Topic 3.Errors measurement

Errors in measurement

Errors will creep into all experiments regardless of the care exerted. Some of these errors are of a random nature, and some will be due to gross blunders on the part of the experimenter. Bad data due to obvious blunders may be discarded immediately. But what of the data points that just "look" bad? We cannot throw out data because they do not conform with our hopes and expectations unless we see something obviously wrong. But, they may be discarded on the basis of some consistent statistical data analysis

1. Errors

Error is the difference between the measured value and the 'true value' of the thing being measured. The word 'error' does not imply that any mistakes have been made. There are two general categories of error: systematic (or bias) errors and random (or precision) errors.

- ***Systematic errors*** (also called ***bias errors***) are ***consistent, repeatable errors***. Systematic errors can be revealed when the conditions are varied, whether deliberately or unintentionally. For example, suppose the first two millimeters of a ruler are broken off, and the user is not aware of it. Everything measured will be short by two millimeters under the effect of this systematic error. The measured values with systematic errors can be related to true values via some algebraic equation
- ***Random errors*** (also called ***precision errors***) are caused by ***a lack of repeatability in the output of the measuring system***. Random errors may arise from uncontrolled test conditions in the measurement system, measurement methods, environmental conditions, data reduction techniques. The most common sign of random errors is ***scatter*** in the measured data. For example, background electrical noise often results in small random errors in the measured output.

A. Systematic (or Bias) Errors

The ***systematic error*** is defined as the ***average of measured values minus the true value***. A *non dimensional* form of bias error is the ***mean bias error***, defined as ***MBE = systematic error / true value***.

Systematic errors arise for many reasons:

- <u>Calibration errors</u> – perhaps due to nonlinearity or errors in the calibration method.
- <u>Loading or intrusion errors</u> – the sensor may actually change the very thing it is trying to measure.
- <u>Spatial errors</u> – these arise when a quantity varies in space, but a measurement is taken only at one location (e.g. temperature in a room - usually the top of a room is warmer than the bottom).
- <u>Human errors</u> – these can arise if a person consistently reads a scale on the low side, for example.
- <u>Defective equipment errors</u> – these arise if the instrument consistently reads too high or too low due to some internal problem or damage (such as our defective ruler example above).

It is reported the following four methodologies to reduce systematic errors [1]:

- **Calibration**, by checking the output(s) for known input(s).
- **Concomitant method**, by using different methods of estimating the same thing and comparing the results.
- **Inter-laboratory comparison**, by comparing the results of similar measurements.
- **Experience**.

B.Random (or Precision) Errors

Random errors are unrepeatable, inconsistent errors in the measurements, resulting in *scatter* in the data. The *random error* of one data point is defined as the *reading minus the average of readings*.

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Example:

> ***Given:*** Five temperature readings are taken of some snow: -1.30, -1.50, -1.20, -1.60, and -1.50^{O}C.
> ***To do:*** Find the maximum magnitude of random error in ^{O}C.

C. Accuracy revisited

Accuracy is the closeness of agreement between a measured value and the true value. Accuracy error is formally defined as the measured value minus the true value.

The accuracy error of a reading (which may also be called ***inaccuracy*** or ***uncertainty***) represents a combination of bias and precision errors.

The ***overall accuracy error*** (or the ***overall inaccuracy***) of a set of readings is defined as the ***average of all readings minus the true value***. Thus, *overall accuracy error is identical to systematic or bias error*.

Example:

> **Given:** Consider the same five temperature readings as in the previous example, i.e., -1.30, -1.50, -1.20, -1.60, and -1.50oC. Also suppose that the true temperature of the snow was -1.45oC.
> **To do:** Calculate the accuracy error of the third data point in oC. What is the overall accuracy error?

D. Precision revisited

Precision characterizes the random error of the instrument's output. Precision error (of one reading) is defined as the **reading minus the average of readings**.

Thus, precision error is identical to random error.

E. Other Sources for Errors

There are many other errors, which all have technical names, as defined here:

- ***Linearity error***: The output deviates from the calibrated linear relationship between the input and the output (see further discussion in the next section on calibration). Linearity error is a type of bias error, but unlike zero error, the degree of error varies with the magnitude of the reading.
- ***Sensitivity error***: The slope of the output vs. input curve is not calibrated exactly in the first place. Since this affects all readings by the instrument, this is a type of systematic or bias error.
- ***Resolution error***: The output precision is limited to discrete steps (e.g., if one reads to the nearest millimeter on a ruler, the resolution error is around +/- 1 mm). Resolution error is a type of random or precision error.
- ***Hysteresis error***: The output is different, depending on whether the input is increasing or decreasing at the time of measurement. This is a separate error from instrument repeatability error.
- *For example, a motor-driven traverse may fall short of its reading due to friction, and the effect would be of opposite sign when the traverse arrives at the same point from the opposite direction; thus, hysteresis error is a systematic error, not a random error.*
- ***Instrument repeatability error***: The instrument gives a different output, when the input returns to the same value, and the procedure to get to that value is the same. The reasons for the differences are usually random, so instrument repeatability error is a type of random error.
- ***Drift error***: The output changes (drifts) from its correct value, even though the input remains constant. Drift error can often be seen in the zero reading, which may fluctuate randomly due to electrical noise and other random causes, or it can drift higher or lower (***zero drift***) due to on random causes, such as a slow increase in air temperature in the room. Thus, drift error can be either random or systematic