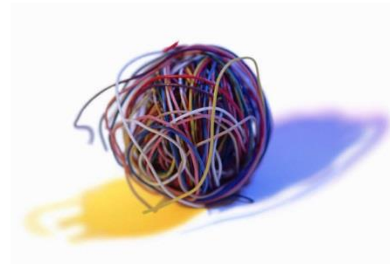
Let's Get Digital: A Guide to Unraveling the Tangled World of Digital Thermometers



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Posted: November 2011

So, You're Looking to Buy a Digital Thermometer?
I've got just the device for you: It slices! It dices! It even *calibrates itself*!

Joking aside, purchasing a digital thermometer for your laboratory can be a difficult task. There are numerous choices available, with prices ranging from just a few bucks to thousands of dollars. So, which one of these devices is right for you? How can you keep costs low without compromising quality? What is the difference between an *RTD* and a *PRT*, and which one works best? And what the heck is a *thermistor*, anyway?

The goal of this article is to provide a little insight into the tangled and mixed-up world of digital temperature measurement. Hopefully, armed with this knowledge, you will have the tools that you need to make the best purchase for your laboratory. So, without any further ado, *LET'S GET DIGITAL*.

Finding the Perfect Fit
I am reminded of a piece of advice that my realtor gave me as I began the daunting process of buying my first house. "There is no such thing as the perfect house," he warned me. "There will be compromises that you will have to make, and every house will have its good points and its bad points." The same holds true of digital thermometers. Each type of device has limitations- whether it be cost, range of use, convenience, or accuracy. And, unfortunately, digital thermometers are not a one-size-fits-all solution to temperature measurement. In fact, you may find that you need several different devices for different applications in your laboratory. The key is to find the best solution(s) that meets your needs while reducing the risk of error and keeping costs low. Most importantly, we must understand the limitations of digital thermometers so that any potential for inaccuracies can be accounted for or avoided.

So Many Choices, So Little Time
The image at the end of the article is a "cheat sheet" that can be used to compare and contrast some of the more common types of digital thermometers available today. This guide includes information on cost, measurement uncertainty, durability, and range of use. Keep in mind that this is only a summary. Entire books have been written on digital thermometers and their applications. This guide is meant to be nothing more than an introduction to a rather complicated subject.

Not Your Grandmother's Thermometers
In my previous article, "Anatomy of a Liquid-in-Glass Thermometer," we dissected the intricate components of these precision instruments. Therefore, it's only fair that in this article I at least mention the makeup of their digital counterparts. While the digital thermometer is arguably much more advanced in construction and material composition than its liquid-in-glass cousin, it can be broken into two primary components: (1) a sensing element, and (2) readout device or CPU. The type of materials used in the sensing element, as well as the manner in which the materials are constructed, determines the type of device.

The CPU puts the "digital" in "digital thermometer." The use of modern computing technology allows for digital thermometers to do much more for us than simply measure and display a temperature. Digital thermometers are available with a variety of features and tools, such as recording the change in temperature over a time interval, or even sounding an alarm when a predetermined temperature is reached. Many digital thermometers can even be connected to an external computer where temperature data can be downloaded for further analysis.

Digging Deeper
In order to recognize the limitations of digital thermometers, we first need to understand a little bit about how they work. Let's discuss each of the four primary types of digital thermometers that we see in laboratories today: platinum resistance thermometers, thermistors, thermocouples, and infrared thermometers. As mentioned previously, the type of device is primarily dependent upon the construction and makeup of the sensing element. Therefore, in this section we will focus only on the makeup of the sensing element of digital thermometers, and not the CPU. However, it is important to mention that, in all cases, the readout device itself can contribute to additional measurement errors, which are not addressed here.

Platinum Resistance Thermometers
Platinum resistance thermometers (PRTs) are a type of resistive thermal detector (RTD) made of a highly pure grade of platinum wire. RTDs are not limited exclusively to the use of platinum sensing elements, and can be constructed out of a variety of materials. The measurement uncertainty of these devices varies as a function of the materials that they are made of. Most RTDs in use today are made of platinum. Platinum is chemically stable and exhibits a linear relationship between temperature and electrical resistance, which makes it an ideal material for temperature measurement. Non-platinum RTDs are not covered in this article due to their lack of popularity and availability.

The platinum wire in a PRT is wound into a coil around an insulation material such as mica, silica, or a high-tech synthetic. The purity of both the platinum resistor and the insulation material is directly correlated to the accuracy of the device, as well as the cost. Standard Platinum Resistance Thermometers (SPRTs) are the golden standard for temperature measurement, and are used by the National Institute of Standards and Technology (NIST), as well as other agencies, to calibrate other thermometric devices.

The resistive properties of platinum can vary when even the slightest strain is applied. Therefore, to ensure accuracy in temperature measurement, the platinum coil in a SPRT must be maintained in a strain-free state. To achieve this, the coil is minimally supported so that it can expand and contract freely without constraint. While this method of assembly leads to a device with outstanding accuracy, it also contributes to the device's instability. With so little support provided for the platinum coil, its integrity is easily compromised. In fact, experts say that if a SPRT is placed onto a countertop or another surface with enough force to create an audible noise, it is enough to throw the device out of calibration. For these reasons, as well as their prohibitive cost, SPRTs are generally impractical for laboratory use.

Industrial Platinum Resistance Thermometers (IPRTs) provide a happy medium. The resistor in an IPRT is provided with more support than in a SPRT, and is therefore subjected to increased strain. This leads to a less fragile device that is also slightly less accurate. While IPRTs are less susceptible to damage than SPRTs, they must still be handled with extreme care. If subjected to vibration or dropped, IPRTs can still easily fall out of calibration. Even shipping, if not done properly, may have detrimental effects on a new or recently calibrated IPRT. When purchasing this type of thermometer, I recommend that you ask the manufacturer or supplier about the shipping method that will be used for your device to ensure that it will not be harmed during transport.

Not all IPRTs are created equal, and the quality of the device is dependent upon the wire diameter, type and purity of materials used, construction, and number of lead wires. Two-wire IPRTs are not recommended, as they tend to have more measurement error due to the required lead-wire circuitry. Three-wire IPRTs still incur some effects of lead wire resistance, but are suitable for most applications. When more precise measurements are needed, four-wire IPRTs are best, as this configuration virtually eliminates lead wire resistance errors. While many IPRTs have a coil resistor similar to that which is used in an SPRT, they also come in film form. Film resistors contain a thin film of platinum affixed to a ceramic insulation material. Film-type IPRTs offer improved shock resistance over coil-type IPRTs. However, the thermal expansion properties of the ceramic substrate vary from that of the platinum film, contributing to even further measurement uncertainties in film-type devices.

When purchasing an IPRT, go for a probe-type sensing element, and not a bare element, unless the device is used in a permanently fixed location. Be sure to check the manufacturer's specifications to ensure that the immersion depth, readability, and measurement uncertainty meet your needs. Before purchasing, I recommend ensuring that the IPRT conforms to the requirements of ASTM E 1137, *Standard Specification for Industrial Platinum Resistance Thermometers*.

Thermistors

Thermistors, or thermal resistors, are made of ceramic materials formulated from metallic oxides. Negative temperature coefficient (NTC) thermistors will decrease in resistance with an increase in temperature. Conversely, positive temperature coefficient (PTC) thermistors display an increase in resistance with an increase in temperature. NTC thermistors are far more common and are widely used in laboratory applications.

Thermistors are hardy devices, and much less susceptible to shock or vibration than PRTs. Even better, they won't cost you an arm and a leg. They offer amazing accuracy, too… at least near room temperature. The ceramics used in thermistors exhibit a non-linear relationship between temperature and resistance. At temperatures around -5ºC to 90ºC, the temperature-resistance relationship is the closest to linear. Beyond this range, thermistors tend to exhibit excessive swings in resistance with even the slightest temperature change. Therefore, these devices tend to provide inaccurate measurements in any application that isn't within this narrow range of use.

Thermistors are generally only calibrated and suitable for a very small temperature range. When purchasing this kind of device, be sure to double-check that the device you'd like to buy will work effectively in the temperature range that you expect to use it in. Also keep in mind that bead-in-glass thermistors tend to offer greater stability than disc-type elements and are more suitable for high-precision applications.

Thermocouples

Thermocouples are composed of two wires, each consisting of a different material. The wires are joined at two points, or junctions. One of the junctions is designated as the measurement junction, and the other as the reference junction. When the measurement junction is exposed to a temperature that differs from that of the reference junction, electrical current flows through the circuit. The voltage difference between the two junctions can be measured and converted into temperature.

When all other conditions remain the same, the voltage produced by the thermocouple circuit tends to change over time, which causes drift in temperature measurement. Moreover, a voltmeter must be added to the circuit in order to determine the voltage difference across the circuit, which in turn introduces a third junction to the system. This necessary third junction contributes to additional measurement errors. For these and other reasons, thermocouples tend to have a high measurement uncertainty. In the best-case scenario, high-end thermocouples may have measurement uncertainties of approximately 1ºC. However, uncertainties greater than 2.2ºC are typical. As such, thermocouples are not recommended for most laboratory applications, unless measurement errors of several degrees are acceptable.

Thermocouples are available in several different types, including B, C, D, J, K, N, R, S, and T. The type of thermocouple is defined by the two materials used to create the circuit in the sensing element. Type K thermocouples, made of chromel and alumel, are commonly used for laboratory and industrial applications due to their low cost, versatility, and reliability. Experts tend to recommend using type K thermocouples for most applications.

Thermocouples are durable devices, and not prone to mechanical shock. They can be quite cost-effective as well. However, when purchasing a thermocouple, it is important not to skimp on quality. Poor quality solders and electrical connections, or contamination of the electrical components, can lead to greater inaccuracies in measurement. It is also important to consider the type of probe that best fits your application. Exposed junction thermocouples have the fastest response time, but are not appropriate for use with liquids, or under pressurized conditions. Grounded thermocouples have a slower response time than ungrounded ones, but are also less susceptible to errors caused by electrical interference. Choose a probe-type thermocouple with a protective metal or ceramic tube-especially if measuring the temperature of liquids. Bead-type thermocouples are more susceptible to damage, but can be used in situations where a probe-type device is not suitable.

Infrared Thermometers

Infrared (IR) thermometers sense heat in the form of infrared energy. The optic mechanism inside an IR thermometer collects the emitted energy and directs it to an infrared detector. The detector transforms the energy into an electrical signal, which is then displayed by the readout device or CPU. While infrared technology offers a non-contact form of temperature measurement, it is often plagued with errors and inaccuracy problems. IR thermometers have measurement uncertainties exceeding 5ºC. Temperature measurement of uneven surfaces, such as asphalt mixtures, soils, and aggregates can exacerbate inaccuracies. Similarly, metal surfaces, or other objects that either emit or absorb heat energy can also cause measurement errors. Experts do not generally recommend the use of IR thermometers for laboratory applications.

Still Stuck?

This article is by no means an all-inclusive guide to temperature measurement, and chances are you will still have questions. In that case, I recommend getting some expert advice. Most thermometer supply companies and manufacturers have knowledgeable staff that can help you find the device that will best meet your needs. Be prepared to describe how the thermometer will be used, the medium that is being measured, as well as the required measurement accuracy.

Until Next Time

One thing's for certain: getting digital isn't always easy. Remember, there is no such thing as the perfect digital thermometer. To choose the device that is right for your application, it is important to understand the limitations of each thermometer type. Of course, once you decide on the digital device that's right for you, you'll need to get it calibrated... so, in my next post, I will turn my attention to an even more tangled and mixed-up subject: calibration of thermometric devices. Wish me luck.

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Unraveling the Tangled World of Digital Thermometers

Type of Device	How Much?	Uncertainty	Durability	Range of Use	Benefits	Downfalls
STANDARD PLATINUM RESISTANCE THERMOMETERS	$6,000 or More $$$$$$	Excellent To Within 0.0001°C ★★★★★★	Low ★	-200°C to 650°C	• Highly Accurate	• High Cost • Susceptible to Damage • Readings tend to drift
INDUSTRIAL PLATINUM RESISTANCE THERMOMETERS	$200 to $2000 $$$	Good 0.02 to 0.1°C ★★★★	Mediocre ★★	-200°C to 650°C	• Great Accuracy • More rugged than SPRT • Reasonable cost	• Somewhat susceptible to damage • Readings tend to drift
THERMISTORS	$200 to $2000 $$$	Great 0.01 to 0.1°C ★★★★★	Good ★★★★	-5°C to 90ºC	• Great Accuracy • Rugged	• Limited Range of use
THERMOCOUPLES	$100 to $1000 $	Mediocre Over 1°C ★	Great ★★★★★	-200°C to 1800°C	• Rugged • Low Cost	• Problems with Accuracy • Readings tend to drift
INFRARED THERMOMETERS	$30 to $200 ½$	Poor Over 2°C ½★	Fair ★★★	-50°C to 1100°F	• Low Cost • Non-Contact Measurement	• Problems with Accuracy • User Error Likely

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Unraveling the Tangled World of Digital Thermometers

Purchasing a Digital Thermometer

There are numerous choices available, with prices ranging from just a few bucks to thousands of dollars. So, which one of these devices is right for you?

Thermistors

If you are looking for great accuracy and fast response time at a reasonable price, you're in luck- thermistors offer just that. Unfortunately, their ultra-limited range of use makes them suitable only for measurements near room temperature. Bead-in-glass elements offer greater stability than disc-type elements and are more suitable for high-precision applications.

Standard Platinum Resistance Thermometers

The golden standard, SPRTs are used by the National Institute of Standards and Technology (NIST) to calibrate other thermometers. While they offer an incredible degree of accuracy, these devices are generally not practical for laboratory use due to their high cost and susceptibility to damage.

Thermocouples

While versatile in range of use, and generally inexpensive, thermocouples tend to have inaccuracy problems and high measurement uncertainties. Thermocouples should only be used when one or more degrees of error in temperature measurement is acceptable. Exposed junction thermocouples have the fastest response time, but are not appropriate for use with liquids, or under pressurized conditions. Grounded thermocouples have a slower response time than ungrounded ones, but are also less susceptible to errors caused by electrical interference. Thermocouples come in several types. The type of thermocouple is dependent upon the materials of which they are made. Types available include B, C, E, J, K, N, R, S, and T. Type K thermocouples are most commonly used for laboratory and industrial applications, and offer reliability and longevity. Choose a probe-type thermocouple with a protective metal or ceramic tube, especially if measuring the temperature of liquids. Bead-type thermocouples are more susceptible to damage, but can be used in situations where a probe-type device is not suitable.

Industrial Platinum Resistance Thermometers

Also called resistive thermal detectors (RTDs), these devices have low measurement uncertainty (and therefore greater accuracy) at a high cost. They offer versatility in their range of use, but are easily susceptible to damage that can occur if the device is dropped or subjected to vibration. IPRTs should only be used in situations where shock or vibration is unlikely, and should always be handled with extreme care. Choose a probe with a 3- or 4-wire configuration. While slightly less accurate, film IPRTs offer greater stability and are less prone to damage, and therefore may be a good option for some applications. Go for a probe-type sensing element, and not a bare element, unless the device is used in a permanently fixed location. Be sure to check the manufacturer's specs to ensure that the immersion depth fits your needs. Before purchasing, ensure that the IPRT conforms to the requirements of ASTM E 1137.

Infrared Thermometers

Infrared thermometers offer a non-contact method of temperature measurement, and can only be used to measure surface temperature. Infrared is the least-accurate form of temperature measurement available for materials testing, having a measurement uncertainty that can exceed 5°C. Temperature measurement of uneven surfaces, such as asphalt mixtures, soils, and aggregates can cause increased inaccuracies. These types of thermometers are not recommended for most laboratory applications, and should only be used on smooth, flat surfaces.

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