Fundamentals of Sensor Measurements Using a Digital Multimeter

Sensors in Our Modern World

Sensors permeate everything you touch in your daily life. A mobile phone alone has dozens of sensors, including sensors for audio, touch screens, radio frequency, proximity, gyroscope positioning, ambient light, and more. Our homes have temperature sensors, security image sensors, biometric door sensors, and more. The use of sensors continues to grow and is essential to almost everything you use.

There are a few key technology trends that are currently driving the growth of the sensor market today. They are the Internet of Things (IoT), Industry 4.0 for factory automation, smartphones in the telecommunication industry, intelligent vehicles, and general advancements in consumer electronic products. These all fuel the need to use many types of sensors.

Global sensor market is growing at an incredible pace of 11.6% CAGR. The revenue is expected to garner $162 billion by 2019 in market size[1] Sensors are used in almost all end-user markets.

What are the distinct types of sensors available in the market?

Sensors are categorized by several types as shown in Figure 1. Sensors convert a physical parameter (such as temperature, pressure, flow, strain, and more) into electrical parameters (such as voltage, current, resistance, and more).

Sensors can further be classified as passive or active sensors.

1 Frost & Sullivan I REPORT: NFIF-32, Global Sensor Outlook 2016Frost & Sullivan I REPORT: NFIF-32, Global Sensor Outlook 2016

Passive sensors change their resistive, capacitive, or inductive characteristics when its corresponding physical parameters change. They require an external power source to induce an electrical output. For example, a thermistor does not generate an electrical signal but changes resistance corresponding to temperature changes. When an electrical current is introduced across its resistance, an output voltage is measured to detect temperature variations.

Active sensors generate electric current when the external physical environment changes. Examples of such sensors are the thermocouples, piezoelectric, and photodiodes.

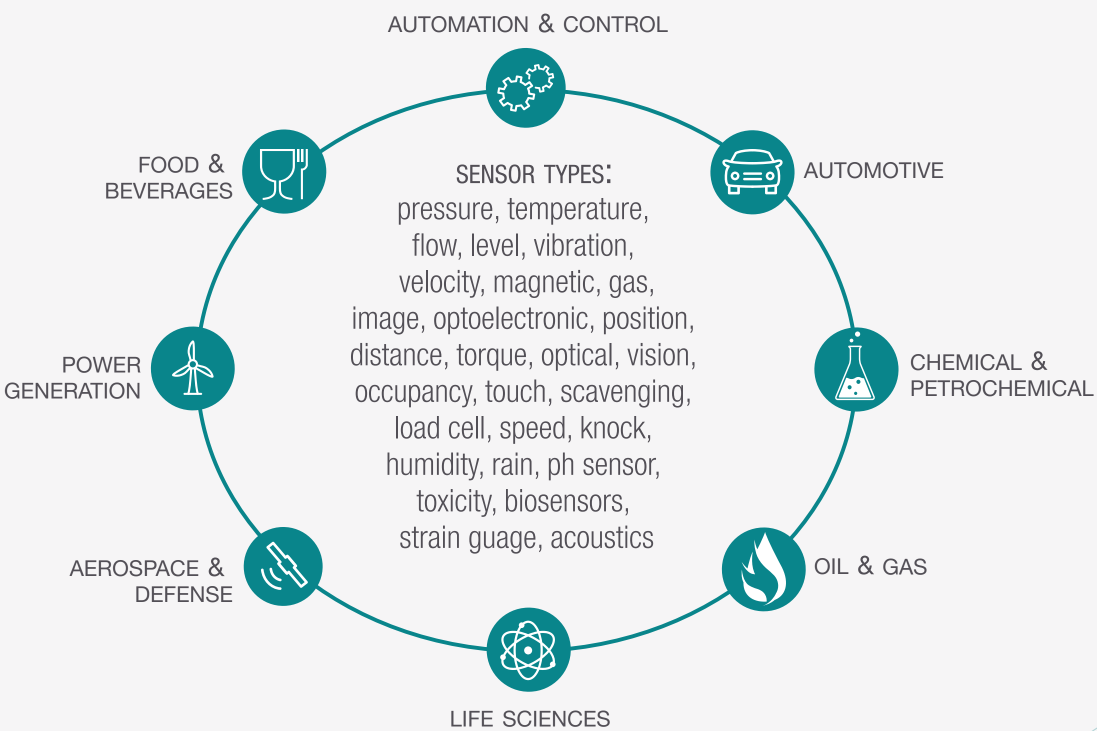


Figure 1: Example of distinct types of sensors and key sensor markets

What Are the Critical Parameters to Test a Sensor?

Whether the sensors are measuring temperature, pressure, flow, strain, light intensity, microwave power, or acoustic level, sensor manufacturers tend to focus on a few key parametric measurements. The key parameters discussed below are important across all sensor types.

Sensitivity

The sensitivity of a sensor is the ratio of change of the physical parametric input measurement versus the change of electrical output voltage or current. Figure 2 shows the sensitivity of two sensors. Not all sensors have linear output. Let us assume these two sensors have linear output. The sensor with the red line has higher sensitivity when compared with the sensor with the blue line.

For example, if the sensor is an optical photodiode, its sensitivity is the change of lumens (light intensity) measured versus the change of output voltage. If the sensor is a thermocouple, its sensitivity is the change of temperature measured versus the change of output voltage.

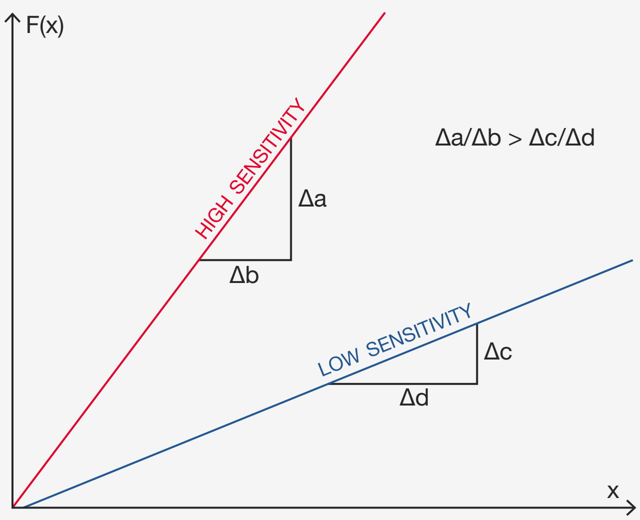


Figure 2: Sensitivity graph

Dynamic range and linearity

Dynamic range is a term that describes the total range that the sensor can measure from the physical input parameters such as light intensity, acoustic level, or temperature and converts them into readable electrical parameters. It is the ratio between the largest and the smallest signals that are measurable by the sensor expressed in decibels (dB).

Figure 3 shows an example of a linear output of a sensor on the red line. The solid line defines the sensor's measurable range, and the dotted line is the possible output that is beyond the measurable capability of the sensor. The solid line determines the sensor's measurable dynamic range.

Linearity is the difference between an actual curved sensor output versus an ideal straight line of a sensor output. Typically, sensors do not produce a typical straight line or linear output. They usually look curvy or may even have an abrupt drop-off or change over its dynamic range. The blue line in Figure 3 shows an example of a non-linear sensor output. Its sensor output difference as compared to an ideal straight line or theoretical best fit line determines the extent of its linearity error.

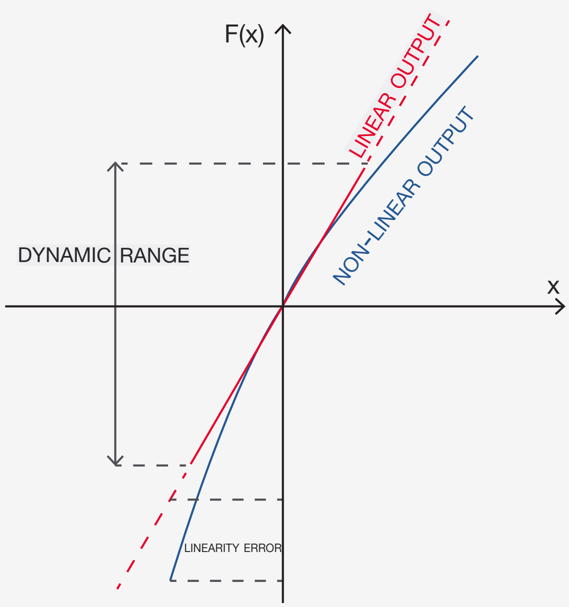


Figure 3: Dynamic range and linearity of sensors

Hysteresis and repeatability

Some types of sensors have a hysteresis effect during measurements. For example, a temperature sensor can exhibit this hysteresis effect. If you measure a known temperature point in a controlled oven from cold to a hot temperature, and then measure again from hot to cold temperature, the residual difference between the two temperature measurements represents the temperature hysteresis effect error. Similar hysteresis effect can also be noted with increasing and decreasing pressure when measured with a pressure sensor.

Hysteresis effect makes it look and feel like the sensor is "resisting" or is "lagging". This lag depends on the inherent properties of the sensor materials or design of the sensing element. Hysteresis contributes to the non-repeatability of the sensor measurement.

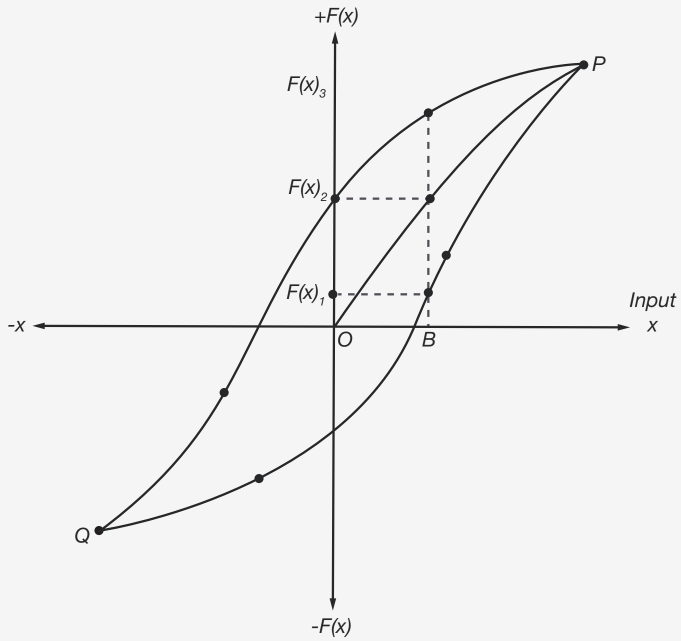
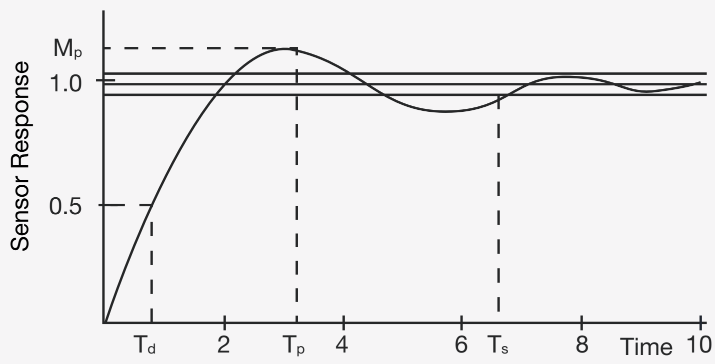


Figure 4: Hysteresis characteristic of a sensor

There are other reasons for non-repeatability besides hysteresis. When measuring at the lowest point of the sensor's dynamic range, non-repeatability can occur due to the sensor's susceptibility to noise. Sometimes, it is due to electromagnetic interference (EMI) from close proximity to other parts of electronic components.

Response time

One of the most critical sensor characteristics is the measurement response time. It is a measurement of how fast the sensor reacts to change. Sometimes it is referred to as a time constant of a sensor when it is subject to a step change.



T_d - *Delay time* is the time it takes to reach 50% of the steady state value for the first time

T_p - *Peak time* is the time it takes to reach the maximum reading for the first time for a given excitement

T_s - *Steady-state* error is the deviation of the actual steady-state value from the desired value. It can be corrected by calibration

Figure 5: Sensor response time

When working with sensors most engineers use a digital multimeter (DMM). When a DMM is part of your measurement chain, it's crucial to make sure it is not affecting your data. Make sure you use a DMM that meets your specific measurement requirements.

What Are the Considerations for Choosing the Right Digital multimeter?

Accuracy, resolution, and speed are key specifications to consider when choosing the right digital multimeter (DMM) for sensor measurements. Figure 6 shows how accuracy relates to resolution on a measurement scale. Accuracy is a measure of how good these numbers are, or how much can you trust them. Resolution is the level of detail that is measurable, or the number of significant digits on a digital multimeter.

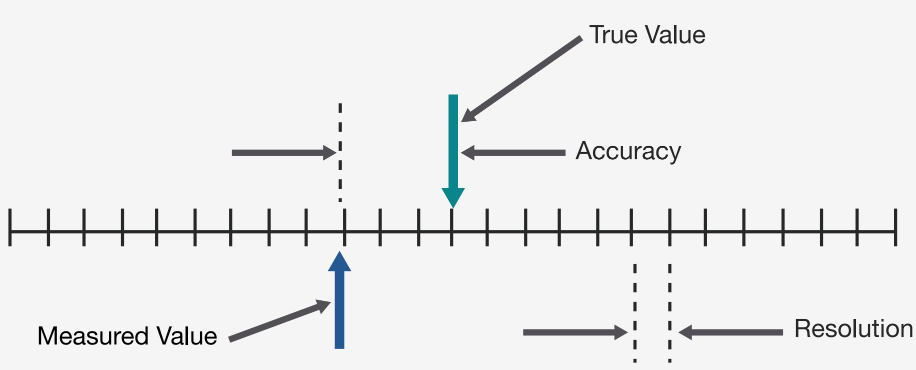


Figure 6: Accuracy and resolution on a measurement scale

Accuracy

Some DMMs have a built-in autocalibration feature that provides a built-in internal reference for calibrating uncertainties due to temperature change and drifts over time. This autocalibration feature gives measurement stability while making highly sensitive accurate measurements in a lab with variable temperatures. It may even calibrate while your digital multimeter is on a system rack full of instruments. While making measurements, the system rack may be 20 °C above room temperature. Higher ambient temperature swings introduce measurement errors; the error is reducible with the autocalibration feature on some DMMs.

Resolution

When measuring a sensor, you want to set your digital multimeter to the highest resolution possible and have the full range that covers your sensor's dynamic range. To get the highest resolution, choose the range that is closest to your sensor's dynamic range. If possible, avoid autoranging to get a seamless measurement without multiple range crossovers.

For example, if your sensor's measurement range is 4 mA – 20 mA, you should choose between the 10 mA and 100 mA ranges of your digital multimeter to make your sensor measurements. If you select the 1 A range for the measurement, you will not get the optimum resolution for this measurement. The resolution result is coarse, and as a result, you get less accurate measurements.

Speed

How about speed? What is its relationship with resolution? Speed is always essential for test measurement throughput in manufacturing. Most products now are packed with sensors — speed is a key factor when purchasing a DMM.

Speed tells how fast an ADC captures samples of data or is the amount of time between samples. Resolution decreases when ADC sampling speed increases. Check the data sheet to determine the resolution of a DAQ across all speeds, and that the highest required speed of the DMM meets your resolution requirements.

Measurement intrusiveness

Sensors are typically very delicate components. Selecting a good DMM that provides less measurement intrusiveness to your sensors is essential. In a rack or on a bench real-world signals are never flat. They have some level of AC signal riding on top from power line noise, other environmental noise, or injected current from the meter. How well your DMM deals with these extraneous factors and eliminates them from the true measurement makes a significant difference to your accuracy.

Keysight's 34465A & 34470A True*volt* DMMs

- Faster insight with graphical capabilities such as trend and histogram charts
- Measure low power devices down to 1 µA range with pA resolution
- Autocalibration feature to compensate for ambient temperature drifts

Learn more by downloading the product data sheet.

Triggering automation

Triggering automation is very important for measuring transient responses from a sensor. For example, if you want to measure the response time of a sensor, the use of trigger automation is essential.

Some digital multimeters provide advanced triggering features such as setting a level threshold, triggering on a positive slope or negative slope, delay timing, and more.

Advanced DMMs have a digitizer to capture consecutive samples at very high-speed into internal memory. Post processing is performed to evaluate step response of your sensors.

Solutions to Key Sensor Challenges

Sensors are the enablers for the technology trends in the world of the Internet of Things (IoT), intelligent vehicles, life sciences, smart grid, Industry 4.0, and more. Here are two key challenges and how DMMs play an important role.

Incorporating more sensors into smaller space

Many smart or intelligent products in the market have multiple types of sensors packed into a small package. For example, a smartphone has an audio microphone, a touch screen capacitive display, a temperature sensor to monitor battery, a gyroscope, a near field communication sensor (NFC), a biometric fingerprint sensor, an image sensor, and more in a small package.

A typical car today has hundreds of sensors packed into it. These sensors play a critical role in the functioning and safety of a driver. For example, a car has a yaw rate sensor, accelerometer, wheel speed sensor, steering angular sensor, and more to control its motion stability. It also has sensors such as tire monitoring sensors, a radiator temperature sensor, a rain sensor, a fuel level sensor, and more. Cars are quickly evolving to become intelligent with new sensors that enhance environmental perception such as long-range and short-range radar sensors, 3-D vision sensors, 3-D laser sensors, ultrasonic sensors, and more.

With multiple sensors cramped into smaller spaces, there is a need for test instruments that are extremely versatile. DMMs today have a built-in signal conditioning circuit to measure various types of sensors. They can generally measure all types of thermocouple sensors, resistive temperature detector (RTD) sensors, thermistor sensors, diodes, capacitors, and resistor-based sensors. Furthermore, there are advanced DMMs that are programmable to add gain and offsets to measure custom sensors.

Reduction of power loss and heat dissipation

Another key challenge for sensors, particularly the sensors that require power to operate, is the power consumption efficiency. Many portable devices such as aerial drones, medical monitoring devices, and autonomous transport vehicles need batteries to operate. These portable devices need to go into hibernation mode when not in use and sensors need to perform at extremely low electric current. The devices must then automatically go into an active mode during operation. Figure 7 shows the power consumption of a device at 1-10 micro-amps while in hibernation mode and at 30-40 milli-amps while in active mode. You need a DMM with a wide dynamic range to measure this signal.

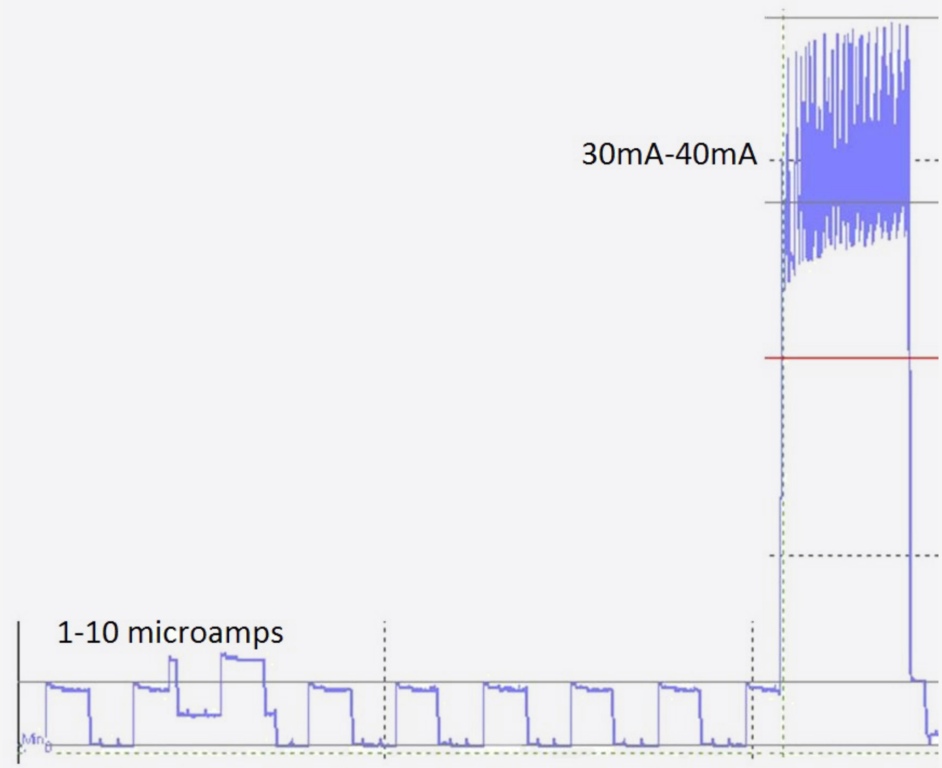


Figure 7: Current consumption graph of a device

DMMs today have better measurement ranges. Some DMMs can measure from micro-amps to amps. You can measure or monitor the current measurements in auto-range mode.

Another solution modern DMMs bring is the digitizer feature. You can set a trigger to capture transitions of power consumption changes from hibernation mode to active mode.

Conclusion

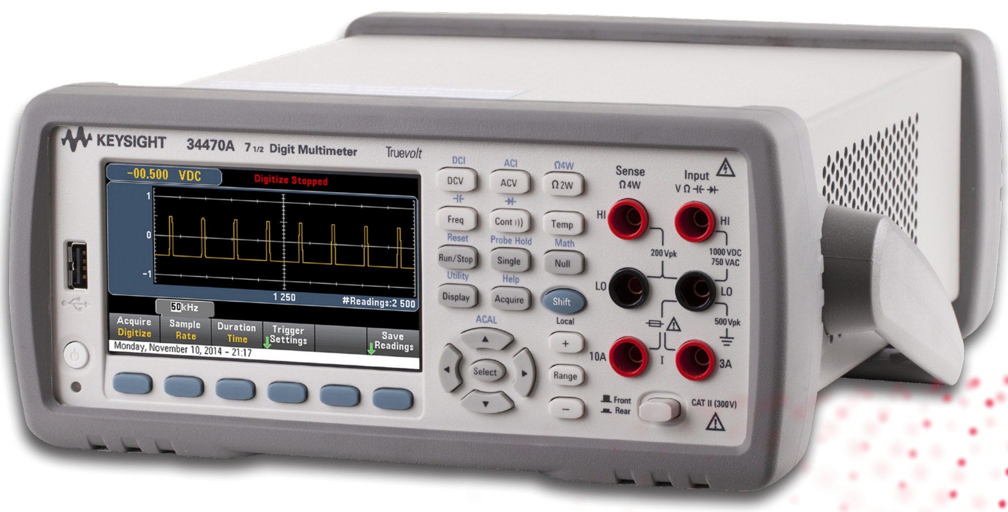
The sensor market is growing at a rapid rate of compound annual growth rate (CAGR) 11%. This growth is driven by technology trends such as the Internet of Things (IoT), Industry 4.0 for factory automation, smartphones in the telecommunication industry, intelligent vehicles, and general advancements in consumer electronic products.

There are a few key sensor parameters that are important to measure across many sensor types, such as sensitivity, dynamic range, linearity, hysteresis, repeatability, and response time.

Sensors have challenges especially in miniaturization and power consumption efficiency.

Modern DMMs are extremely versatile and are applicable to test and characterize sensors.

To learn more about Keysight True*volt* Digital Multimeters, go to
www.keysight.com/find/truevolt



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