WHITE PAPER

The 6 Most Important Parts of a Temperature Monitoring System

Guard Critical Products and Processes

In the last few years it's become increasingly common for hospitals, clinics, healthcare and life science organizations and other business to use a electronic temperature monitoring system to safeguard their products and satisfy regulatory demands. You may know that you need a monitoring system possibly with alarming capabilities but aren't sure how to select the best one to meet your needs. To complicate matters, there are literally dozens of different types of temperature monitoring systems with different features and a wide range of prices. Whether you're tasked with recommending what to buy, a purchasing agent or the ultimate end user, you can ensure that you're getting the right system by learning a bit about the most important parts to focus on. At CAS DataLoggers we've put together this basic tutorial covering the 6 parts to a typical Temperature Monitoring System to help you know what to look for.

Consider each of these six factors when specifying/selecting a temperature monitoring system:

1. **Temperature Probe or Sensor** — The type of temperature probe type will affect the measurement accuracy and the temperature measurement range. Common sensor types include:
    1. Thermocouple
    2. RTD
    3. Thermistor

2. **Thermal Buffer**—A thermal buffer helps smooth rapid temperature fluctuations at the sensor due to compressor cycling, door opening, or loading/removing products. Thermal buffers come in the form of:
    1. Nylon block
    2. Bottle filled with ethylene glycol
    3. Bottle filled with glass beads.

3. **Temperature Measurement Device**—The heart of the system, it connects to the probe to measure and possibly record the temperature. There are many kinds of these:
    1. Standalone monitoring device with local memory to store measured data
    2. Networked/LAN or WiFi measurement device with or without local memory
    3. Wireless measurement device using proprietary communication protocol with base station or gateway, again with or without local memory

4. **Data Storage**— While all monitoring applications require some type of immediate data reporting, most also include recording values for historical purposes. The location and amount of memory determines how much historical data will be available. Memory can be:
    1. Internal memory
    2. Local base station or gateway
    3. Local PC
    4. Cloud-based service

5. **Software**—Of course, any system will require some software to control the operation of the system. Software functions include:
    1. Configuration
    2. Charting
    3. Alarm management
    4. Data retrieval
    5. Reporting

6. **Alarming**—Most users want immediate notification of temperature excursions outside of the safe operating range. Alarm delivery methods include:
    1. Visual indicator
    2. Audible alarm
    3. Email message
    4. SMS—Text message
    5. Phone call

Part 1: Temperature Probes

Temperature is among the most common measurements across a broad variety of industries including food, medical and life science, pharmaceutical, machine/equipment monitoring, environmental monitoring, and in practically every other field. Temperature monitoring systems capture temperature data via a sensor such as a thermocouple probe. Since temperature sensors are designed for such a wide variety of needs, it's important that you decide on the type of sensors or inputs you'll use.

Figure 1: Typical Thermocouple Sensor

The 3 most common temperature sensors used with temperature monitoring systems are: thermocouples, thermistors and RTDs.

Thermocouples are the most common temperature sensors; they have the widest measurement range and are typically the least expensive but also have limited accuracy, typically ± 1-2°F (± 1°C). RTDs have higher accuracy than a thermocouple, on the order of ±0.2 – 0.5°F (± 0.1 – 0.3°C). RTDs have a narrower operating range, with a maximum temperature of 150-600°C depending on the material and construction. Thermistors offer even more precise measurements, ± 0.1°C or better, but have a very non-linear response and therefore require a more advanced measurement system. They also have a more limited operating range than RTDs or thermocouples.

It is worth noting that most sensor manufacturers can embed the temperature sensor in a variety of probe types. From stainless steel probes, probes suitable for immersion in liquids and magnetic surface contact probes, you can find what your application requires. We'll cover each type so you can choose which is best for your application.

1. **Thermocouples** are the most widely used temperature sensor and also one of the least expensive sensors available. They are widely used where cost, simplicity and wide operating range are paramount and where extremely high accuracy is not required. A thermocouple is 2 different metal wires of very specific alloys which are fused together at a single point. A thermocouple produces an output voltage (typically in the millivolt level) proportional to the temperature. The measurement system samples the voltage created by the thermocouple junction and then applies a calibration equation to convert the voltage to temperature. The monitoring system also incorporates a cold junction reference to compensate for any offset voltage that occurs at the connections between the thermocouple wires and the measurement device itself. Because of variations in the composition of the thermocouple wire, typical thermocouple accuracies are on the order of 1-2°F, although special composition wires with reduced errors are also available.

Consider thermocouples when you just want a low-cost device that's easy to use. Care should be taken with the environment in which you are recording the temperature. Because of their wide operating range, thermocouples can be used in almost any temperature monitoring application from liquid nitrogen cryostats to metal heat treating ovens. Due to a thermocouples low level voltage, there can be adverse effects in electrically noisy environments; especially when the sensor wire length is large.

2. An **RTD sensor** provides a change in resistance that is related to temperature. —they are more accurate readings than thermocouples but have a narrower operating range. The most common RTD consists of a fine platinum wire wound around a cylinder, but nickel and copper wire are also used. The resistance vs. temperature curve has a very specific slope and the RTD is made so that it has a specific resistance at 0°C, with 100 Ω being the most common value. To measure temperature, the monitoring system will source a known current through the RTD and measure the resulting voltage from which it can calculate the resistance using Ohm's law. Finally, using the slope of the resistance vs. temperature curve and the 0°C resistance, it can calculate the temperature. RTDs are typically more stable and accurate than thermocouples, but at the expense of a more limited operating range. Consider RTD sensors when you need high-precision measurements for a narrow temperature window. They are ideal for temperature monitoring system for freezers and refrigerators.

3. **Thermistors** are similar to RTDs (they're sensors whose resistance changes with temperature) but their resistance change is highly non-linear. Like RTD sensors they take more accurate readings than thermocouples. Because of this characteristic, thermistors can offer very accurate temperature measurements, down to an accuracy of 0.01°C, but only over a very limited temperature range (typically 0°C to 100°C). Like RTDs, thermistors are designed to have a specific resistance at 0°C (2252 Ω is a common value) and each family of thermistors has a specific resistance vs temperature characteristic that the measurement system must be able to accommodate. Consider using thermistors when you need to record at the highest accuracy, have a limited measurement range and are using a temperature monitoring system that can accept the non-linear resistance curve for example skin temperature measurements.

Part 2: Thermal Buffers

Thermal buffers are thermal masses (materials and liquids) which are attached to the temperature probe to increase the time constant (slow the response time) of the temperature probes in order to more closely match the temperature of the material being stored. This has the major benefit of making the reported temperature more closely mimic the actual temperature of your refrigerated product. Glycol bottles, nylon blocks and vials full of glass beads are common types of thermal buffers used in cold storage applications.

A common example is a probe that is measuring the temperature of a refrigerator used to store vaccines. These probes have a much faster response time than old fashioned mercury thermometers. Whenever the door is opened, warm air from the room displaces the cold air in the cavity. A bare probe can respond to this change and a rise in temperature will be detected by the monitoring system. If the door is only open a brief period of time, the temperature will decrease back to the nominal temperature of the cavity within a minute or 2. However, during the brief temperature 'spike,' the temperature of the vaccines do not exhibit the same spike in temperature due to their own thermal mass. By using a thermal buffer surrounding the temperature probe, the air temperature spike will be "buffered" so that the probe will not experience the same jump in temperature. Due to CDC recommendations, thermal buffers are becoming standard in hospitals, clinics and pharmacies but also in laboratories and even cold chain settings. By using a buffer you can eliminate the temperature spikes in the data from the monitoring system caused by opening the fridge or freezer door.

We conducted an experiment detailed in our White Paper "Comparison of Thermal Buffer Effectiveness," showing how bare probes displayed temperature fluctuations that were greatly reduced through the use of various types of thermal buffers. Even the compressor cycling of your storage unit can cause false alarms and pose a major inconvenience along with widely-varying temperature data that does not reflect the actual product temperature. As an example of this from our thermal buffer experiment, see Figure 2 below.

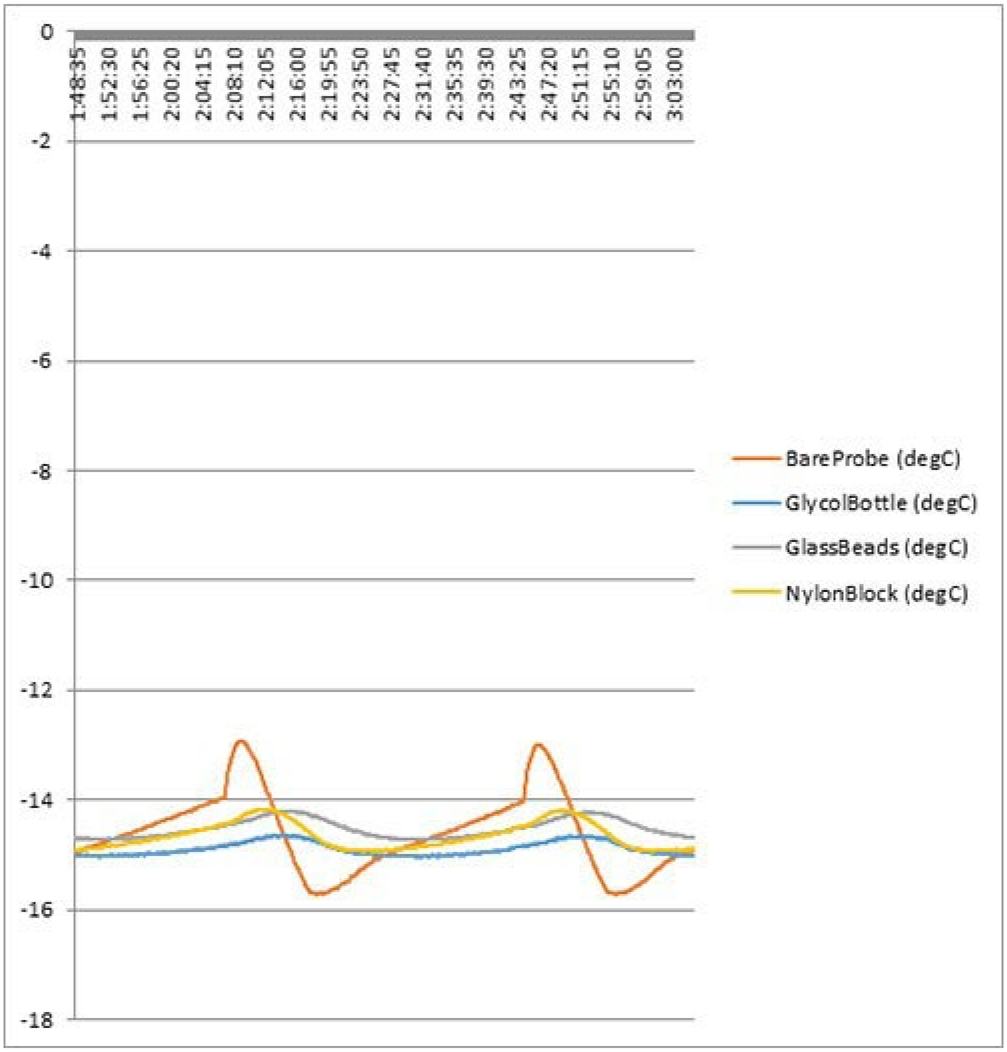


Figure 2: Freezer Cycle Temperature Data

As the data shows, the bare probe's readings were extremely variable compared against the buffered probes. In fact if this had been an actual medical monitoring application, the bare probe could generate false alarms simply due to the normal cycling of the refrigeration compressor. If the limits are set too tightly, even a small variation in the cycling can trigger an alarm. Since stabilizing your temperature readings is so critical, you can avoid nuisance alarms and get much more accurate data by using thermal buffers on all your probes.

Part 3: Measurement Device

The heart of the system is the actual temperature measurement device. These come in many forms from simple single channel devices with a USB interface, to multi-channel intelligent data logging systems. The measurement device connects to temperature sensors, digitizes the temperature value, performs any local alarm evaluation and records the readings memory or transmits it to a server in the case of a network based system. The measurement device can be battery operated or may have options for external power. They may have fixed input types and include the sensors, or they may have universal inputs with screw terminal connections to let the user attach their choice of sensor types. The least expensive measurement devices feature a single input type (only one type of measurement per device) and a fixed number of inputs, i.e. no expansion.

No matter the type of measurement device there are a few characteristics that need to be considered to help you make the right choice.

Sampling Rate

After determining what temperature range you need to log and where you need to record it, it helps to decide how often you need the temperature monitoring system to take a measurement. You might need second or sub-second sampling for their industrial process or you might only need to take a reading once every 30 minutes or every hour just to keep tabs on long term ultracold storage environment.

Most monitoring systems can handle recording at rates up to about 1Hz (once per second). If you need a faster sample rate, be aware that as the speed of the system increases, the price does as well. Also make sure that the recording rate you are specifying is appropriate. For example using a K-Type thermocouple, the sensor/sample may take several seconds to register a change in temperature. Recording such a temperature at 5Hz would provide redundant or useless data.

While monitoring devices usually consume very low power, if the unit operates solely on batteries you'll want to look at the battery life which varies considerably based on the manufacturer, model and how often it's configured to make a measurement.

Measurement accuracy is another important factor to consider. While most temperature monitoring devices are accurate enough to cover typical applications, for example if you're monitoring a room temperature a system a system that's accurate within a degrees or two should be enough. But if you are monitoring a vaccine or other refrigerated sample you might need a high-accuracy model accurate within a half of a degree or better.

Probably one of the biggest differences between devices from different manufacturers is whether the temperature monitor is designed to be used as a stand-alone or if it has to be connected to a PC or network and if so the communications interface which connects the temperature monitoring system to the PC or network. Communication can be done in many different ways, including serial or RS-232 interface, USB interface, Ethernet interface, wireless connection including Wi-Fi and proprietary RF links or cellular 3G or 4G/LTE.

1. **Standalone Temperature Monitoring Systems**

Many temperature monitoring systems can operate in standalone mode meaning that they don't require a PC or other devices to record temperature and process alarms. These devices commonly have an LCD display showing current temperatures with some type of indictor or LED alert you when the temperature is out of spec. Some devices such as standalone data loggers are very durable and will continue to reliably operate for years, while other types like cold chain recorders are designed as low cost, single use devices.

Standalone devices typically have internal batteries providing months to years of operation, but be aware that sample rate is inversely tied to battery life. These devices usually have built-in non-volatile memory which ensures that recorded data is still safe if the battery fails or power is lost. Units with a display will often have an indicator to warn you when the battery's getting low. There are 3 types of batteries, rechargeable, non-rechargeable user-replaceable and non-rechargeable non-replaceable (single use).

Finally, there is the question of how to connect to the monitoring system to make configuration changes or download stored data. Today, USB connection is the most popular choice, but other options include serial (RS-232) and Ethernet, WiFi and Bluetooth.

Networked/LAN/Wi-Fi Temperature Monitoring Systems

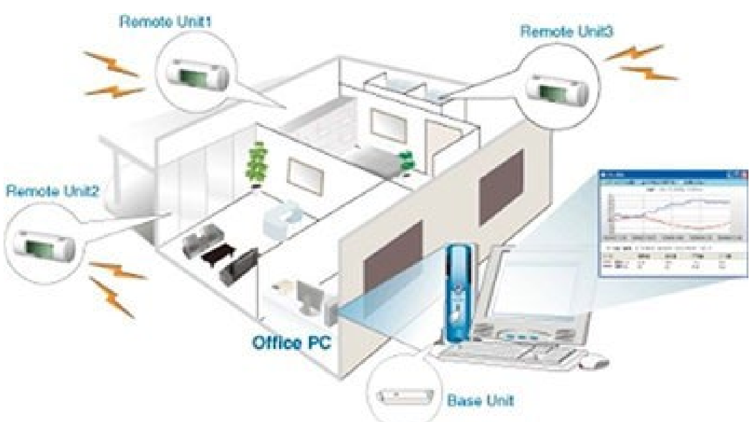
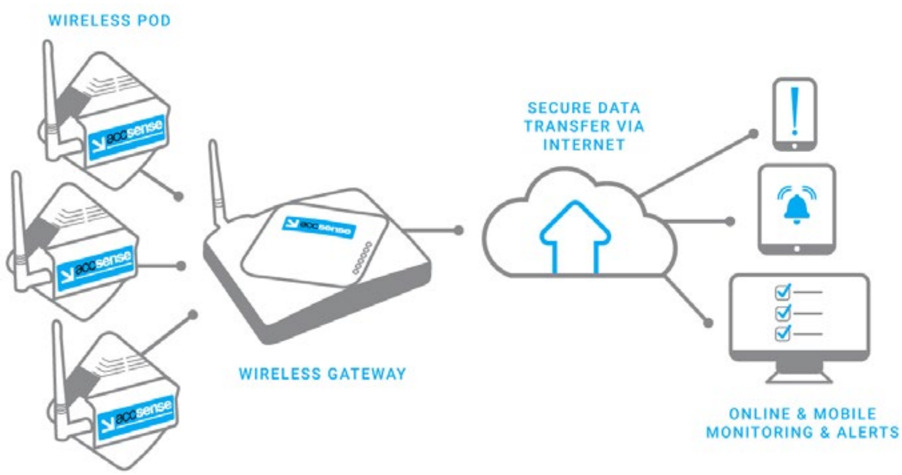


Figure 3: Networked System in an Office

In contrast to standalone temperature monitoring devices, more advanced models have the ability to automatically send their data to PC, server or the cloud. They can connect to a LAN using an Ethernet or a WiFi interface to automatically send data. Cloud based systems provide the advantage of managing data from long distances. For example you can view current temperatures anywhere, anytime using a standard web browser on a PC or mobile device. Depending on the manufacturer, cloud based systems can also send warning emails, text messages or voice notifications whenever values go outside safe windows.

3. **Wireless Temperature Monitoring Systems**

Figure 4: Accsense Wireless Monitoring System



Wireless technology is quickly becoming the standard in many applications including temperature monitoring. For example, life science and healthcare applications are major markets for wireless temperature monitoring systems. These systems are very effective for temperature monitoring and alarming in refrigerators and freezers, cryostats, storage areas, and incubators. Key features of wireless monitoring system include wireless range, data update rate and cost which are based on the wireless technology that is employed.

Wireless systems are ideal when:

- You have a number of distributed points where you need to measure temperature
- It would be difficult or expensive to run wires from your measurement points back to a central location
- Data needs to be collected and transmitted from a truck or other vehicle while it is in motion, preventing the use of wired sensors
- Data and/or alarms need to be collected from a site that is difficult to access or does not offer regular internet connectivity.

Many manufacturers now provide systems that use remote devices that collect the temperature measurements at the point being monitored and then automatically send their readings via a wireless communications link to a base station or wireless gateway. From the base station/gateway, downloaded data can be sent by e-mail to specified addresses or over the network to a local or remote server including cloud based services. Moreover, the base station can be set up to monitor for warnings and send alarm messages. Systems like this which automatically transfer their readings saves the time and trouble of traveling to each device to retrieve the data or check status.

There are many other options for the actual wireless link including standard protocols such as Zigbee and proprietary wireless systems. These system normally operate on one of the unlicensed frequency bands such as 932 MHz (US) and 2.4 GHz. Depending on the device and frequency the wireless range can be from 50 to 1000 feet. Many systems offer wireless repeaters to extend the wireless. In some cases the physical layout can make wireless system deployment difficult. Consider whether the units would have clear line of sight to a gateway or a repeater or if their communication would be obstructed by walls or objects.

Part 4: Data Storage

Depending on your temperature recording application, you may need to only capture a few minutes' worth of data or you may need to be able to store years' worth of readings. You can determine the amount of data storage required by multiplying the number of channels by the sample rate and recording duration:

Total Number of Points = Number of Channels X Sample Rate X Recording Duration

When it comes to semi-permanent storage of data from a temperature monitoring system there are a number of different options:

1. **Local Memory**—Many monitoring systems store recorded data on their internal memory, and there are as many different options for memory size. Depending on the device there will be some sort of limit based on the size of the internal memory. Note that some monitoring devices have no internal memory; they utilize external memory such as a USB stick or SD memory card for data storage. A good monitoring system solutions provider will be clear with you about local memory options and limitations.

2. **Local gateway**—Wireless temperature monitoring systems connect to gateways which automatically collect temperature data. They may buffer it locally for later retrieval or transmit it to PC, server or on-line storage device.

3. **Local PC**—PCs remain a popular and inexpensive method for storing data. Many temperature monitoring systems come with software that allows data to be automatically downloaded and stored on a local PC.

4. **Cloud**—Cloud storage is a relatively recent capability but more and more manufacturers are offering advanced temperature monitoring systems that automatically transmit data to a server managed by the vendor. These can be free or paid services. The cloud server typically provides tools for displaying and downloading data. Other features of cloud based systems include alarming, system configuration management and report generation. These systems offer a convenient solution when there are multiple locations that require monitoring or when multiple users all need access to the data.

When looking at data storage options, it’s also important to consider what sample rate is practical for your application. Many users initially state that they want to record data at one sample per second or faster. One problem with this is that this would quickly fill the available memory and lead to more frequent downloads. When you really look at the rate of temperature change of a sample stored in a refrigerator or freezer it quickly becomes apparent that it can take minutes for the temperature to change by more than a degree or 2. Just think how long it takes that pot roast to thaw out when you remove it from the freezer! Even worse, with high speed sampling it becomes impractical to analyze all the data – with a sample rate of 10 Hz, one day would fill 864,000 rows in Excel.

Part 5: Software

Ultimately you have to retrieve the data from the monitoring system and then based on the application you may choose to chart it, create a report or simply archive the data in case you need it at some point in the future. Typically, the monitoring system is supplied with software that handles data display, configuration/setup, alarming, and more. In some cases the software might come included with the monitoring system or cost extra depending on the manufacturer and model. The latest generation of devices offer web based software packages which only require a standard web browser such as Edge or Chrome for configuration and data retrieval. Just as with PC software, some interfaces are more user-friendly than others, so if you're new to data logging or your staff is required to work with the software, be sure to ask your vendor about the following features/capabilities:

1. **Configuration**—This is an area where a user-friendly interface really pays off—you want to be able to quickly move through naming sensors and setting temperature limits and sample rates.
2. **Alarm management**—Here you choose who will receive alarms and how they'll be notified, whether over email, text message or even landline phone calls with some models.
3. **Data retrieval**—You'll want to be able to retrieve your data as quickly and easily as possible, and an intuitive software really helps here
4. **Charting**—Useful for identifying and displaying data trends such as temperature profiles or spikes. Many software packages also generate and print reports.
5. **Report generation**—The ability to easily generate compliance reports may be necessary for FDA or other regulatory bodies.

Part 6: Alarms

For most temperature monitoring applications, alarming, the capability to alert someone, somehow whenever the programmed limits are reached, is a core requirement. As noted above, alarms can be local where you have to be in the vicinity of the system to be alerted or they can be remote allowing you to be notified where ever you are. Another feature to look for is a watchdog alarm to send a message if the system ever goes off-line or if there is a power outage. Functions like this are critical when the product being monitored is irreplaceable.

Local alarms can consist of anything from LED indicators and buzzers to external alarm relay outputs for connection to sirens, horns etc. More sophisticated models will automatically send you an email or text alarm to your smartphone so you're always on top of potentially critical changes in your product or process. Historically, very simple monitoring systems used a phone autodialer to provide a voice alarm, but modern monitoring systems send your data directly to a secure cloud server that provides more advanced features like sequential call lists with acknowledgement verification.

1. **Audible**—If you know that personnel will be in the vicinity or if you're in no danger of losing product, an audible alarm might be enough for your purposes. Just be sure that there are no negative consequences to miss an alarm such as process delays or spoiled food! A good rule of thumb is to assume that someone might not be in the room when the alarm goes off.
2. **Visible**—As with audible alarms, first ensure that the data recorder is located somewhere with high traffic so personnel have a fast response time.
3. **Email**—Email alerts are equally convenient, although for critical applications you'll want to ensure that you're aware of when you're emailed—many users use their mobile devices to give them an audible when they have an incoming alarm email.
4. **SMS**—SMS text alerts are a popular way to get an instant heads-up on alarm events. Once configured the temperature monitoring system will automatically sends alarms out to specified personnel.
5. **Phone**—Some systems provide dial-out capability enabling immediate notification virtually anywhere. There are systems that support both batch and sequential call lists and customizable lists to allow each probe to have its own set of contacts.

Summary

With this basic understanding of the different parts of a temperature monitoring system, you're now informed enough to think about how you want to get your data and how you want to work with it. This is a great place to start contacting solution providers and seeing products and feature lists. Post-installation you should start seeing the benefits whether in the form of reduced product loss, lower operating process costs, greater vendor reputation, or whatever your specific needs are.

For further information on temperature monitoring systems or to find the ideal solution for your application-specific needs, contact a CAS Data Logger Application Specialist at **(800) 956-4437** or www.DataLoggerInc.com.