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INFLUENCE OF PRACTICAL FACTORS AFFECTING ELECTROPHYSIOLOGICAL SIGNAL ACQUISITION

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Abstract

Electrophysiological signal acquisition is a process that involves congregation of physiological signals that are very helpful in detecting a variety of ailments like epilepsy, sleep disorders, cardiac arrhythmia, best disease, muscular and nervous-system disorders, dominant cystoids macular dystrophy, brain death and coma. Electrophysiological signals can also be used for tracking the human kinesiology and also in enhancing human machine interaction. Electrophysiological signal acquisition has a long history of use in healthcare and research, but there are certain practical factors that can affect the electrophysiological signal acquisition. This work discusses about the practical factors affecting electrophysiological signal acquisition and also proposes some of the possible engineering solutions to overcome these factors.

Introduction

Any ionic signal which can be converted from a medical or a biological source into an electrical one is called as an electrophysiological signal or simply bio-signal. Electrophysiological signals are generally acquired for detecting and estimating specific states for the purpose of diagnosis and evaluation. The term electrophysiological signal acquisition refers to acquiring bio-electric signals from living beings that can be measured and monitored (Buczkowski et al., 2013). The source of these electrophysiological signals may be at a molecular or cell level. The different types of electrophysiological signals that can be monitored are Electroencephalogram (EEG), Electrocardiogram (ECG), Electromyogram (EMG), Electrooculography (EOG), Magneto-encephalogram (MEG), Galvanic Skin Response (GSR).

Electroencephalogram (EEG) – EEG is the measure of electrical activity of the brain.

The human head is a place of massive electrical activity. Active nerve cells present inside the head communicate with each other via electric potentials (Aungsakun et al., 2011). Whenever electrical signals are transmitted along an axon or dendrite they get separated for very short distances forming small batteries with positive and negative polarities (Karakis et al., 2010).

These small positive and negative polarities constitute the primary currents. When these primary currents are embedded in scalp conductive medium they induce another set of electric potentials called secondary currents or volume currents. Basically volume currents are used for EEG signal acquisition. The EEG signal acquired is the measure of voltage differences of the scalp (Hidajat, 2004). The EEG signal is used to evaluate brain disorders like coma, stroke and also determine brain death.

Electrocardiogram (ECG) – ECG is the measure of electrical activity of the heart caused due to the depolarization of the heart muscles during every heartbeat. Electrocardiogram is actually a plot of voltage verses time of the electric potentials generated by the heart's muscles (Oostenveld and Praamstra, 2001). This electrophysiological signal is used monitor the blood flow, detect heart-attack and other heart related arrhythmias.

Electromyogram (EMG) – EMG is the measure of electrical activity generated by the movement of muscle cells in a human body. This electrophysiological signal can be used to study the mechanics of movement in human and animal bodies (Usakli et al., 2010). EMG is used to detect muscle and nerve related problems. Electrooculography (EOG) – EOG is used to measure the electric potential generated by movement of human eye (Singh, 2014). This electrophysiological signal is used for ophthalmological diagnosis and recording movement of human eyes. Magneto-encephalogram (MEG) – measure of magnetic fields in the brain produced due to the electrical activity of nerve cells (Teplan, 2002). This electrophysiological signal provides the timing and spatial information about the brain. The MEG electrophysiological signal can be used to find the exact place where the electrical activity originates. Galvanic Skin Response (GSR) – there exists continues variation in the electrical activity of the skin. This variation is called as electro dermal activity (Israel et al., 2005). This activity contributes to the flow of electric current between a limb and a muscle during contraction and expansion. Electrophysiological signal acquisition is the backbone of a procedure that includes acquisition, analysis and result generation (Smith, 2005). Since the signal acquisition is the first step it is given more importance. Without acquiring the correct electrophysiological signal, analysis cannot be done, result will not be obtained. Careful signal acquisition with proper precautions can eliminate errors and reduce the time taken for signal acquisition (Roberts and Gabaldon, 2008). The practical factors that affect the electrophysiological signal acquisition are depicted in Figure 1.

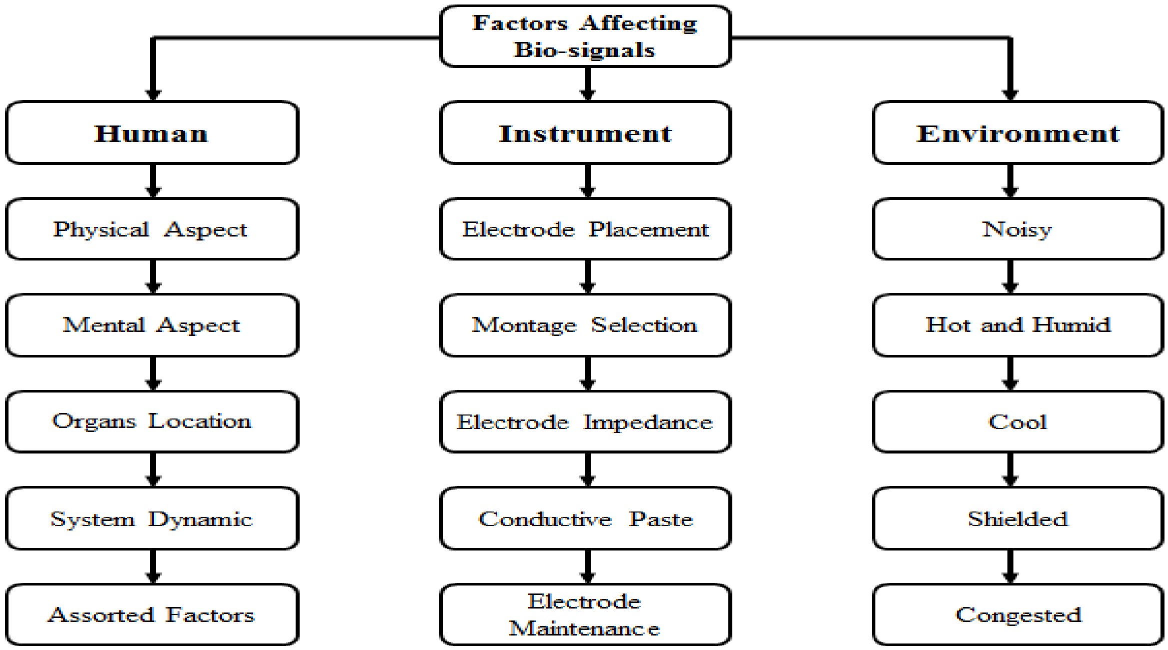

Figure 1. Practical factors affecting the electrophysiological (bio-signals) signals.

Factors Affecting Electrophysiological Signal Acquisition

Noise

Any sound that is unpleasant, unwanted, unexpected is categorized under noise. Basically there are two types of noise (Figure 2) affecting the acquisition of electrophysiological signals; External and Internal noise.

External noise – these noises are caused by external forces or factors such as the instruments surrounding the electrophysiological signal instrument setup like sounds from the blades of a fan, sound from the central processing unit of a nearby computer, mobile phones. Mobile phones are notorious for electromagnetic radiation which interferes with electrophysiological signals (Buczkowski et al., 2013).

The power line or 50 Hz interference noise also causes problem in electrophysiological signal acquisition by combining with the original electrophysiological signal. This creates difficulty in separating the power line noise from the original electrophysiological signal.

Internal noise – Internal noise is accumulated from physiological interferences like EMG, ECG, EOG and so on. One example is the EOG signal which is the most common source of contamination for the EEG signal (Aungsakun et al., 2011). The GSR is also a common source for contamination of other electrophysiological signals due to the varying electrical activities.

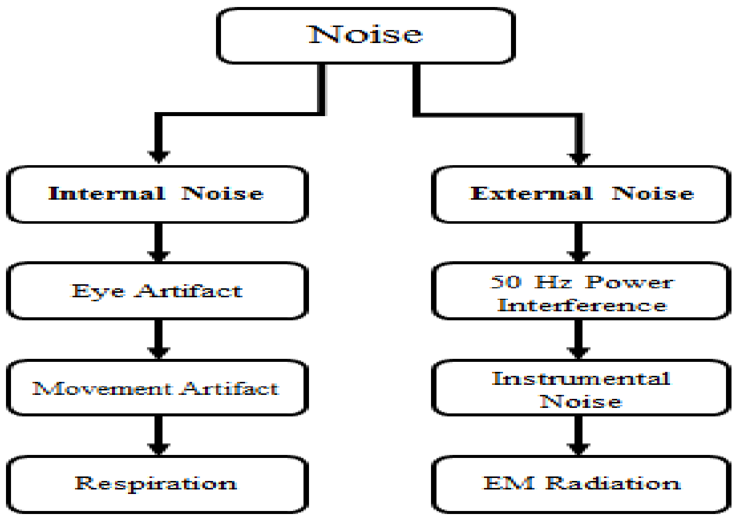

Figure-2. Classification of noise that affects the bio-signal acquisition.

Electrode Placement

Electrode placement is a means of placing the electrodes on the subject's body. Improper electrode placement will hamper the ability of the electrodes to sense the electrophysiological signals. For example, improper electrode placement while taking ECG readings leads to a phenomenon called Technical Dextocardia.

The term Technical Dextocardia refers to an ECG reading that has no basis on the subject's anatomy (Karakis et al., 2010). Improper electrode placement while acquiring EMG signals will create problems in recording bi-potential changes.

Montage Selection

Representation of electrophysiological signal channels is called as montage. Montage selection is very important as there are different methods of representing electrophysiological signal channels (Karakis et al., 2010). This causes compatibility and complexity issues. There are no proper guidelines for montage selection.

Electrode Impedance

Electrode impedance matching plays an important role in acquisition of electrophysiological signals. Improper impedance setting will arise due to improper placing of the electrodes on the subject's skin (Karakis et al., 2010). Poor quality conductivity paste will also affect impedance thereby affecting the electrode's sensitivity to electric potentials.

Electro-conductive Paste

This is a paste or solution used to stick the electrodes to the skin of the subject. Electro-conductive paste of poor quality will corrode the electrodes thereby reducing the life time of the electrodes (Oostenveld and Praamstra, 2001). Conductive paste as the name suggests must be electrically conductive but then again the conductivity depends on the quality of paste used. Another important property of conductive paste is adhesiveness (Usakli et al., 2010). The conductivity paste which gives maximum adhesiveness and conductivity is generally preferred for electrophysiological signal acquisition.

Electrode Maintenance

Improper maintenance of electrodes used to measure electrophysiological signals will cause the degradation of the electrodes over time. Prolonged usage without maintenance causes oxidization of the electrodes thus affecting its responsiveness to electric potentials (Usakli et al., 2010). Electrodes are given a layer of chrome coating during their manufacture and over time the chrome coating degrades thereby leading to the formation of rust.

Instrument Maintenance

The instrument which is used to measure the electrophysiological signals is a specialized setup. Dust accumulation is a major issue with the signal acquisition instruments as it affects the performance by clogging internal and external components. Temperature both internal (internal components) and external (surroundings) plays an important role in increasing or decreasing the efficiency and life time of the instrument.

Improper instrument calibration due to any faults in the instrument or any errors in the control settings is also responsible for the irregular functioning of the instrument. High cost of spares also plays a part in the instrument maintenance. Duplicate spare parts will degrade the instrument performance.

Human Factors

The subject who is the source of the electrophysiological signal also plays an important factor in the successful acquisition of electrophysiological signals. There are two important human factors in consideration. They are physical and mental factors. Physical – This is a very vital factor as the individual who is the source for signal acquisition is given importance. Since the electrodes are placed on the subject’s body.

When electrodes come in contact with the skin, scalp; the sweat present on the skin surface, dandruff on the scalp can block or decrease the sensitivity of electrodes to the bio-electric potentials. Mental – The mental health of the subject whose readings are acquired also plays an important role in determining the quality of the signals achieved (Smith, 2005). Subjects who are subjected to mental stress are detrimental for electrophysiological signal acquisition due to the fact that stress reduces the electrophysiological signal quality.

Environment

The Environment under which the electrophysiological signals are measured also plays an important role. Hot and humid environment leads to sweating in the subject's body there by blocking the electrodes form achieving a suitable reading (Roberts and Gabaldon, 2008). Congested surroundings will decrease the effectiveness of the measuring instrument. Surroundings prone to radiation also prove hazardous to signal measurement.

Time Synchronization: In acquiring evoked potentials, the improper coordination of the intervals of the stimuli with the corresponding intervals of the electrophysiological signals results in accumulation of undesired signals (Aziz et al., 2014).

Accessibility

Most of the organs of interest for example the cardiovascular system and the brain are located deep inside the human body and are difficult to access (Bosma et al., 2008). Even the muscular system is hidden under the skin so it is difficult to get complete access to the electric potentials being generated.

Variability

The systems that make up the human body are dynamic in nature and comprise of several variables that change regularly. Electrophysiological signals represent dynamic activity of psychological systems (Bosma et al., 2008; Luz et al., 2014). Every electrophysiological signal has its separate instrument setup and electrode arrangement.

Miscellaneous

This factor is caused by faulty connections due to wrong connections, loose wires (Mills, 2005). In the case of long term monitoring of electrophysiological signals the human observer or acquirer will be susceptible to fatigue, boredom and can get distracted by his surrounding and miss important and sudden transients.

Possible Engineering Solutions

Noise

Noise can be overcome by securing the environment where electrophysiological signal is acquired. Sound proof rooms are constructed for eliminating external noise. Mobiles phones should not be allowed near the signal acquisition instrument to eliminate effects due to radiation. The other electrophysiological signals like EMG or ECG signals can be filtered by selecting the EMG/ECG filter option available in modern instruments used for acquiring the electrophysiological signal (Singh, 2014). While signal acquisition is going on, it must be ensured that the subject does not breathe excessively or moves his eyelids rapidly to prevent the contamination of the targeted electrophysiological signal.

Electrode Placement

Electrode placement is not a science but proper electrode placement ensures best result for the electrophysiological signal acquisition unit. For example, the most common and internationally acclaimed electrode placement system in EEG signal acquisition is the 10-20 electrode placement system (Oostenveld and Praamstra, 2001; Teplan, 2002). This is an internationally recognized method to describe the location of scalp electrodes in the EEG. The 10-20 system was developed so that a subject's electrophysiological signal could be compared with time and other electrophysiological signals. But now a new electrode system has been developed to support higher resolution called "5%" system (Oostenveld and Praamstra, 2001). Similarly the ECG follows a standard 12 lead system for electrode placement for detailed and accurate measurement and there is also a 3 lead system for basic monitoring measurements.

Montage Selection

Correct montage selection will reduce the time taken to acquire the readings, also decrease the number of times the readings should be obtained from the subject (Karakis et al., 2010). Basically any electrophysiological signal can be monitored with either a bipolar montage or a referential montage. Bipolar involves two electrodes per one channel, so there is a reference electrode for each channel. The referential montage means there is a common reference electrode for all the channels.

Electrode Impedance

Generally low electrode impedance is preferred than high electrode impedance due to the fact that a high electrode impedance would be in parallel to the source impedance of the skin, this will cause the signal to flow through the subject's skin rather than the electrodes. Basically the impedance range preferred is between (10-20 kΩ) (Mills, 2005).

Electro-conductive Paste

The paste or solution used should be electrically conductive and provide a perfect balance between adhesiveness and conductivity. The electro conductive paste is used to reduce the skin impedance in order to get stable readings. Conductive paste cannot be used on patients with history of skin allergies or on those sensitive to lotions and cosmetics (Teplan, 2002; Mills, 2005). There is a cheaper locally available alternative known as "white wax" which can be used on patients with skin related ailments but its conductivity and adhesiveness balance is less when compared to that of the electro-conductive paste.

Electrode Maintenance

Maintenance of electrodes is advisable in order to increase their lifetime and maintain their sensitivity. The electrodes mainly used in any non-invasive electrophysiological signal acquisition setup are surface electrodes whose surface is given a layer of chromium coating (Oostenveld and Praamstra, 2001).

This chromium layer plays an important role in increasing the sensitivity of the electrodes to the electric potentials of the brain. Prolonged usage causes oxidization of the electrodes thus affecting its responsiveness to electric potentials. So it is advisable that such electrodes be replaced. Furthermore after every signal acquisition session the electrodes must be thoroughly cleaned in soap and water by a soft cloth or brush and sterilized using any antiseptic to prevent the electrodes from getting infected.

Instrument Maintenance

The instrument used for electrophysiological signal acquisition must be secured from physical damages such as dents and spills from any liquid. The manufacturer should employ strong construction materials, anti-spill coating to resist physical damage. Service of the instrument must be done according to the manual. In cases where replacement of internal components becomes necessary, it must be replaced with original and manufacturer prescribed components. Calibration is necessary as electrophysiological signals are very weak signals. Hence calibration must be done before every electrophysiological signal acquisition session. Localizing the manufacturing of instrument parts will help to reduce the cost of spares and will prevent duplication.

Human Factors

Physical – The electrodes generally come in contact with both the skin surface and scalp. It would be preferable that the subject maintains a clean skin and scalp. For example in the case of EEG signal dandruff free scalp is necessary as dandruff can block or decrease the sensitivity of electrodes to the EEG signals (Oostenveld and Praamstra, 2001; Teplan, 2002). In the case of acquisition of electrophysiological signals like ECG, EMG and so on it is necessary for the subject to take a bath before the signal acquisition starts as the skin surface must be clean, free of sweat in order to achieve good quality signals. Mental – It is advisable for subjects to restrain from mental stress and maintain a peaceful state of mind before the readings are obtained. The general procedure is to ask the subject to perform meditation following which the readings are quickly acquired. Generally the subjects who practice meditation display better mental health and provide good quality signals than those who abstain from practicing meditation.

Environment

The electrophysiological signals of the subject must be taken in a cool environment, preferably air conditioned environment so as to prevent the subject from sweating. Sweat blocks the electrode and thus reduces the sensitivity and can also create a separate path for the electrode potentials to escape. Operating in an air-conditioned environment will also help in maintaining cooler operating temperatures within the internal components of the electrophysiological signal acquisition instrument, thereby increasing its lifetime.

Prevention of congestion in the surrounding where the instrument is installed also helps in increasing the efficiency of the machine. Some instruments may get affected by magnetic fields and radio waves. It is advisable to place such instruments in a shielded environment so as to achieve the desired electrophysiological signal.

Time Synchronization

Time synchronization plays an important role in the case acquisition of electrophysiological signals using evoked potentials. In such situations the test case stimuli will be introduced at certain time intervals. The lack of coordination between the intervals of the stimuli with the corresponding intervals of the desired bio-signal results in accumulation of undesired signals.

Accessibility: Accessibility factors can be overcome by use of invasive and non-invasive electrodes. Invasive electrodes like needle electrodes are used if the signal required is more specific whereas non-invasive electrodes like surface electrodes are used for simple monitoring purposes like observing ECG signals.

Variability

Variability factors are difficult to overcome due to dynamic characteristics of human and animal bodies. Steps have to be taken for creation of a common setup or apparatus wherein all electrophysiological signals can be measured.

Miscellaneous

For long term electrophysiological signal monitoring, the operator or the observer can take shifts as fresher eyes can monitor and detect the sudden transients that may occur during the course of acquisition. The observer should monitor the instrument for wrong, loose connections or loose individual wires. Observing via turns will prevent boredom and reduce fatigue.

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