ELEC 207
Instrumentation and Control

2 – Measurement System

Dr Roberto Ferrero

Email: Roberto.Ferrero@liverpool.ac.uk

Telephone: 0151 7946613

Office: Room 506, EEE A block

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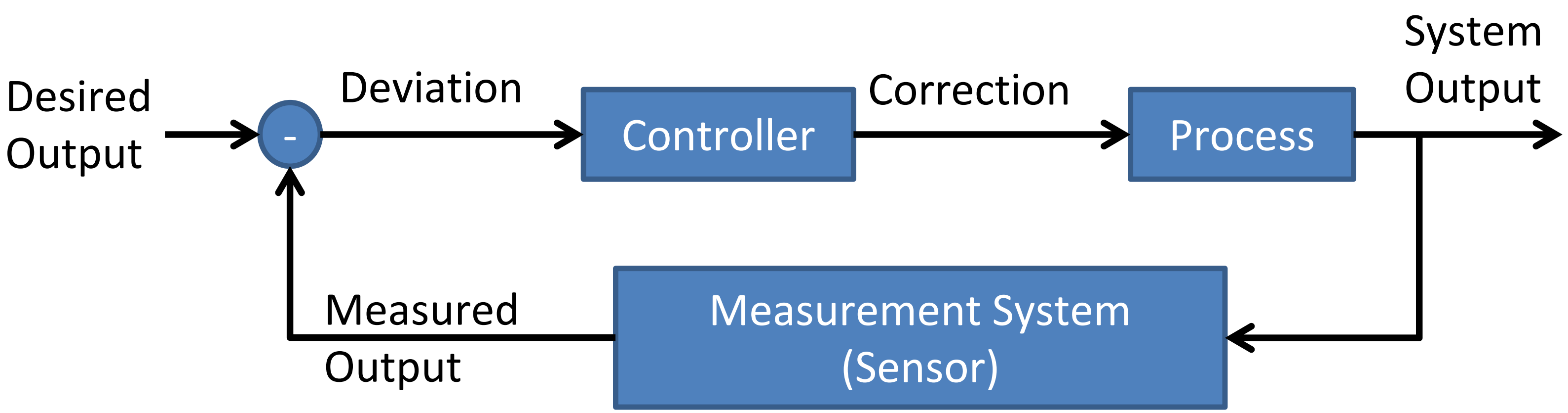
Instrumentation and control

Typical system structure

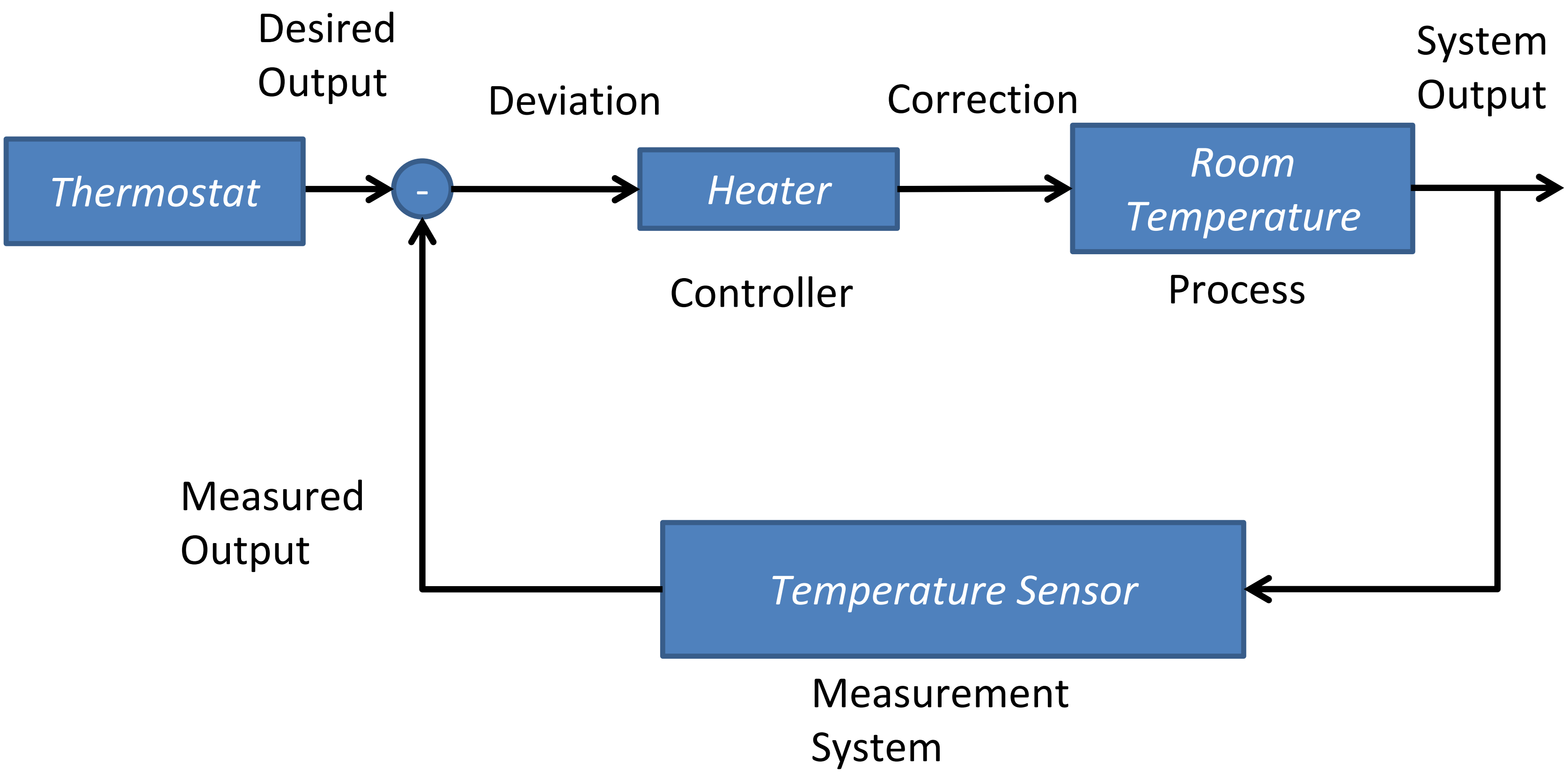
General structure of a closed-loop control system:



- The **measurement system** is used here to provide the feedback.

Instrumentation and control

An example: Temperature control



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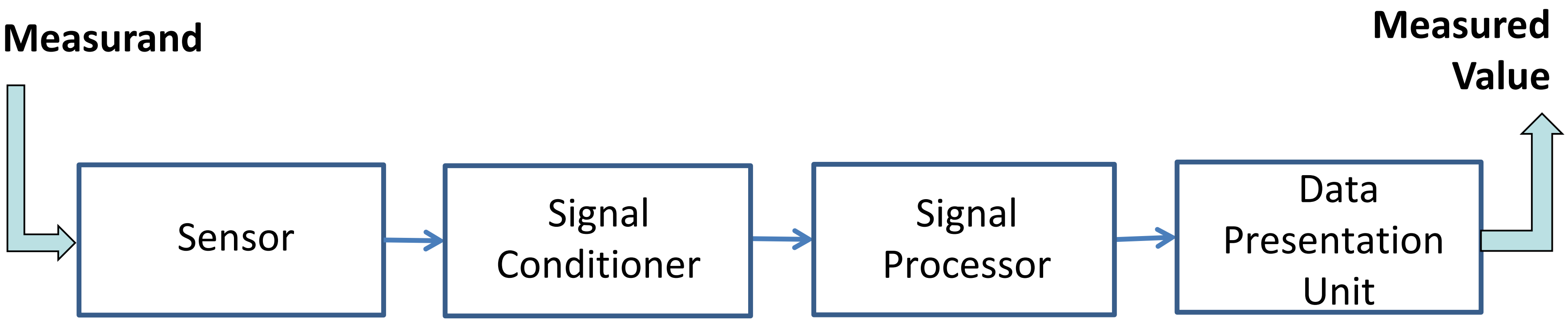
Measurement system

General structure



- Temperature
- Displacement
- Strain
- Acceleration

- Amplifier
- Bridge

- Analog-to-Digital Converter (ADC)
- Microcontroller

- LED (Display)
- Visual display unit
- Chart recorder

Measurement system

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Measurement system

Basic definitions (1)

The main elements in a measurement system are:

- **Measurand**:
  - ➢ The physical quantity being measured. It can be electrical such as voltage, current, charge, or non-electrical such as temperature, strain, displacement, acceleration, etc.
- **Sensor**:
  - ➢ A device that can detect a physical variable (displacement, temperature, etc.) and has the ability to give a measurable electrical output (voltage, frequency, amplitude). This output varies with the input (physical variable). For example, human fingers have sensors to detect surface roughness, temperature and force.

Measurement system

Basic definitions (2)

- **Signal conditioner**:
  - A device that converts the output of a sensor and suitably adjusts it to match the input signal range of the signal processing unit. For example, weak signals may be amplified through **amplifiers** (mV → V).

- **Transducer**:
  - A device that converts one form of energy (electrical, acoustic, electromagnetic etc.) into another (usually electrical). For example, a current transducer converts a current into a voltage signal.
  - The transducer is often confused with the sensor, but it is a complete package which may include both the sensing and the signal conditioning elements.

Measurement system

Basic definitions (3)

- **Signal processor**:
  - It converts the output of the conditioning element into a suitable form for presentation.
  - It usually includes a **data acquisition** system and an **Analog-to-Digital Converter (ADC)**, which digitises the signal and presents it in a digital format, which is more convenient for long distance transmission, storage and data analysis.
  - Signal processing usually include **calculations** performed by computers or other types of processors.

Digital

Analog

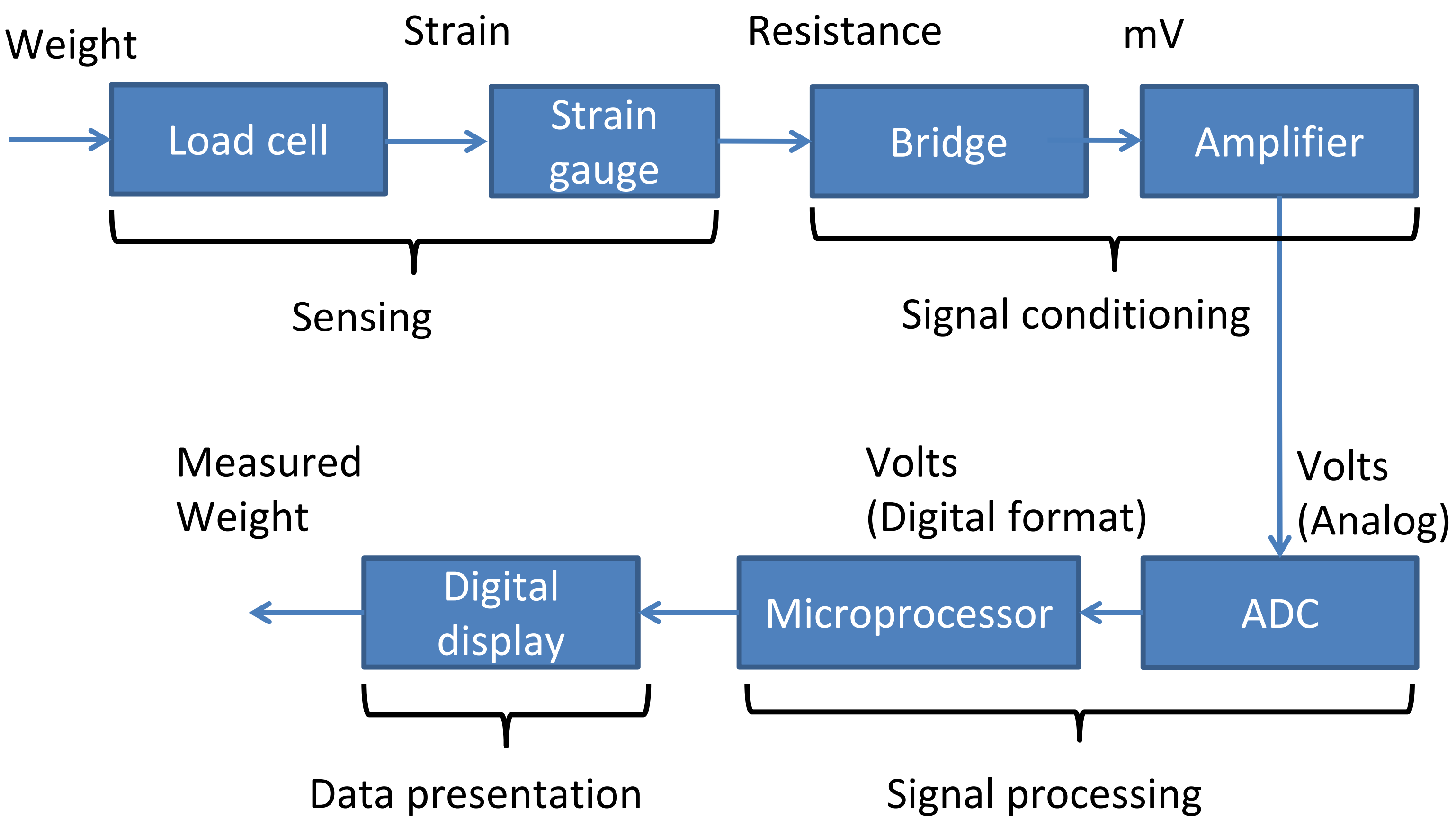
Measurement system

Basic definitions (4)

- **Signal transmission line**:
  - Measured signals are often transmitted over long distances from the point of measurement to the place where the measurement data are utilised.
  - The transmission line can be analog or digital; the latter is more suitable for long distances and/or noisy environments.
- **Data presentation unit**:
  - This presents the measured value in a form which can be easily recognised by the user. It can be a numerical display, a waveform graph, etc.

Measurement system

An example: Weight measurement



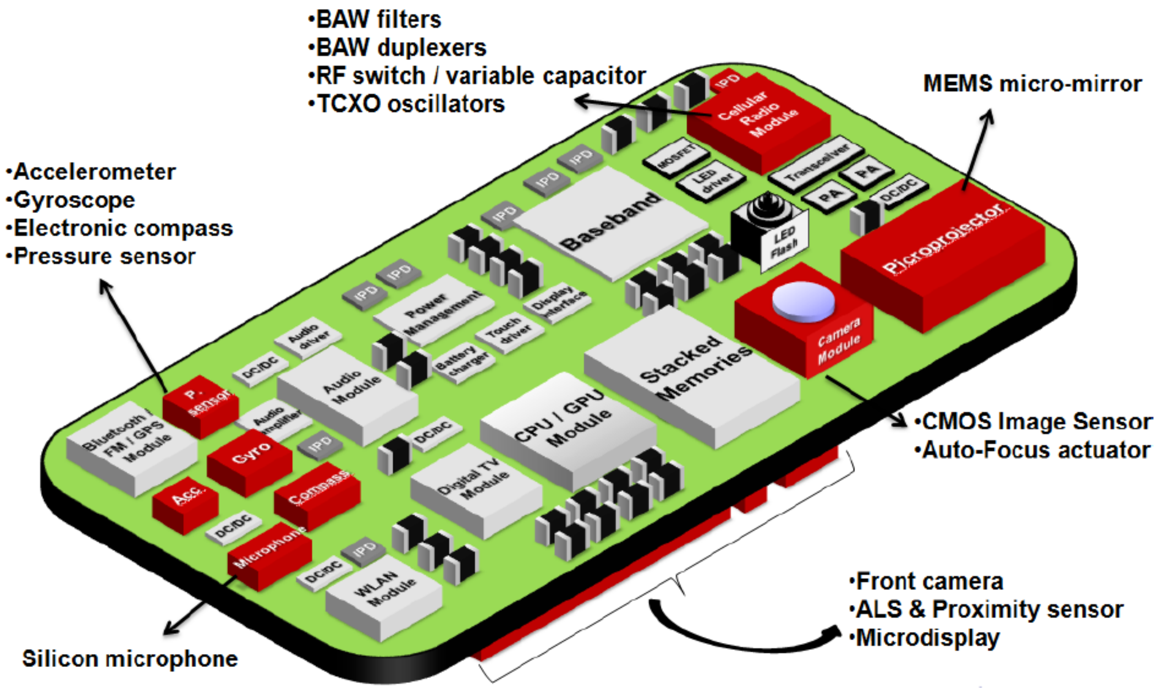
Measurement system

Micro-Electro-Mechanical Systems (MEMS)

MEMS are the integration of a number of micro-components on a single chip, which allows microsystem to measure and control the system:

- Typically, they include all main components of a measurement system: sensor, signal conditioner and signal processor;
- These components are typically integrated on a single chip using IC fabrication techniques similar to integrated circuits;
- Typical dimensions are in micrometers (1 µm = 10^{-6} m);
- Their global market for mobile phones and tablet exceeds 1 billion $.

Measurement system
MEMS - Example



Source: Prof. Steeve Beeby, University of Southampton, UK

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Measurement uncertainty

Errors in the measurement system

The output of a measurement system is always different from the ‘true’ value of the measurand:

- There is **always** an **error**: *e = measured value – ‘true’ value*

Errors arise from many different causes:

- Environmental disturbances, including noise;
- Non-ideal characteristics of the measurement instrument;
- Signal processing;
- Signal transmission;
- …

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Measurement uncertainty

Systematic and random errors

Errors are divided in systematic and random errors, depending on their cause and how they affect the measurement result:

- **Systematic errors** affect the measurement result always in the same way (e.g. an offset):
  - ➢ They can be reduced by **calibration**.
- **Random errors** are unpredictable variations of the measurement results, which affect different measurements in different (and unknown) ways:
  - ➢ They can be reduced by **repeating the same measurement** several times in the same conditions and **averaging the results** (when possible).

Measurement uncertainty

Error vs uncertainty

Each measurement is **always affected by an unknown error** (at least because of the random error); therefore the 'true' value can never be known:

- The definition of error is never applicable;

- It is only possible to refer to a **measurement uncertainty**, defined as a "parameter, associated with the result of a measurement, that characterizes the **dispersion** of the values that could reasonably be attributed to the measurand" [*JCGM 100:2008, Guide to the Expression of Uncertainty in Measurement*]

    - The concept of uncertainty refers to **random errors** (which can never be eliminated) and therefore can be estimated based on the **probability distribution** of the measurement result (e.g. standard deviation of a set of data).

References

Textbook: Principles of Measurement Systems, 4^{th} ed.

For further explanation about the points covered in this lecture, please refer to the following chapters and sections in the **Bentley** textbook:

- Chapter 1, Sec. 1.1: **Purpose and performance of measurement systems**;
- Chapter 1, Sec. 1.2: **Structure of measurement systems**;
- Chapter 1, Sec. 1.3: **Examples of measurement systems**.

NOTE: Topics not covered in the lecture are not required for the exam.

References

Textbook: Measurement and Instrumentation, 2nd ed.

For further explanation about the points covered in this lecture, please refer to the following chapters and sections in the **Morris-Langari** textbook:

- Chapter 1, Sec. 1.3: **Measurement system design**;
- Chapter 1, Sec. 1.4: **Measurement system applications**;
- Chapter 3, Sec. 3.1: **Introduction [of measurement uncertainty]**.

NOTE: Topics not covered in the lecture are not required for the exam.