An introduction to EEG artifacts

Mat-2.4108 Independent research projects in applied mathematics

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Contents

1 Introduction

The aim of this work is to present the most common artifacts related to EEG, i.e. electroencephalography measurement. An artifact is considered a disturbance in a measured brain signal not originating from the brains. The different sources of artifacts are classified to external and internal categories. Some typical artifacts are identified and illustrated from a recorded signal.

Some EEG signal processing methods for detection of artifacts are presented and experimented in practice. Moreover, the significance of identification is emphasized with an example from ICU, i.e. intensive care unit. It will be shown that an epileptic seizure and an artifact can easily be mixed with each other.

2 EEG phenomenology

The EEG is the brain electrical activity measured by putting electrodes on the scalp. The joint activity of millions of cortical neurons, at the depth of several millimeters, produces an electrical field which is sufficiently strong to be measured from the human scalp. [1] Typically, the amplitude of an EEG signal is approximately from 40 to 100 μV with the frequency range from 0 to 100 Hz. [2]

On the cellular level bioelectrical signals are related to ionic processes which arise as a result of electrochemical activity of cells having an ability to conduct an electrical current. A potential arises when membrane channels of cells open so that ion may diffuse across the membrane, which creates an increase in positive electrical charge. Figure 1 illustrates how this mechanism is implemented in nerve cells. The axon and dendrite are connected with a synapse, which transmits the signal from a presynaptic neuron to a postsynaptic neuron. When some stimulus evokes a nerve impulse to travel across the brain, the signal is moving from a neuron to another. On the brain cortex, the parallel nerve cells becomes synchronously positively and negatively charged, thus these dipoles generate an electrical field. [1]

In the examples of this report electrodes are placed on patients forehead

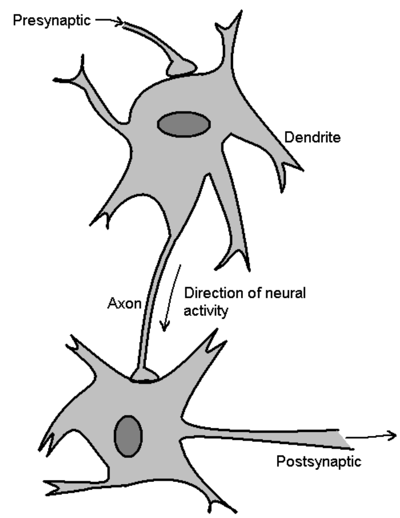

Figure 1: Two neurons transmitting a signal

shown in Figure 2. The EEG signal is represented as a graph of voltage versus time. The measured voltage is obtained as the potential difference between two electrode sites placed on the scalp.

The potential difference is a measured potential respect to the reference point (noted by R). The measured signal is amplified and the actual signals are *lf*, i.e. left frontal, *rf*, i.e. right frontal, *lt*, i.e. low temporal and *rt*, i.e. right temporal are then produced by subtracting the measured potential differences related to the reference point R, which becomes to a simple form

$$2\text{-R - (3 - R) = 2-3 = lf} \tag{1}$$

The recorded signals and their names are shown in Table 1. This electrode installation is a so called sub-hairline montage. It is easy to use, because it enables the use of sticker electrodes, which do not require skin preparation,

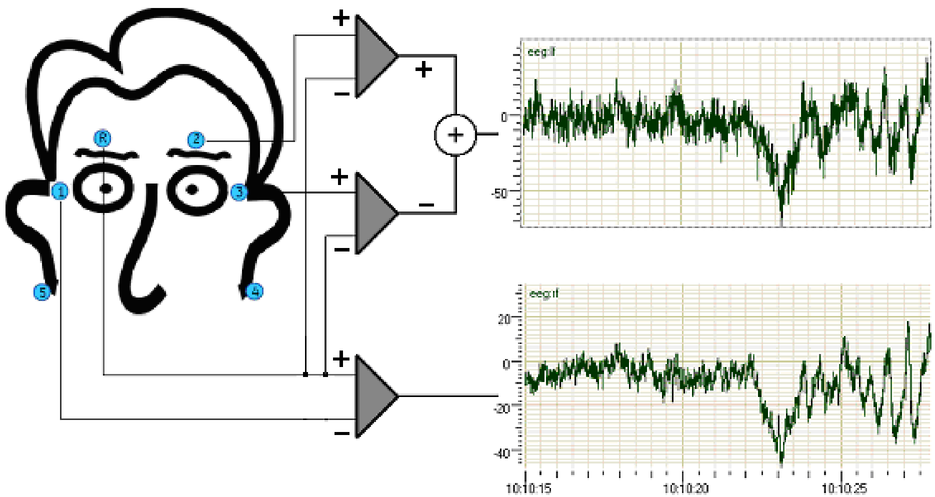

Figure 2: Installations of electrodes and recordings of channels *lf* and *rf*

Table 1: Measured EEG channels

R-2	f	front
R-1	rf	right frontal
1-5	rt	right temporal
2-3	lf	left frontal
3-4	lt	left temporal

use of electrode paste, or hair-cutting. The sticker electrodes are used in ECG, i.e. electrocardiography as well.

Commonly, the electrodes are placed according to an internationally recognized "10-20" system. In this "10-20" system electrodes are placed all around the human scalp. "10" and "20" refers to distances between adjacent electrodes. [3]

The human brain is divided to two lobes, left and right. The signal over the lobes is rarely analyzed, because brain signals hardly cross the lobes. Symmetrically measured signals are supposed to be almost the same on both sides. Asymmetrical differences between left and right signals give rise to suspect some disease, a tumor for example or an artifact. [3]

Monitoring the patients EEG signal provides information of the subjects state of consciousness. The frequency of signal describes the activity level of brains. Different frequencies and associated appearances are classified in Table 2. Even a naive observer will recognize that the voltage record during deep sleep has a bigger amplitude and contains much more low-frequency content.

The main appliance of the EEG is diagnosing and research of neurological diseases such as epilepsy. The EEG measurements can be used to diagnose different stages of sleep and analyze a quality of subjects sleep. In addition, the brain signal can also be used to monitor a drug-effect, e.g. a right amount of dose during anesthesia. [9] In Figure 3 is signal from channels *lf*, *rf*, *lt* and *rt* during delta activity and the patient is presumably in deep sleep.

Table 2: Comparison of brain activites

	Frequency/Hz	Activity
Beta	13-35	Wakefullness
Alpha	8-13	Light Sleep
Theta	4-8	Sleep
Delta	0-4	Deep Sleep

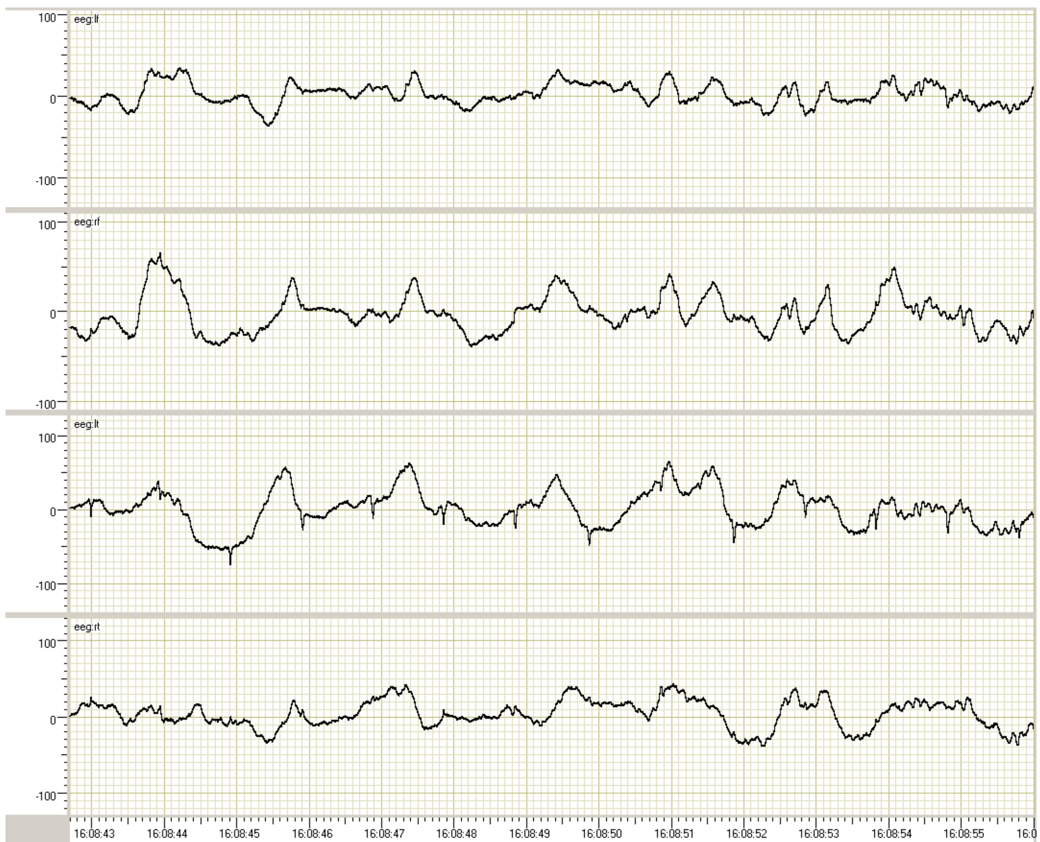

Figure 3: Channels *lf*, *rf*, *lt* and *rt* during delta activity. The x-axis presents time and y-axis is in microvolts.

3 Artifacts

The EEG signals contain artifacts in practice. Artifacts are considered unwanted signals or interference in a signal. Different types of artifacts can be divided to external and internal artifacts. External artifacts are caused by outer actions and internal artifacts are associated with the actions made by subject itself. The classification of artifacts is summarized in Table 3.

3.1 External artifacts

External artifacts result often from unsatisfactory technology. EEG measurement technology consists of apparatus and connections. The mains frequency may cause an artifact by appearing as a 50 Hz component in EEG signal. This same phenomenon may appear as well in recordings where a battery is used as a power supply. The surrounding walls and electric cables produce a constant electric field. In addition, external electronic devices may fault measured signal by creating electric and magnetic fields. [3]

The revolution that has taken place in the design and construction of EEG apparatus has reduced the incidence of machine faults. On the other hand, the possibility of machine faults have risen along with machines greater complexity. Purely mechanical machine faults normally appear as a total loss of signal or somehow easily detectable feature. More significant machine faults concern software development and a proper algorithm design. [3]

It is possible, that electrodes simply detaches from patients forehead which vanishes the signal shown in Figure 4. As a result, first the potential difference rises to infinity and thereafter there is no longer potential difference between electrodes and the signal strives to zero. In Figure 4, there is also noteworthy noise in channels *lf* and *rt* that is presumably connected to removal of electrodes. The signal of *lt* channel obviously consists in addition to EEG signal features of ECG activity. There is also ECG signal illustrated in Figure 4.

Moreover, sometimes electrodes are attached on the hair area or the contact is not ensured by moisturizing patients skin. It is also possible that the electrodes are pressed or pushed. The two discontinuous spikes in channel *rf*

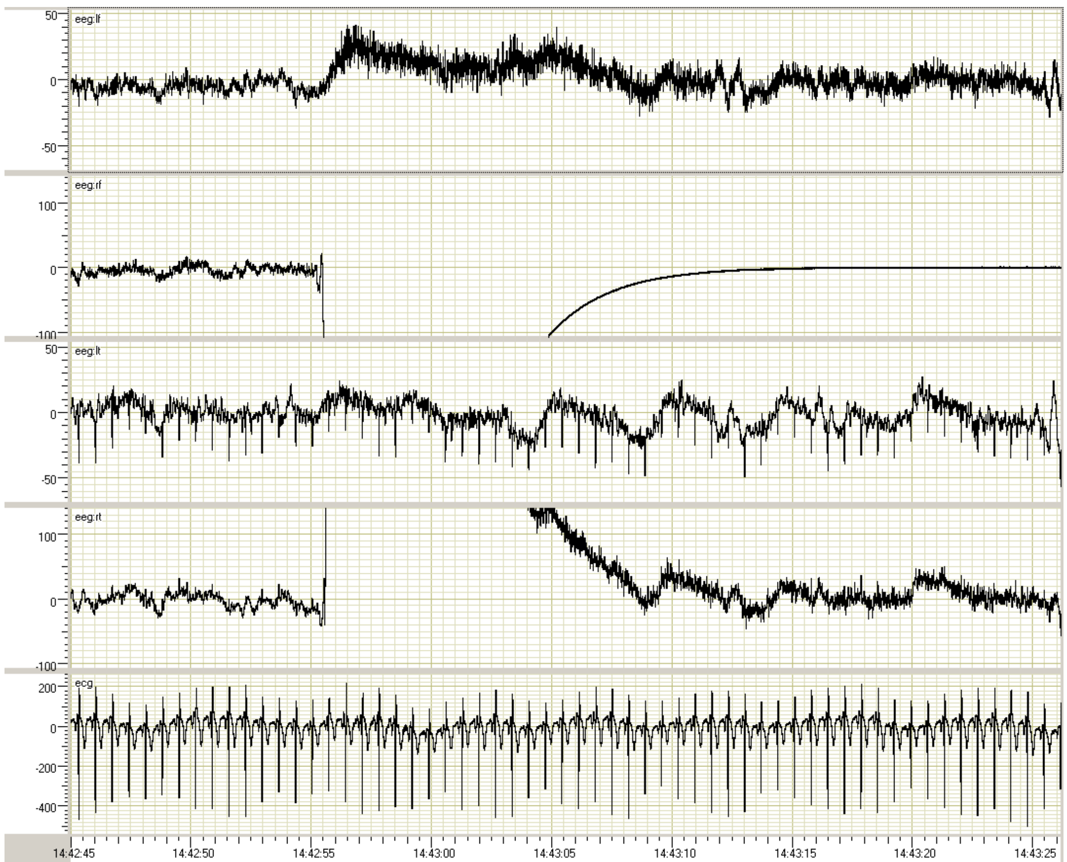

Figure 4: EEG signal disappears when an electrode of *rf* and *rt* detach. The x-axis presents time and y-axis is in microvolts. The lowest graph represents ECG signal and the y-axis is in millivolts.

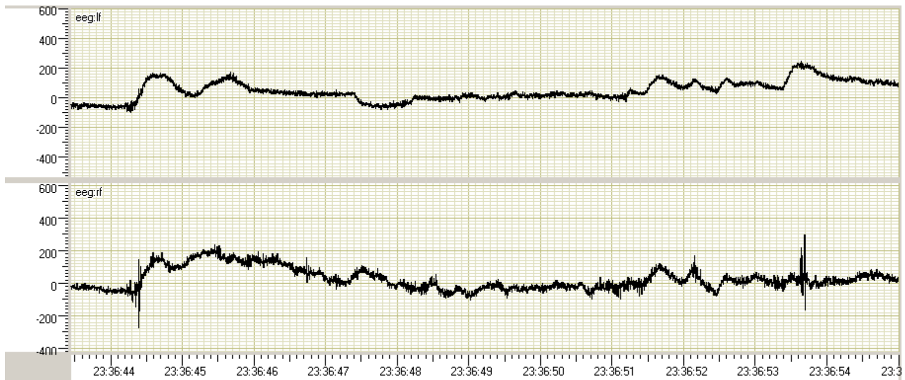

Figure 5: EEG signal when electrode of *rf* channel is touched. The x-axis presents time and y-axis is in microvolts.

shown in Figure 5 are very likely caused by a touch. [3]

The source of an artifact may be very unexpected. For example, if someone sways the patients bed, the hospital bed generalizes a signal component with 8 Hz frequency. Moreover, the frequent artifacts can also be related to patients breathing. In ICU it is possible that patient is in ventilator. The ventilator causes a pressure directed to patient's forehead, which generates rhythmic movement shown as an repeating artifact in EEG signal. [3]

3.2 Internal artiacts

Internal artifacts arise from body activities that are either due to movements or bioelectrical potentials. The potential between electrodes changes as a result from such as eye movement or muscular activity. [2]

3.2.1 Movement artifacts

Imperfect contacts are normally consequences of patients movement or improperly attached electrodes. Movement may cause pulling and tension to the electrodes. In Figure 6 there is EEG and accelerometer signals from a longer time scale. The accelerometer signal is divided to x and y directions.

The observed patient is moving and probably awake. The movement of patient causes the change of potential in accelerometers attached to patients forehead. The accelerometers in use are prototypes and the signal is collected with a pressure receptors, thus the signal is expressed in Torrs.

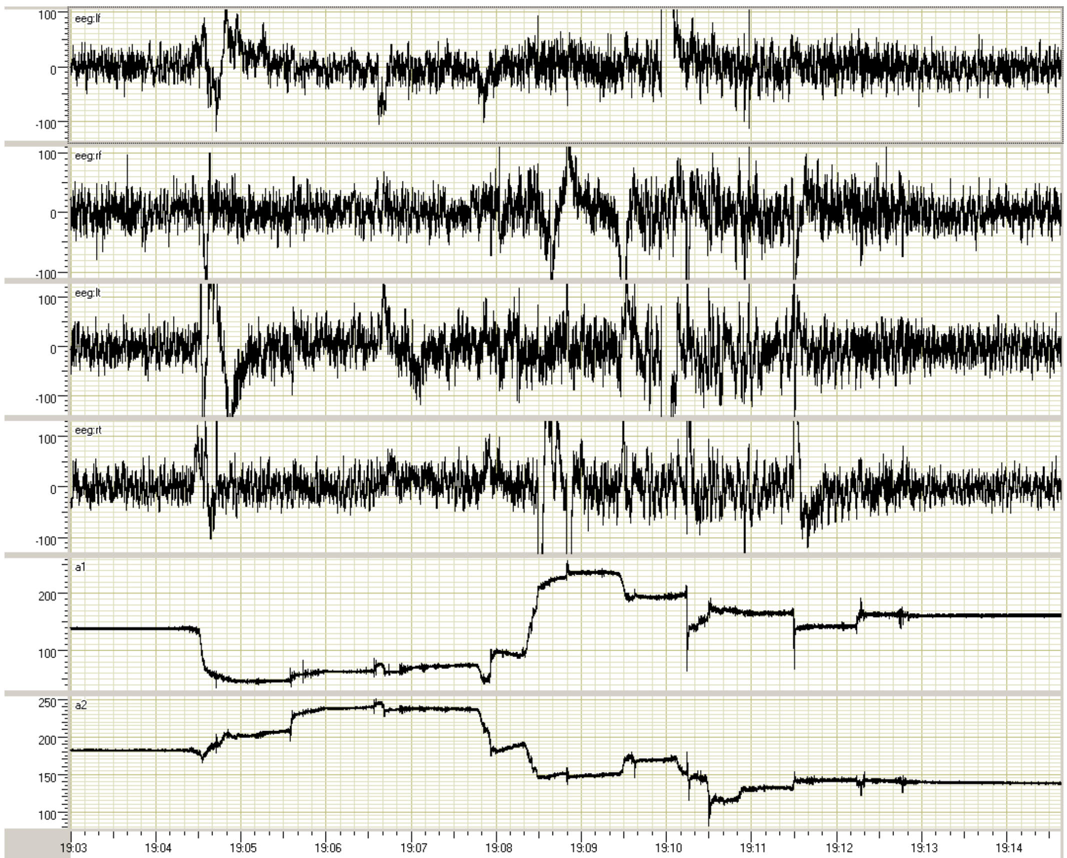

Figure 6: EEG and accelerometer signal during patient's movement. The x-axis presents time and y-axis of EEG signals is in microvolts. In the two lowest graphs, the y-axis is in Torrs, which represents the position of accelerometers.

3.2.2 Oculogenic potentials

A movement of eyeballs or eyelids causes a change in the electrical field that will be picked up by electrodes nearby. The human eye can be considered a dipole that is positively charged in front and negatively behind. Movement of eyeballs and eyelids produce different kind of artifacts. The movement of eyeballs is illustrated in Figure 7 and the movement of eyelids i.e. a blinks are illustrated in Figure 8. These artifacts are somewhat easy to detect because of their typical shape and there are algorithms developed to detect these sort of artifacts automatically from EEG signal. These sort of artifacts are realized especially in channels *rf* and *lf*, because the potential varies between electrodes concerned.[4]

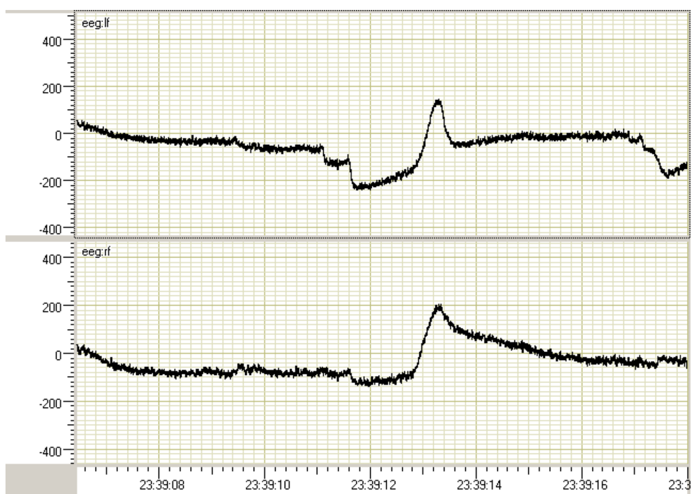

Figure 7: Eyeball movement

3.2.3 Myogenic potentials

Muscle potentials on the scalp, which can be localized or widespread, occur in a variety of forms. The effects of muscle potentials may be reduced by muscle relaxants or a change of posture. Mostly muscular potentials are caused by jaw and facial movements, such as those associated with talking,

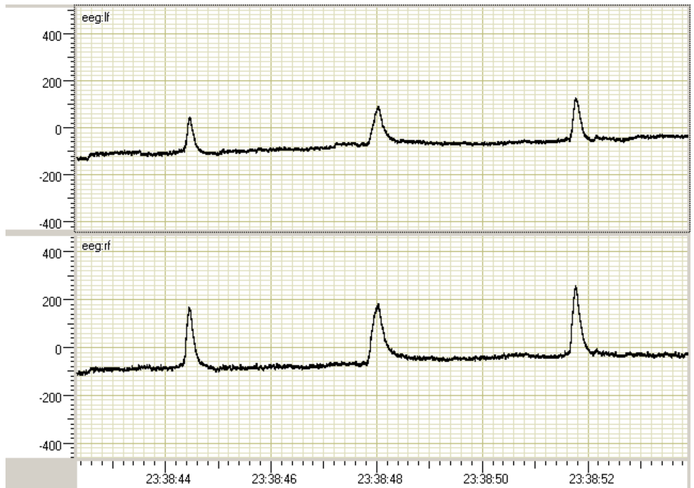

Figure 8: Blinks in beta activity EEG signal. The x-axis presents time and y-axis is in microvolts.

chewing, swallowing, smiling etc. One is able to detect muscular activity as an overall composite signal in Figure 7. [3]

3.2.4 Potentials related to cardiac activity

A pulsating heart produces an electric field. The electrical activity of heart is conducted to the scalp. Electrical activity occurs as potential changes in measured potential usually especially in *lt* signal, because the heart is typically situated on the left side of human body. This is shown as an ECG artifact in Figure 9. [12]

Additionally, cardiac activity may express itself as a pulse artifact in EEG. The pulse artifact occurs when an electrode is placed over a pulsating vessel and the electrode moves physically.

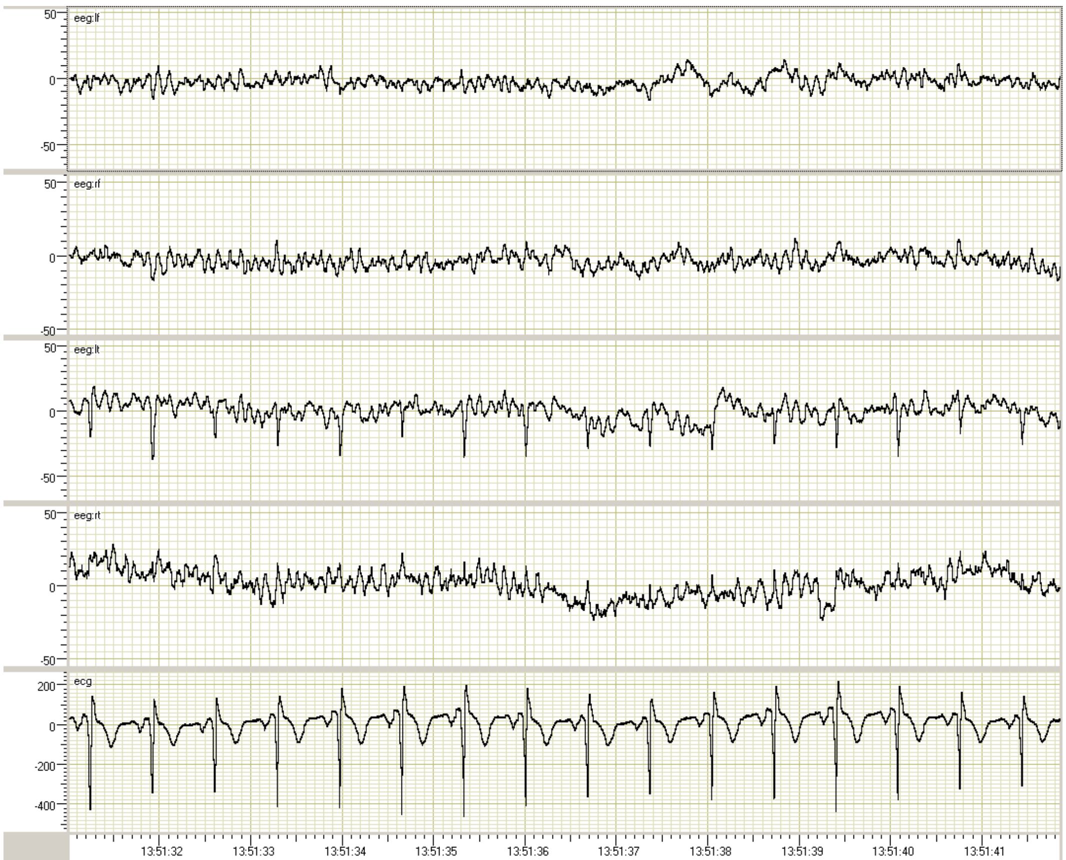

Figure 9: ECG artifact shown in channel *lt* in theta activity EEG signal. The x-axis presents time and y-axis is in microvolts in EEG measurements and in microvolts in the lowest ECG graph.

Table 3: External and internal artifacts

External artifacts	Internal artifacts
Mains frequency	Oculogenic potentials
Electrode failure	Myogenic potentials
Machine fault	ECG artifact
Electrode press	Pulse artifact
Ventilation	Skin resistance
Bed vibration	Patient movement

3.2.5 Other sources of internal artifacts

Additionally, the changes of skin potential and resistance is one potential cause of artifacts. Sweat is a common cause of changes in impedance between skin and an electrode. [2] Good planning of recordings and good placing of electrodes may help.

4 Artifact detection

There is not only one specific way to detect an artifact automatically. Below some of the basic methods to detect an artifact in the EEG signal are analyzed. There are only the basic ideas of detection, every method needs adjusting of parameters and fitting the computing routine.

4.1 Removal of rhytmical artifacts

Rhytmical artifacts sources with high frequencies , such as noise of mains current can be detected by using a spectral function. In addition, the removal of transient artifacts, e.g. the ECG artifact is a rather simple procedure. Only the derivation of the signal is enough to remove the parts of signal with a large difference.. The observed differentiation signal is calculated from the signal $X = [x_1, x_2, x_3, ..., x_n]$, by taking the absolute value of the derivative in time.

$$\frac{dX}{dt} = |[x_2 - x_1, x_3 - x_2, ..., x_n - x_{n-1}]|$$

The result of this calculation is shown in Figure 10. Now it is possible to set a threshold value, that determines the cardiac activity based artifacts in signal. Afterwards, these sections can be removed. [8]

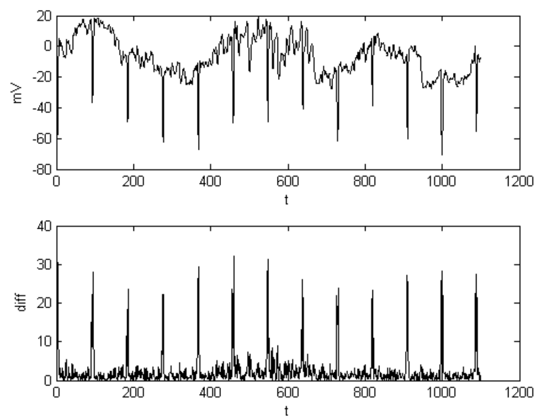

Figure 10: The absolute value of differentation of signal above

4.2 Removal of eye blink artifacts

Since blinks have an identifiable appearance in EEG signal, they can be expressed with pre-existing waveforms, templates. First, templates are created by using the training data. The collected templates are combined as a template library. Then the templates are matched to the candidate blinks in the recorded signal. There are different methods to calculate the correlation between blinks and templates to determine whether signal contains a blink or not. [4]

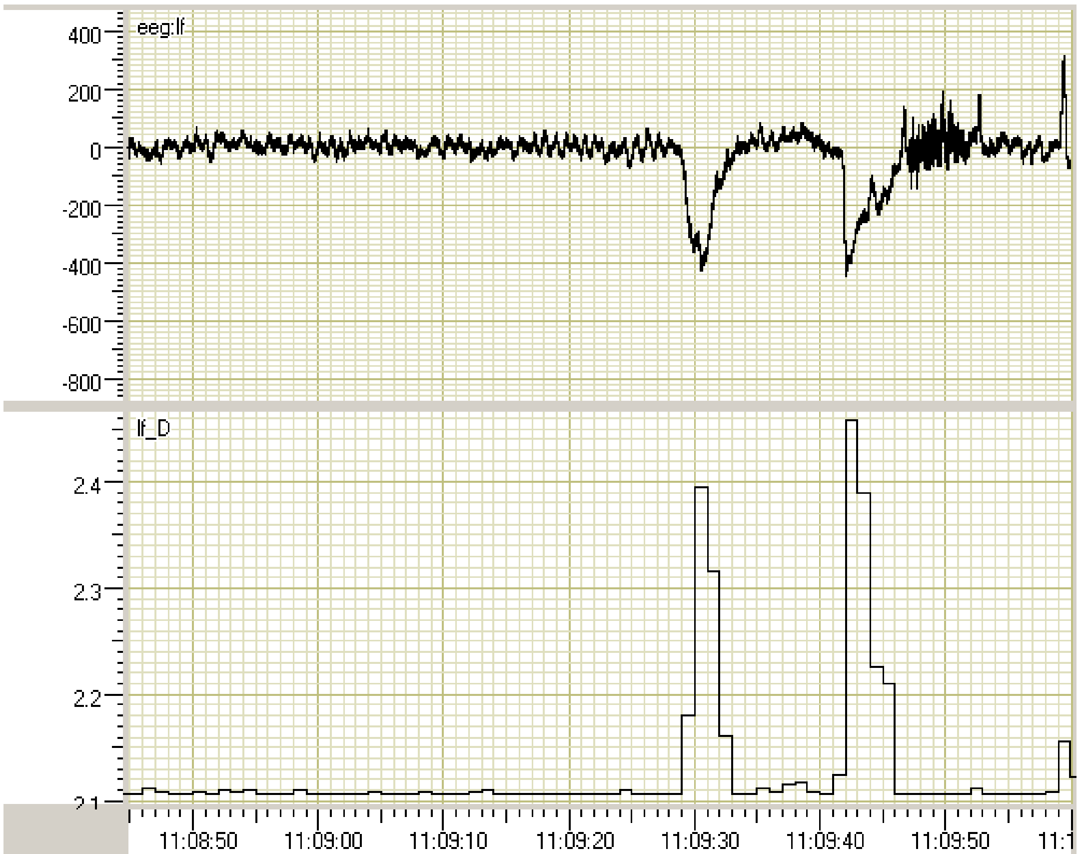

Figure 11: Variance of AR-model's error per every second. The x-axis is time and y-axis is variance.

4.3 AR-modeling

An AR-modeling is a proper method to detect a sudden artifacts that raise the amplitude momentarily. For example, the movement artifacts generate this sort of artifacts. The AR-models parameters are first estimated in a given time window. Then AR-model will predict the next value of the signal and the prediction error is analyzed. If the prediction error exceed some threshold value, there is supposed to be an artifact in the signal. [5]

The AR-modeling can be applied to EEG signal as well as to other time series.

In this case, the length of a time window, where the AR-model's parameters are estimated may be set to 2 seconds and the order of AR-model to 10. The algorithm in question produces the variance of the AR-model error per every second. It is essential, that the AR-model is estimated within a window, that consists signal without artifacts. Consequently, the algorithm detects artifacts more efficiently. This sort of model produces consequently positive result that varies according to unexpected components of the EEG signal. The produced model is the basic AR-model

$$x_t = \sum_{i=1}^{10} \theta_i \, x_{t-i} + \varepsilon_t$$

where $\theta_1, \ldots, \theta_p$ are the parameters of the model and ε_t is white noise [10].

The parameters θ_i may be estimated in the time window of 2 seconds in the beginning of the processed signal. Next, every value of signal are estimated and the variance of the error e_t is calculated per every second, for instance. [6] AR-modeling with the above-mentioned parameters and computing yields a variance which is illustrated in Figure 11.

5 Characteristic properties of EEG in intensive care unit

It is important to note, that critically ill patients in the intensive care unit has a higher risk of seizures and status epilepticus, i.e. a condition in which the brain is in a state of persistent seizure. Nonconvulsive seizures (NCSz), i.e. an epileptic seizure without observable cramps and nonconvulsive status epilepticus (NCSE) can be detected only with the EEG monitoring. They are increasingly recognized as common occurrences in the ICU, where 8 - 48 percent of comatose patients may have NCSz or NCSE. Repetitive seizures lead to permanent brain injuries, such as cell loss and increase the risk for developing epilepsy. [7]

For example, there is an extremely intense seizure i.e. a periodic epileptiform discharge shown in Figure 12. As you can see, it is easily confused with cardiac activity based artifact. This would be an extremely wrong diagnosis.

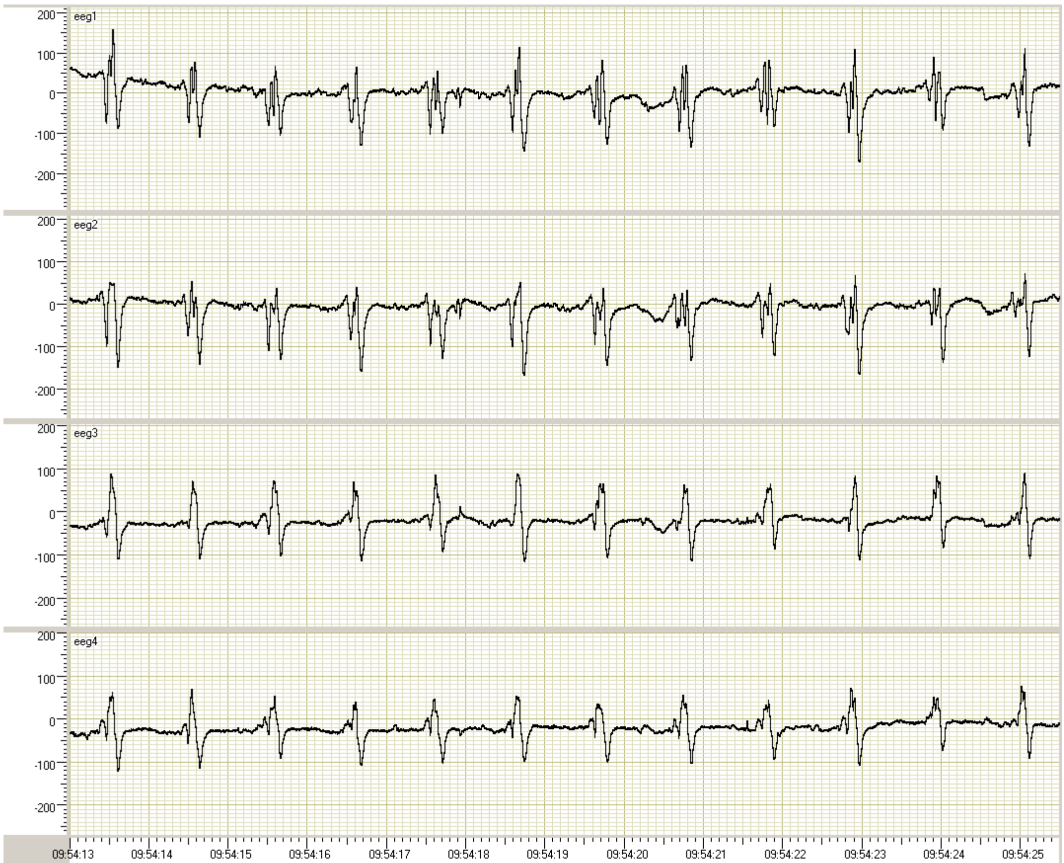

Figure 12: Periodic epileptiform discharges. The x-axis presents time and y-axis is in microvolts.

6 Conclusions

The basics of electroencephalography, i.e. EEG and associated measurement installations used in these recordings were presented. Additionally, different sort of brain activities and sources of artifacts were analyzed. Furthermore, the sources artifacts were divided to external and internal classes.

Artifacts are manifested differently in EEG signal and there is not such a one single method to deal with. It is always depended on the certain situation, how to concern artifacts wether it is needed or not. Although, the most common methods to detect artifacts were presented, that are based on basic mathematical functions, such as derivation and Fourier transform and estimation theory. After the artifacts have been detected, the removal of artifactual periods from the signal is trivial: the detected part of the signal is simply deleted. The removal criterions such as threshold values and length of deleted period can be determined by means of ROC analysis. [11]

It was pointed out that it is important to be aware of artifacts within EEG recording in intensive care unit. Thus one doesn't draw wrong conclusions of recordings. The nonconvulsive epileptic seizures were analyzed to show the troublesome essence of artifacts. Seizures and artifacts are easily mixed up which may cause serious brain injuries. This gives rise to further research to firstly removal of artifacts and secondly automatic detection of seizures. Consequently the number of serious brain injuries could be decreased.

References

[1] Sornmo L, Laguna P. *Bioelectrical signal processing in cardiac and neurological applications*, Elsevier Academic Press, 2005. ISBN: 0-12-437552-9

[2] Fisch, BJ. *EEG PRIMER Basic principles of digital and analog EEG*, 3rd edition, Elsevier Academic Press, 1999. ISBN: 0-444-82147-3

[3] Binnie C, Cooper R, Mauguire F, Osselton J, Prior P, Tedman B. *Clinical Neurophysiology*, Elsevier Academic Press, 2003. ISBN: 0-444-51257-8

[4] Polkko J. *A Method for Detecting Eye Blinks from Single-Channel Biopotential Signal in the Intensive Care Unit* Master's Thesis, 2007.

[5] Pardey J, Roberts S, Tarassenko L. *A review of parametric modelling techniques for EEG analysis* Med. Eng. Phys., 1996, Vol. 18, 2-11, January

[6] Lopes Da Silva F.H., Van Hulten K, Lommen JG, Storm Van Leeuwen W, Van Veelen CWM, Vliegenthart W. *Automatic Detection and localization of epileptic foci*, Electroencephalography and Clinical Neurophysiology, 1977, 43:1-13

[7] Friedman D, Claassen J, Hirsch LJ. *Continuous Electroencephalogram Monitoring in the Intensive Care Unit* Anesthesia Analgesia, Vol. 109, No. 2, August 2009

[8] Ifeachor EC, Jervis BW. *Digital Signal Processing* Addison-Wesley Publishers Ltd., 1993. ISBN: 0-201-54413-X

[9] Sarkela M. *Monitoring Depth of Anesthesia with Electroencephalogram: Methods and Performance Evaluation* TKK Dissertations, 2008. ISBN: 978-951-22-9288-2

[10] Box GE, Ljung G *Time Series Analysis: Forecast and Control* Holden-Day Inc, 1970.

[11] Fawcett T, *An introduction to ROC analysis* Pattern Recognition Letters 27, 2006, 861-874

[12] Dirlich G, Dietl T, Vogl L, Strian F *Topography and morphology of heart action-related EEG potentials* Electroencephalography and Clinical Neurophysiology, 1998, 108:299-305