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Ryszard S. Romaniuk
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Introduction

The **SPIE-IEEE-PSP WILGA** Symposium [wilga.ise.pw.edu.pl] is a kind of international Forum of Young Science in Photonics, Advanced Electronics and Internet Engineering. It is organized twice a year under the eminent patronage of two big international engineering institutions SPIE [www.spie.org] and IEEE [www.ieee.org] and their Polish counterparts: PSP—Photonics Society of Poland [www.photonics.pl], successor of Polish Chapter of SPIE [www.spie.pl] and IEEE Poland Section [www.ieee.pl], with participation of IEEE R8 [ewh.ieee.org/reg/8/sac/cms]. The patrons of the symposium are: PAS—Polish Academy of Science (The Committee on Electronics and Telecommunication) [keit.pan.pl], Association of Polish Electrical Engineers (SEP) [www.sep.com.pl], Polish Committee of Optoelectronics SEP [pkopto.ise.pw.edu.pl], Warsaw University of Technology [www.pw.edu.pl], Institute of Electronic Systems [www.ise.pw.edu.pl].

WILGA Organizers: The Symposium is organized by a group of devoted young people - photonics, mechatronics, and electronics researchers - gathered in the PERG/ELHEP Research Group [Zespół Badawczy PERG] of the Institute of Electronic Systems at the Faculty of Electronics and Information Technology of WUT. Most of these young researchers are active members of PSP, SEP, SPIE, OSA and IEEE. The symposium is diligently done by young researchers for young fellow researchers and the main aim is to have a lot of fun and to learn a lot.

WILGA Publications: The WILGA Symposium publishes its papers in the following proceedings series, technical and peer-reviewed journals: Proceedings of SPIE, since 2002; IEEE eXplore, Internet publication data base; Photonics Letters of Poland, since 2009; Elektronika, SEP Journal, since 1998; JET—Intl. Journal of Electronics and Telecommunications, PAS.

WILGA Proceedings of SPIE: There has been now quite a long tradition of WILGA publishing its works in the Proceedings of SPIE. This volume is the 11th published of the WILGA-SPIE series. The WILGA-SPIE volume series contains more than 1000 papers; all WILGA Symposiums have published more than 2000 papers with around 4000 participants. This is an extraordinary achievement for a modest symposium oriented solely on young researchers. No one event of similar character could compare to this achievement. This success was only possible due to big involvement of young researchers in their work. The following WILGA SPIE Proceedings were published: Wilga 2002 – Proc. SPIE 5125; Wilga 2003 – Proc. SPIE 5484; Wilga 2004 – Proc. SPIE 5775; Wilga 2005 bis – Proc. SPIE 5948 (Warsaw SPIE COO'05); Wilga 2005 – Proc SPIE 6159; Wilga 2006 – Proc. SPIE 6347; Wilga 2007 – Proc. SPIE 6937; Wilga 2008 – Proc. SPIE 7124; Wilga 2009 – Proc. SPIE 7502; Wilga 2010 – Proc. SPIE 7745; WILGA 2011 – Proc. SPIE 8008.

SPIE Poland 2005: The SPIE Poland meetings in 2005 were very special because then the Polish Chapter of SPIE (predecessor of Photonics Society of Poland) hosted together with SPIE and some other regional SPIE Chapters, the SPIE Warsaw Congress on Optics and Optoelectronics – SPIE COO Warsaw 2005. WILGA 2005 Symposium was split to two parts – one held usually in WILGA and the second jointly with the COO'05.

WILGA ways and topics: The official language of the Symposium is English. Peer reviewed papers are published in a renowned, worldwide recognized series Proceedings of SPIE in USA. The symposium is designed mainly for for Ph.D., M.Sc., and B.Sc. students (from physics, electronics and mechatronics, as well as material research) and their tutors/mentors. WILGA has a number of main topical tracks. Historically, the first one was Photonics and Web Engineering. Generally, WILGA embraces advanced photonic, mechatronic and electronic systems, in the following aspects: theory, modeling, algorithms, simulations, emulations, design, hardware, software, hardware-software interaction and integration, measurements, testing, commissioning and exploitation. WILGA also addresses new research tendencies like 3D photonics and electronics design, micro- and nano-systems, material engineering including meta-materials.

Topical sessions are organized by leading experts. Sessions usually begin with current tutorials and are filled with contributed papers by students and young researchers. One of the most important session tracks in WILGA are photonics applications and systems for superconductive accelerator (and free electron laser) technology and high energy physics experiments. We warmly invite students, young researchers, and their tutors to participate in WILGA.

WILGA 28th: The WILGA 2011 Symposium January edition was held 28–30 January 2011 at WUT's FE&IT. WILGA 2011; the May edition took place 23–29 May 2011 in a resort owned by Warsaw University of Technology. Nearly 200 presentations were presented during both editions of Wilga, covering a broad area of photonics applications and web engineering, and nearly 250 persons participated. An exceptionally efficient chair of the Organization Committee of WILGA 2011 was Dr Maciek Linczuk [M.Linczuk@elka.pw.edu.pl].

The working research sessions of 28th WILGA 2011 were: general photonics, optical fiber technology, optical communications, optoelectronics, applications of optical fibers, integration of electronics, photonics and mechatronics, distributed measurement systems, LHC and CMS at CERN, optics and optoelectronics for astronomy, fundamentals of FPGA-DSP systems, object oriented design of hardware, terabit optical data links, software-hardware co-design, biomedical engineering, computational intelligence of advanced systems, development of photonics and electronics in Europe and Poland, radar technology, terahertz photonics, etc.

WILGA 2011 - SPIE–PSP award for the best student paper presentation: The WILGA 2011 Award Committee was managed skillfully by Dr Ryszard Kossowski of WUT [kossowski@ia.pw.edu.pl]. The awards were a single category intended for students having just finished their M.Sc (including B.Sc.) degrees. The winners of SPIE-PSP WILGA 2011 competitions, and the titles of their presentations were: M.Sc. and B.Sc. category: 1 – Robert Plaga, Faculty of Physics WUT, "Fiber optic structures for dynamic stress sensing"; 2 – Tomasz Janicki, PERG-ELHEP-ISE Lab., "FPGA mezzanine card DSP module," (prepared with Ph.D. student Radoslaw Cieszewski); 3 – Krzysztof Sielewicz, PERG-ELHEP-ISE Lab., "Intelligent thermal imaging camera with network interface." The winning papers are published in this volume.

WILGA offsprings: The WILGA Symposium gave birth to a few topical meetings and conferences which then flourished on their own. These include student regional meetings (Opole, Wrocław, Kielce, Białystok, Lublin, Toruń and other), of SPIE student chapters, IEEE student branches, but also stand-alone conferences. Some of these meetings are still held periodically with Wilga, while some of them gained complete independence. WILGA is very proud of this sort of partnership, since the very good idea of WILGA is proliferating elsewhere. One of such meetings is, now fully independent, SPS – Signal Processing Symposium which started at Wilga in 2003.

SPIE – PSP WILGA 2012: The organizers of WILGA 2012 Symposium, to be held on 28 May – 03 June 2012, warmly invite interested young researchers and students in photonics and related fields to participate in this exceptional and very friendly research event oriented to host young researchers from Poland and all over Europe.

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Simulation of electroencephalographic signals for depth of anesthesia assessment

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ABSTRACT

The problem of simulating electroencephalographic (EEG) signals for different stages of anesthesia is considered. Review of existing techniques for EEG simulation is made and the new technique for simulating the EEG using only preliminary definition of magnitudes of harmonic components for every frequency ranges is presented. During experimental part EEG signals for four stages of ether anesthesia were simulated.

Keywords: EEG, depth of anesthesia, EEG simulation, narcosis

1. INTRODUCTION

Despite the high level and variety of diagnostic equipment in modern surgical operating rooms, there is still no single indicator that would adequately assess depth of anesthesia (DA) of a patient. The depth of anesthesia is currently measured by many indicators of the patient's life simultaneously, such as pupillary reflex, parameters of the cardiovascular system (heart rate, blood pressure, parameters of electrocardiogram etc.), analysis of expired gases. These parameters separately are not very reliable for evaluation of depth of narcosis because they depend on many factors, including age, sex, nature of human disease and nature of surgical intervention. The DA also depends of the type of anesthetic drugs used, type and scheme of intervention [1-3]. All these make anesthesia still hardly controlled process with many influencing factors. Therefore, the invention of a universal criterion of depth of anesthesia is a priority. It is known that the human brain is responsible for consciousness and unconsciousness, and thus for the depth of anesthesia. Thus to find a more appropriate unified criterion of DA monitoring, the estimation of a central nervous system state is widely used, mostly by means of brain electrical activity analysis with electroencephalography.

Many techniques of electroencephalogram (EEG) analysis are used for creating the parameters for DA but there is still a need for more sophisticated measures of evaluating the DA. One of the tasks in developing such elaborated techniques is its testing with the EEG signals corresponding to the different brain states. Full sets of signals corresponding to the various states and conditions affecting EEG during anesthesia are rarely available for the analysis. The aim of this work is to develop the technique for simulation of EEG signal for different stages of brain activity during the transition from consciousness to deep narcosis.

2. SIMULATION OF EEG SIGNALS DURING NARCOSIS

2.1. SELECTION OF SIMULATION TECHNIQUE

Simulation of EEG signal starts from the decision about what parameters of real EEG should be reproduced in the simulated signal. Depending on this, various techniques could be applied: autoregression, physiological modeling of EEG as the activity of artificial neurons, statistical simulation of EEG as noise signals [4-7].

EEG signal could be simulated as an output signal of some linear system with white noise input. In the most common autoregressive approach each EEG sample is defined as a weighted sum of previous samples. The main task is to define the system parameters, i.e. the coefficients of difference equation. Several EEG channels could be simulated in the framework of multivariate autoregressive approach, where samples of each channel depend on the previous samples in all channels. The problem in using this approach consists of finding of appropriate linear system parameters for different stages of narcosis and in its on-line adjusting for reflecting the transitions between stages. Moreover this approach could be used for linear models only, while EEG during anesthesia might have nonlinear characteristics.

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Nonlinear technique such as generalized autoregressive conditional heteroskedasticity approach could be promising for this case.

EEG signal can be also modeled as the random quasi-stationary signal, i.e. considered to be stationary and Gaussian only within short intervals. But there is no evidences about whether the EEG during anesthesia is stationary, what are probability density distributions and intervals of stationarity. It is believed now that during changes in functional state of the brain Gaussian assumption is rarely valid. Thus a lot of work is to be done for adequately simulate the EEG during transition between anesthesia stages as a random signal.

Physiological modeling of large sets of spiking neurons also could be used in the simulation of EEG. The basis of this approach is classical Hodgkin-Huxley model of action potential of single neurons by estimating the ion currents through voltage-driven channels. This model describes time change of membrane potential depending on the initial membrane potentials, characteristics of ion channels etc. More complex models could be constructed for the neurons interconnections and signal transfer through synapse and for the neuronal networks. The signals generated by these models could be used as a model of EEG signal while appropriate parameters and number of neurons are selected. Beside this kind of models are considered to be potentially the most adequate to the real brain electrical activity, its use is complicated because of the need of huge amount of parameters identification and resulting large-scale differential equation systems.

Now there are four more or less established electroencephalographic stages of narcosis: 1) analgesia; 2) excitation; 3) surgical (consisting of 4 sub-stages during which the surgery should be conducted); 4) agony (terminal stage). All these stages are achievable with administrating the appropriate amount of anesthetic drugs. There are clinical data about brain electrical activity during each stage. For example, the parameters of EEG signal for various stage of Ether anesthesia are given in Table 1, the same parameters for Ftorothan are given in Table 2.

The aim of this work is to represent the properties of EEG, which are important and useful for accessing the DA in the simulated signal. Thus the first task is to find what parameters are used for evaluating the DA and anesthetic drugs administration control.

Thus in the case considered here only the average magnitudes of oscillations in some frequency ranges are known, thus we have very limited information about brain electrical activity during anesthesia. The simulation technique for this case should use only the available parameters, that's why no method mentioned above could be used without additional knowledge of EEG parameters.

Table 1 – Stages of anesthesia and corresponding EEG parameters for the case of ether administration.

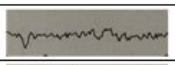
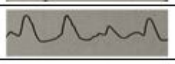
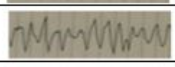
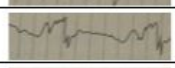
Ether Anesthesia						
Stages			Magnitude, uV	Frequency, Hz	Example	Comments
1	Analgesia		5-10	20-40		Slight increase of signal magnitude
2	Excitation					
3	Surgical Anesthesia	1st stage	20-50	4-40		High frequency oscillations with background low-frequency waves (4-7 Hz)
		2nd stage	20-80	1-3		Slow high-magnitude waves
		3rd stage	5-50	1-3		Delta waves with inclusions of low magnitude zones
		4th stage				
4	Agony		***	***		Total decrease of brain electrical activity

Table 2 – Stages of anesthesia and corresponding EEG parameters for the case of Ftorothan administration.

Ftorothan Anesthesia						
Stages			Magnitude, uV	Frequency, Hz	Example	Comments
1	Analgesia		10-25	15-25		Fast low-magnitude oscillations
2	Excitation		50	3-25		Low-magnitude oscillations overlapped with 3-6 Hz, 50 uV waves
3	Surgical Anesthesia	1st stage	50-100	4		Absence of fast low-magnitude activity
		2nd stage	200-300	1-3		Slow waves
		3rd stage	25-200	1-8		1 Hz, 100-200 uV oscillations overlapped with 6-8 Hz, 25-50 uV oscillations
		4th stage	50-200	6-8		Oscillations of 200 uV magnitudes with low-magnitude 6-8 Hz activity
4	Agony		***	***		Absence of cortical activity

2.2. EEG SIMULATION TECHNIQUE

The proposed approach to EEG simulation is based on the technique previously described in [8], where simulation was done by setting the average power spectral density for each EEG frequency band. In the case considered here only the average amplitudes for the frequency bands are given for all stages of anesthesia, thus the previous technique needs to be modified as follows. Oscillations in every EEG's frequency range are constructed separately as the sum of harmonics with the frequencies prescribed by the corresponding range limits. For the sake of simplicity the values of spectral amplitudes $S_r[f_n]$ in every rhythm are defined as constants over the whole range interval:

$$S_r[f_n] = \begin{cases} a_r, \ if \quad f_n \in [F_{rs}, F_{re}] \\ 0, \ otherwise \end{cases}, \tag{1}$$

where f_n – frequency of the harmonic component; a_r – the average value of harmonic amplitude; F_{rs} and F_{re} are starting and end frequency of every EEG range, Hz.

Total number of harmonics for the range is $N_r = (F_{re} - F_{rs})T$. The whole amplitude spectrum of simulated EEG is constructed as the sum of separate $S_r[f_n]$ for all ranges with indexes r $(r \in \Re = \{\theta, \delta, \alpha, \beta\})$:

$$S[f_n] = \sum_{r \in \Re} S_r[f_n]. \tag{2}$$

To calculate the samples of EEG signal in time domain, the representation of the signal as the sum of harmonic oscillations with frequencies f_n and amplitudes $S[f_n]$ (2) can be written as inverse Fourier transform:

$$EEG[n] = \sum_{r \in \Re} \sum_{f_n = F_{rs}}^{F_{re}} S_r[f_n] \cos(2\pi f_n t - \varphi_n), \tag{3}$$

where φ_n – initial phase angle. To additionally enhance the randomness inherent to EEG signals, the value of φ_n is selected to be random uniformly distributed numbers within the range from 0 to 2π. This will not affect the average value of the signal but will reflect the random nature of brain's potential oscillations. Thus by using simple technique of

adjusting the average amplitude of harmonics in required frequency range EEG signals with desired properties for every stage of anesthesia could be obtained.

The values of $S[f_n]$ may be defined not only as average amplitudes for frequency bands, but also using more complicated functions. It gives possibility to increase accuracy and quality of resulting simulated signal. One way to describe amplitude spectra is to define it using Bell Curves:

$$S[f_n] = \sum_{m=1}^{M} k_m \exp\left(-\frac{(f_n - f_{0m})^2}{w_m}\right), \tag{4}$$

where k_m –amplitude of m-th Bell Curves, f_{0m} – frequency of m-th curve's peak, w_m – width of m-th curve, M – number of Bell Curves. Then resulting signal will be obtained as:

$$EEG[n] = \sum_{n=0}^{N} S[f_n]\cos(2\pi f_n t - \varphi_n) = \sum_{n=0}^{N}\left(\sum_{m=1}^{M} k_m \exp\left(-\frac{(f_n - f_{0m})^2}{w_m}\right)\right)\cos(2\pi f_n t - \varphi_n), \tag{5}$$

where N – number of number of harmonic oscillations.

The main feature of such technique is a possibility to control the contribution of every harmonic component into resulting signal by setting appropriate amplitude. The model is independent of sampling frequency and may have adjustable shape of harmonics magnitude's distribution in every frequency band.

The technique described above is used for simulating only one EEG channel but it could be easily extended for constructing multichannel signals. Each EEG lead could be simulated independently from each other and may have different parameters, thus possible non-uniform surface distribution of signals with appropriate spectral components' magnitudes is also taken into account in the proposed technique. This could be beneficial for simulation of signal from different brain regions and thus allows to more precise description of brain electric activity during anesthesia. This is useful for studying the DA assessment techniques with different number of registering electrodes and at various electrode locations. The issues of the difference in stages of EEG activity for sleep and for anesthesia are highlighted and considered in the model.

3. EXPERIMENTAL RESULTS

The EEG signals for the case of ether anesthesia were simulated using the abovementioned technique. The samples of one channel of EEG for each stage from Table 1 were calculated for sampling rate 256 Hz. Normal EEG signal of conditionally healthy conscious person is presented on Fig. 1 for reference. Obtained signals for different stages of anesthesia and their power spectral densities' estimates by Welch method are shown on Fig. 2-5. Signal corresponding to same stage (excitation and analgesia) as on Fig. 2 but for the case of Ftorothan administration is presented on the Fig. 6.

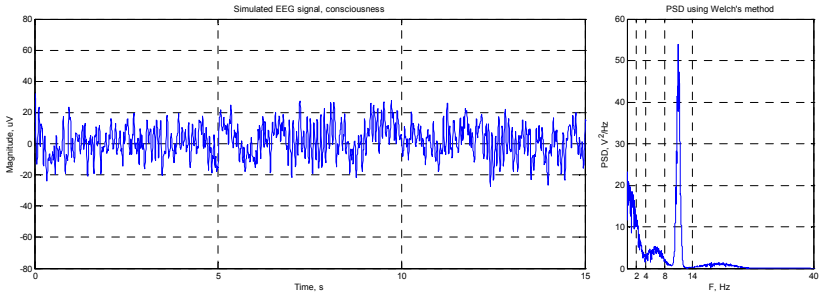


Figure 1 – Simulated EEG signal for healthy conscious person and it's power spectral density

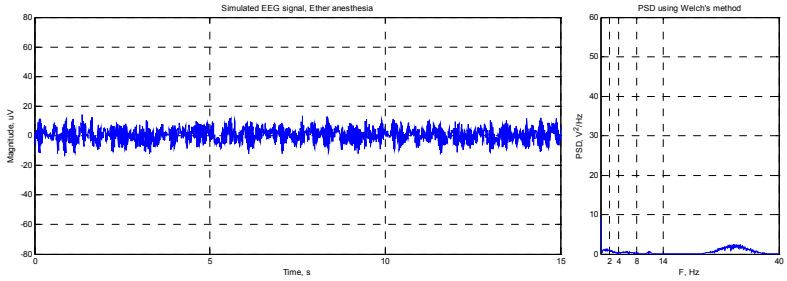


Figure 2 – Simulated EEG signal for ether anesthesia (analgesia and excitation stage) and it's power spectral density

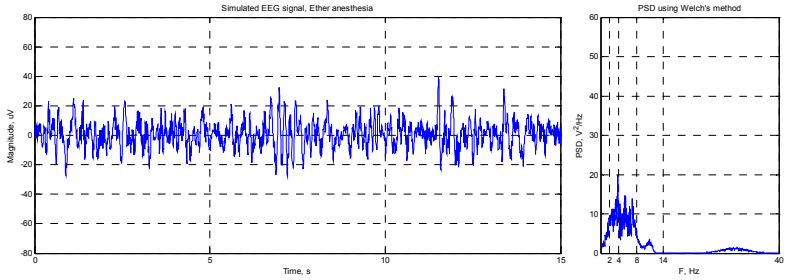


Figure 3 – Simulated EEG signal for ether anesthesia (1st surgical stage) and it's power spectral density

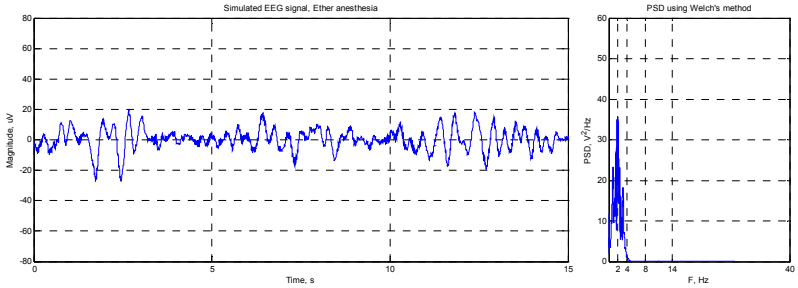


Figure 4 – Simulated EEG signal for ether anesthesia (2nd surgical stage) and it's power spectral density

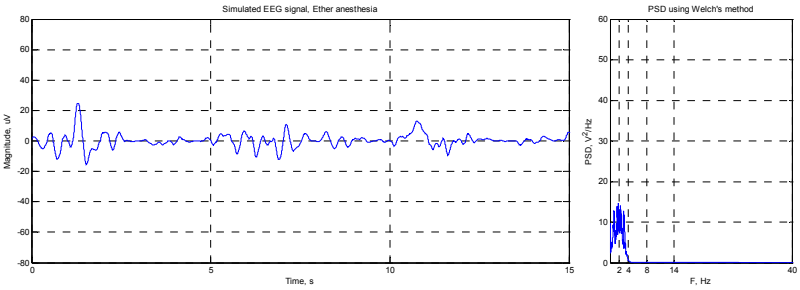


Figure 5 – Simulated EEG signal for ether anesthesia (3rd and 4th surgical stages) and it's power spectral density

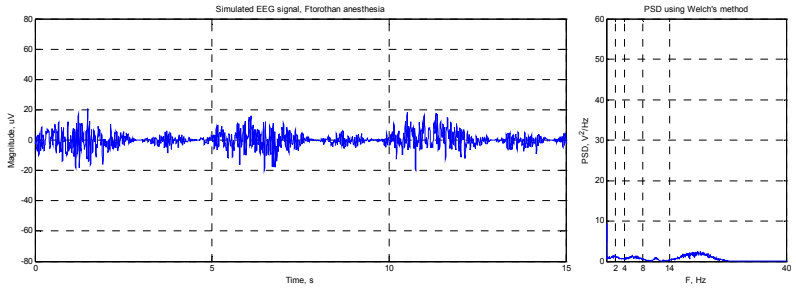


Figure 6 – Simulated EEG signal for Ftorothan anesthesia (analgesia and excitation stage) and it's power spectral density

4. CONCLUSIONS

Technique for constructing simulated EEG for different brain states basing on required average magnitude of spectral components in predefined frequency ranges corresponding to different stages of anesthesia is proposed. Representation of obtained artificial EEG signal as the sum of harmonic oscillations with random initial phases is proposed. The main feature of such representation is a possibility to control the contribution of every harmonic component into resulting signal by setting appropriate amplitude. The model is independent of sampling frequency and allows adjustable shape of harmonics magnitude distribution in every frequency band.

After reviewing obtained simulated signals it can be concluded that EEG signals for different stages of anesthesia as well as for different anesthetic drugs could be simulated by application of proposed technique using only the average magnitude of harmonic components for various frequency ranges. These signals cold be used for preliminary testing of the algorithms of depth of anesthesia assessment.

5. ACKNOWLEDGMENTS

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