Biomedical Instrumentation I

Lecture-1: Introduction to BM Instrumentation System

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https://sites.google.com/site/mdotarif/teaching/bmi

Course Instructor

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Course Info

- Discipline: Biomedical Engineering
- Batch: 11-BM
- Term: 1st Term, 3rd Year
- Credit Hours: 4 Hours per Week
- Starting Date: 07-01-2013
- Suspension Date: 28-04-2013

Course Web Site

- https://sites.google.com/site/mdotarif/teaching/bmi
- Teaching Plan
- Announcements (check regularly!)
- Lecture Notes
- Assignments
- Test Results
- Sessional Marks
- Past Quiz/Test papers etc.

Course Teaching Staff

- Theory Lectures: Dr. Muhammad Arif

- Labs Practical/Tutorials: Engr. Sanwal Memon

Course Outline

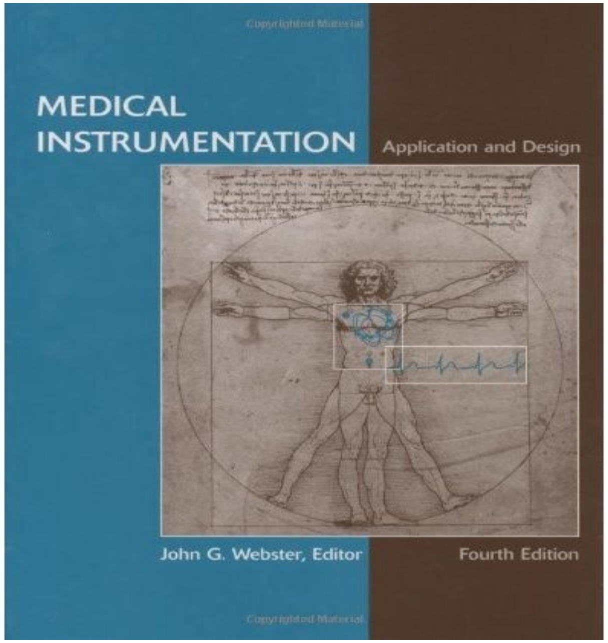
- Introduction to Biomedical Instrumentation (BMI) System
- Transducers/Sensors
- The Origin of Biopotentials
- Biopotential Electrodes
- The Heart & Electrocardiogram (ECG)
- Biopotential Amplifiers
- Defibrillators & Pacemakers
- Measurement of Blood Pressure & Heart Sound
- Measurement of Blood Flow & Cardiac Output
- Measurements of the Respiratory System
- Spirometers, Ventilators & Respirators
- Principles of Ultrasonic Measurements
- Electrical Safety of Medical Equipment

About Lecture Slides

- Lectures slides of the course are a summary of material only.
- They do not contain enough detail on their own.
- They may contain illustrations, block diagrams, problems, key points and short definitions of the corresponding topics.
- So, all students are advised to see the recommended texts for more details.

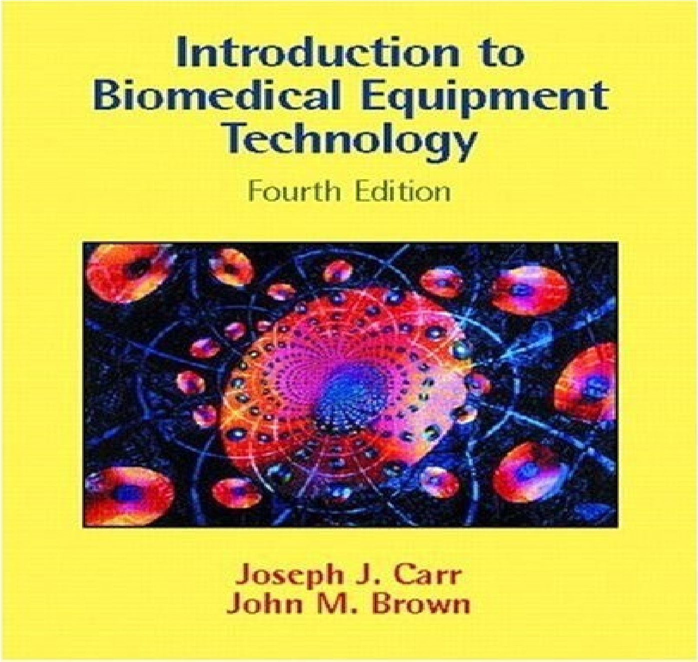
Recommended Texts

1. Medical Instrumentation: application and design, by John G. Webster (Editor), John Wiley & Sons, 4th Edition.



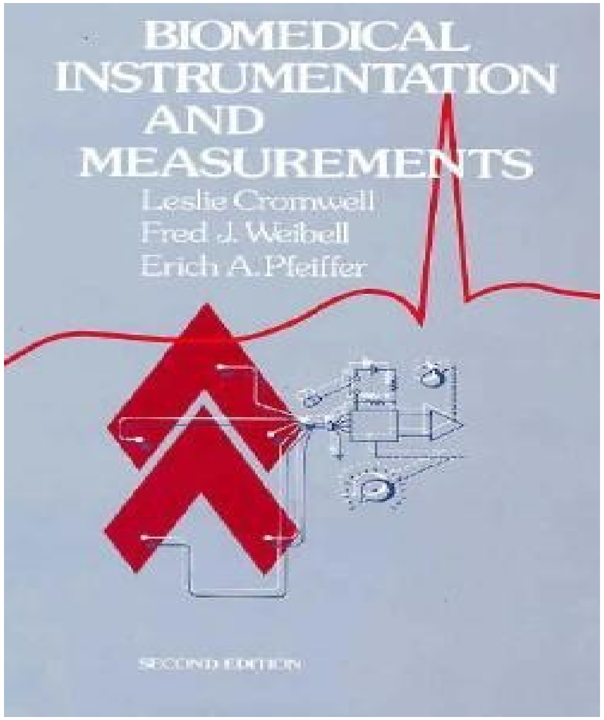
Recommended Texts

2. Introduction to Biomedical Equipment Technology, by Joseph J Carr, Prentice Hall, 4th Edition.



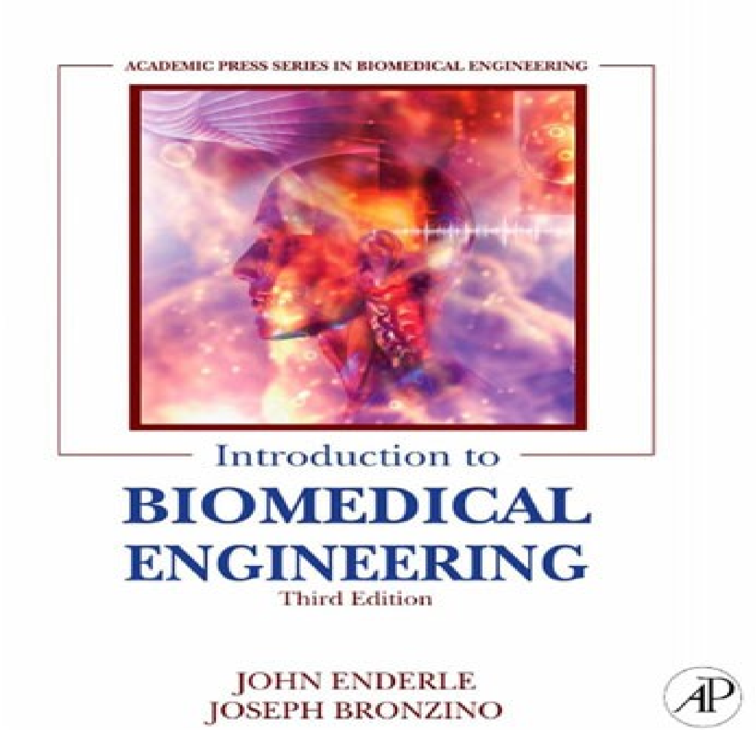
Reference Texts

1. Biomedical Instrumentation and Measurements by Leslie Cromwell, 2nd Edition.

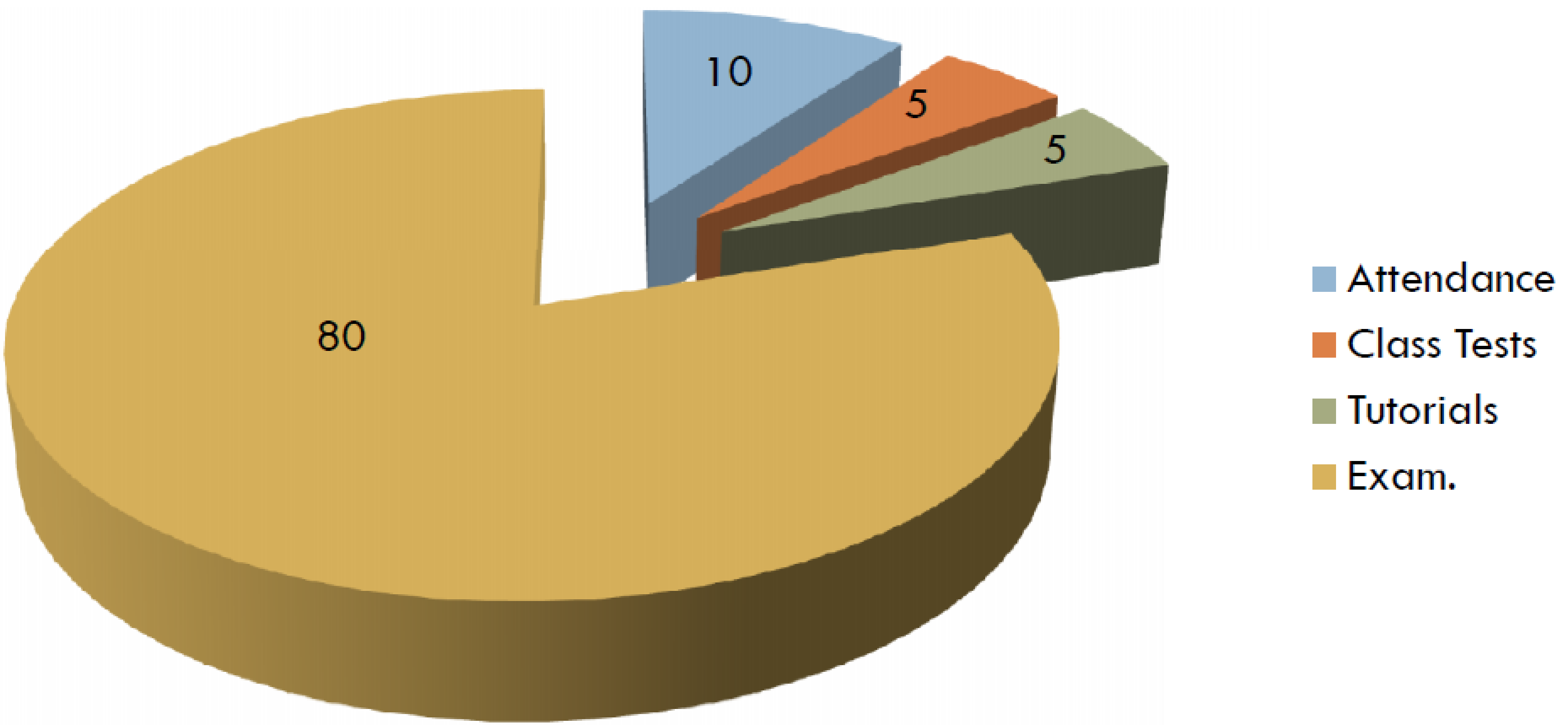


Reference Texts

2. Introduction to Biomedical Engineering, by John D. Enderle, 3^{rd} Edition.



Assessment



Why Study Biomedical Instrumentation

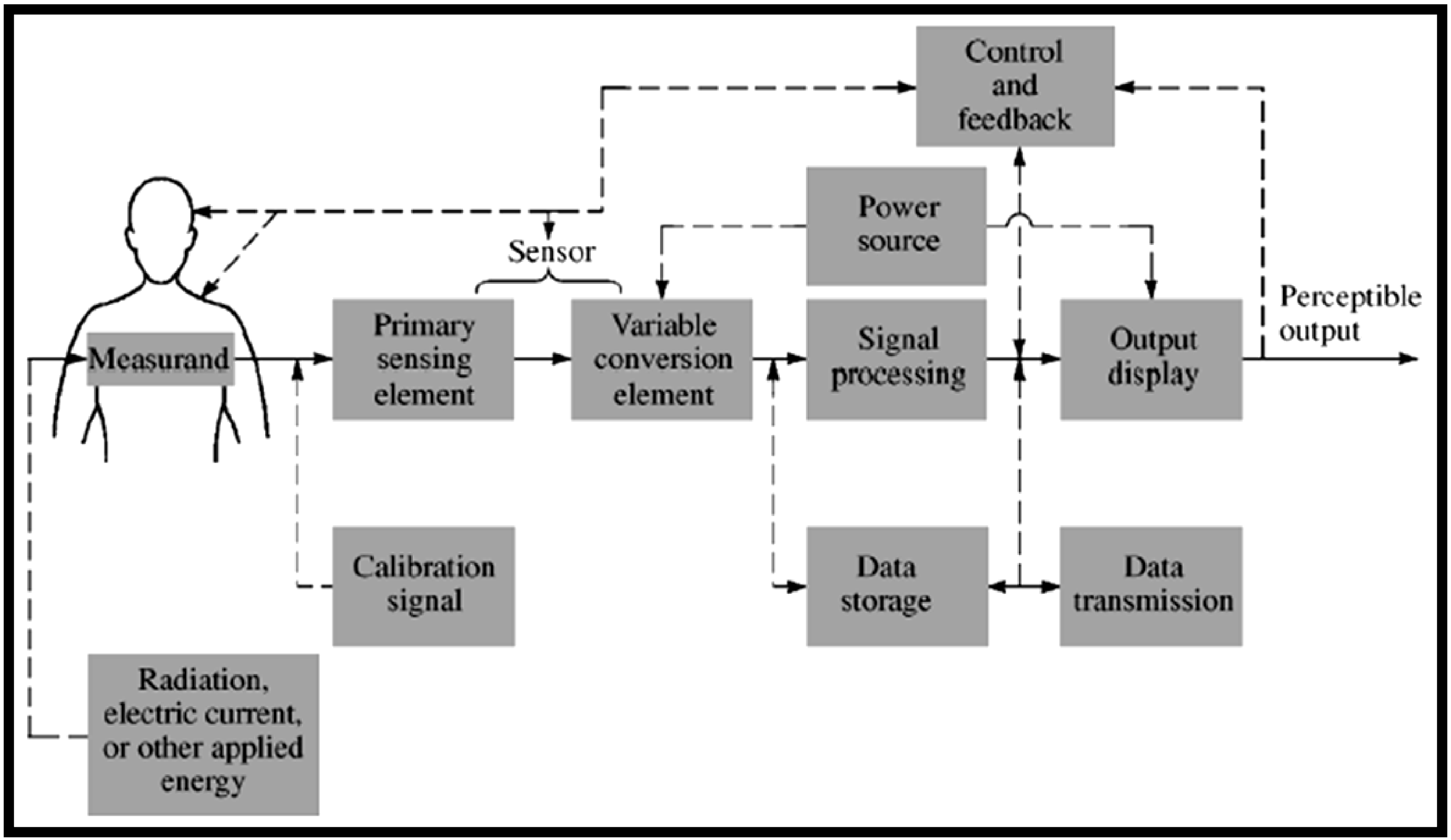
- Medical devices are used for
  i. Diagnosing of disease
  ii. Treatment of disease
  iii. Care and monitoring of patients

- Important to know about medical devices
  i. Technical, design, development aspects
  ii. Physiological basis
  iii. Clinical applications
  iv. Safety and regulatory environment

Lecture Outline

- Generalized Medical Instrumentation System
- Components of Medical Systems
- Instrument Operational Modes
- Medical Measurand Constraints
- Classification of Medical Instruments
- Measurement Input Sources
- Characteristics of Instrument Performance
- System Static & Dynamic Characteristics
- General Design Criteria & Process of Medical Instruments
- Commercial Medical Instrumentation Development Process

Generalized Medical Instrumentation System



* Elements and connections shown by dashed lines are optional for some applications.

Components of Medical System

Measurand:

- The physical quantity, property, or condition that the system measures.
- The accessibility of the measurand is important because it may be:
  i. Internal (eg. Blood Pressure)
  ii. On the body surface (e.g. Electrocardiogram Potential)
  iii. Emanate from the body (e.g. Infrared Radiation)
  iv. Derived from a tissue sample (e.g. Blood or Biopsy)

•Medically Important measurands can be grouped in the following categories:

i.Biopotential

ii.Pressure

iii.Flow

iv.Dimensions (imaging)

v.Displacement (velocity, acceleration, and force)

vi.Impedance

vii.Temperature

viii.Chemical concentrations.

Components of Medical System

Transducer/Sensors:

- A ***transducer*** is a device that converts one form of energy to another.
- A ***sensor*** is a device that converts a physical measurand to an electric output.
- The sensor should be noninvasive or minimally invasive.
- The sensor should respond only to the form of energy present in the measurand, to the exclusion of all others.

Components of Medical System

Signal Conditioning:

- Signal conditioner may amplifies, filter or merely match the impedance of the sensor to the display.
- Often, sensor outputs are converted to digital form and processed by specialized digital circuits or a microcomputer.

Components of Medical System

Output Display:

•The results of the measurement process must be displayed in a form that the human operator can perceive.

•The best form for the display may be;

i.Numerical or Graphical

ii.Discrete or Continuous

iii.Permanent or Temporary

iv.Visual or Hearing

Components of Medical System

Auxiliary Component:

i. A calibration signal with properties of the measurand should be applied to the sensor input or as early in the signal-processing chain as possible.

ii. Many forms of control and feedback may be required to elicit the measurand, to adjust the sensor and signal conditioner, and to direct the flow of output for display, storage or transmission. The control and feedback may be automatic or manual.

Components of Medical System

Auxiliary Component: (continue)

iii. Data may be stored briefly to meet requirements of signal conditioning or to enable operator to examine the data that precede alarm conditions. Or data may be stored before signal conditioning, so that different processing schemes can be utilized.

iv. Conventional principles of communication can often be used to transmit data to remote displays at nurses' stations, medical centers, or medical data-processing facilities.

Instrument Operational Modes

Direct Mode

- Direct measurement of accessible measurands.
- If the sensor is invasive, direct contact with the measurand is possible but expensive, risky and least acceptable.
  i. Temperature
  ii. Heart Beat

Indirect Mode

- Indirect measurement of inaccessible measurands
  i. Morphology of internal organ: X-ray shadows
  ii. Volume of blood pumped per minute by the heart: respiration and blood gas concentration
  iii. Pulmonary volumes: variation in thoracic impedance plethysmography

Instrument Operational Modes

Sampling Mode

•Infrequent monitoring of slow changing measurands
i.Body temperature
ii.Ion concentrations

Continuous Mode

•Frequent or constant monitoring of vital/critical measurands
i.Electrocardiogram
ii.Respiratory gas flow

Instrument Operational Modes

Generating Mode

- Generating sensors produce their outputs from energy taken from measurand.
- Also known as self-powered modes.

  Example: **Photovoltaic cell** is a generating sensor because it provides an output voltage related to its irradiation, without any additional external energy source.

Modulating Mode

- Modulating Sensors uses the measurand to alter the flow of energy from an external source .

  Example: **Photoconductive cell** is a modulating sensor; to measure its change in resistance with irradiation, we must apply external energy to the sensor.

Instrument Operational Modes

Analogue Mode

- Analogue or Continuous signal is able to take any value within a dynamic range.
- Most currently available sensors operate in the analog mode.

Digital Mode

- Digital or Discrete signal is able to take on only a finite number of values.
- The advantages of the digital mode of operation include greater accuracy, repeatability, reliability, and immunity to noise.

Instrument Operational Modes

Real-Time Mode

- The results are displayed almost immediately.

Delayed-Time Mode

- The results are delayed due to considerable signal processing.

Medical Measurement Constraints

- The signal to be measured imposes constraints on how it should be acquired and processed
- Many measurand in living systems are inaccessible
- Placement of sensor(s) in/on the body plays a key role in medical instrumentation design
- Magnitude and frequency range of medical measurand are very low
- Interference and cross-talk artifacts
- Proper sensor interface with measurand cannot be obtained
- Medical variables are seldom deterministic (varying with time)
- Many medical measurements vary widely among normal patients, even when conditions are similar.
- Safety of patient and medical personnel also must be considered
- Safe levels of stimulation or applied energy are difficult to establish,
- External energy must be minimized to avoid any damage
- Equipment must be reliable, easy to operate, and durable
- Government regulations

Common Medical Measurands

Measurement	Range	Frequency, Hz	Method
Blood flow	1 to 300 mL/s	0 to 20	Electromagnetic or ultrasonic
Blood pressure	0 to 400 mmHg	0 to 50	Cuff or strain gage
Cardiac output	4 to 25 L/min	0 to 20	Fick, dye dilution
Electrocardiography	0.5 to 4 mV	0.05 to 150	Skin electrodes
Electroencephalography	5 to 300 μ V	0.5 to 150	Scalp electrodes
Electromyography	0.1 to 5 mV	0 to 10000	Needle electrodes
Electroretinography	0 to 900 μ V	0 to 50	Contact lens electrodes
pH	3 to 13 pH units	0 to 1	pH electrode
pCO_2	40 to 100 mmHg	0 to 2	pCO_2 electrode
pO_2	30 to 100 mmHg	0 to 2	pO_2 electrode
Pneumotachography	0 to 600 L/min	0 to 40	Pneumotachometer
Respiratory rate	2 to 50 breaths/min	0.1 to 10	Impedance
Temperature	32 to 40 ℃	0 to 0.1	Thermistor

Classifications of Biomedical Instruments

Quantity that is sensed

- Makes comparison of different technologies easy

i. Pressure
ii. Flow
iii. Temperature

Principle of transduction

- Makes development of new applications easy

i. Resistive
ii. Capacitive
iii. Electrochemical
iv. Ultrasound

Organ systems

- Isolates all important measurements for specialists who need to know about a specific area

i. Cardiovascular system
ii. Pulmonary system
iii. Nervous system

Clinical specialties

- Easy for medical personnel interested in specialized equipment.
    i. Pediatrics
    ii. Cardiology
    iii. Radiology

Measurement Input Sources

1. **Desired Inputs:** measurands that the instrument is designed to isolate.

2. **Interfering Inputs:** quantities that inadvertently affect the instrument as a consequence of the principles used to acquire and process the desired inputs.

3. **Modifying Inputs:** undesired quantities that indirectly affect the output by altering the performance of the instrument itself.

Measurement Input Sources

Example: ECG Signal Measurement

1. **Desired Input:** ECG voltage
2. **Interfering Input:** 60/50 Hz noise voltage, displacement currents
3. **Modifying Input:** – orientation of the patient cables when the plane of the cable is perpendicular to the magnetic field the magnetic interference is maximal

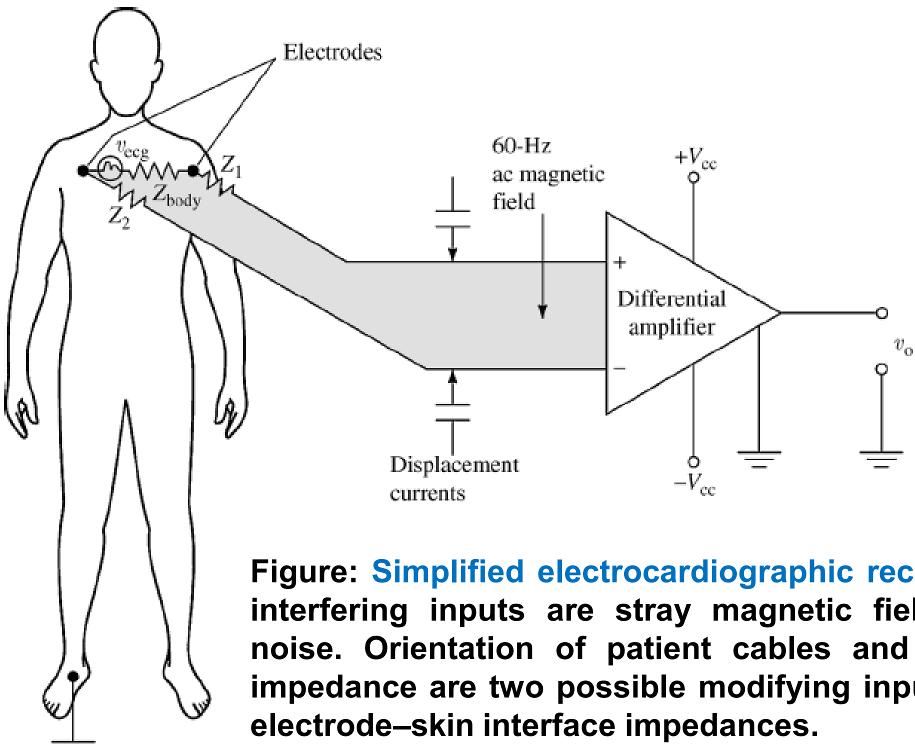


Figure: Simplified electrocardiographic recording system Two possible interfering inputs are stray magnetic fields and capacitive coupled noise. Orientation of patient cables and changes in electrode–skin impedance are two possible modifying inputs. Z1 and Z2 represent the electrode–skin interface impedances.

Characteristics of Instrument Performance

- Performance of a new instrument is evaluated using the two classes of characteristics which are based on the frequency of the input signals.
- This provides a quantitative criteria for the instruments performance.
- These criteria must specify how well an instrument measures the desired input and how much output depends on interfering and modifying inputs.

1. **Static Characteristics:** describe the performance for *dc* or very low frequency input.

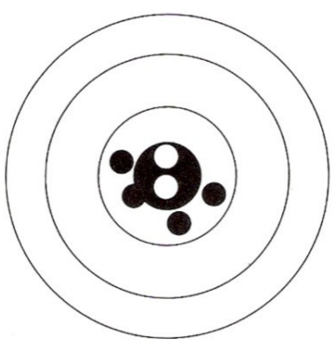
2. **Dynamic Characteristics:** describe the performance for *ac* and high frequency input

Generalized Static Characteristics

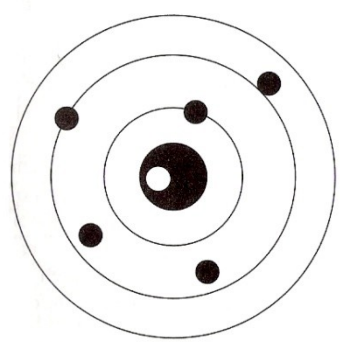
Following are the parameters used to evaluate medical instrument:

- **Accuracy:** refers to the degree of conformity between the measurand and the standard. It can be calculated using the difference between the true value and the measured value divided by the true value.

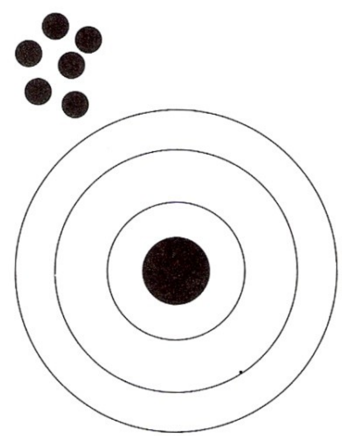
- **Precision:** refers to the degree of refinement of measurement. The number of distinguishable alternatives from which a given results is selected {2.434 or 2.43}



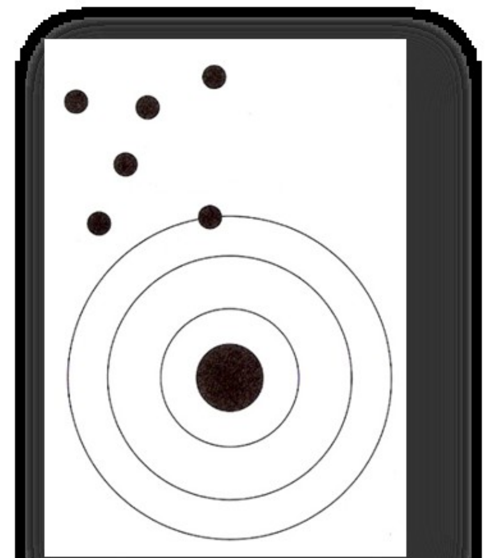
Good Accuracy, Good Precision



Good Accuracy, Poor Precision



Poor Accuracy, Good Precision



Poor Accuracy, Poor Precision

Generalized Static Characteristics

- **Resolution:** The smallest increment quantity that can be measured with certainty.
- **Reproducibility:** The ability to give the same output for equal inputs applied over some period of time.
- **Statistical control:** ensures that random variations in measured quantities that result from all factors that influence the measurement process is tolerable.
- **Static sensitivity:** is the ratio of the incremental output quantity to the incremental input quantity.

Generalized Static Characteristics

- **Zero drift:** occurs when all the output values increase or decrease by the same absolute amount due to manufacturing misalignment, variation in ambient temperature, vibration etc.

- **Sensitivity drift:** causes output change in proportion to the magnitude of the input. Change in the slope of the calibration curve.

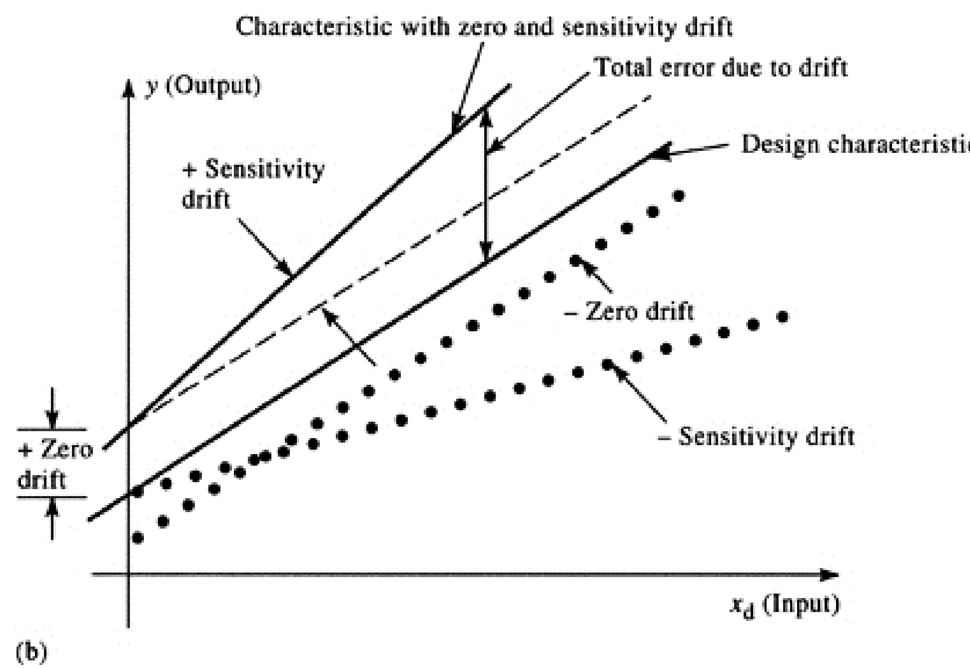


Figure: Static sensitivity: zero drift and sensitivity drift. Dotted lines indicate that zero drift and sensitivity drift can be negative.

Generalized Static Characteristics

- **Linearity:**
  - If $y_1 = x_1$ and $y_2 = x_2$, then $y_1+y_2 = x_1+x_2$ and $Ky_1 = Kx_1$

- **Input ranges:** Normal linear operating range specifies the maximal inputs that give linear output.

- **Input impedance:** Ratio of the phasor equivalent of a steady-state effort input to flow input variable.

Generalized Dynamic Characteristics

- Most of the biological signals time-varying in nature and therefore we should make sure that the instrument is a time-invariant system for an accurate measurement.

- The dynamic characteristics of an instrument include its transfer function, its frequency response, and its phase or time delay.

- Dynamic characteristics require the use of differential or integral equations to describe the quality of the measurements.

- Transfer functions are used to predict the stability of a system.

- Zero-order instruments
  - A derivative where the output is proportional to the input for all frequencies.
  - E.g. Linear potentiometer.

Generalized Dynamic Characteristics

- First-order instruments
  - Devices that have a single energy storage element.
  - E.g. Low-pass RC filter.

- Second-order instruments
  - Instruments that need a second-order differential equation to describe its dynamic response.
  - E.g. Force-measuring spring scale.

- Time delay
  - Instruments that produce exactly the same output as input, however with delayed time.
  - E.g. Equipment that require significant signal processing schemes.

General Design Criteria and Process of Medical Instrument

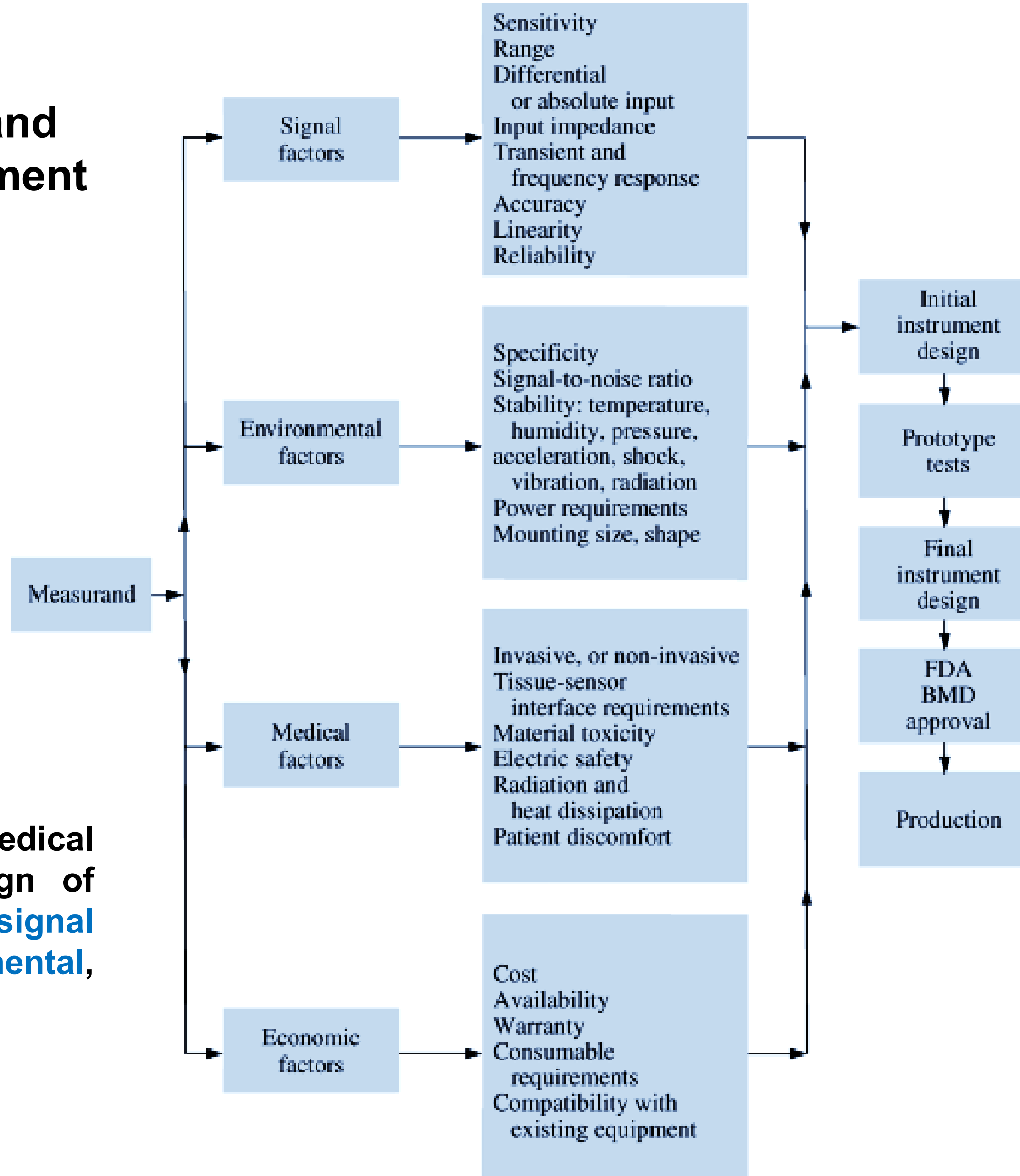


Figure: Design process for medical instruments Choice and design of instruments are affected by signal factors, and also by environmental, medical, and economic factors.

Commercial Medical Instrumentation Development Process

- Ideas: come from people working in the health care
- Detailed evaluation and signed disclosure
- Feasibility analysis and product description
  - Medical need
  - Technical feasibility
- Brief business plan (financial, sales, patents, standards, competition)
- Product Specification (interface, size, weight, color)

  "What" is required but nothing about "how"
- Design and development (software and hardware)
- Prototype development
- Testing on animals or human subjects
- Final design review (test results for, specifications, subject feedback, cost)
- Production (packaging, manual and documents)
- Technical support

Questions?