Instructors

Lecture

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Web Site

UBlearns and http://www.eng.buffalo.edu/Courses/mae334

Username and Password for the homework solutions are both “334”

Textbook

R. S. Figliola & D. E. Beasley, Theory and Design for Mechanical Measurements, John Wiley & Sons, NY, Fourth Edition, 2006.

Third edition texts are also acceptable. Some of the section and page numbers will have changed but this should not significantly affect your ability to learn the material.

Grading Policy

Examinations

There will be a midterm and a cumulative final examination covering material from the lectures and the laboratories. Exams will be closed book, mostly multiple choice questions with a few short answer calculations. See the Course Notes Page for examination dates and example of past exams.

Grading

The course grade will be composed of the following components:

Midterm Examination (and pop quizzes) - 15%

Final Examination (and pop quizzes)- 25%

Laboratory Reports and Presentations - 60%

There will be 10 unannounced in-class quizzes. Quiz points earned prior to the midterm exam will be added to your midterm exam grade. Those earned after the midterm will be added to your final exam grade.

Your lab grade will be curved based on the grades of those students graded by a particular TA, not the entire class. If the other students in your lab section are receiving lower grades on average than you are then you can assume your final lab grade will be above a "C+" (of course the opposite scenario is also true.)

Your final numeric average will be based on the above ratios and then curved based on the class statistics. The class median will correspond to about a C+ and one standard deviation above the median will be approximately a B+ and one standard deviation below will be approximately a D+.

The exact math used to calculate your course numerical average is

Average = (Midterm+Quizzes)*15% + (Final+Quizzes)*25% + (Curved Lab Average)*60%

Both the midterm and final exams will be worth 100 points the quizzes will be worth approximately 40. This means there is a possibility of scoring above 100% on the midterm or final exam portion of your weighted average.

Remember because this class is curved based on the performance of your classmates not attending class and taking the quizzes will reduce your grade compared to those students who do take the quizzes.

"If you have any condition, such as a physical, learning or mental disability which will make it difficult for you to carry out the course work as outlined or require extended time on examinations, please notify me during the first two weeks of the course so we may discuss appropriate arrangements and/or reasonable accommodations."

Course Objective

- Enable you to successfully design experiments, interact with measurement systems and process results to obtain a meaningful understanding of a physical phenomena

Material Introduced

- several common physical measurement systems
- several common sensors (like an accelerometer or strain gage)
- modern methods of computerized data acquisition
- common statistical techniques
- experimental uncertainty analysis
- guidelines for planning and documenting experiments
- achieving meaningful objectives from digital data
- quality data not massive quantities

The laboratory sessions

- reinforce the above concepts
- provide hands-on experience
    - with a modern computerized data acquisition system
    - modern instrumentation and sensors
- Secondary objective is to teach good laboratory practice, work habits and experiment design.

We will make extensive use of spreadsheets for graphing data, performing statistical calculations and general computations. **If you are not proficient in the use of spreadsheets you are advised that significantly more independent effort on your part will be required.**

The Analog and Digital Worlds

We are aware of the **analog** world through the use of our senses or physiological methods of perception. (Sight/light, Hearing/sound, Taste, Smell & Touch: a limited classification attributed to Aristotle which does not include pain, balance, motion & acceleration, time, temperature and possibly direction) These analog signals, like the light bouncing off this page, are continuously variable in intensity. They have what is referred to as infinite resolution.

The **digital** world is generally thought of as consisting of *bits* of information each stored as either a 1 or 0. These bits are often combined to form *words* of a given length. A *word* is said to have a finite resolution of a certain number of *bits*.

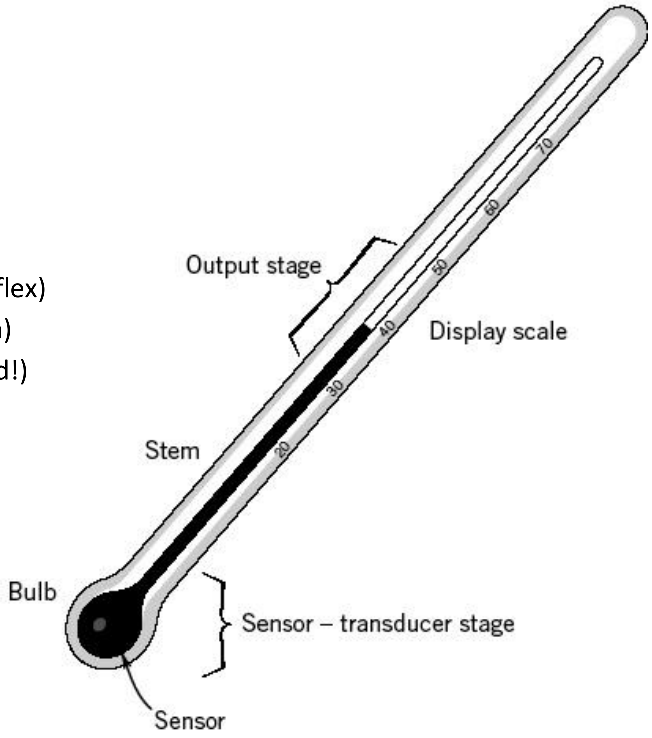
Data acquisition bridges these two worlds, turning an infinite resolution analog signal into a finite resolution measurement to be stored or manipulated. Not only is data acquisition pervasive in your life, your safety or possibly even your life often depends on it. Your cell phone, cruise control, anti-lock-braking, adaptive cruise control, heart monitors (Electrocardiogram or EKG), power grid and countless other consumer items use data acquisition to capture and manipulate signals.

Proper implementation of these high-precision, life-saving data acquisition applications is the consumer's expectation and the engineers bane. We will focus on the basic concepts needed as a engineering user (not a designer) of a data acquisition system to properly sample analog signals for engineering objectives with a typical data acquisition system.

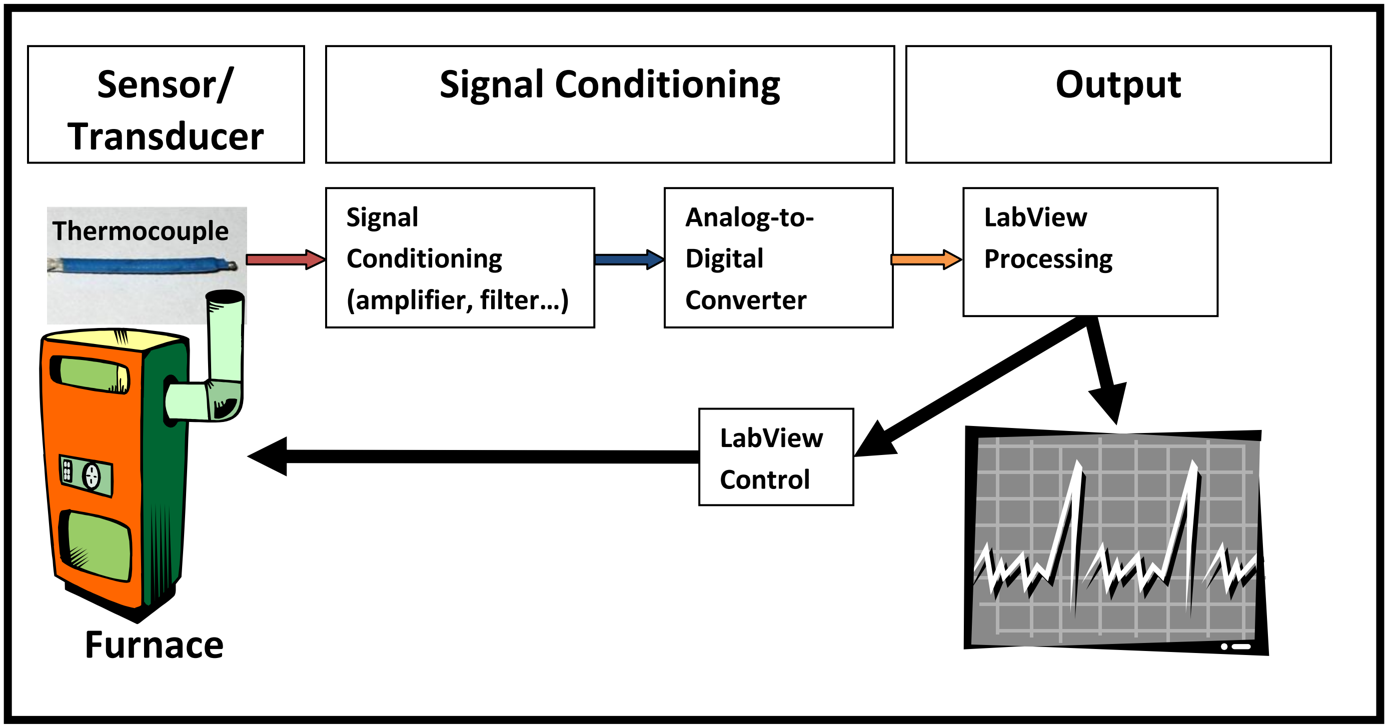
Basic Measurement Concepts

Measurement System Components

1. Sensor (i.e. ear drum)
2. Transducer (i.e. middle ear bones, *ossicles*)
3. Signal Conditioning (i.e. stapedius muscle reflex)
4. Output (i.e. nerve impulses from the cochlea)
5. Feedback & Control (i.e. turn down your iPod!)



Control of a Furnace Example:



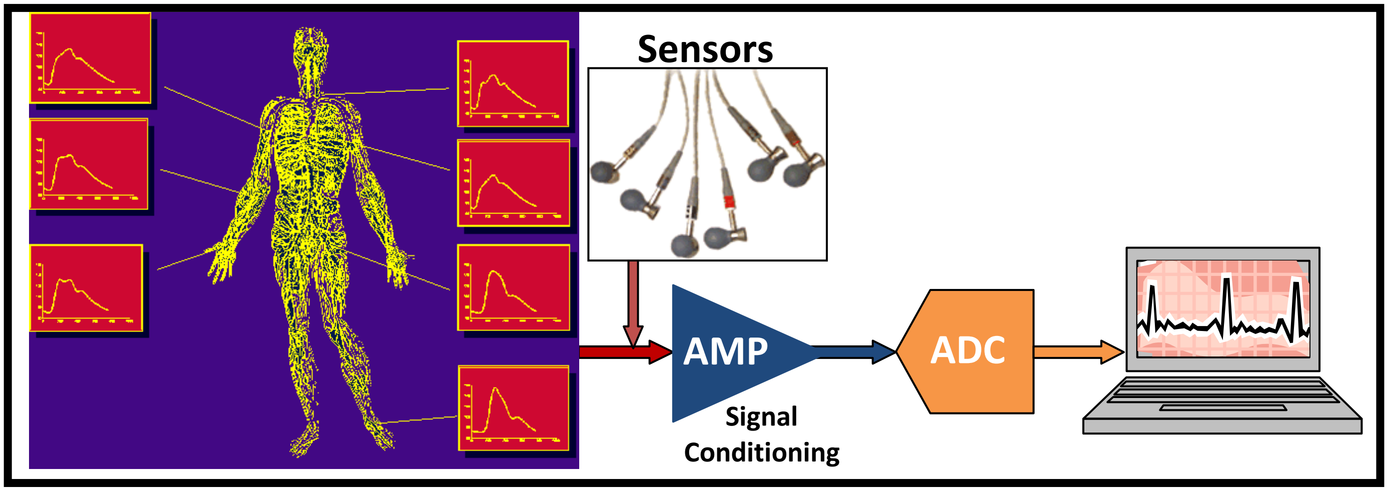
The thermocouple produces a voltage which is proportional to a temperature difference.

The signal conditioning filters and amplifies the low level, low power, low frequency output of the thermocouple. The filtering is used to reduce electronic noise or interference. The amplification boosts the signal to a level suitable for the data acquisition system.

The Analog-to-Digital Converter (ADC) converts the signal conditioner output voltage to a digital value which is fed to the computer.

LabView is a software package developed by National Instruments, Inc. used to interact with data acquisition systems. In this example the program converts the thermocouple output voltage to a corresponding temperature. The value may be plotted on the screen, and/or printed out, and/or stored and/or used to control the furnace heat source.

EKG Example:



Some Definitions

Variable - a physical quantity that can change.

Independent Variable - a variable you can change without affecting other independent variables.

Dependent Variable - variable which changes when one or more independent variable changes.

Parameter - a combination of variables, usually dimensionless - a dimensionless group.

Extraneous Variable - a variable which is not controlled during a measurement. Ambient temperature is frequently an extraneous variable.

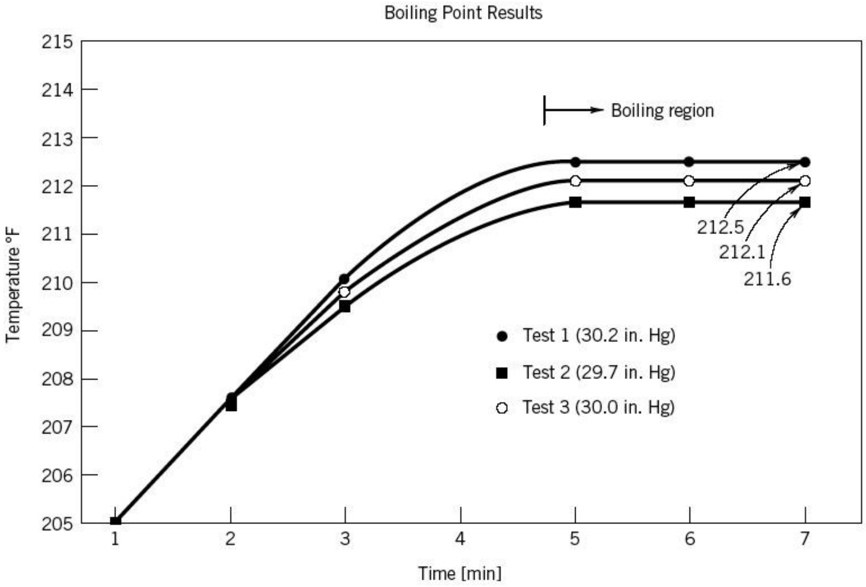


Figure 1.3 Results of a boiling point test for water.

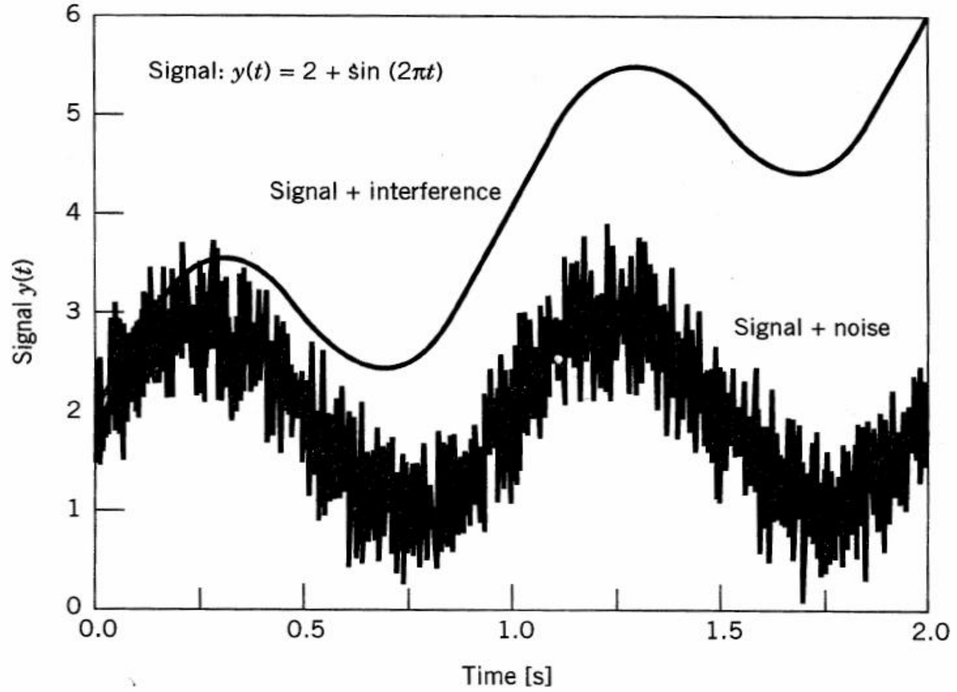


Figure 1.4 Effects of noise and interference superimposed on the signal $y(t) = 2 + \sin 2\pi t$.

Noise - a random variation in the value of the measured signal produce in response to variations in extraneous variables. **Thermal noise** is present in any conductor (such as a resistor) and is due to the conductor's thermoelectric qualities in which heat causes electrons to become agitated and exhibit random motion. **Flicker noise** is the result of catch and release physical interactions of charge carriers in all active devices and carbon resistors.

Interference - a deterministic variation of the measured signal in response to extraneous variables. 60 Hz electromagnetic signals from power sources frequently cause interference.

Minimizing Unwanted Effects

Proper signal conditioning is essential minimizing the effects of noise and interference. In the case of an EKG signal which has a fundamental frequency of approximately 1 beat/second, is very weak and must be well isolated to prevent electrocution, the objective of the signal conditioning is intuitively obvious. Other sources of noise or interference are often much less obvious and far more difficult to deal with.

In order to determine the characteristics of an instrument and to estimate its accuracy it is necessary to perform a calibration. This consists of applying known values of the independent variable and observing the output.

To find the relationship between a dependent and one independent variable:

1. Hold all other independent variables constant.
2. Vary the independent variable in a random order.
3. Replicate the test several times.
4. Where possible, check result using a different method.

Unfortunately, we frequently do not know what the extraneous variables are! Nevertheless, the above procedure will minimize their effect. This process is used to calibrate a sensor as well as obtain a measurement for an engineering objective.

Calibration

Two Types:

1. Static - steady state (constant) input vs. output
2. Dynamic – fluctuating or changing input vs. output

The calibration should be performed as nearly as possible to the actual measurement conditions, and should follow the procedures for minimizing the effect of extraneous variables.

Static Calibration Instrument Characteristics

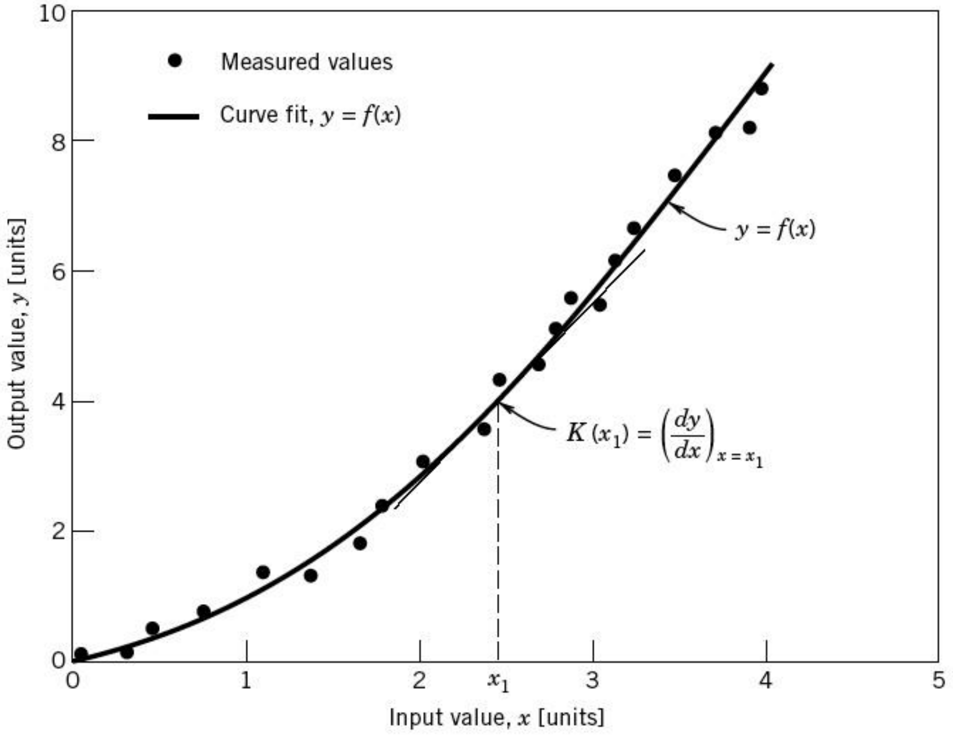


Figure 1.6 Representative static calibration curve.

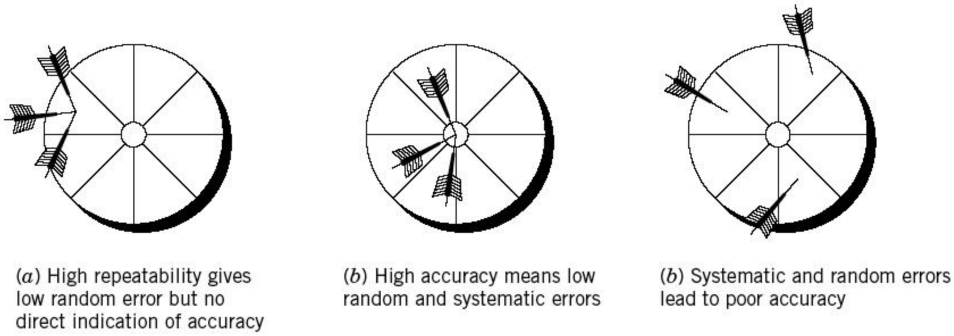
The ***Static Sensitivity*** or static gain is the slope of the relationship between the input and output. A very sensitive instrument would produce a large output change in response to a small input variation. You should notice that the static sensitivity in Figure 1.6 is not constant.

Range – maximum and minimum input values. In Figure 1.6 the input range is from 0 to 4 units. The corresponding output values go from 0 to 9 units. As an example: the input units could be volts produced by a pressure transducer (0-4 Volts) and the output could be pressure in PSI (0-9 PSI).

Linearity – the degree to which an instrument's static calibration can be represented as a line. A linear instrument has an output which is a linear function of input. Linearity is desirable because it provides a constant static sensitivity over the entire range and also because calculations are much simpler. The instrument calibrated in Figure 1.6 is not linear.

Accuracy – the degree with which an instrument indicates the "true value" of the input. Instrument errors causing other than "true value" readings are classified as either:

> **Precision errors** – random fluctuations in output for repeated applications of the same input.
>
> **Bias Errors** – consistent inaccuracies in output for the same input.


(*a*) High repeatability gives low random error but no direct indication of accuracy

(*b*) High accuracy means low random and systematic errors

(*b*) Systematic and random errors lead to poor accuracy

Figure 1.8 Throws of a dart: illustration of random and systematic errors and accuracy.

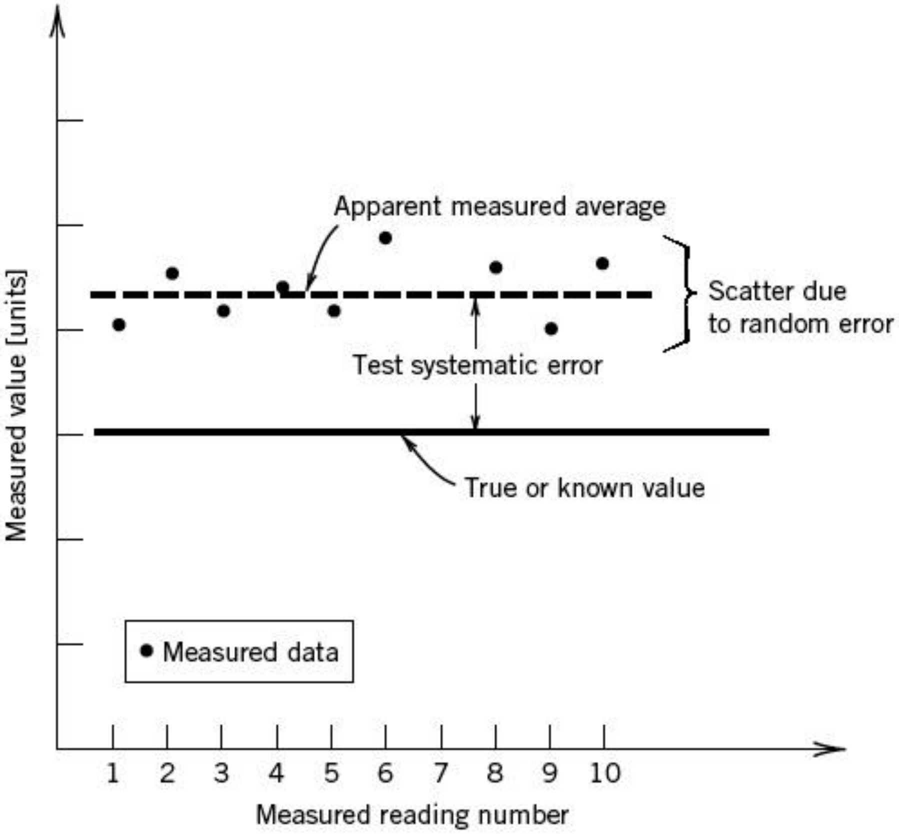
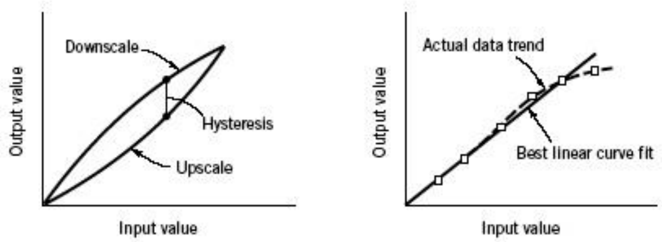


Figure 1.9 Effects of random and systematic errors on calibration readings.

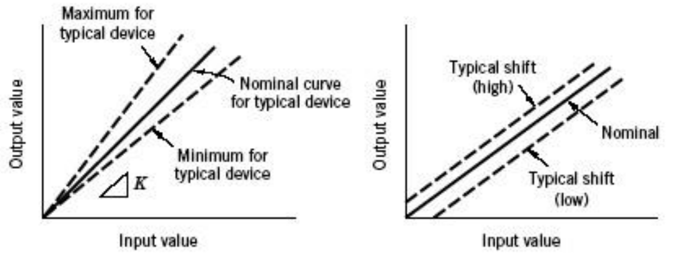
Figure 1.9 shows an apparent systemic **bias error** resulting in an offset of the measured average from the true average as well as **precision error** resulting in scatter in the measured data. A proper calibration will remove the bias error. Proper experimental practices will minimize the effects of the precision error.

TABLE 1.1 Manufacturer's Specifications: Typical Pressure Transducer	
Operation	
Input Range	**0 tp 1000 cm H_20**
Excitation	**±15% V dc**
Output range	**0 to 5 V**
Performance	
Linearity error	**±0.5% full scale**
Hysteresis error	**Less than ±0.15% full scale**
Sensitivity error	**±0.25% of reading**
Thermal sensitivity error	**±0.02%1^{o}C of reading**
Thermal zero drift	**0.02%1^{0}C full scale**
Temperature range	**0 to 50 ^{0}C**

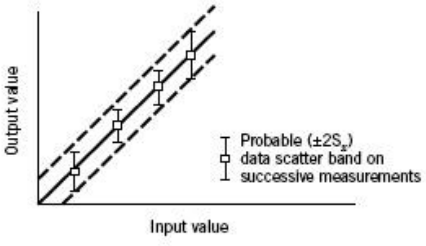
Graphical Representation of Instrument Performance Errors



(*a*) Hysteresis error (*b*) Linearity error



(*c*) Sensitivity error (*d*) Zero shift (null) error



(*e*) Repeatability error

Figure 1.10 Examples of some common elements of instrument error. (*a*) Hysteresis error. (*b*) Linearity error. (*c*) Sensitivity error. (*d*) Zero shift (null) error. (*e*) Repeatability error.

Dynamics Instrument Characteristics

Frequency Response – is a measure of the ability of an instrument to flow a dynamic signal. An instrument with infinite frequency response will accurately track a fluctuating signal of any frequency. An instrument with limited frequency response (all real instruments) cannot 'keep up' with a fluctuating signal and lags behind.

Dynamic Range – is a measure of the frequencies over which an instrument accurately tracks a fluctuating input signal. The dynamic range of 'perfect' human ear drums is 20 Hz to 20,000 Hz.

Rise Time – is a measure of the amount of time an instrument takes to get to 90% of its steady state value in response to a step change in input.

Settling Time – is a measure of the amount of time an instrument takes to stay within +/- 10% of its steady state value in response to a step change in input.

Standards

Primary Standards - define the size of a unit

Interlaboratory Transfer Standards - maintained by national laboratories such as the US National Institute for Science and Technology

Local Standards - maintained by companies and individual laboratories

Working Instruments - our laboratory thermometers.

TABLE 1.2 Standard Dimensions and Units		
	Unit	
Dimension	**SI**	**US**
Primary		
Length	**meter (m)**	**foot (ft)**
Mass	**kilogram (kg)**	**pound-mass (lb$_m$)**
Time	**second (s)**	**second (s)**
Force	**Newton (N)**	**pound-force (lb)**
Temperature	**Kelvin (K)**	**Rankine (R)**
Derived		
Voltage	**volt (V)**	**volt (V)**
Current	**ampere (A)**	**ampere (A)**
Resistance	**ohm (Ω)**	**ohm (Ω)**
Capacitance	**farad (F)**	**farad (F)**
Inductance	**henry (H)**	**henry (H)**
Pressure	**pascal (Pa)**	**pound/foot (psf)**
Energy	**joule (J)**	**British thermal unit (BTU)**
Power	**watt (W)**	**foot-pound (ft-lb)**

Homework

Read sections: 1.1-1.7

Problems: 1.4-6, 9-22, 25, 33, 34