How Accurate Do Your Measurements Need to Be?

At CAS DataLoggers, our callers and customers often ask us for the specifications on our most accurate measurement instruments. The higher the accuracy, the better the system…right? But how accurate do your measurements *actually* need to be?

In our latest White Paper, we detail the most important factors that go into selecting an ideal measurement system for your application—and for the right cost!

What Do the Specs Really Tell You?

Specifications, aka "specs", are the technical constraints of data loggers and data acquisition systems. Much like a graphics card or a hard drive installed in your PC, the separate components of your monitoring system will jointly determine the upper end of its performance.

- **Accuracy**: A measurement system's accuracy is how close its measurements are compared to the actual value of what it's monitoring (i.e. engine temperature, water level, etc.). Your system's accuracy is determined by several components and features: A/D converters, signal amplifiers, and mathematical capabilities, just to name a few. As a benchmark, an average accuracy might be .1%, which is 1 part in 1,000.

- **Repeatability**: This is your system's reliability, i.e. how often it can reproduce a measurement under the same conditions. Systems with high repeatability produce highly trustworthy data and are often required in scientific and academic applications.

- **Resolution**: How far can your system 'drill down' into the data? This is its resolution, i.e. the detail of each measurement. This spec tells you the smallest difference you'll see in the returned value from your measurement system. Say that a given device measures between 0-10 volts, and we have a 12-bit A/D converter in our measurement system. Therefore, the smallest difference we can detect is .024 volts. This is our device's resolution spec.

Note that resolution is not equivalent to accuracy! For example, on the spec sheet, a .003V resolution is not identical to a .003 accuracy. Many people sourcing a system will request a certain measurement resolution spec when they really need a certain measurement accuracy spec, and this can result in some confusion or mismatched expectations.

Bear in mind that all measurements are inherently inaccurate to some extent from the original value, for reasons we'll soon explore.

While shopping for specifications is important, your main priority in fact should be to define what exactly you require for your application. This may seem obvious but is always useful to keep in mind throughout the process of selecting a measurement system, since you may find that you don't need a high-performance system for your project.

Occasionally one of our callers will request a system with a high level of measurement accuracy (such as .01 accuracy). Upon asking what this system will be used for, we may learn that the application just involves a simple temperature monitoring setup. However, that high level of accuracy is excessive for just taking a thermocouple measurement—nor do users in these common applications need to pay extra for higher specs!

Analog vs. Digital Signals:

CAS DataLoggers Engineering Manager Terry Nagy explains: "We live in a digital world, which can only represent discrete values, not infinite ones. When we need information, we ask ourselves everyday questions like, "Is the switch on or off? How many donuts are left in the box?"

"However, reality is in fact analog, meaning that it has much greater complexity. For example, going by the digital values you see displayed on a data logger LCD, you might think of a voltage signal as stable, but in fact it continuously varies over time in its original analog state. Consequently, our measurement instruments use an Analog-to-Digital (A/D) converter to take that signal input and digitize it into a specific (discrete) number so the data we see is relevant."

An A/D converter uses a certain number of numerical/categorical divisions, often called bins, or intervals, so it can condense the analog value (the signal of what's being measured) into a digital value like 1-10, etc. The digital number shows which of these bins the number most correctly fits into (5.15 becomes 5 not 6, etc).
Now let's go a bit further behind the scenes and examine how accurate our measurements really are.

How Accurate are Your System's Measurements Really?

Naturally, when shopping for specs, price is often a consideration. Higher-accuracy A/D boards are often more expensive owing to more advanced components in the signal conditioner, A/D converter, and reference–all of which affect measurement accuracy in a system.

As an example, let's use a typical thermocouple measurement. Thermocouples involve very low-voltage measurements at the microvolt range. Similarly, A/D converters usually range from 0-10 or -10 to +10V. Because temperature monitoring occurs at such low-level signals, measurement systems utilize signal conditioning to amplify or to instead 'excite' the signal from its original low-voltage value before it can be converted into a digital value.

Naturally, there's always some inherent inaccuracy in any measurement system. An A/D board's circuits are never perfect; there's always some amount of gain, offset voltage, or other error. Measurement drift is also present, so you might encounter different levels of error at different temperatures. Stabilizing effects also occur when monitoring temperatures.

In fact, measurement system accuracy is often given as two separate specifications—one at room temperature, another with a wider range depending on the temperature of the device. This is owing to the inherent drift in the measurement system components. As an example of drift error, if you input a certain analog signal, the data value returned could be anywhere between 4.98 to 5.02. A/D boards also have a reference voltage that drifts along with temperature and over time.

Bringing it back to temperature measurements, a tiny millivolt-level signal from a thermocouple can fluctuate very rapidly, varying at 60Hz. Many of our callers tell us that they want to sample a thermocouple at 1,000 Hz without realizing that this will produce wildly varying measurements. For this reason, sampling rate and system speed are not the end-all, be-all specs that many users may assume.

Advanced Systems Will Smooth Signals:

As another example, let's say we're using a high-quality handheld meter to measure pressure. At the moment our meter is reading a value of 200, but often records readings in a range between 201-199. When we switch to another measurement device to record the same source, it reads 200 but soon bounces within a larger range between 190-210.

We might conclude from this that our second device's repeatability is poor, but in fact this is not the case. The quality meter is first heavily smoothing the signal using its more advanced components, whereas the second instrument is producing more varied measurements because it's taking readings without first doing math or calculations.

How Many Bits Are Enough?

Bits are a specification of the A/D converter detailing its resolution. Here are some benchmarks:

- **12-bits**: Relatively low resolution
- **16-bits**: Lower-end resolution devices
- **18-bit**: Mid-range resolution for many systems
- **Over 20-bit**: Higher-end devices with advanced capabilities

Note that your application may not necessarily need a high level of accuracy. If you only plan on making simple temperature measurements, an 18-bit A/D board is probably going to be more than you need, and more expensive too.

For example, a 12-bit converter can place any given measurement into one of 4,096 bins to define measurements—and that may be more than enough resolution for your application. Suppose this converter is housed within a temperature data logger measuring between -50° to 150°F (typical for a cold chain temperature logger). So, 200 divided by 4,096 (the bins available to our 12-bit A/D) gives us a resolution of .0488, i.e. a measurement resolution of about .05°. This should be sufficient resolution for our temperature monitoring application.

However, even though resolution is specified at 12-bits, not all those 12 bits listed on the A/D board specs are useable! This is because of signal noise and other sources of error, which are preventing all the bits from being used if the system in question doesn't contain the other components and features needed to condition the signal.

As with any important detail, be sure to ask an experienced solutions provider. Typically, if you're unsure what your future needs may be, it can be practical to source a system with specifications greater than those needed for your current application.

Dealing with Signal Noise to Improve Repeatability:

Whenever your device takes a measurement, signal noise is always present. There are no perfectly quiet signals—some noise is always present causing error. There are many different error sources, including errors in the amplifier, A/D converter, etc. On top of all that, your measurement system will encounter external line cycle noise from the environment. This noise could originate from the power supply, from environmental noise in the circuitry, from electromagnetic interference, etc.

Owing to its universal presence, signal noise is very difficult to reduce. In fact, one of the most common sources of noise is electric lighting (=60Hz noise).

Even when recording DC measurements (i.e. 4-20 milliamp) which are more stable than AC readings, you'll always have to deal with some amount of signal noise.

Internal error is always present, too. A thermocouple's own material might have an inherent error, say 1-2 degrees of measurement drift, which isn't at a constant. To get reliable readings when working with a very low-current measurement device, you can use several different filters (such as a digital filter) to lower the line noise.

In some sense, temperature is in fact a relative measurement. Consider how your thermocouple's battery itself generates a low voltage, and in turn leads to your measurement instrument, where the signal is sent to a signal conditioner and A/D board, which both have inherent error themselves. To compensate for this, many systems feature a reference junction. Therefore, if you want to find the accuracy of the thermocouple sensor, look for the measurement system's reference junction.

The more readings you record using your data logger or data acquisition system, the more they will tend toward an average. Therefore, in most industrial temperature measurement applications, it's most useful to take 'snapshots' of the data; that is, to sample the data at certain intervals as opposed to continually monitoring them over a prolonged period. You can then set your measurement system to average them over the line cycle. Referred to as signal averaging, this technique is especially useful when your signals are being distorted by component or background noise. The more line cycles you can record using signal averaging, the more repeatable and accurate your measurements will be.

Conclusion: Match the Right System to Your Application

When you're examining measurement device specifications including accuracy, measurement speed, and repeatability, bear in mind that there are many other factors affecting your measurements which are inherent in its system components and sensors.

Keeping this in mind, the question of 'What specs does this system need?' really depends on what you want to accomplish in your specific measurement application. For instance, this could simply be to determine if a storage tank's temperature reads the same as it did yesterday, or to continually monitor the interior of a storage unit containing your food product.

While there are many specific measurement applications where you certainly do require a high level of accuracy, you'll often only need to have repeatability, i.e. measurements that don't vary much from your previously-recorded temperature data.
While there are many specifications and factors to consider when selecting the ideal measurement system for your application, you'll greatly simplify your search by first examining the requirements of your own application. This not only makes it easier to identify the functionality you'll need for your specific project but can also significantly save on cost.

For more info on Data Loggers and Data Acquisition Systems, or to find the ideal solution for your application-specific needs, contact a CAS DataLoggers Application Specialist at **(800) 956-4437** or visit our website at www.DataLoggerInc.com.