Experiments, Tests, and Data

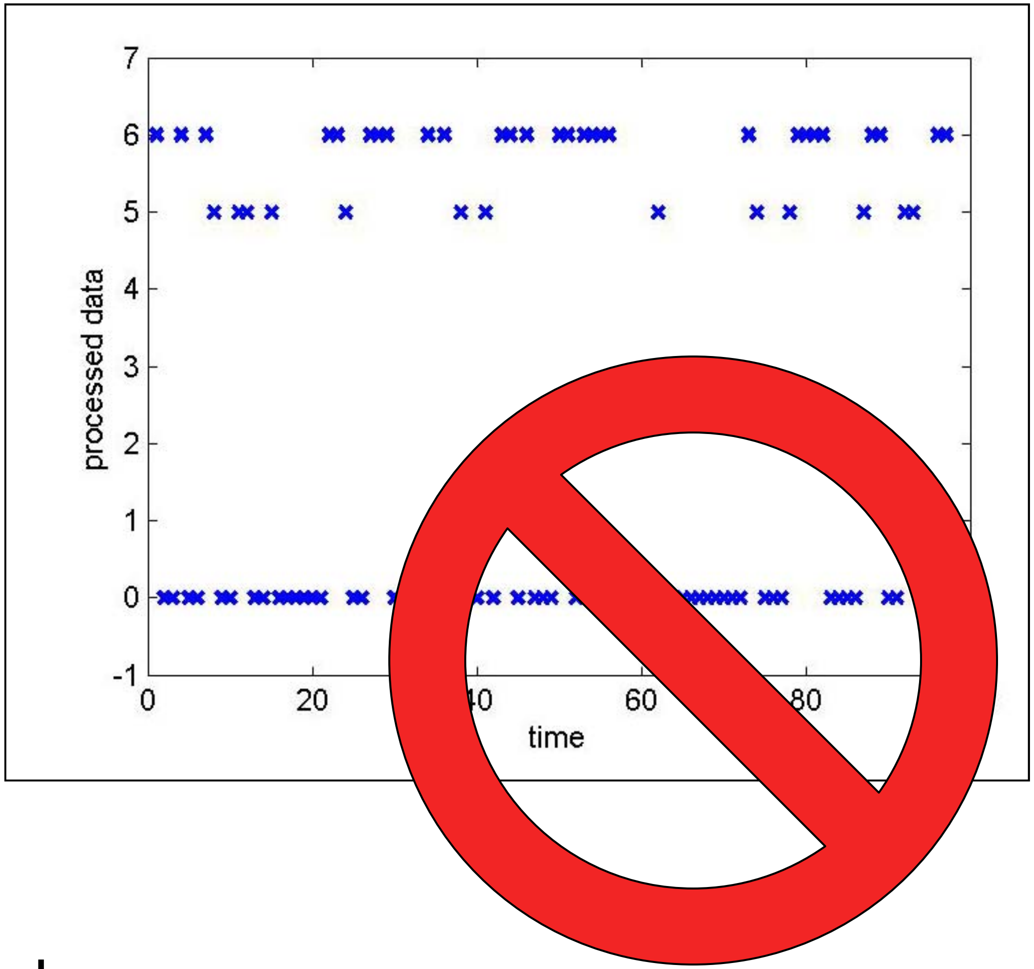
Purpose of Experiments and Tests

- Prove or Support a Hypothesis
  - *The Earth's diameter is 6500km.*
  - *Multiple propellers on a single shaft can reduce cavitation (Turbinia).*
  - *Prokaryotes in the ocean fix carbon and consume other organisms, and the balance has profound impact on ocean uptake of CO_2. (Ed Delong, Ann Pearson, etc.)*
  - *Outriggers provide better roll stability than does a single hull in random beam seas, when wavelength is much larger than the beam.*

- Prove a Capability, Support Design
  - *Manned flight to the upper atmosphere can be achieved bi-weekly with a specialized aircraft (X-Prize).*
  - *Characteristic of lift force as a function of elevator aspect ratio and inflow angle.*
  - *Delay calculation in pulsed 20kHz acoustic signals is possible with the TattleTale Model 8, and the performance obtained is XX.*

- *Does the work stand up to scrutiny?*

  - Use of controls
  - Calibration
  - Data quality
  - Data processing
  - Documentation and record-keeping!

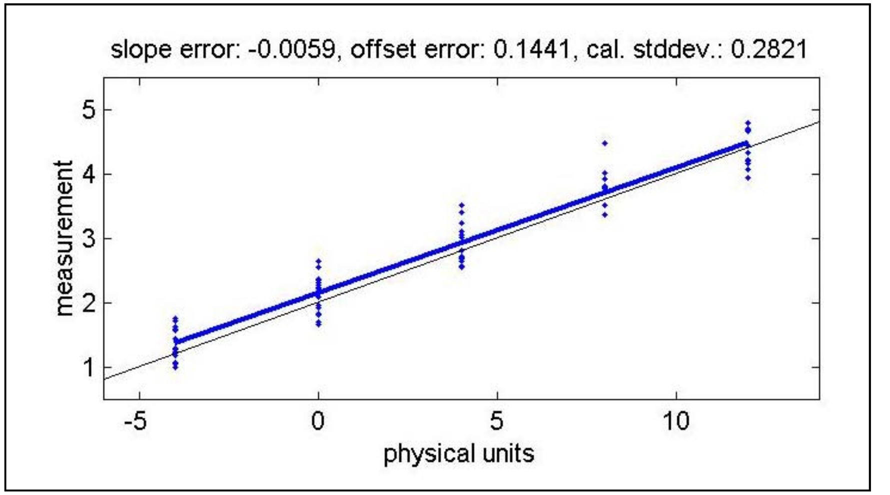


Controls

- Did you really measure what you thought?
- *Rat Maze: Is the maze acoustically navigable? (R. Feynman)*
- *Mass Spectroscopy: When you put in a sample of known composition, are the other bins clean?*
- *When measuring electrical resistance, touch the probes together. Check a precision resistor too.*
- *Resonance in load measurement rigs?*
- *When measuring hull resistance, does zero speed give zero force?*

DUH!

Calibration



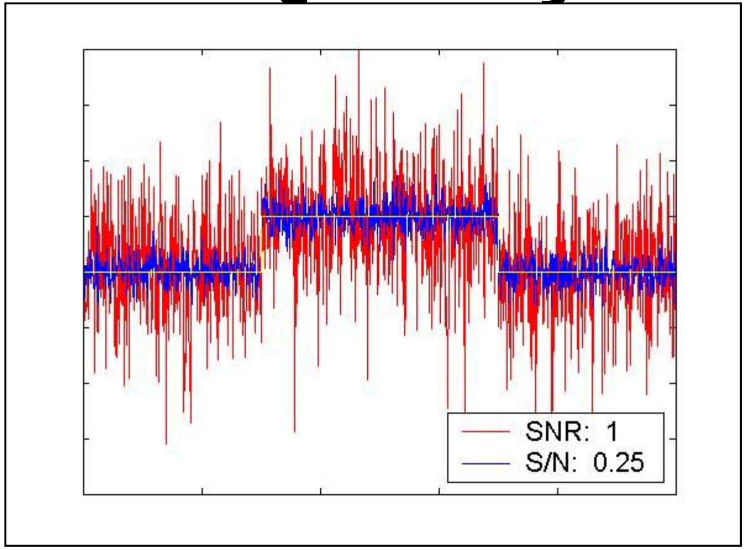
- More time can be spent on calibration than the rest of the experiment!
- Sensors should be calibrated and re-checked using independent references, such as:
  - *Manufacturer's specifications*
  - *Another sensor with very well-known calibration* ←→
  - *A tape measure, protractor, calipers, weights & balance, stopwatch, etc..*
- Calibration range should include the <u>expected range</u> in the experiment.
- Some statistics of the calibration:
  - *Precision of fit (r-value or σ)*
  - *Linearity (if applicable)*
- Understand special properties of the sensor, e.g., drift, PWM

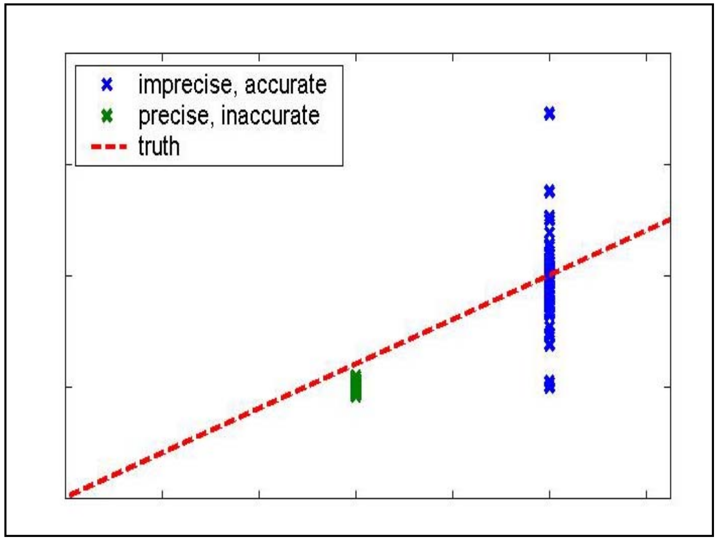
Data and Sensor Quality

- Signal-to-Noise Ratio (SNR): compares σ to the signal you want

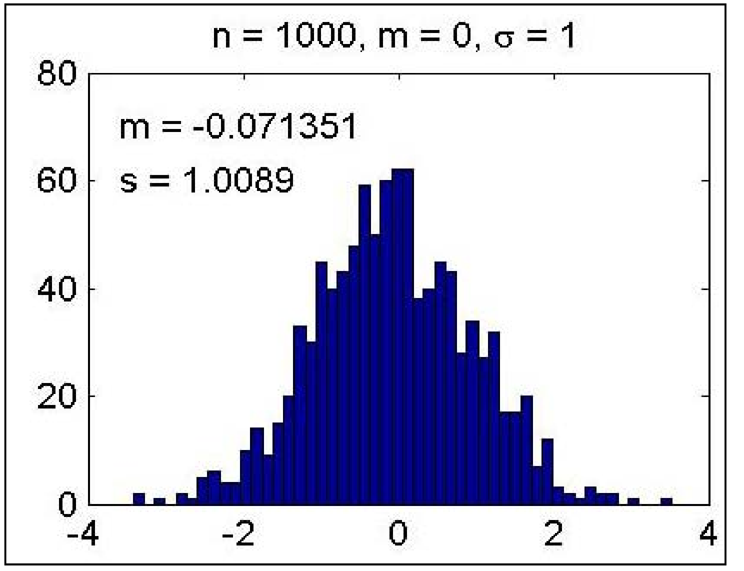
- Repeatability/Precision: If we run the same test again, how close is the answer?

- Accuracy: Take the average of a large number of tests – is it the right value?





Sample Statistics



- *Sample* mean m:
- *Sample* standard dev. σ:

  σ = sqrt [($(x_1\text{-}m)^2 + (x_2\text{-}m)^2 + \ldots + (x_n\text{-}m)^2$) / (n-1)]

- Error budgets for multiplication and addition (σA is standard deviation of A):

  $(A + \sigma A)(B + \sigma B) \sim AB + A\sigma B + B\sigma A$

  Example: $(1.0 + \sigma 0.2)(3.0 + \sigma 0.3) \sim 3.0 + \sigma 0.9$

  $(A + \sigma A) + (B + \sigma B) = A + B + \sigma(A+B)$

  Example: (1.0 + s0.2) + (3.0 + s0.3) = 4.0 + σ0.5

Gaussian (Normal) Distribution

Probability Density Function f(x) ~ *Histogram*

$$f(x) = \exp\left[-(x-m)^2 / 2\sigma^2 \right] / \mathrm{sqrt}(2\pi) / \sigma$$

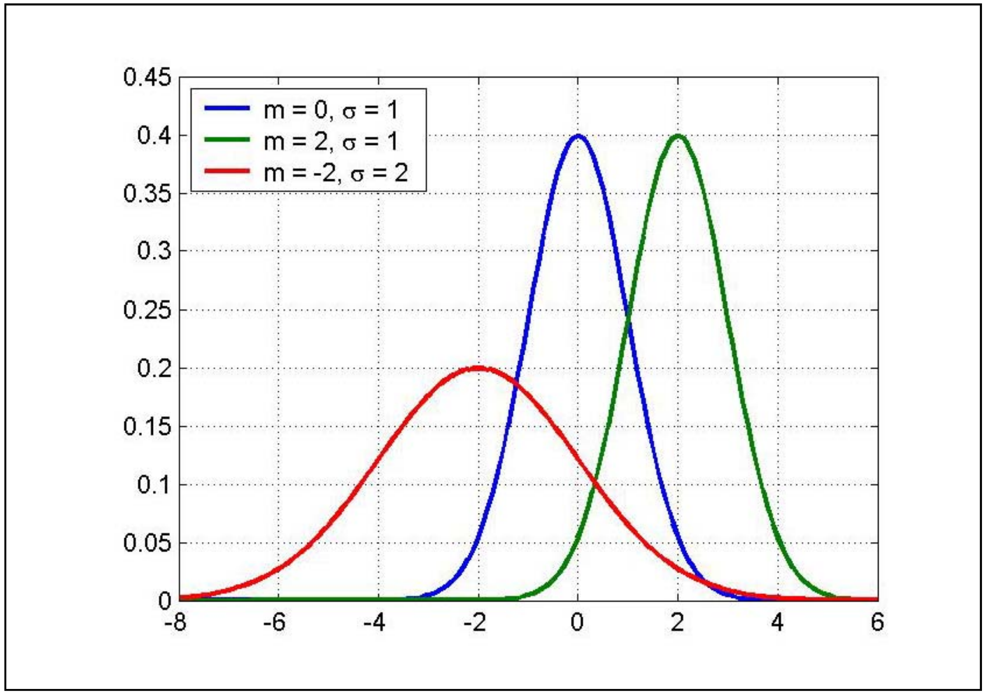
This is the most common distribution encountered in sensors and systems.

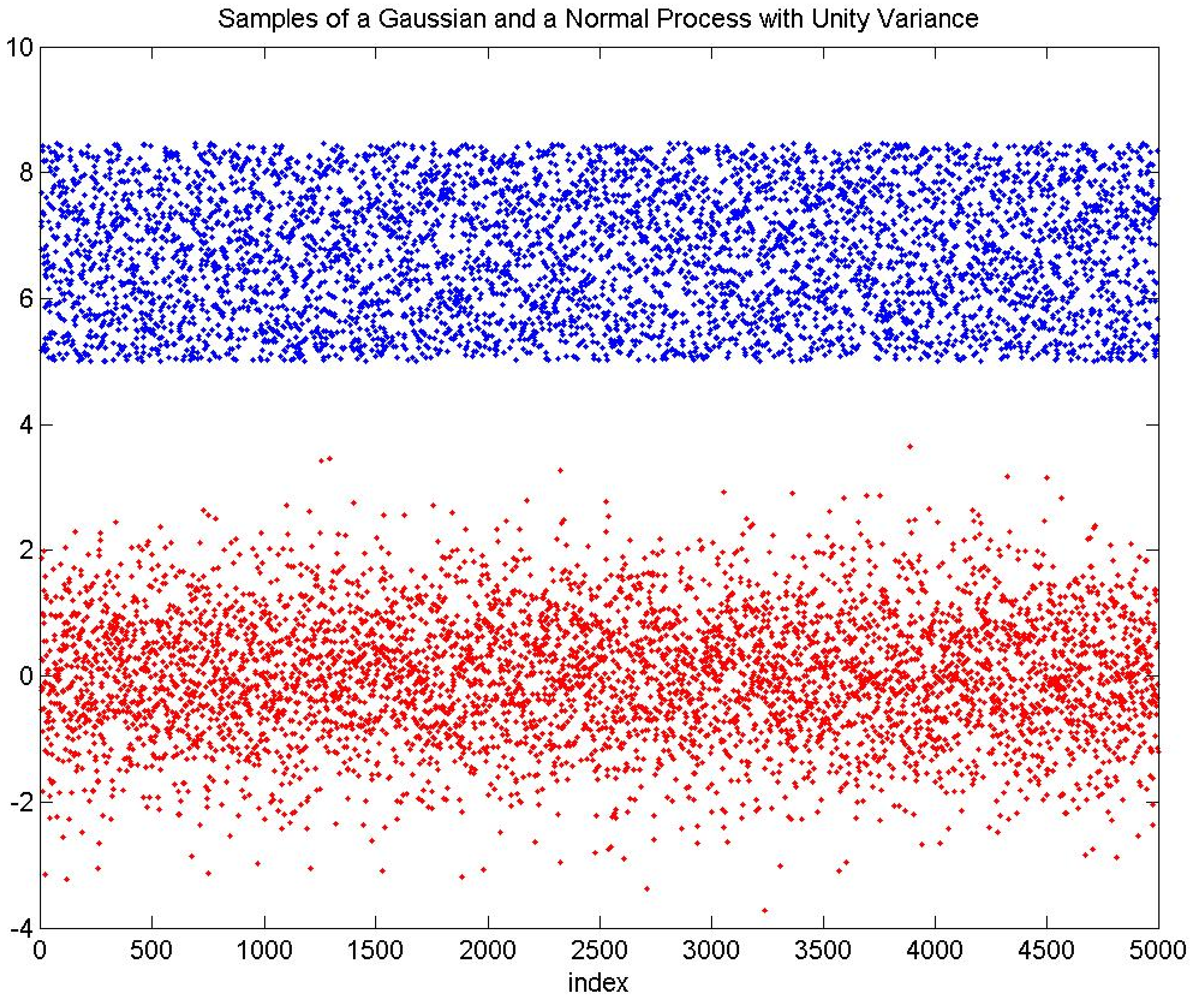
+/- 1σ covers 68.3%

+/- 2σ covers 95.4%

+/- 3σ covers 99.7%

Area under f(x) is 1!





Samples of a Gaussian and a Normal Process with Unity Variance
10
8
6
4
2
0
-2
-4
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
index