Capturing electromedical signals

by Prof. Cedric Smith, Tshwane University of Technology

Capturing electro-medical signals requires the use of some special techniques, described in the following article.

Human beings rely on the electrical signals that course through their bodies for their survival. Without an electrical signal there would be no nerve transmissions and no movement of any muscles in the body. The brain would not function. A body is pronounced legally dead when the electrical signals in the brain stop. These vital signals are generated through a number of different chemical processes that in turn depend on diet and physical condition in order to operate effectively. The body consists of billions of cells that are all individual bioelectric generators that must all work together in harmony in order to live a fulfilled life. A typical human body cell varies in size from 1 micron to 100 microns in diameter and up to one metre in length for some nerve cells. There is no standard cell that is used for building the complete human body. There are brain cells and muscle cells as well as thousands of other different types of cells. The human body is a very noisy electrical environment.

The human cell

The internal resting potential of a body cell is approximately -85 mV and changes to approximately 20 mV during activity.

For a cell to become active it must receive stimulation from somewhere outside of the cell. In the 1950s the Hodgkin-Huxley theory explained how this occurs. It was soon shown that the Nernst Equation allowed physiologists to calculate the cell potentials and to predict what would happen when a cell was activated [1].

There is a difference in the sodium and potassium ion concentration between the inside and the outside of the cell. There is thus an electrical potential gradient between the inside and the outside of the resting or polarised cell. This potential gradient will affect the movement of the potassium and sodium ions across the cell membrane differently, mainly due to different ion sizes.

When the cell receives an external stimulus the permeability of the membrane to the sodium ions increases and a current flows that tries to balance the potential gradient across the cell wall. The cell is now said to be depolarised. The stimulation can be due to an electrical stimulation or a chemical reaction or something else. The potential that the cell generates as it depolarises and re-polarises is called the action potential and is in the form of a single positive going signal with a small recovery portion on the trailing end as the cell repolarises. These action potentials occur throughout the body many millions of times of every second. The measured signals are usually made up from the sum of a number of these signals.

The action potential

The action potential is the output signature of every living cell in the body. The shape and duration of the action potential depends largely on the specific type of cell and the cell size. These are the electrical signals that the doctor needs to monitor in order to make a diagnosis of what has happened to you and what the present condition is of your body. Each type of action potential has been given a specific name depending on its origin. Some of the more common of these signals are:

The combined signal from a large number of heart cells forms the ECG

The electrocardiogram or ECG signal originates from the muscles of the heart. The combined signal from a large number of heart cells forms the ECG and is a clearly defined indication of what is happening with your heart. The ECG signal shows changes during fibrillation or during an infarction or heart attack that are of use to the doctor for diagnosis and therapy.

The second type of electrophysiological signal is the electro-myogram or EMG signal that originates in the muscles of the body. The EMG indicates the condition of the specific muscle motor group under observation.

Another well-known signal is the electro-neurogram that originates from the activity of the nerves in the body.

Another signal that is often measured is the electro encephalogram or brain wave signal that originates from the different areas of the brain and is very important to neurologists and psychologists.

Other well-known electro-medical signal groups include the electro-occulogram, electro-retinogram and audiogram among others.

Problems

The problems that we have when trying to capture and isolate any electrophysiological signal includes the following:

Human beings live and work in an electrically noisy environment. The noise levels from the power lines in an average work environment can easily exceed 500 mV of 50 Hz background radiation. This makes it very difficult to capture signals that are seldom more than 10mV in size on the skin.

The second problem is that most physiological signals are due to large numbers of cells operating in concert with other cells. It becomes a problem to selectively capture the correct signal from the selected areas where there are literally hundreds of interfering signals providing a very noisy environment.

The signals that are present in the human body are normally from medium to high impedance sources that make it difficult to isolate the desired signals from low impedance sources.

Methodology

There are few different techniques that are applied for isolating and capturing these physiological signals from the extremely noisy background of unwanted signals. The signals are usually captured by means of surface electrodes and sometimes by means of needle electrodes that are stuck into the area under observation. Some of the more common electronic techniques are discussed here.

Shielded signal lines

The simplest and most common method is to make use of well shielded signal lines. In most cases the shielding is not part of the signal path and is used solely for shielding the signal conductors from external radiation and the pickup of environmental noise. The reduction in the noise figure is still far below what is required to be in a position to extract the signal from the noise but an improvement of more than 6 dB is normal.

Filtering

One of the best methods of getting rid of the background. 50Hz radiation is to eliminate it from the equation by filtering it out at the input to the measuring instrument. A normal first order band pass filter does not have a good enough response to make a significant difference to the signal interference. The filter of choice in the older equipment is the Notch “T” filter that provides a second order filtering on the two edges of the response curve for the filter. With the advent of switched mode filters by many companies such as Maxim it is now easier to implement more complex filters that can be designed to cut out the 50 Hz frequency notch. Filters are an essential component in the chain of components that are required for selecting the desired signal out of the noise.

The amplifier

The next component in the chain is the amplifier. To ensure that only the desired signal is detected and amplified there are two requirements. The first is that the amplifier must be able to amplify a balanced line signal and the second is that the amplifier must have a very good common mode rejection ratio. For electro-medical signals a CMMR of more than 80 dB, or better than 10 000 times, reduction in common mode noise is required for these amplifiers.

To achieve these very high common mode rejection figures the design of choice is the well-known instrument amplifier. This amplifier makes use of two separate but identical input amplifiers that are connected to a differential amplifier second stage. This allows CMRR ratios in excess of 110 dB to be achieved quite easily. Most instrumentation amplifiers are not compensated for DC voltage offsets. By adding a capacitor between the two input amplifiers in an instrumentation amplifier it is possible to amplify a signal that is only 1mV in size while there may be a DC offset of more than 20 V between the two input signal lines [2].

There is one additional technique that is used to increase the CMRR in a medical amplifier and that is to make use of what is called a driven amplifier. In this case the common mode error signal is detected, inverted and fed back to the patient. This inverted signal then compensates for the error at the source, on the patient [3].

By using these techniques it is possible to reduce the background noise for the majority of electro-physiological signals. It is still not sufficient to enable the very low signals such as the EEG signals to be detected from the brain. For this there is an additional technique that is also used for the detection of some other very small body signals.

In order to detect the EEG signal which is in the order of tens of micro-volts, the equipment designers make use of a triggered sampling technique. The patient is subjected to a small electrical stimulus that will trigger a specific response in the brain. The trigger signal is used as the clock for the signal and the returning signal train is sampled possibly a few hundred times at a specific time interval after the trigger pulse is given. The output signal is then processed by a computer to remove spurious noise and only the signal is highlighted in the resulting waveform. The very low signal can then be detected and analysed by the medical practitioner.

Safety

The risks of electrocution are very high in a hospital environment for a number of reasons. Firstly, the patient is usually in a weak condition and is therefore more susceptible to the effects of an electric shock. Secondly, the patient is often connected to a piece of electrical equipment by means of conductive electrodes that are placed across sensitive areas of the body like the heart or the brain or critical muscle groups. If something should go wrong with the components or the circuit, the patient could receive an electric shock that could be fatal.

Thirdly the patient may have electrodes connected to internal organs of the body such as the heart during surgery. This makes the patient very vulnerable to shock if a fault should occur. Because of this very real possibility of electrocution the equipment that is approved for connection to the body must meet very stringent requirements as far as isolation is concerned. These requirements are specified by the IEC 601 regulations.

The patient connections are usually isolated by means of isolation amplifiers that are galvanically isolated from the monitoring equipment. Isolation is performed by means of two major types of signal amplifiers. The first is a transformer coupled amplifier. In this amplifier the signal path is isolated by means of two small signal transformers in the amplifier. The power to the amplifier comes via a small power transformer in the unit that is fully isolated from the power source in the monitoring device. The result is that the amplifier as well as the signal path is totally isolated from the main power sources by transformers that can withstand at least 1 kV.

The second form of isolation amplifier that is in common use makes use of a transformer for isolating the power supply of the amplifier and makes use of optical isolators for the signal path. This makes it possible for very high frequency signals to pass from the patient to the monitoring equipment that are unaffected by the characteristics of a signal isolation transformer.

There are many manufacturers of these amplifiers. For example they are available from companies like Analog Devices and Burr Brown as well as many others.

General

The same techniques that are used for capturing very low physiological signals from a very noisy background can be used for capturing signals in any other noisy environment. The medical environment has some unique problems that can result in very serious injury or even death if they are not addressed in the monitoring equipment. There may not be the same criticality in the industrial environment as there is in the medical arena but this does not stop the use of the same techniques to get the results that are required.

However make sure that screened signal leads and instrumentation amplifiers at the very least. Sampling techniques and isolation amplifiers can only help signal capturing projects to obtain better results.

References

[1] Guyton. Textbook of Medical physiology, 5th edition, W B Saunders company Philadelphia.

[2] Smith C. A study of the detection, analysis and understanding of EMG signals from muscles in vivo. MSc (Eng) thesis, University of Pretoria August 1984.

[3] Carr J, Brown J, Introduction to biomedical equipment technology, 4th edition, Prentice Hall, New Jersey.

Contact Cedric Smith, Tshwane University of Technology, Tel (012) 318-5737, smithcs@tut.ac.za ❑