to determine such a transformation ω, which provides an unambiguous display of the elements of the number A to the corresponding elements B

$$A_m \xrightarrow{\omega} B_n, \qquad (11)$$

EMG signal processing allows for ongoing monitoring the effectiveness of therapeutic effects due to the optimal selection parameters of stimulating effects.

5. Conclusions

Quantitative analysis of the total electromyogram of the trained and untrained muscle *m. biceps brachii* revealed the following patterns:

– the average amplitude of the EMG signal for trained subjects reaches the highest values 345,62±148,10 μV, for the untrained equals 189,27±84,00 μV;

– the median frequency is characterized by the lowest values 111,44±27,62 Hz for trained subjects and 123,00±30,07 Hz for untrained;

– the upper cutoff frequency for trained subjects is 409,07±69,91 Hz and 446,90±66,22 Hz for untrained;

– the effective spectrum width for trained subjects is 382,09±71,42 Hz and 415,92±65,35 Hz for untrained.

Comparative analysis of the calculated parameters for trained and untrained subjects: indicators of the upper cutoff frequency, median frequency and effective spectrum width for untrained subjects exceed the corresponding values for trained subjects.

The proposed amplitude-frequency criterion allows one to take into account basic parameters of non-stationary bioelectric signal (amplitude and frequency) and thus to carry out quick and effective express diagnostics of the functional state of the neuromuscular system using automated complexes of time-frequency processing of EMG signals.

Thus, carrying out qualitative and quantitative analyzes the structure of an EMG signal that is unsteady in natureand the dynamics of its parameters in the process of muscle contraction is performed based on the spectrogram, realizing graphical visualization of the amplitude, frequency and time components of the biomedical signal in real time. Consequently, specific parameters of stimulating effects can be selected based on the data of the EMG signal, which makes it possible to implement an effective technical device for carrying out individual therapeutic procedures.

6. References

[1] O. A. Yeroshenko, I. V. Prasol, V. V. Semenets, About building a system of muscle electrical stimulation for cadets,The use of information technology in the training and operation of law enforcement: materials International. scientific-practical conf. Mar 14-15 2018 Kharkiv: NANGU (2018) 120–122.

[2] O. M. Datsok, I. V. Prasol, O.A. Yeroshenko, Construction of a biotechnical system of muscular electrical stimulation,Bulletin of NTU "KhPI". Series: Informaticsandmodeling. Kharkiv: NTU "KhPI", № 13 (1338). (2019)165–175.doi: 10.20998/2411-0558.2019.13.15

[3] P. P. Pestrikov, T.V. Pestrikova, Measuring system for recording signals from surface electromyography of forearm muscles,Electronic scientific publication "Scientific notes of PNU". Volume 10. No. 2. (2019) 173–180.

[4] O. Yeroshenko, I. Prasol, O. Datsok, Simulationofanelectromyographicsignalconverterforadaptiveelectricalstimulationtasks, The current state of research and technology in industry. № 1 (15). (2021) 113–119. doi: 10.30837/ITSSI.2021.15.113

[5] S. S. Nikitin, Electromyographic stages of the denervation-reinnervation process in neuromuscular diseases: the need for revision, Neuromuscular diseases. Moscow. №2. (2015) 16–24.

[6] C. J.De Luca, The use of surface electromyography in biomechanics, Journal of Applied Biomechanics. № 13 (2). (1997).

[7] S. H.Roy, G. DeLuca, S.Cheng, A.Johansson, L. D.Gilmore, C. J.De Luca, Electro-Mechanical stability of surface EMG sensors, Medical and biological engineering and computing. № 45. (2007).

[8] M.Voelker Implantable EMG measuring system, AMA Conferences. (2015).

[9] O. Yeroshenko, I. Prasol, O. Trubitsyn, and L. Rebezyuk, Organization of a Wireless System for Individual Biomedical Data Collection, International Journal of Innovative Technology and Exploring Engineering, vol. 9, no. 4, (2020)2418–2421.doi: 10.35940/ijitee.D1870.029420

[10] A. N. Osipov, S. K. Dick, K. G. Senkovsky, Complex biotechnical feedback in electrostimulation systems, Moscow: Medical technology, № 6. (2007) 27– 29.

[11] K. Jermey, Atlas of Musculoskeletal Anatomy, AST Publishing House. (2008) 382 p.

[12] S.H.Roy, G.Luca De, S.Cheng, A.Johansson, L.D. Gilmore, C.J.Luca De, Electro-Mechanical stability of surface EMG sensors, Medical and biological engineering and computing. Vol. 45. (2007).

[13] M. M. Mezhennaya, Time-frequency analysis of the total electromyogram in the qualitative and quantitative assessment of the functional state of the human neuromuscular system. Biomedical radioelectronics. № 2. (2012) 3-11.

[14] S. G. Nikolaev, Workshop on clinical electromyography, Ivanovo.(2001) 264 p.
[15] B. M. Gekht, Theoretical and clinical electromyography. (1990) 229 p.
[16] A. V. Sidorenko, V. I. Khodulev, A. P. Selitskiy, Nonlinear analysis of electromyograms, Biomedical technologies and electronics. №11. (200) 53–59.
[17] M. M.Mezhennaya, Choice of parameters of time-frequency processing of electromyograms of the neuromuscular apparatus, RT-2010: materials of the 6th Int. youth scientific-tech. conf. Sevastopol: SevNTU. (2010) 464 p.
[18] I. Perova, Ye. Bodyanskiy, Adaptive Human Machine Interaction Approach for Feature Selection-Extraction Task in Medical Data Mining, International Journal of Computing, no. 17(2). (2018) 113-119.
[19] M. Akay, Time-frequency representationsof signals, Detection and estimation methods forbiomedical signals. San Diego: Academic Press. (1996) 111–152.
[20] M. Hosokawa, Time-Frequency Analysis of Electronystagmogram Signals in Patients with Congenital Nystagmus, Japanese Ophthalmological Society. Vol. 48. (2004) 262–267
[21] J. Kaipio, Simulation and Estimation ofNonstationary EEG, Natural and Environmental Sciences. Vol. 40. (1996) 110.
[22] Z.Y Lin, D.Z Chen, Time-frequency representation ofthe electrogastrogram – application of the exponential distributions, IEEE TransBiomed Eng. Vol. 41. (1994) 267–275.
[23] Rohtash Dhiman et al. Detecting the useful electromyogram signals–extracting, conditioning andclassification, IJCSE. – Aug.–Sep. 2011. V. 2. № 4. (2011) 634–637.
[24] A.S.Borgul, A.A.Margun, K.A.Zimenko, A.SKremlev., A.Y. Krasnov Intuitive Control for Robotic Rehabilitation Devices by Human-Machine Interface with EMG and EEG Signals, 17th international conferenceon Methods and Models in Automation and Robotics (MMAR 2012). Proceedings. Międzyzdroje: IEEEXplore digital library.(2012) 308–311.
[25] A.A. Vorobyev, A.V. Petrukhin, O.A. Zasypkina,P.S. Krivonozhkina, A.M. Pozdnyakov, Exoskeleton as a newmeans in habilitation and rehabilitation of invalids (review),Sovremennye tehnologii v medicine (2015) 185–197.doi:10.17691/stm2015.7.2.22.
[26] H. Kawamoto, Y. Sankai, Power assist methodbased on phase sequence and muscle force conditionfor HAL, Adv Robotic (2005)717–734.doi: 10.1163/1568553054455103.
[27] D.P. Ferris, G.S. Sawicki, M.A. Daley, A physiologist'sperspective on robotic exoskeletons for human locomotion,Int J HR (2007) 507–528.doi: 10.1142/s0219843607001138
[28] K.E. Gordon, M. Wu, J.H. Kahn, B.D. Schmit, Feedbackand feedforward locomotor adaptations to ankle-foot load inpeople with incomplete spinal cord injury, J Neurophysiol (2010)1325–1338.Doi: 10.1152/jn.00604.2009.
[29] C.K. Battye, A. Nightengale, J. Whillis The use of myoelectric current in the operation of prostheses, J Bone JointSurg Br 37-B(3). (1995) 506–510.
[30] F.R. Finley, R.W. Wirta,Myocoder studies of multiplemyopotential response, Arch Phys Med Rehabil 48(11).(1967) 598–601.
[31] B.Peerdeman, D.Boere, H.Witteveen, R.Huis in`tVeld, H.Hermens, i S.Stramigiol, H.Rietman, P.Veltink,S. Misra,Myoelectric forearm prostheses: state of the art froma user-centered perspective, J Rehabil Res Dev 48(6).(2011)719.doi: 10.1682/jrrd.2010.08.0161.
[32] M. Aminoff Electromyography in clinical practice,Addison-Wesley (1978).
[33] J.M. Wakeling Spectral properties of the surface EMGcan characterize motor unit recruitment strategies, J ApplPhysiol; 105(5).(2008) 1676–1677.
[34] C. Fleischer, A. Wege, K. Kondak, G.Hommel, Application of EMG signals for controlling exoskeletonrobots, Biomed Tech 51(5–6). (2006)314–319.doc: 10.1515/BMT.2006.063.
[35] D. Farina, L. Mesin, S. Marina, R.A. Merletti, SurfaceEMG generation model with multilayer cylindrical descriptionof the volume conductor, IEEE Trans Biomed Eng 51(3).(2004) 415–426.doi: 10.1109/TBME.2003.820998.
[36] H.J. Hermens, B. Freriks, C. Disselhorst-Klug, G. Rau,Development of recommendations for SEMG sensors andsensor placement procedures, J Electromyogr Kinesiol 10(5).(2000)361–374.doi: 10.1016/S1050-6411(00)00027-4.

[37] F. Sylos-Labini, V La Scaleia, A. d'Avella, I. Pisotta,F. Tamburella, G. Scivoletto, M. Molinari, S. Wang, L. Wang,E. van Asseldonk, H. van der Kooij, T. Hoellinger, G. Cheron,F. Thorsteinsson, M. Ilzkovitz, J.Gancet, R.Hauffe, F.Zanov,F.Lacquaniti, Y.P. Ivanenko,EMG patterns during assistedwalking in the exoskeleton, Front Hum Neurosci 8.(2014)423.doi: 10.3389/fnhum.2014.00423.

[38] R.Merletti, M.Aventaggiato, A.Botter, A.Holobar,H.Marateb, T. Vieira,Advances in surface EMG: recentprogress in detection and processing techniques, Crit RevBiomed Eng 38(4).(2011) 305–345.doi: 10.1615/CritRevBiomedEng.v38.i4.10.

[39] D. Farina, C. Cescon, Concentric-ring electrode systemfor noninvasive detection of single motor unit activity, IEEETrans Biomed Eng 48(11).(2001) 1326–1334.doi: 10.1109/10.959328.

[40] J.L. Nielsen, S.Holmgaard, N.Jiang, K.Englehart,D.Farina, P. Parker,Enhanced EMG signal processing forsimultaneous and proportional myoelectric control, Conf ProcIEEE Eng Med Biol Soc (2009) 4335–4338. doi: 10.1109/IEMBS.2009.5332745.

[41] D.P.Ferris, C.L. Lewis,Robotic lower limb exoskeletonsusing proportional myoelectric control, Conf Proc IEEEEng Med Biol Soc (2009) 2119–2124.doi: 10.1109/IEMBS.2009.5333984.