Means of processing information on motor activity of patient during sleep

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Abstract. Information about the physical activity of a person during sleep is an important component of information about the state of one’s nervous system, the interpretation of which can be used for disease monitoring, diagnostics and prediction of diseases of the nervous system. This will significantly reduce the risks of disability and improve the quality of life of the patient in accordance with the concept of mobile telemedicine (mHealth).

1. Introduction

Motor activity during sleep is its necessary component, both for animals and for humans. This is confirmed by numerous experiments, as well as by the fact that excessive physical activity or, conversely, its failure, and, perhaps, the complete absence is a sign of various disorders of various nature, primarily neurological, such as parasomnia (sleep disorder), Parkinson's disease, restless legs syndrome, epilepsy and others. Thus, information about motor activity during sleep is an important part of health, and definitely affects the quality of life. This is confirmed by the fact that studies of night movements have long been of great importance, since the recording of movements - an actography - was before the introduction into functional diagnostics of electroencephalographic (EEG) studies as the main indicator of the activity of the brain during sleep. However, this method of research can only be carried out by preparing the patient for examination, the medical staff of appropriate qualifications and is usually performed on an outpatient basis and mostly in the day time, which in practice leads to use during the session of so-called test samples which cause increased activity of the brain. In addition, a certified specialist in this area of research must interpret the data recorded in EEG [1]. These factors significantly limit the use of EEG, especially in small settlements, and existing devices for actography do not meet modern conditions, in particular, processing of registered information. Thus, at present, the main problems are the shortage of specialists and shortcomings of these methods and means of obtaining and processing information about the studied process. It should be noted that, like most processes in medical practice, motor activity during sleep is a random non-stationary process and, therefore, requires a large amount of data obtained in similar conditions (ensembles of realizations) which in turn leads to an increase in the time for the interpretation of the recorded data, and, therefore, the increased workload for which there is not enough staff.

Undoubtedly, the practical implementation of these conditions, when using existing means because of the above problems, is impossible. Thus, to resolve these issues, the necessary tools for measurement and record of motor activity during sleep, which should be used by the patient without medical
assistance at home, and recorded data should be given to the medical staff of any widely available means of telecommunications and interpreted by application software, available to such employees. This concept corresponds to the direction of mobile telemedicine (mHealth) [2] and in the authors’ opinion has a great potential for development. Currently available non-EEG based ambulatory seizure detection designed for home use device such as a wrist accelerometer of Empatica[3], intended for registration of epileptic seizures in patients already diagnosed for preventing sudden unexpected death in epilepsy (SUDEP), but these devices do not allow the study to predict the disease.

2. Materials and methods

The proposed solution to the problem is the tool the authors developed for processing information on motor activity during sleep.

This system consists of a device for measuring and recording information about the motor activity of a person during sleep and an analysis program for this information. Since motor activity during sleep is characterized by motor activity of the extremities, measurement and registration of the motor activity of the extremities are sufficient for measuring and recording it. Therefore, to implement this tool, the device for measuring and recording information about motor activity during sleep is fixed on the wrists or (and) at the ankles of a person. During the design, considerations were adopted that ensure the operational characteristics of the system in accordance with the task in hand. First of all, this is the low cost of the measuring and recording device and the principle of "turned on and off" when it is applied and the maximum availability of the battery element of the device, since increased motor activity in sleep is a consequence of neurological diseases that are especially acute in low-income countries and in elderly people. That is why it was decided not to use smartphones and other similar devices in our device. The measuring component of this device is an accelerometer sensor with a number of axes of at least three. The computing component of the device is a microcontroller. Information about the motor activity is recorded on a memory card, for example, microSD [4]. Structurally, this device is unitary and is powered by a galvanic power source located in it. The information registered on the memory card can be presented to the physician both personally and via telecommunication channels and then interpreted by the developed application program located on the doctor's computer. This regulation of the interaction between the doctor and the patient will reduce the number of visits to the hospital by the patient and reduce the time spent by the neurologist on the analysis of the findings to establish the diagnosis. In addition, it will allow one to carry out instrumental monitoring of the selected treatment tactics and predicting the patient's condition, which is especially important with prolonged therapeutic treatment, for example, with epilepsy for at least two years, since long-term administration of any medication has undesirable side effects besides the positive effect.

3. Practical results

At present, with the authors’ system, comparative studies have been conducted in 10 practically healthy persons (control group) and in 10 patients with the established diagnosis of "epilepsy". To process the obtained results, the authors took into account the main provisions for the analysis of the nonstationary process for a single implementation, as described in Chapter 12 [5]. For this, the time of one night monitoring session was divided into equal time intervals, which allowed us to obtain several realizations under the same conditions. This made it possible to reduce the nonstationary process under investigation to the form of a nonstationary process with stationary elements and to carry out a conventional statistical analysis, since on short time intervals the nonstationary process with stationary elements can be considered quasistationary. To quantify the process, the term "coefficient of motor activity" is used numerically:

$$A = \frac{\sum_{i=1}^{N} r_i}{N} \cdot 100\% \quad (1)$$
\[ N = \begin{bmatrix} T \\ t \end{bmatrix} \] (2)

\[ \frac{U(t)_{x_{\text{max}}}}{U(t)_{x_{\text{min}}}} - 1 = A_x \] (3)

\[ \frac{U(t)_{y_{\text{max}}}}{U(t)_{y_{\text{min}}}} - 1 = A_y \] (4)

\[ \frac{U(t)_{z_{\text{max}}}}{U(t)_{z_{\text{min}}}} - 1 = A_z \] (5)

\[ n_i = \begin{cases} 1, (A_x > 0.15) \lor (A_y > 0.15) \lor (A_z > 0.15) \\ 0, (A_x \leq 0.15) \land (A_y \leq 0.15) \land (A_z \leq 0.15) \end{cases} \] (6)

\( A \) - coefficient of motor activity,
\( T \) – one implementation,
\( t \) – duration of interval partitioning,
\( U \) – the measured value of motor activity,
\( x, y, z \) – spatial coordinate axis,
\( \max, \min \) – maximum and minimum value,
\( A_x, A_y, A_z \) - the relative peak amplitude peak-to-peak.

Analysis of the obtained data showed that for value \( t = 60 \) [s] and condition (6), value (1) in healthy persons does not exceed 9%, while in 80% of persons from this group it does not exceed 7%, and in persons from the first group it is from 9% to 12% in persons receiving therapeautic care and above 12% in the rest. In our opinion, this provides a basis for the conditional division of motor activity in the monitoring of night sleep in the following zones: up to 7% - green, 7-9% - yellow, 9-12% orange, more than 12% red "and can be an indicator for assessing the patient’s condition in the computer analysis of recorded data [6].

As already mentioned, the motor activity in sleep, especially the motor activity of the limbs, is characteristic of many neurological diseases, so the identification of patterns for a particular disease is the main problem of this area of research [7,8,9]. It is generally recognized that one of the important factors in the analysis of motor activity is not only the amplitude, but also the biomechanical characteristic of velocity qualities as the rate of change of force known as the force gradient \( \nabla F \) [10]:

\[ \frac{dF}{dt} = \nabla F \]

\( \vec{F} = F_x + F_y + F_z \)

\( \vec{F} \) - vector of the force acting on the accelerometer sensor, \( F_x, F_y, F_z \) - projections \( \vec{F} \) onto the corresponding coordinate axes.

The design of the ADXL 327 accelerometer used in our case is such that the signal values at its outputs correspond to the projections of the force vector acting on it to the corresponding coordinate axis and, consequently, we are able to calculate the strength gradient over each of the coordinate axes:

\[ |\nabla F_i| = \frac{|\Delta F_i|}{\Delta t} \] (7)
\[ |\nabla F_t| = \frac{|\Delta F_t|}{\Delta t} \]  
\[ (8) \]

\[ |\nabla F_z| = \frac{|\Delta F_z|}{\Delta t} \]  
\[ (9) \]

\( \Delta t \) - the time interval for which the change occurred, \( df \).

Thus, the fulfillment of conditions (1) - (6) is not only an assessment of the monitoring of motor activity during sleep, but also the primary sorting of information for analysis and building a process measurement model to establish a prognosis or diagnosis of the disease with arguments (7-9). In this case, an ensemble of realizations satisfying condition (6) with \( n_i = 1 \) must be considered.

4. Conclusion

New devices are needed for monitoring seizures to predict disease. They must be unobtrusive, automated and bearable in everyday life. This study quantifies the performance of new wrist-worn convulsive seizure detectors.

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