Electronics and Medicine

An instrumentation system is defined as the set of all instruments and equipments used to measure one or more characteristics of the physical system and to present it in a useful form.
Biomedical instrumentation is the study of instruments used in the field of medical engineering. It is similar to general instrumentation but the source of inputs signals to the biomedical instruments system is living tissue or energy applied to living tissue.
Biomedical instrumentation implies measurement of biological variables, often called biometrics which is normally used in mathematical and statistical methods.

Classification of biomedical instrumentation

Biomedical instrumentation can be classified into two major types they are clinical instrumentation and research instrumentation. Clinical instrumentation is for diagnosis and treatment of diseases, whereas the research instrumentation is for research and human organism.
Those working and research and development area of medical engineering are called biomedical engineers, where those working with physicians and patient are called clinical engineers.
Similarly, based on the type of analysis, it can be further classified into two categories. One is in vivo and the other is in vitro. If the measurements are made on the living organism itself, then it is called in vivo. If the measurements are made outside the human body by taking samples from the body, then it is called in vitro. For example, in both methods, one can measure the PH value of the blood. In vivo method, the pH of the blood will be measured in the bloodstream itself. On the other hand, in vitro method, the pH of the blood sample taken from the body is used.

Types of biomedical instrumentation system

In addition to the above said classifications, biomedical instrumentation can be classified based on the quantity to be measured, principle of transduction and organ system. Following are the types of biomedical instrumentation:

1) direct or indirect measurement
2) invasive or non-invasive measurement
3) contact type or remote type measurement
4) sensor or actuator
5) real- time or static instruments

Direct or indirect measurement

In the direct measurement, the measuring system measures physiological parameters directly such as the average volume of a blood flow in an artery. In an indirect measurement, it measured measures parameter related to the physiological parameter of interest indirectly such as ECG recording at the body surface. It is related to the propagation of the electric signals in the heart, but is a direct measurement of the propagation waveform.

Invasive or non-invasive measurement

Direct electrical recording of the bio- signals in nerve fibres using an implantable electrode system is an example of an invasive measurement. An imaging system measuring a blood flow dynamics in an artery (e.g., ultrasound blood flow imaging) is an example of non-invasive measurement.

Contact type or remote type measurement

In contact type, the measuring system is attached to the body. For example, a strain gauge sensor attached to a muscle fiber can record deformaties and forces in a muscle. On the other hand, an MRI or ultrasound imaging system can measure internal deformaties and forces without contact with the tissue.

Sensor or Actuator

A sensor detects biochemical or bioelectrical or biophysical parameters. An actuator delivers and controls biochemical, bioelectrical, or by physical parameter.

An automated insulin delivery pump is an example of direct contact actuator. Noninvasive surgery with high-intensity focused ultrasound (HIFU) is an example of remote noninvasive actuator.

Real-Time or Static Instruments

Static instruments measure temporal averages per physiological parameter. Real-time instruments can plot a time response faster than or equal to the physiologic time constants of the sensed parameter. For example, a real-time ultrasound Doppler system can measure changes in arterial blood velocity over a cardiac cycle.

Sources of Biomedical Signals

The signals used to extract information of biological systems are called biomedical signals. Biomedical signals may be a simple wrist pulse of a person or a complex ultrasound signal of an internal soft tissue. Following are the various types of biomedical signals:

Bioelectric signals

The signals generated by nerve cells and muscle cells are called bioelectric signals. Electrocardiographs (ECG) and Electroencephalographs (EEG) are these types of signals. The source of this type of signal is the electric field generated by action potentials of many cells.

Bioacoustics signals

These signals from the sounds created by the biological system and provide information about the underlying phenomena. Flow of blood in the heart through valves, flow of air through airways and flow of air in the lungs are responsible for these basic acoustic signals.

Biomechanical signals

These signals are obtained from the mechanical function of the biological system. The motion of the chest wall is a good example for this type of signal. These types include all types of motion and displacement signals, pressure and flow signals.

Biochemical signals

These types of signals are obtained from the measurements of chemical composition either composition of various ions or partial pressure of oxygen or carbon dioxide in the living tissue or from the samples.

Bio-magnetic signals

In addition to bioelectric signals, some of the organs produce very weak electromagnetic signals. Measurement of these signals is called bio-magnetic signals. For example brain, heart, and lungs are the organs producing magnetic signals. One such measurement made on the brain is called electroencephalograph.

Bio-optic signals

These measurements are made by using the optical property of the biological systems. For example, blood oxygenation may be estimated by using opaque or scattering property of the blood to the particular frequency of light.

Bio-impedance signals

Tissue impedance gives important information like composition, blood distribution and blood volume. The measurement of resistance to a sinusoidal signal injected in to the tissue may be used to measure the impedance. Measurement of galvanic skin resistance and measurement of respiratory rate based on bio-impedance technique are typical examples of this type.

Components of the Biomedical Instrumentation System

The block diagram of a generalized biomedical instrumentation system is shown in figure (1.1). The basic components of this system are same as in any instrumentation system except the subject. In the biomedical instrumentation system, a living human being is a subject. The components of biomedical system are the subject, stimulus, transducer, signal condition equipment and display equipment. The system components are discussed as follows:

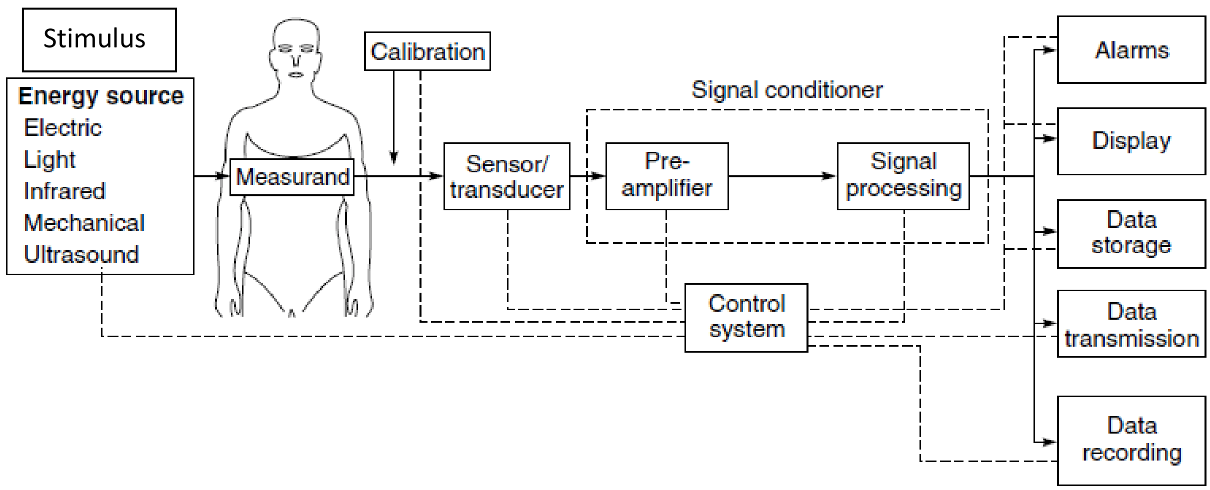

Figure 1.1 General block diagram of biomedical instrumentation.

The subject

The subject is the human body on which the measurements are made. It is very important to now the physiological systems that constitute the human body so that the biomedical instrumentation system can be easily understood.

Stimulus

In some investigations, measurement of response to external stimulation is required. The instrumentation used to generate such stimulus to the subject is an important part of biomedical instrumentation system. The stimulus generally used may be a flash of light, a tone, a tactile, or a direct electrical stimulation of some part of the nervous system.

Transducer

A device which converts one form of energy to another form of energy is called a transducer. In biomedical instrumentation, transducers are used to convert variables of interest in the human body into electrical signals. It may be used to convert temperature, pressure, flow and other variables of interest in the human body into electrical signals.

Signal conditioning equipment

It is necessary to convert the transducer signal into a meaningful signal so that the signal can be sent to the display unit or recording unit or storage unit. Instrumentation systems that convert the transducer signals into meaningful signals are called signal conditioning equipment. The functions of signal conditioning equipment are amplification, and changes in the shape of the waveform. Signals conditioning equipment may also be called signal processing unit. In some cases, it is required to combine two or three signals into a single signal.

Display equipment

Display equipment used to present the signal from the signal conditioning equipment in a form which can be understood by the user. The output display equipment may be a printer, a display monitor, or storage equipment.

Design Factors of Biomedical Instrumentation

Factors to be considered while designing/selecting an instrument are range, sensitivity, linearity, hysteresis, frequency response, accuracy, signal to noise ratio, isolation, simplicity and calibration. Design factors of biomedical instrumentation will be discussed in the following sections:

Range

Range of an instrument is amplitude and frequency of input over which the device is expected to operate. A good instrument should read the smallest expected value to the largest possible value to be measured.

Sensitivity

It is the smallest change of a variable or parameter that can be sensed by the instrument. Resolution of an instrument is directly proportional to sensitivity. Resolution is the minimum variation that can be read accurately. Sensitivity of a biomedical instrument or a biomedical instrumentation system is the ratio of the magnitude of the response (output signal) magnitude of the quantity being measured (input signal).

$$Sensitivity\ K = \frac{\text{Change of output signal}}{\text{Change of input signal}}$$

Sensitivity is represented by the slope of the calibration curve. If the calibration curves linear, then the sensitivity is constant. If the calibration curve is nonlinear, then the sensitivity is not a constant, and it is function of input signal. In electronic system of measurement term gain is used instead of sensitivity. Similarly, in mechanical instruments the amplification is used instead of sensitivity.

Linearity

An instrument is said to be linear when the instrument has a constant gain for the entire range of measurements. In other words, the sensitivity will be the same for entire range of input working range of most of the instruments provides a linear relationship between the output and input. A good instrument will have linearity over the entire range. If not possible the better to have it at least in the important sub range. In some instruments, nonlinearity may deliberately introduced for some special purpose.

Hysteresis

If the instrument does not give the same output for same input during increasing trend as well as decreasing trend, then the instrument is said to have hysteresis. This error may mislead observer.

Flat Frequency Response

If sensitivity or gain of the instrument is equal for the entire operating range of frequencies, then the instrument is said to have flat frequency response. Flat response is desirable for at least the operating region of frequency. The usual requirement is that the frequency of input signal should not exceed 60 per cent of the natural frequency of the measuring instrument.

Accuracy

Accuracy is the ability of the instrument to measure the value closer to true value.

Signal to noise ratio

In the user environment, it is not possible to have interference free instruments. The instruments are subjected to power line, electromagnetic and electrostatic interferences. The ratio be the output magnitude of the instrument and noise level is called signal to noise ratio. For ideal instrument, it is infinity.

Isolation

Biomedical signals are obtained from patients or experimental animals in such a way that the instrument does not have any electrical contact with either the subject or ground. This condition is necessary for the purpose of electrical safety and to avoid any electrical interference across different instruments used simultaneously. To achieve this, electrical isolation can be provided using magnetic or optical coupling methods or by using wireless telemetry. Telemetry will be very useful in the case of moving subject (patient/animal).

Simplicity

If a system is complex, then there may be a chance of human error and chance of elimination of a component. Therefore, all systems and instruments should be as simple as possible.

Calibration

Calibration of an instrument is comparing the performance of the instrument with higher accuracy instrument and carrying out necessary modifications so that the instrument gives acceptable accurate output. All the instrumentation systems require calibration before they implemented in practice. Calibration should be with standard instrument which has more accuracy than the instrument under use. The standard instrument used must be as simple as possible.