Processing, storage and display of physiological measurements

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Abstract

Modern anaesthesia demands the monitoring of many biological variables. It is no longer sufficient to be satisfied by a patient of good colour with a temporal pulse of reasonable character, volume and rate, though in times of power loss and technological malfunction these are skills that may still be relied upon! The journey of a biological variable from patient to monitor requires several distinct processes, often imagined within a singular 'black box': (i) detection; (ii) transduction; (iii) processing; (iv) display; (v) storage. The aim of this article is to examine each of these elements in turn, to inspect the ways in which different biological variables require distinct handling techniques and to give running examples to portray each step in a way applicable to daily practice.

Keywords Accuracy; analogue; biological signals; calibration; damping; digital; drift; noise; precision; resonance

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Learning objectives

After reading this article, you should be able to:
- categorize the steps that lead from signal detection to display
- outline the common pitfalls of measurement and processing (e.g. drift, noise, resonance) and discuss the ways in which these can be overcome (e.g. calibration, filtering)
- classify the degrees of damping and illustrate these graphically
- summarize the advantages and disadvantages of analogue and digital signals
- compare the various modes of data storage in common use

Signal detection

In order to display a biological variable to be interpreted by the anaesthetist, the variable's signal must be detected. Signal detection devices must have the ability to sense energy in the form produced by each variable:
- **electrical**: ECG, EEG
- **mechanical**: blood pressure, spirometry
- **thermal**: temperature.

Electrical signals

Detection of electrical signals is achieved by the application of electrodes. For example, the myocardial electrical activity shown in an ECG is identified using silver−silver chloride electrodes applied to the skin. The ability to detect a true signal is hindered by impedance and noise.

Impedance is the resistance of alternating current flow. High impedance is often due to poor skin contact due to drying of electrode gel, hair or sweating. This can lead to imprecision in detection and leave the signal open to disruption and interference by extraneous energies. These unwanted extraneous signals are termed 'noise' and can originate from mains electricity and from other biological processes, e.g. muscle activity.

Mains electricity produces electrostatic and electromagnetic noise in the 50 Hz frequency. Commonly, ECG signals are also disrupted by the radiofrequency noise from diathermy. As if a 'clean' signal was not difficult enough to achieve for an ECG in the millivolts range, the potential for interference in the microvolts range of EEG monitoring is huge, e.g. from the myocardium and from scalp muscle activity.

The capacity to isolate the true signal from the extraneous noise is termed the signal-to-noise ratio. This can be improved by selectively removing parts of the detected signal, a method discussed later.

Transduction

The transmission of information from the patient to the processor requires certain variables to be converted to an electrical signal. The conversion of energy from one form to another is achieved by a transducer. A good example is during the invasive measurement of intra-arterial pressure. In order to transport this signal for processing, it requires conversion from mechanical to electrical energy. The pressure transducer often used here is a strain gauge.

Having successfully cannulated the artery, a continuous column of fluid connects the cannula to a flexible diaphragm. Changes in arterial pressure are transmitted down this column to the diaphragm, which is part of the strain gauge. Pressure is sensed through a Wheatstone bridge which sits next to the diaphragm; essentially, this comprises a circuit of four wires which each has its own resistance − two known, one variable and one to be measured. Changes in pressure at the diaphragm result in a change in wire length which subsequently alters the resistance of the wires. The Wheatstone bridge circuit is configured to balance the resistances such that there is no current ('null deflection'). Because the variable resistance (which is altered to equal the measured resistance) can be controlled by a computer, a continuous pressure to electrical transduction can be achieved. More information on the science of pressure transducers can be found in a separate article in this publication.

Just as errors can occur during signal detection, this transduction phase is also subject to potential inaccuracy.

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Oscillation, damping and resonance

Oscillation is the tendency of a system to move either side of a baseline. The degree to which the system oscillates can be controlled by damping.

Imagine a child's swing. After a push, it is expected that the swing will oscillate for a short time before coming to rest at a vertical position. A highly damped swing would not oscillate following a push, would never reach the height expected of the push given and would return slowly back to the vertical position. An undamped swing would continue to oscillate long after the push and would reach much higher than expected for the push given. Clearly, both of these situations are undesirable for a clinical measurement device as well as for a swing; at some point the child needs to get off! If a single accurate measurement of swing height is needed before a slow return to vertical, 'critical damping' is required. However, usually multiple measurements are required on a continuous basis — a compromise position is needed. 'Optimal damping' provides this compromise: a near-true value is obtained followed by relatively rapid return to baseline with only a little oscillation to allow for future measurement. The degree of damping in a system is given by the damping coefficient. This lies between zero (an undamped system) and one (a critically damped system). A graphical representation of this concept is found in Figure 1.

Under and over damping can often be seen in arterial pressure waveforms. These situations can be minimized by ensuring the optimum conditions are provided: a short, wide cannula and short fluid column in a system with stiff walls and a rigid diaphragm. The presence of air bubbles, blood clots and multiple attachments or 3-way taps can result in inaccuracy due to damping.

Each system will have a particular frequency at which it resonates — where the amplitude is greatly exaggerated — called the natural frequency. An example is the ability of an opera singer to shatter a wine glass with her voice alone. If the pitch (frequency) corresponds to the natural frequency of the glass, it will resonate. In certain conditions this can cause such exaggerated amplitude that the glass is broken apart with its own vibration. It is easy to see how this can lead to wild inaccuracies in a measurement system.

Calibration and drift

Frequent calibration (comparing a test to a known value) is important to ensure that values measured are true. Calibration requires testing the system against an accurate control. This could be an alternative measurement device, or a known value such as atmospheric pressure or oxygen concentration.

In a system requiring batteries, the resultant display may differ from the true value because the batteries discharge over time, therefore the voltages used for reference can drift. Equally, a system that is slow to reach a steady state may be said to be subject to drift — a reading taken could be false as the system has not yet reached its true value. Two-point calibration takes drift (i.e. change with time) into account.

Accuracy and precision

When all the conditions above are favourable, the system can be said to be accurate — the resulting number corresponds well to the true value. This is not synonymous with precision, which is the degree of refinement of the measurement, e.g. the number of decimal places to which temperature is measured: 36 °C vs 36.25 °C.

Signal processing

Having detected a signal and converted it into electrical energy via a transducer, it can be processed in preparation for display.

The problems encountered with signals like the ECG discussed earlier can be tackled in several ways.

Digital signalling

Digital signals rely on a binary system to sample an analogue waveform at a set frequency and at a given resolution. These digital signals are much more robust and less susceptible to interference from extraneous noise. They are also subject to less degradation over distance than their analogue counterparts. Disadvantages in the early use of digital signalling were the amplitude resolution and sampling frequency achieved by the first converters — a continuous waveform was transformed into a series of boxes resulting in a vast oversimplification of the true signal. Whilst reasonable for a slowly changing and simple waveform, this is clearly inadequate for accurate assessment of an ECG. Higher resolutions and sampling frequencies available nowadays allow more specific representations of biological signals to be produced (Figure 2). Clearly this requires much more elaborate and expensive hardware to create and interpret as well as large amounts of computer memory to store.

Sine waves, amplification and filtering

Physiological waveforms such as the ECG and EEG are actually many sine waveforms superimposed onto one another. The total waveform produced can be broken down into its constituent sine waves using a process called Fourier analysis. These waves can then be processed individually. The slowest sine wave is called the 'fundamental frequency'. The rest of the signal is made up of 'harmonics' or multiples of the fundamental frequency.

Biological electrical signals are of very small amplitude and would be impossible to interpret at this size. Amplification increases this size in order to render the signals interpretable. The bandwidth used during this process must be adequate to include the fundamental frequency and sufficient harmonics to reproduce the signal, but not so high a range as to include extraneous noise.

It is possible to reduce noise through the use of filtering. Filters will reject signals of a given frequency in order to clean up the useful signal. Unfortunately it is not possible to remove this noise altogether — for example due to overlap of frequencies between those wanted (ECG) and unwanted (mains). Reduction in the bandwidth may reduce the 50 Hz mains noise but make analysis of the ST segment difficult or impossible.

Common mode rejection removes the part of the signal that is common to two input signals (i.e. background noise present in both) and only amplifies that which is different. For ECG signals this has helped to reduce the amplification of noise.

Display

The detected, transduced, amplified and processed signal must now be displayed for continuous monitoring and interpretation

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