Introduction to Measurements

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January 19, 2006

1 Wheeler & Ganji, pp.1-5

Read all of chapter 1 carefully. The rest of the course will be expansion on these initial concepts.

1.1 Experiments

- Experiments define science.
- In engineering they're needed to
  1. Find and check theory(TY),
  2. Develop new methods(MD), products(PD) and systems(SY),
  3. Evaluate performance and behaviour of TY, MD, PD and SY.

1.2 Measurements

Measurements are used in

- Experiments to generate new information and
- SY for monitoring and control

1.3 "Carbon Fibre"

This is an example of a product that recently went from research to development and finally to product.

- Research into methods to produce small quantities; feasibility.
- Development of processes to produce production lots; "Corvette".
- Products using composite must be evaluated; bicycle frames, hockey stick and golf clubs.

1.4 Instruments and Measurements

- Research instruments are themselves subjects of research. Require skill and understanding to use.
- Instruments for monitoring and control must be easy to use without acquiring any particular skill.

1.5 Measurement in Systems

- Simple: domestic heating system
- Integrated, miniature: EMS, dash guages
- Process control: many, interrelated, robust, gracefully degradable

1.6 Units

A system of units is necessary for measurement.

- Mass(M) ... kilogram(kg) ... pound mass(lbm)
- Length(L) ... metre(m) ... foot(ft)
- Time(T) ... second(s)
- Temp.(θ) ... Kelvin(K) ... Rankine deg.(°R)
- Current(I) ... Ampère(A)

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General Characteristics

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2 Wheeler & Ganji, pp.6-33

Read all of chapter 2 carefully. The rest of the course will be expansion to *specific* characteristics.

2.1 General System

Examine Fig. 1. This is an attempt to fit much of chapter 2 into a single picture. Other concepts are itemized below.

- Like beauty, perfect accuracy unnecessary. Otto Röschel says, "Anything, that makes a man more beautiful than an ape, is pure luxury."
- The tri-modular separation in Fig. 1 is usually obvious in modern electronic systems.
- "Range" means *useable* from-to values of measurand, V_{min}, V_{max}.
- "Span" means $S_p = V_{max} - V_{min}$.
- "Spatial error" means that accurate thermometer on the wall may measure something other than average room temperature.
- "Accuracy" is $V_{o(max)} - V_t$, often expressed as the fraction $\pm\frac{V_{o(max)}}{V_{t(max)}}$ or the % it represents. See Figs. 2.3,2.4.
- "Precision" is like accuracy but pertains to E_r as opposed to E. A precise instrument can be made accurate via "Calibration".
- See Example 2.3 and Figs. E23. Your first problem is summarized in Fig. 2.

A linear fit $y = ax + b$ may be established as follows.

$$a = \frac{n\sum_{i=1}^{n} x_i y_i - \sum x_i \sum y_i}{n\sum x_i^2 - \left(\sum x_i\right)^2}, \quad b = \left(\sum y_i - a\sum x_i\right)/n$$

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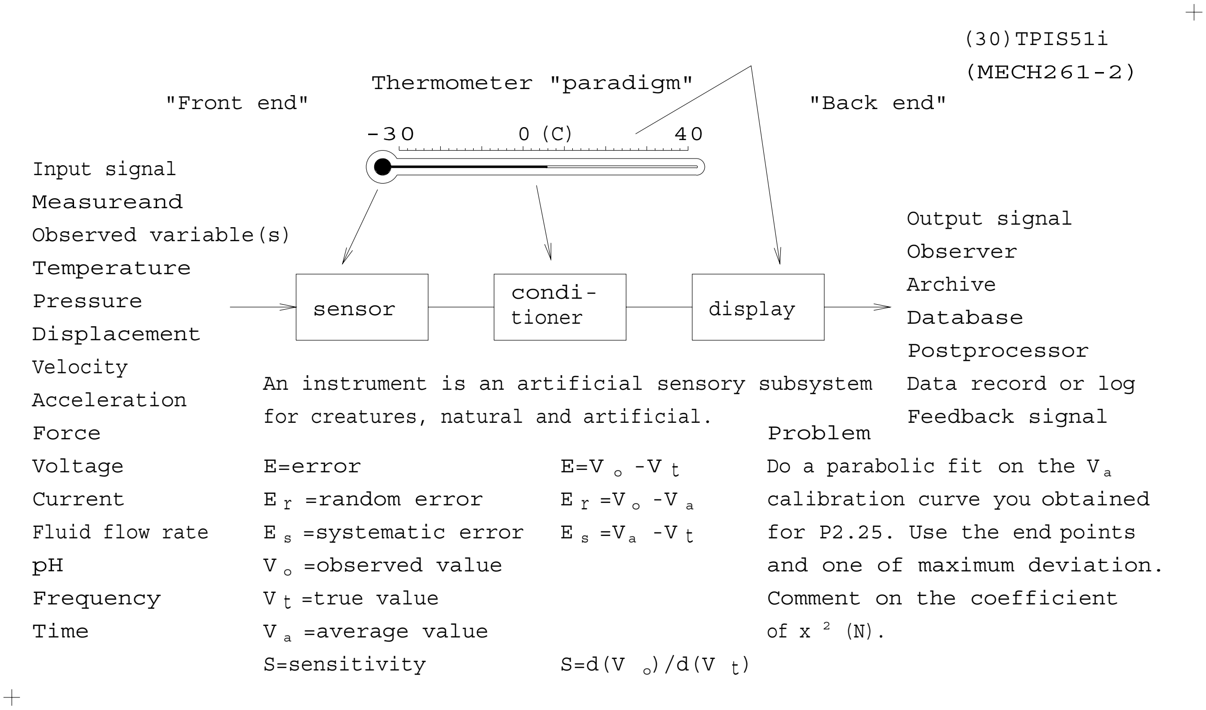

Figure 1: The System Represented by a Thermometer

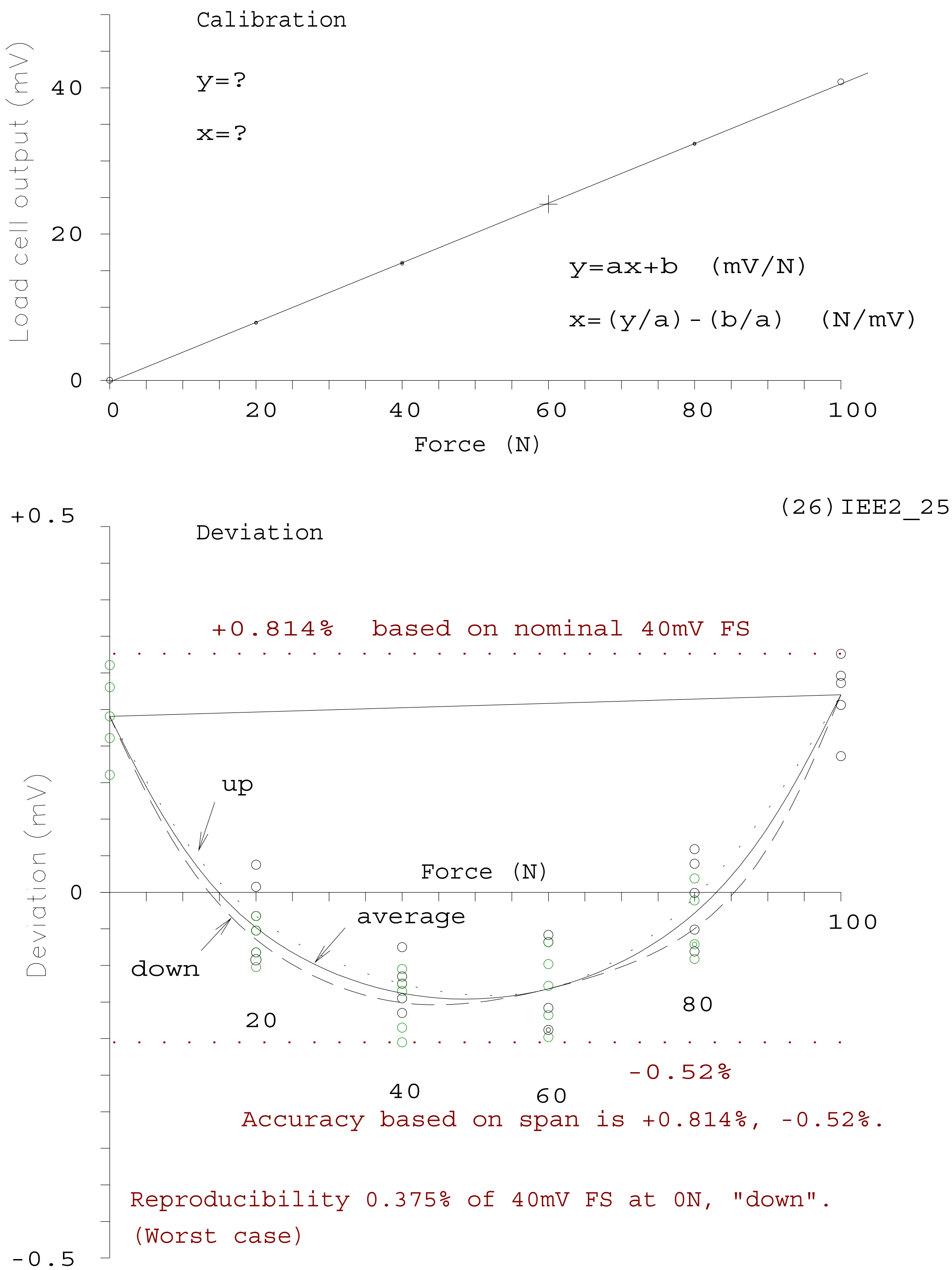

Figure 2: The System Represented by a Thermometer

Simple Straight Line Fit

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1 Given Data

The following set of $n = 5$ data pairs is given to be fit with a straight line so as to minimize the sum of the squares of the y-distances from the line to be determined.

x	y
2.20	5.70
3.80	15.10
8.40	23.60
13.10	32.90
16.60	44.70
$\Sigma x = 44.10$	$\Sigma y = 122.00$
$\bar{x} = \frac{\Sigma y}{n} = 8.85$	$\bar{y} = \frac{\Sigma y}{n} = 24.40$

2 Straight Line Equation

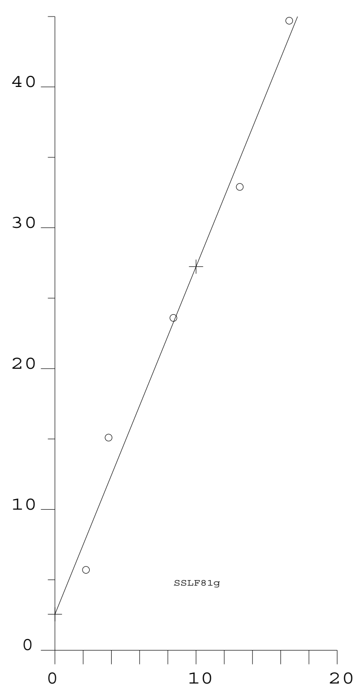


Figure 1: Line Fit Minimizing $\Sigma \Delta y^2$

The equation we seek is $y = ax + b$, *i.e*, to find a and b. Intermediate results are tabulated below.

$x_i = x - \bar{x}$	$y_i = y - \bar{y}$	x_i^2	$x_i y_i$
-6.65	-18.7	44.2225	124.6875
-5.05	-9.3	25.5025	46.9650
-0.45	-0.8	0.2025	0.3600
4.25	8.5	18.0615	36.1250
7.75	20.3	60.0625	157.3250
$\Sigma x_i = -0.15$	$\Sigma y_i = 0.6$	$\Sigma x_i^2 = 148.0525$	$\Sigma x_i y_i = 365.4625$

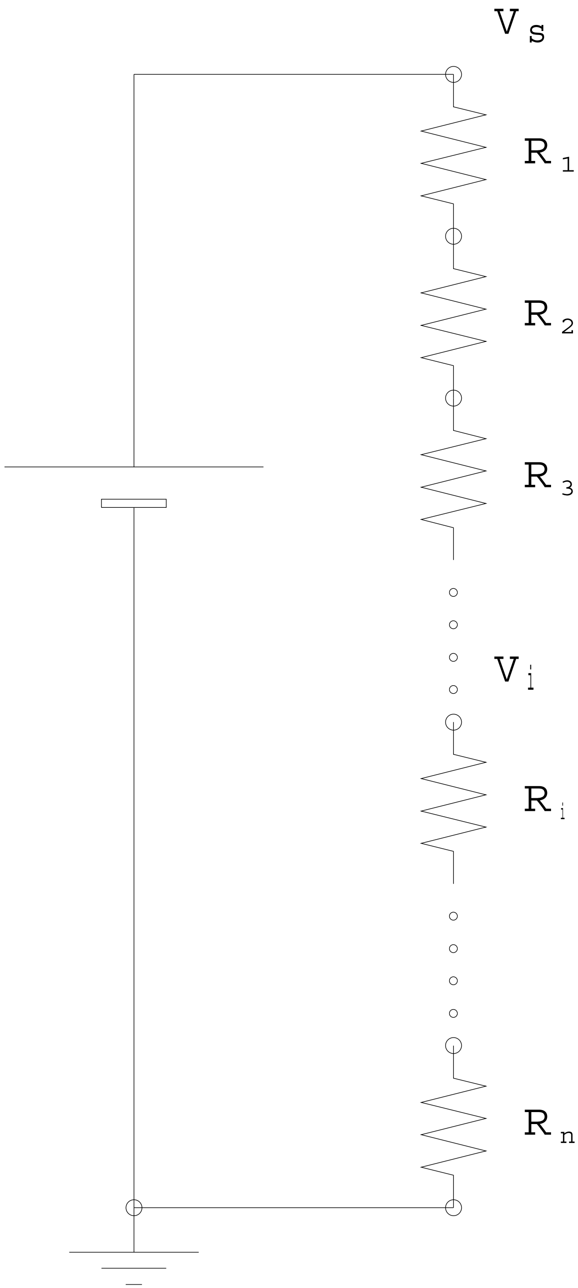
$$a = n\frac{\Sigma x_i y_i - \Sigma x_i \Sigma y_i}{n\Sigma x_i^2 - (\Sigma x_i)^2}$$

$$a = \frac{5 \times 365.4625 - (-0.15 \times 0.6)}{5 \times 148.0525 - (-0.15)^2} = \frac{1827.4025}{740.24} = 2.468662191$$

At $x = \bar{x} = 8.85$, there $y = \bar{y} = 24.3$ so

$$24.4 = 2.468992191 \times 8.85 + b, \quad b = 2.552339613$$

Question:- Why is this better than literally following a procedure that does not make use of the deviations from the mean, $x - \bar{x}$ and $y - \bar{y}$, *i.e.*, the equation at the bottom of p.2? Note that there x_i and y_i refer to the raw data, without having subtracted the means $\bar{x}$ and $\bar{y}$.



$$V_i = V_s - \frac{V_s \sum R_j}{\sum R_k}$$

$j=1,2,\ \ldots\ i-1,\ k=1,2,\ \ldots\ n$

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