ABC of Computing

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MANAGING BIOLOGICAL SIGNALS

Some examples of biological signal processing.

Electrocardiogram.

Detailed analysis for diagnostic purposes, commonly from 3 or 12 lead electrocardiogram
Arrhythmia analysis for use in patient monitoring
Analysis of 24 hour recordings of electrocardiogram to count incidence of abnormal events

Blood pressure

Analysis of data from cardiac catheterisation procedures, such as calculation of cardiac output

Electroencephalogram and electromyogram

Sleep staging
Evoked response averaging

Respiration

Calculation of airway resistance
Detection of apnoea in 24 hour recording

Doppler ultrasound signals

Frequency analysis techniques to extract blood velocity from the signal

Gait analysis

Because of their ability to store information and perform calculations digital computers are ideal tools for managing biological signals, and this article explains some of the ways in which they are being used.

Signal conversion

Many biological signals are initially available as electrical analogues—for example, a voltage which varies with the arterial blood pressure. In other cases it is the electrical signal itself which is interesting, as in the electrocardiogram. If the computer is to analyse the signal its amplitude must be regularly sampled and converted to a series of numbers using an analogue to digital convertor (ADC). For instance, an electrocardiogram cycle might be digitised at millisecond intervals and one cycle could yield several hundred numbers.

Accurate representation of the waveform in digital form requires careful selection of the sampling rate. If the rate is too low the digitised waveform can be very misleading, due to an effect called aliasing, and subsequent calculations may be useless. An excessive sampling rate, on the other hand, results in unnecessary data being sent to the computer and computer time being wasted in storage and processing.

Real time analysis or recorded data analysis?

A common computer application, particularly suited to dedicated microprocessors, is the calculation of derived values from the raw data as they are presented in real time. Measurement of lung volumes or diffusion rates in pulmonary function studies, for example, may require calculations involving gas concentration values and spirometer readings. Real time processing, however, is limited to those calculations that can be performed in less time than the rate of sampling: the computer must have finished the previous calculation and be ready for the next piece of information before it arrives. In this context saving computer time is important and efficient programming vital. To save computer time many programmers use a fast, low level computing language (assembler language), which is difficult to use but very fast in operation. If the data are not available in real time but recorded on magnetic tape the processing speed is less critical, as the tape can be slowed down to allow the program to cope.

Mimicking the human observer

In some circumstances—for example, when detecting arrhythmias in ambulant patients—it is impractical to keep patients connected to the computer to allow real time operation, so their electrocardiograms are recorded on miniature portable battery powered cassette recorders. If the tape is run very slowly a cassette can store 24 hours of electrocardiographic tracings. This recording can then be analysed in a shorter time by replaying the tape at high speed through an analyser consisting of special electronic circuits connected to a computer. The special circuitry, which might, for example, be used to detect the R wave, is used to overcome the problems of high speed processing, when the actual signal may be replayed at 60 times normal speed. As well as counting the occurrence of abnormal electrocardiographic complexes, the computer can also present the data as a trend plot in which the time scale is compressed. This allows long term variations in the measurement to be seen. Miniature portable battery powered microprocessor arrhythmia analysers are being developed, but analogue recording of the electrocardiogram is still the more common method. Similar techniques are used with other signals such as respiration or the electroencephalogram.

Many analytical methods were developed by mimicking methods used by human observers. The diagnostic categorisation of electrocardiographic complexes is a typical example, which shows some of the many processing methods. An advantage of this type of analysis is that the decision making route is obvious—in contrast with the mathematical techniques discussed below, where the decision path is difficult to understand.

Computer techniques are now available that will diagnose abnormalities from short, carefully recorded, and, it is hoped, representative periods of the electrocardiographic signal. The identification of a constant point in the electrocardiographic cycle is the starting point for most analytical methods.

Peak detection—An observer mentally analyses the electrocardiogram by finding an obvious feature, such as the QRS complex, and then locating and naming the troughs and peaks either side of it. Given this information the observer can then consider the time intervals and eventually make a diagnosis. A computer can recognise the QRS complex by its height, such that if the signal passes a certain threshold, that point will be assigned to the QRS complex. This method of threshold detection is easily defeated by a signal containing artefacts, so a more sophisticated method, called hysteresis detection, can be used where a QRS complex is considered genuine only if it passes a high threshold on the way up and a low one on the way down.

Differentiation is a method of detecting the rate of change of a signal in time—that is, its gradient—and it is often used in electrocardiogram analysis for peak detection, since the other prominent feature of the QRS, apart from its height, is the steepness of its slope. Differentiation is undertaken by calculating the difference between successive amplitude measurements of the signal when sampled at equal intervals of time. The spiky peak of the QRS will then show larger differences than the slow T wave and can thereby be distinguished.

Once the peaks and the troughs have been located it is then possible to calculate the time intervals within the waveform, such as the PR interval, and between waveforms, such as the RR interval, which allows calculation of the heart rate. By comparing the different leads in the diagnostic electrocardiogram, and after calculating amplitude and time ratios, the computer can begin to work through the complicated diagnostic decision tree to produce a suggested clinical diagnosis.

A major advantage of this type of computer analysis is that once it has been given the rules the computer will apply them consistently. The danger is that an unpredicted combination of circumstances may occur which could be incorrectly interpreted. Any electrocardiogram report generated by computer must therefore be checked by the cardiologist before release.

Artefact recognition and signal enhancement

The human eye is probably the most sophisticated signal processor known and can easily recognise patterns containing artefacts, but it is a considerable problem to program a computer to do this reliably. Some artefacts containing frequencies higher than that of the real signal can be reduced by the use of analogue filters, but filters will never completely remove the artefact. One important consideration in dealing with artefacts is to decide whether they need to be removed at all. In some cases there is such an abundant supply of information—one electrocardiographic cycle each second—that it may be necessary only to detect the artefact so that data input can be suspended to prevent corrupted information from being processed. The loss of the information is not important as there is plenty more. On the other hand, if information is scarce and what little there is is obscured by an artefact then the real signal will have to be extracted from the artefact.

Artefact recognition—An electrocardiogram with many additional peaks, due, for example, to patient movement, would easily defeat a simple arrhythmia recognition program, but in fact the downfall of the program is itself important information. If a program finds more peaks than can ever be possible in a given time this is a good reason for rejecting that cycle as possibly containing an artefact. Another clue which a computer can use is the regularity of the trace. If the complex is outside the normal regular pattern it can be regarded as suspect and inspected to see whether it could possibly be an ectopic beat. Another approach to artefact recognition is to use a template technique, whereby the computer uses a run of manually selected normal complexes from which it constructs a mathematical template of what is normal. When this normal template has been established it is applied, allowing a margin for errors, to each new complex. If the complex does not fit, it can be regarded as suspect, and the computer will move to part of the program designed to distinguish between normal phenomena and artefacts. Because of the amount of processing needed special circuits may be used when this technique is used with fast analysis of tape recordings.

Signal enhancement—Some physiological signals can be triggered by a stimulus, and repeated stimuli can be used to generate a series of waveforms. If the evoked waveform is of low amplitude then it may be obscured by electrical signals from other parts of the body such as the heart or muscles. Averaging is a signal enhancement technique whereby the stimulus is repeatedly applied and the evoked waveforms are added together one on top of the other, with the stimulus being used for synchronisation. The effect of this is to enhance the real signal, which should always be the same, and to reduce the artefact, which, being random, should cancel out. Typical applications of this technique are found in the study of evoked electroencephalograms, nerve conduction velocity measurements, and audiological investigations.

Mathematical techniques

Mathematical techniques which have been used by engineers for many years are now being applied to medical signals. Some of these techniques are designed more to extract information which is not obvious than to automate the method of a human observer. For this reason, they may produce information which is useful when comparing signals but which does not have an obvious intuitive physiological meaning. There is a wide range of mathematical techniques and only a few examples can be given.

Frequency analysis—Any signal waveform can be duplicated by adding sine waves of different amplitudes, phases, and frequencies. The reverse process, that of decomposing a physiological waveform into its

Arterial doppler flow signal. Height shows blood velocity towards or away from the probe and brightness is related to mass of blood moving.

Use of computer models

components, is called Fourier analysis and is used to show which frequencies are present in the signal. In the past Fourier analysis has been done by analogue techniques, but now it is usually carried out with the fast Fourier transform on a digital computer. Analysts of electroencephalograms often try to gauge by eye the frequency content of a particular electroencephalographic trace. The computer can calculate the frequency content exactly, and this information can be easily displayed as a frequency histogram. This technique is used in automated sleep state recognition. The frequency of a reflected ultrasound signal from a blood vessel depends on the velocity of the corpuscles. The signal is difficult to gauge by eye as each moving corpuscle reflecting the ultrasound is moving at a slightly different velocity. Special purpose, dedicated computer circuits have been developed to perform high speed Fourier analysis on ultrasound signals to give direct readings of the blood velocity.

Time series analysis is a group of techniques designed to analyse the time intervals between events in a signal which is effectively a series of pulses. The R wave of the electrocardiogram or the action potential of a nerve can for this purpose be regarded as a pulse. A simple form of analysis is to produce a time interval histogram, which shows the distribution of intervals during the recording.

Cross correlation analysis is used to show whether the same signal is present in two different waveforms. It can be used for instance in gut electromyography to show that a recorded waveform is in fact travelling down the gut rather than being generated independently at the two recording sites.

Mathematical transformations—Fourier analysis is one example of a mathematical transformation, but many others are used in pattern recognition—for example, in the computer recognition of handwriting. One technique which has been applied to physiological data is principal component analysis, in which the waveform is broken down into key patterns or features rather than constituent frequencies.

When analysing biological waveforms it is valuable to know as much information as possible about the processes causing the waveforms. Several computer models have been developed which simulate various physiological processes in the body. Such models can be used to estimate clinically important indices which are difficult to measure directly. For instance, a simple model for the mechanical function of the lung during artificial ventilation can enable airway resistance and elastance to be computed via measurements of flow rate and mouth and intraoesophageal pressure. The mathematical values in the model are varied until the waveforms produced by the model match closely those measured from the patient, when the model values for airway resistance and elastance should correspond to those of the patient.

With more complex models some sort of stimulus or trigger mechanism may be given and the model adjusted to give the same transient response that occurs in the patient. For instance, in a model of the circulatory system this could be an injection of a vasodilator. By comparing the actual response in the patient with the computer model, useful diagnostic information can be obtained. The early promise of this technique has not yet been fulfilled but the increasing sophistication of models which can now be developed with larger computers may provide the way forward.

There is a wide range of computer techniques used in medicine, but in many cases the applications are in their infancy, since it is only in the last few years that computers have come out of the research units and into hospitals. As computers, and especially computer memory, becomes cheaper computer analysis of biomedical signals in the ward or clinic will become commonplace.

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