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Temperature Sensors (App Note)

This is the start of an application note about temperature sensors,

Quick Summary:

If you are measuring in the range of -50 to +150 °C, consider using a silicon type temperature sensor. They are generally the cheapest solution, the easiest solution, and the most accurate solution.

Beyond that range, thermocouples are usually the best option.

Thermistors and RTDs can seem to be very accurate when you look at the raw specs, but that is just the accuracy of resistance versus temperature. It can be difficult to measure that resistance with enough accuracy to achieve the stated accuracy of the sensor element itself.

Digital sensors have similar range limits as analog silicon type sensors, and are a great solution depending on which LabJack and software plans. The T4 and T7 have high-level support for SBUS sensors (EI-1050, SHT1x, SHT7x) in hardware, so it is easy to read temperature and humidity in any software. Older devices (U12, U3, U6, UE9) provide high-level support through software, so require a software application that makes specific calls to the UD or U12 library. Other sensors speaking SPI, I2C, Asynch, or 1-Wire, are also an option but will require a software application that makes specific calls to the LJM, UD or U12 library.

Silicon Type Sensors (Analog):

In the range from -50 to +150 °C, analog silicon temperature sensors are generally cheaper, easier to use, and more accurate, than other types of temperature sensors. With no or minimal extra components, they provide a high-level linear voltage output that connects directly to a LabJack's analog inputs.

Signals from silicon type sensors are easy to acquire with any LabJack (U12/U3/U6/UE9).

Following are silicon type analog output temperature sensors available in through-hole style packages convenient for soldering to the end of a cable. If you consider digital output sensors and/or surface-mount packages you can find even better sensors:

EI-1034: A silicon based temperature probe made by Electronic Innovations and sold by LabJack. It uses an LM34CAZ sensor element from National Semiconductor with a 10k load resistor from signal to ground. The LM34 provides an easy-to-use 10 mV/°F. Range with 5V/0V supply is -17 to +110 °C (0 to 230 °F). Accuracy (max) is +/-0.56 °C (+/-1.0 °F) at room temp and +/-1.1 °C (+/-2 °F) across range. Non-linearity is +/-0.3 °C (+/-0.6 °F) max across range, so a simple calibration can provide more accurate measurements. Assembly has a 6ft cable, which can be extended to 25ft, or much longer if you add a 10k series resistor to prevent oscillation. Uses a 6" x 0.25" waterproof stainless steel probe.

EI-1022: A silicon based temperature probe made by Electronic Innovations and sold by LabJack. It uses an LM335A sensor element from National Semiconductor with a 2k current setting resistor. The LM335A provides an easy-to-use 10 mV/°K. Range with 5V/0V supply is -40 to +100 °C (-40 to 212 °F). Accuracy (max) is +/-3 °C (+/-5.4 °F) at room temp and +/-5 °C (+/-11 °F) across range. Non-linearity is +/-1.5 °C (+/-2.7 °F) max across range, so a simple calibration can provide more accurate measurements. Assembly has a 6ft cable, which can be extended to much longer distances with no added components. Uses a 4" x 0.25" plastic probe.

LM34CAZ: TO-92 package with 10 mV/°F output. Buy fromLabJack, Digikey, and others. Range with 5V/0V supply is -17 to +110 °C (0 to 230 °F). Accuracy (max) is +/-0.56 °C (+/-1.0 °F) at room temp and +/-1.1 °C (+/-2 °F) across range. Non-linearity is +/-0.3 °C (+/-0.6 °F) max across range, so a simple calibration can provide more accurate measurements. For lower temperatures, to -40 °C (-40 °F), you need to add a negative bias on the signal output (on the U6/T7 you can use a 220k pull-down to VM-). Note that even if you want to measure in Celsius, the LM34 is better than the LM35 because you get more voltage per temperature (18 mV/°C versus 10 mV/°C) and you can measure lower with a single supply (-17 °C versus +1 °C). Regardless of cable length we always recommend a 10k resistor from Vout to GND (preferably right at the sensor), and this is usually good for cables up to 25ft. Beyond 25ft see the "Capacitive Loads" section in the LM34 datasheet and consider adding a series resistor.

LM34AH: TO-46 package with 10 mV/°F output. Buy fromDigikey and others. Range with 5V/0V supply is -17 to +150 °C (0 to 300 °F). Accuracy (max) is +/-0.56 °C (+/-1.0 °F) at room temp and +/-1.1 °C (+/-2 °F) across range. Non-linearity is +/-0.4 °C (+/-0.7 °F) max across range, so a simple calibration can provide more accurate measurements. For lower temperatures, to -40 °C (-40 °F), you need to add a negative bias on the signal output (on the U6/T7 you can use a 220k pull-down to VM-). Note that even if you want to measure in Celsius, the LM34 is better than the LM35 because you get more voltage per temperature (18 mV/°C versus 10 mV/°C) and you can measure lower with a single supply (-17 °C versus +1 °C). Regardless of cable length we always recommend a 10k resistor from Vout to GND (preferably right at the sensor), and this is usually good for cables up to 25ft. Beyond 25ft see the "Capacitive Loads" section in the LM34 datasheet and consider adding a series resistor.

LM135A: TO-46 package with 10 mV/°K output. Buy fromDigikey and others. Range with 5V/0V supply is -55 to +150 °C (-67 to 300 °F). Accuracy (max) is +/-1.0 °C (+/-1.8 °F) at room temp and +/-2.7 °C (+/-4.9 °F) across range. Non-linearity is +/-0.5 °C (+/-0.9 °F) max across range, so a simple calibration can provide more accurate measurements. Very long cables can be used with no added components. The other sensors are 3-terminal series sensors, but the

LM135A is a 2-terminal shunt sensor that requires a resistor to control current (self-heating might need to be considered).

LM60BIZ: TO-92 package with 6.25 mV/°C output (plus 0.424V offset). Buy from Digikey and others. Range with 5V/0V supply is -40 to +125 °C (-40 to 230 °F). Accuracy (max) is +/-3 °C (+/-5.4 °F) across -25 to +125 °C range. Non-linearity is +/-0.6 °C (+/-1.1 °F) max across range, so a simple calibration can provide more accurate measurements. Specified for use with long cables without added components.

LMT70: Unfriendly DSBGA package, but great accuracy and range. Running off a 2.0V to 5.5V supply, this sensor outputs 1400 mV to 300 mV corresponding to -55 °C to +150 °C and has an accuracy of +/-0.36 °C across that entire range. Linear interpolation or a 3rd order equation is required to convert voltage to temperature, but a computer does not care about that. Maleetronic sells a flex probe carrier that makes it much easier to attach wires. The LMT70 datasheet says it is stable with capacitive loads up to 1 nF.

Thermocouples:

If you can't use a silicon type sensor, a thermocouple is usually the next best option. They are not particularly accurate, but often fine when you are measuring hundreds of degrees. See the Thermocouples App Note for more detail.

Thermistors:

Thermistors often have great-looking accuracy specs for low cost, but that is the accuracy of resistance versus temperature. Trying to measure the resistance with an accuracy that matches the accuracy of the sensor spec can be difficult.

The LJTick-Resistance is recommended for handling thermistors.

T-series devices can handle thermistor math in hardware using their Thermistor AIN-EF ability.

RTDs:

RTDs (PT100, PT500, PT1000, etc.) often have great-looking accuracy specifications at reasonable prices, but the problem is that specification is the accuracy of a small resistance change versus temperature, as opposed to voltage versus temperature like you get with a silicon sensor or thermocouple. Trying to measure resistance with an accuracy that matches the accuracy of the sensor spec can be difficult.

The LJTick-Resistance is recommended for handling RTDs. Get 1 LJTR-1k for each 2 RTDs.

T-series devices can handle RTD math in hardware using their RTD AIN-EF ability.

Here is a good RTD topic from our old forum and another newer RTD topic is here.

Digital Sensors:

Digital sensors have similar range limits as analog silicon type sensors, and are a great solution depending on which LabJack and software plans. In addition to temperature, digital sensors are available for many other parameters such as humidity, acceleration, and light.

SBUS is a serial protocol used with SHT1X and SHT7x sensors from Sensirion, which measure temperature and humidity. SBUS is similar to I2C, but not exactly the same. The EI-1050 probe assembly uses the SHT11 sensor. Other available sensors are the SHT10, SHT15, SHT71, and SHT75. The T4 and T7 have high-level support for SBUS sensors (EI-1050, SHT1x, SHT7x) in hardware, so it is easy to read temperature and humidity in any software. Older devices (U12, U3, U6, UE9) provide high-level support through software, so require a software application that makes specific calls to the UD or U12 library.

Other sensors speaking the synchronous protocols SPI (all devices), I2C (all except U12), or 1-Wire (all except U12), are also an option but will require a software application that makes specific calls to the LJM, UD or U12 library. In our experience, SPI is pretty easy to use, I2C is not too bad, and 1-Wire is definitely the trickiest. All devices also have varying support for asynchronous serial communication. This asynch support is compatible with logic-level UARTs, and with added transceiver circuity is compatible with RS-232, RS-485, and RS-422, although with the RS- protocols you are usually better off using a specific USB dongle that supports that protocol unless there is a good reason to go through a LabJack.