Common Types of Sensors and Motors

Process sensors are used in petrochemical, pharmaceutical and semiconductor industries to measure and control the chemical reactions needed to create these important raw materials.
Position sensors are found in vehicles and aircrafts.
Motion sensors are used there as well as in smartphones and security systems.
Ergonomic sensors are found in tablets, PCs, and phones. Chemical sensors protect us from fire and toxic vapor hazards.
Electrical sensors are found in lab instruments and security systems.

Four classes of actuators are used in your automobiles, production equipment, and appliances in your home.

- *Hydraulic sensors*, or hydraulic actuators, use pressure from highly compressed oil to push large cylinders inside construction equipment such as lifts, cranes, and excavators. Slow speed of response due to the long time it takes to compressed oil and the high gear ratios in the mechanisms that deploy them.
- *Pneumatic actuators* give a faster speed of response due to a faster compression of air versus oil. They're most commonly found in production assembly equipment. The downside is they're really noisy and small leaks in these seals lead to large losses in compression.
- *Mechanical actuators* such as gears, and belts, and lead screws, either they boost up the torque or they convert the rotary motion to linear motion.
- *Electrical actuators*: motors convert electrical energy to rotary motion

Electrical actuators come in three flavors.

- A *stepper motor* has multiple coils organized in phases. Energizing the coils sequentially allows the stepper motor to rotate in very precise steps.
- A *brushed DC motor* has a coil that generates a magnetic field around that armature. One side of that armature is repelled by the north pole of a magnet located in the motor casing while the other side is attracted to the south pole of that magnet. The opposing forces cause the armature to rotate in one direction.
- *Brushless DC* motors resolved this issue by using permanent magnets rotating around a fixed armature. An electronic controller switches the phase to the windings allowing rotation within the motor.

Analog and Digital Interfaces

Most things we want to measure, for example, temperature or pressure, are continuously varying. The sensor data must be converted to a digital format before it can be interpreted by a microprocessor.

Excitation: Applying power to a sensor so that it produces a usable output.
Signal conditioning: Analog circuitry excites filters and amplifies the raw sensor signal

Once processed in this way, the signal is sent to an ADC, short for analog-to-digital converter. The output of the ADC is typically 8, 12, 16, or 24 bits. Data from an ADC is usually converted to a serial format, such as I2C, SPI or RS-232.

Certain sensors, humidity in particular, incorporate the analog front end on a single chip solution, producing a digital output easily connected to a microprocessor. The raw output of most sensors is easily corrupted, hence, signal conditioning circuitry is located very close to the sensor, helping to shield against external interference.

Once converted, the digital signal can easily be transmitted over great distances with minimal error. It is helpful to use a microcontroller for sensor systems.

Temperature Sensors and Applications

There's four major types of thermal sensors, of which all but infrared sensors are commonly used in embedded systems.

- A *thermal couple* consists of two wires of dissimilar metals joined at the heated end road junction and connected to circuitry at the other end. The voltage read by the circuitry is proportional to the temperature at the heated junction. Thermal couples can measure temperatures up to 1800°C. As such, they are very popular for metal and semiconductor fabrication. Subject to drifting over time as their metallurgy properties change with large numbers of thermal cycles. They need to be recalibrated yearly.

- A *resistance temperature detector* or RTD for short, works under the simple principle that the resistance of metal increases as the temperature increases. And for platon, the most common metal used in RTDs, the relationship is nearly linear. Rtds can measure temperature up to 800°C. There are more precise and more stable than thermal couples. And as such they popular in the pharmaceutical and biotechnology industries, where processes must pass strict audits for accuracy and repeatability. Stable over many years and there's no need for annual re calibrations. However, you need to provide an accurate current source for RTDs. Need 3-4 wires to prevent inaccuracy from self-heating. Linear.

- A *thermistor* is made of centered semiconductor or metal oxide particles. NTC thermistors exhibit a large decrease in electrical resistance for a relatively small increase in temperature. And even with the severe nonlinear charity, they are very accurate. Their small package size makes them ideal for measuring temperature in phones and computers. Narrow range, non-linear.

- An *infrared sensor* is the only non-contact temperature sensor. As such it's excellent for measuring very high temperatures safely from afar. They are commonly used to measure temperatures in hostile environments. For example, firefighters use them to know if flames are burning behind a wall in a burning building. An infrared sensor calculates the surface temperature of an object from that objects emitted infrared energy. Must know emissivity in advance. Must capture all IR energy within a spot size.

Thermistors: Basic Facts

Being a semiconductor, the exact nonlinear curve or temperature versus resistance is highly material dependent. Most thermistors in use are NTC, which stands for Negative Temperature Coefficient. Their resistance decreases drastically as temperature increases. The base resistance of a thermistor is its resistance at 25 degrees Celsius. The most common base resistances are 2,252 Ohms and 10,000 Ohms. These are used in the narrow band applications for smartphones and computers essentially between minus 50 degrees C and plus 70 degrees C. Thermistors are packaged in glass or epoxy, which limits their upper temperature range. You can measure up to 200 degrees Celsius with a thermistor but you need to use higher base resistances such as 30,000 Ohms or 50,000 Ohms to get the accuracy you need. They're commonly used for overheating protection in smartphones, PCs, and laptops.

Thermistors: How They Work

The Steinhart Hart Equation models with the highly non-linear behavior of thermistors.
$T = [b_0 + b_1 \ln R_t + b_3(\ln R_t)^3]^{-1}$.

T is temp in Kelvin
Rt is resistance in ohms
B0, b... are constants

The logarithmic turns in the equation and the inverse relation of the terms to temperature do two things. They explain the large fall off in resistance over a narrow temperature range, and they make for a very smooth shaped curve. Note that the temperature must be calculated in degrees Kelvin and there are three proportionality constants to keep track of.

Another form of the equation

$T = (1/T_0 + \ln R_t/R_0 / B) – 1$.
First, you make the substitutions for constants b0, b1, and b3 as shown here in the slide. Then you are left with an equation for temperature that depends on any two points are in T and only one material constant beta. The equation is easier to program and firmware, it measure the resistance of the thermistor and then you solve for temperature

RTDs: Basic Facts

Resistance temperature detector

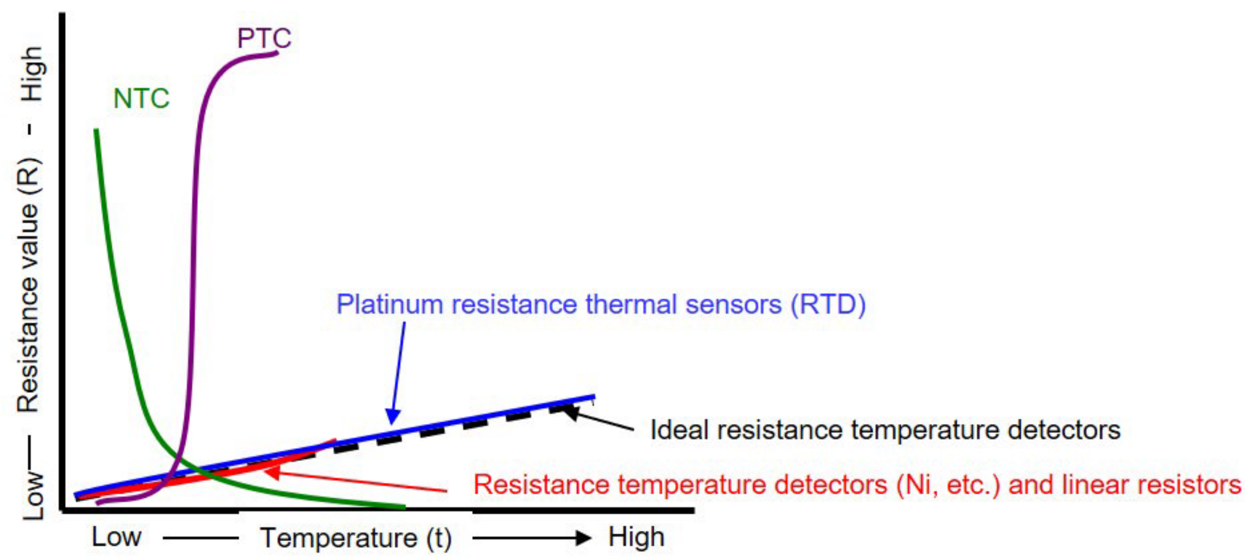
The first RTDs consisted of coils of platinum wire wound around a ceramic core or a glass tube. And in order to protect the wires from damage, a glass, ceramic, or a metal sheath would cover these fragile linings.

Today, thin film RTDs are made by depositing thin, parallel layers of platinum onto a ceramic substrate. The length of the pattern determines the exact resistance that is needed for the sensor. Temperature range is -200 degrees C to 800 degrees C.

The European standard, DIN or IEC 60751, specifies a resistance of 100 ohms at 0 degrees C and a temperature coefficient of resistance of 0.00385 ohms per ohm degree C between 0 and 100 degrees C.

There are two types of specs for tolerances, Class A and Class B, both of which involve the equations shown in the slide, that depend on temperature.

Class A is the one with the 0.06 ohms of tolerance at 0 degrees C.
And class B has double that, or 0.12 ohms of tolerance at 0 degrees C.



<R-T Approximate expression>

- Ideal resistance temperature detectors： $R=R_0(C_1+C_2t)$
- Resistance temperature detectors： $R \fallingdotseq R_0(1+C_1t+C_2t^2)$
- NTC thermistors： $R \fallingdotseq R_0\exp\{B(1/t-1/t_0)\}$

The less used PTC, or positive temperature coefficient thermistor, is the one with a positive but a curved slope upwards.

The RTD looks like a plain old straight line with a positive slope. In reality, though, the curve is very linear but not perfectly linear. You need to calibrate an RTD sensor if you want it to be perfectly linear. RTDs get used wherever a high-accuracy temperature measurement is needed, as long as the data is somewhere within the range of -200 degrees C to plus 800 degrees C. They're popular in applications where people want to install the sensor, take the data, and not have to, or in the case of the space shuttle, not be able to access the sensor ever again.

The excellent repeatability of RTDs appeals to the pharmaceutical industry.

Measuring temperature in a gas or an air stream is another popular application. In that case, you will want the bare RTD element exposed to the gas in order to minimize the speed of response of the sensor.

A hot wire anemometer is an RTD run in reverse.

RTDs: How They Work

You need a lead wire to attach the RTD to imbedded circuit and that lead wire has a resistance that's not accounted for in the specs.
The lead wire impedance contributes a significant error to our temp measurement
A one ohmn lead impedance leads to 1/0.385 = 2.6 C error in measurement.

What to do
TCR = Thermal coefficient of resistance
Delta T = change in temp
V_O = voltages

Construct a Wheatstone bridge.
3 resistors have a smaller TCR than the RTD, V_O ~ delta T
The resistors then see the large delta T of the RTD-> throws off the reading
Add the lead wires to the RTD so the resistors maintain constant temp
But the change in lead wire resistance throws off V_O
Use 3 wire bridge -> 2 are opposite
Resistance effects of those 2 are canceled and the third carries no current
But we lose the linear relationship between V_O and T
Then perform circuit analysis

RTD Linearization
For -200 to 0 C: $R_t = R[1 + At + B\,t^2 + Ct^3\ (T - 100°C)]$
For 0 to 800 C: $R_t = R[1 + At + Bt^2]$

Thermocouples: Basic Facts

I use the abbreviation T/C. A thermocouple consists of two wires of dissimilar metals joined at the heated end or junction as it's called, and connected to circuitry on the other end. The voltage read at the heated junction is proportional to the temperature at that end and the choice of the two metals. A guy named Thomas Seebeck discovered this phenomenon back in 1821. We call it the Seebeck effects. The measurable temperature range varies greatly by which alloy pairs you pick. Range: - 200 to 1800 C typical. One pair of obscure alloys, known as a Type C thermocouple, will accurately measure temperature up to 2300 degrees Celsius as long as you use a titanium sheath to protect it.

Type K is the most popular one in use because of its broad temperature range and its low cost. Typical accuracy is 1% of reading. Types K and T allow you to measure very cold temperatures found on the outer planets. Type C is good for jet engines. Thermocouples get used mostly for low cost contact temperature measurements above 800 degrees C. And as such, you find heavy usage in the aerospace, the heat treating and the metal forming industries where people have no choice but to use thermocouples.

Thermocouples: How They Work

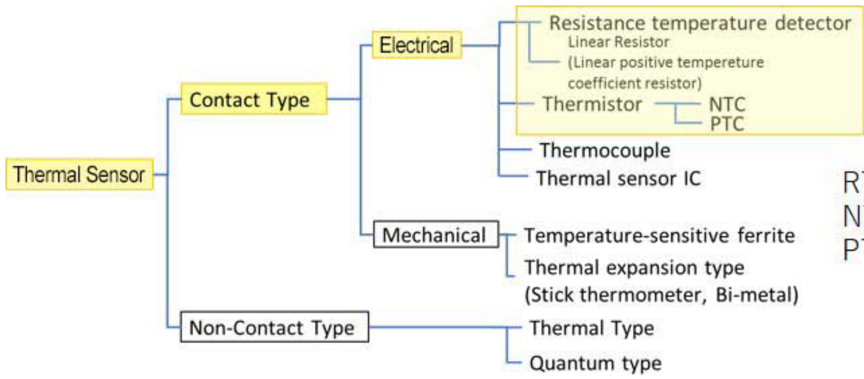
Law of intermediate metals

law of intermediate metal says that when you insert a third metal between the two other dissimilar metals at an isothermal block, that your thermoelectric block won't change.

What this means is we can ignore the chromel connector wire between junctions J2 and J4, and the system will function the same as if that alumel wire on the right was connected directly to the copper wire.

Cold junction compensation, or CJC for short.
a process that adjusts the output voltage of a thermocouple to account for the temperature of the cold junction. This allows for more accurate temperature measurements.

- Measure the voltage of the thermocouple output
- Measure the temperature of the cold junction
- Use a thermocouple reference table to find the voltage that corresponds to the cold junction temperature
- Add the voltage found in step 3 to the voltage found in step 1
- Use the thermocouple reference table to find the temperature that corresponds to the new voltage



RTD: Resistance Temperature Detector
NTC: Negative Temperature Detector
PTC: Positive Temperature Detector

Which of the following types of sensor in your smart phone? Temp, Gyroscope, GPS, Capacitive touch

What advantage does a thermocouple have over the NTC thermistor?
*It can measure lower temperatures than the NTC thermistor * It can measure higher temperatures than the NTC thermistor.

Which of the following is true about an NTC thermistor? It has an excellent accuracy of 0.1% - 0.2%

What is the Steinhart Hart Equation? A highly nonlinear equation that models the behavior of thermistors

Which fact is not true about RTD's? They have a temperature coefficient of resistance (TCR) of 3.85 Ω/Ω/°C

Suppose we include the lead resistance in the calculation of temperature for an RTD. If R 3 = 5000 ohms, R a = 50 ohms, V 0 = 3 volts, and V = 6.5 volts, what is R? (Type in a one-decimal number.) Ans = 150

What happens if you don't perform cold junction compensation in a thermocouple circuit?
The temperature reading will be inaccurate because you have no way to compensate the circuit for thermoelectric voltages created at the junctions of dissimilar metals.

Which is the most common thermocouple in use? Type k

In what temperature measurement applications are thermocouples used? Where a large number of measurement points are needed you need to keep the cost of sensors down, when accuracy of worse than 1% is acceptable, measuring temps > 1400 C, when it is acceptable to do periodic calibration checks