Processing, storage and display of physiological measurements

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Abstract

The key to the successful and safe management of patients is regular and accurate recording of their 'vital signs' as indicators of well-being. Some physiological parameters can be measured and processed manually (blood pressure, pulse rate and respiratory rate), whereas others (pH, partial pressure of oxygen (P_aO_2) and partial pressure of carbon dioxide in arterial blood (P_aCO_2)) rely on electronic interpretation. In modern operating theatre and critical care settings, fully integrated, electronic, multiparameter monitoring systems based on microprocessors are standard. It is important that anaesthetists, as well as other healthcare professionals, understand the basic principles behind patient monitoring, including data processing, storage and display. Most physiological measurement systems include a sensor, transmission pathway, signal-processing stage and a display and storage device. This system may be simplified by regarding the different elements as a series of black boxes with the output from one box forming the input to the subsequent box. The initial input is a biological signal that results from the natural physiological processes occurring within the body. This signal may be chemical, electrical or mechanical in origin and is sensed by a transducer that converts it into an electrical output. Signal processing must then occur which aims to produce a meaningful output through amplification, digitization and 'noise' reduction. Once data have been acquired, there is usually a requirement to retain them for both immediate and long-term reference and to display them via a visual display unit.

Keywords amplifiers; analogue to digital converter (ADC); digital signal storage devices; electrical noise; physiological measurements; signal processing; visual display unit

Standards of monitoring

The Association of Anaesthetists of Great Britain and Ireland (AAGBI) has updated its recommendations for the standards of monitoring during anaesthesia and recovery (March 2007). Essential monitors for both induction and maintenance of anaesthesia are pulse oximetry, non-invasive blood pressure, electrocardiograph (ECG), airway gases and airway pressure. Nerve stimulators and thermometers should be available. These standards also apply in critical care areas where parameters such as invasive vascular or intracranial pressures, cardiac output and the processed electroencephalograph (EEG) are routinely measured.

Physiological measurements

Biological signals result from natural physiological processes occurring within the body. These signals may be chemical, electrical (currents/potentials) or mechanical (pressure/temperature) and can be measured in respect of time. Each signal has a finite range, frequency and method of sensing. A device that converts the energy of one signal into another form is known as a transducer, and examples used in physiological measurement are shown in Table 1.

Bioelectrical signals

Bioelectrical signals result from the movement of ions across cell membranes, when myocardial, skeletal muscle or neuronal cells become excitable. The resulting depolarization and repolarization

Examples of transducers used in clinical measurement

Physiological measurement	Transducer	Conversion
Pressure	Strain gauge	Resistance change
	Capacitance transducer	Capacitance change
Temperature	Thermistor	Resistance change
	Thermocouple	Thermojunction voltage change
	Platinum wire	Resistance change
ECG/EMG/EEG	Ag/AgCl electrodes	Potentiometric change
pH	pH electrodes	Potentiometric change
P_aCO_2	Severinghaus electrode	Amperometric change
P_aO_2	Clarke electrode	Amperometric change
	Fuel cell	Potentiometric change
Cardiac output	Ultrasound (piezoelectric crystal)	Frequency change
	Ag/AgCl electrodes	Thoracic bioimpedance change
S_aO_2	Photoplethysmograph	Potentiometric change

ECG, electrocardiograph; EEG, electroencephalograph; EMG, electromyogram.

Table 1

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potentials are usually sensed by electrodes on the skin surface. The ECG, EEG and electromyogram (EMG) are the most common bioelectrical potentials measured.

A typical surface electrode is the silver/silver chloride electrode, and a chloride gel applied to the skin acts as an ionic conductor. The following reaction takes place:

$$Ag + Cl^- \Leftrightarrow AgCl + e^-$$

Both reversible and irreversible electrochemical changes occur at the electrode resulting in current flow within the ECG leads. The potential difference required for current to flow is measured by the front end of the monitor before the signal is processed.

Mechanical signals

A bonded strain gauge transducer attached to a diaphragm can sense dynamic changes in pressure. Small changes in the length of the strain gauge, and therefore its resistance, result from movement of the diaphragm. This is incorporated into a Wheatstone bridge arrangement whose resulting output, in the order of a few millivolts, is directly proportional to the applied stress.

The ability of a transducer to respond to a stimulus that is constantly changing is called the dynamic response.

Signal processing

These small measurements will need processing prior to their display. This may be simplified by regarding the different elements as a series of 'black boxes' with the output from one box forming the input to the subsequent box until the final signal enters a microprocessor unit (Figure 1). Once sensed, these small analogue signals will require amplification.

The processing sequence of an electronic signal

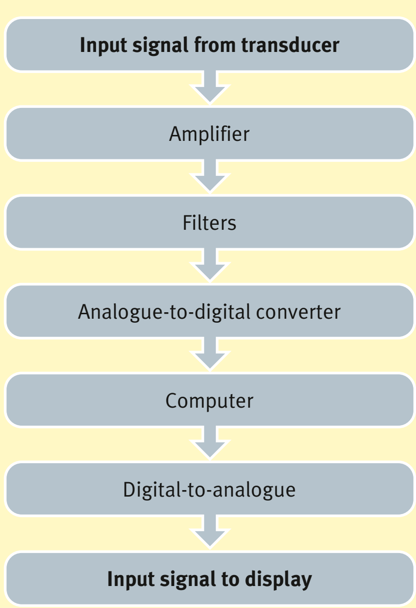


Figure 1

Amplifiers

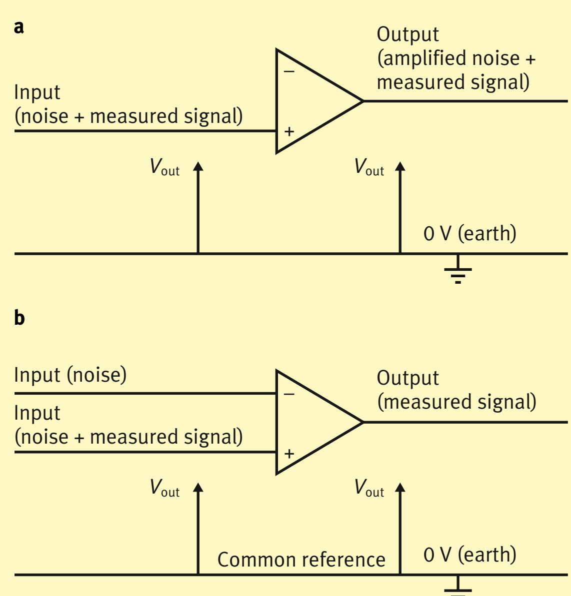
These are electronic components that increase the amplitude of the input signal. The voltage output is called the gain (output voltage/input voltage).

Single-ended amplifiers

The simplest form is shown in Figure 2a. It amplifies an input signal that is applied between the input and the earth or ground. Since there is only one input (the wire connected to the electrode), it can pick up interference from external electrical fields, which in turn is amplified causing gross distortion of the signal. This is called noise.

Signal noise may be defined as 'an undesired disturbance within the frequency band of interest or the summation of unwanted or disturbing energy introduced into a communications system from man-made and natural sources'. Examples of external interference in a theatre environment include surgical diathermy (500 kHz to 2 MHz), 50 Hz mains electricity or electrode movement artefact. Signal-to-noise ratio (often abbreviated as SNR or S/N) is an electrical engineering concept defined as the ratio of a signal power to the noise power corrupting the signal. It is measured using the logarithmic bel scale so that 1 bel is a ratio of 10:1 and 2 bel is a ratio of 100:1. For convenience, bels are often multiplied by 10 to give decibels. So, when presented with a low signal-to-noise ratio, a variety of signal-processing techniques are employed to improve the signal quality. These include the use of differential amplifiers, electronic filters or signal averaging techniques.

Single-ended and differential amplifiers



a Single-ended amplifier. The amplifier is unable to differentiate between the signal to be measured and the noise. **b** Differential amplifier. There is zero output when identical signals are applied to the two inputs, with only the measured signal remaining. This is called *common mode rejection*.

Figure 2