Basic measurement concepts

Gary Thomas

Elana Owen

Abstract

Precise measurement of physiological parameters during anaesthesia is vital, and enables clinicians to deliver safe and appropriate care to patients. Monitoring devices are essential tools in the clinical environment, and accurate records of the measurements provided by these monitors must be kept. The physical parameter to be measured is known as a measurand. Examples of measurands in clinical practice include temperature, voltage and pressure. In the process of measurement, a measurand should be quantitatively compared with a predefined standard. The fundamental components of a basic measurement system consist of a sensor, signal, display at a human interface and a feedback loop. The signal or surrogate marker of a measurand is often processed before display. It is important that the output of a measurement system accurately reflects the value of the measurand. Challenges presented by measurement systems involve the maintenance of precision and accuracy. The input relative to output of a transducer is ideally linear in nature but is subject to hysteresis and drift making regular calibration essential. Outputs of measuring devices will also depend on their ability to respond to static or dynamic change. The readings obtained from measurement devices are also subject to human error.

Keywords Calibration; drift; error; hysteresis; linearity; measurement; sensor; transducer

Royal College of Anaesthetists CPD matrix: 1A03

Learning objectives

After reading this article, you should be able to:

- Describe the essential components of a measuring system and how they are related
- Define the term transducer and give examples used in clinical measurement
- Outline how measured data is processed and displayed
- Understand the challenges associated with maintaining the accuracy of a measuring system

Introduction

Our reliance on monitoring devices in the clinical setting is becoming greater as the development of new technologies continues. Despite the advancement of monitoring techniques, the basic principles involved in data processing, storage and display remain the same. In this article we review the essential components of a measuring system and discuss some of the challenges presented by such systems.

Measurement

A specific physical parameter to be measured is known as a *measurand*. In the process of *measurement*, a measurand should be quantitatively compared with a pre-defined *standard*. Examples of measurands include temperature, voltage, pressure and height.

Standard

The standard should be of the same nature as the measurand, and is predefined internationally. The most important standards are the fundamental and derived International System (SI) of units.

Range

This is the interval between the upper and lower limits within which an instrument is designed to operate for measuring, indicating or recording a value.

Span

This represents the difference between the upper and lower values of a measuring instrument.

Resolution

This is the smallest increment of measurement that an instrument can detect and display.

Components of measurement systems

A measurement system aims to convert a physical signal into a form that can be observed and recorded. Each measurement system must contain four vital components that allow the measured variable to be compared to the standard and then displayed (Figure 1):

- sensor
- signal
- display or output
- control or feedback.

Sensor

This is a device that produces a physical or chemical change in response to variations in the measured parameter, and allows conversion into an interpretable reading. The mechanism by which sensors convert a signal into a useful and meaningful value can be simple or complex. Signals to be measured that are produced by the body may be chemical, electrical (currents and potentials) or physical (pressure and temperature).

A device that converts the energy of one signal into another form is known as a ***transducer*** and examples used in the medical field are shown (Table 1).

Most transducers produce an electrical signal in the form of current, voltage or resistance. These electrical signals will need further processing prior to display.

Simpler monitoring devices that are 'non-electrical' require very little modification before display. They do, however, rely on a calibrated linear or non-linear scale to allow an observer to

Gary Thomas ***MB BCh (Wales) FRCA*** *is a Consultant Anaesthetist at The Princess of Wales Hospital, Bridgend, Wales, United Kingdom. Conflicts of interest: none declared.*

Elana Owen ***BSc (Hons) MB BCh (Wales) FRCA*** *is a Specialist Trainee 4 in Anaesthesia on the Welsh School Rotation, United Kingdom. Conflicts of interest: none declared.*

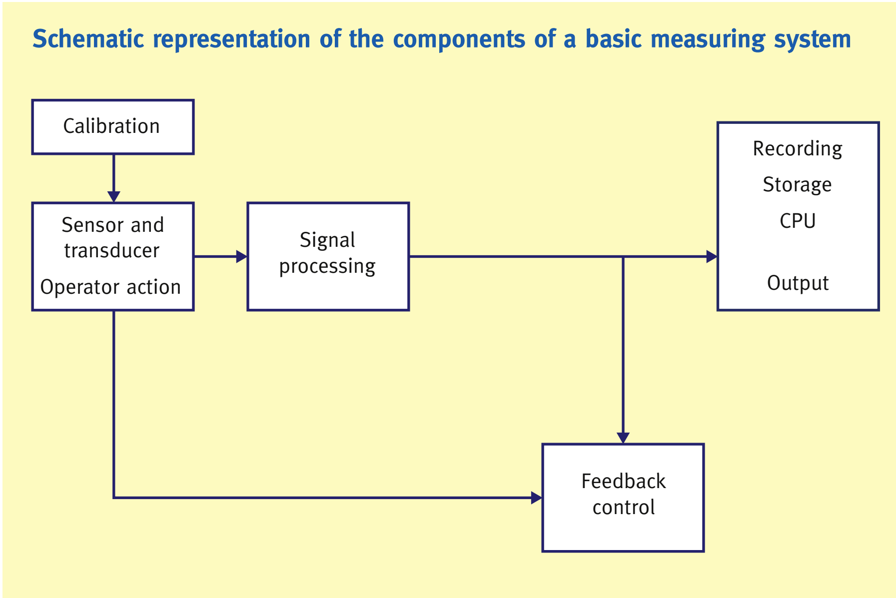

Figure 1

read and interpret a numerical value. Examples include those for temperature measurement (Bourdon gauge, liquid expansion and bimetallic strip thermometers) and pressure measurement (sphygmomanometer).

Processing of electrical signals

Amplification: electrical signals produced by transducers are processed before display. Amplifiers increase the scale of a received signal because the signals from transducers are usually too small to be displayed. The ratio of the signal strength (voltage, current or power) at the output of the amplifier, compared to the signal strength at the input is known as the ***gain***.

An important aspect of amplifiers is their ability to reduce interference from other electrical systems, which in turn would distort the measured signal. This interference is known as "signal noise". Differential amplifiers are able to perform an important step in reducing interference using a process called ***common mode rejection***. Other methods of reducing noise include the use of electrical filters or shielding cables.

Amplifiers must be suitable for the range of frequencies or ***bandwidth*** produced by the measured biological signal. They must also be appropriate for the voltage range of the signal being measured.

Examples of transducers used in clinical measurement

Physiological measurements	Transducer	Conversion
Pressure	Resistance	Resistance change
	Capacitative	Capacitance change
Temperature	Thermistor	Resistance change
	Thermocouple	Thermojunction voltage change
	Platinum wire	Resistance change
	Pyroelectric	Potentiometric
	Liquid in a bulb	Volume and length change
	Gas in a Bourdon gauge	Volume change
EMG, ECG and EEG	Ag/AgCl electrodes	Potentiometric change
pH	pH electrode	Potentiometric change
$PaCO_2$	Severinghaus electrode	Amperometric change
PaO_2	Fuel cell	Potentiometric change
	Clarke electrode	Amperometric change
SaO_2	Optical	Potentiometric change
Cardiac output	Ag/AgCl electrodes	Impedance change
	Piezoelectric	Frequency change

Table 1

Digitization: slowly changing or steady signals can be displayed in an analogue form, where there is a change in amplitude and frequency with time.

Digital signals are presented as a set of values or figures. It is useful in measurement systems for analogue signals to be converted into a digital format, and this is done using an analogue-to-digital converter (ADC). These digital signals can be transmitted to a receiver for storage (e.g. on a computer hard drive), or converted back to the original analogue signal for display via a digital-to-analogue converter (DAC). Digital signals are less prone to the effects of electrical interference and can easily be compressed, enabling large amounts of information to be stored.

Display and recording

Non-electrical methods of measurement may rely on linear (liquid expansion thermometer) or non-linear scales (measurement of gas flow with a rotameter). Probe indicators consist of a graduated dial and a needle, the latter driven by a mechanical linkage. Examples include the Bourdon gauge for the measurement of pressure and the galvanometer for the measurement of current. With the advent of electronics, digital displays and linear encoders are superseding mechanical methods of display.