SECTION 1
INTRODUCTION
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This book deals with sensors and associated signal conditioning circuits. The topic is broad, but the focus of this book is to concentrate on circuit and signal processing applications of sensors rather than the details of the actual sensors themselves.

Strictly speaking, a *sensor* is a device that receives a signal or stimulus and responds with an electrical signal, while a *transducer* is a converter of one type of energy into another. In practice, however, the terms are often used interchangeably.

Sensors and their associated circuits are used to measure various physical properties such as temperature, force, pressure, flow, position, light intensity, etc. These properties act as the stimulus to the sensor, and the sensor output is conditioned and processed to provide the corresponding measurement of the physical property. We will not cover all possible types of sensors, only the most popular ones, and specifically, those that lend themselves to process control and data acquisition systems.

Sensors do not operate by themselves. They are generally part of a larger system consisting of signal conditioners and various analog or digital signal processing circuits. The *system* could be a measurement system, data acquisition system, or process control system, for example.

Sensors may be classified in a number of ways. From a signal conditioning viewpoint it is useful to classify sensors as either *active* or *passive*. An *active* sensor requires an external source of excitation. Resistor-based sensors such as thermistors, RTDs (Resistance Temperature Detectors), and strain gages are examples of active sensors, because a current must be passed through them and the corresponding voltage measured in order to determine the resistance value. An alternative would be to place the devices in a bridge circuit, however in either case, an external current or voltage is required.

On the other hand, *passive* (or *self-generating*) sensors generate their own electrical output signal without requiring external voltages or currents. Examples of passive sensors are thermocouples and photodiodes which generate thermoelectric voltages and photocurrents, respectively, which are independent of external circuits.

It should be noted that these definitions (*active* vs. *passive*) refer to the need (or lack thereof) of external active circuitry to produce the electrical output signal from the sensor. It would seem equally logical to consider a thermocouple to be active in the sense that it produces an output voltage with no external circuitry, however the convention in the industry is to classify the sensor with respect to the external circuit requirement as defined above.

SENSOR OVERVIEW

- **Sensors:**
  Convert a Signal or Stimulus (Representing a Physical Property) into an Electrical Output

- **Transducers:**
  Convert One Type of Energy into Another

- **The Terms are often Interchanged**

- ***Active* Sensors Require an External Source of Excitation:**
  RTDs, Strain-Gages

- ***Passive* (Self-Generating) Sensors do not:**
  Thermocouples, Photodiodes

Figure 1.1

TYPICAL SENSORS AND THEIR OUTPUTS

PROPERTY	SENSOR	ACTIVE/ PASSIVE	OUTPUT
Temperature	Thermocouple	Passive	Voltage
	Silicon	Active	Voltage/Current
	RTD	Active	Resistance
	Thermistor	Active	Resistance
Force / Pressure	Strain Gage	Active	Resistance
	Piezoelectric	Passive	Voltage
Acceleration	Accelerometer	Active	Capacitance
Position	LVDT	Active	AC Voltage
Light Intensity	Photodiode	Passive	Current

Figure 1.2

A logical way to classify sensors is with respect to the physical property the sensor is designed to measure. Thus we have temperature sensors, force sensors, pressure sensors, motion sensors, etc. However, sensors which measure different properties may have the same type of electrical output. For instance, a Resistance Temperature Detector (RTD) is a variable resistance, as is a resistive strain gauge. Both RTDs and strain gages are often placed in bridge circuits, and the conditioning circuits are therefore quite similar. In fact, bridges and their conditioning circuits deserve a detailed discussion.

The full-scale outputs of most sensors (passive or active) are relatively small voltages, currents, or resistance changes, and therefore their outputs must be properly conditioned before further analog or digital processing can occur. Because of this, an entire class of circuits have evolved, generally referred to as *signal conditioning* circuits. Amplification, level translation, galvanic isolation, impedance transformation, linearization, and filtering are fundamental signal conditioning functions which may be required.

Whatever form the conditioning takes, however, the circuitry and performance will be governed by the electrical character of the sensor and its output. Accurate characterization of the sensor in terms of parameters appropriate to the application, e.g., sensitivity, voltage and current levels, linearity, impedances, gain, offset, drift, time constants, maximum electrical ratings, and stray impedances and other important considerations can spell the difference between substandard and successful application of the device, especially in cases where high resolution and precision, or low-level measurements are involved.

Higher levels of integration now allow ICs to play a significant role in both analog and digital signal conditioning. ADCs specifically designed for measurement applications often contain on-chip programmable-gain amplifiers (PGAs) and other useful circuits, such as current sources for driving RTDs, thereby minimizing the external conditioning circuit requirements.

Most sensor outputs are non-linear with respect to the stimulus, and their outputs must be linearized in order to yield correct measurements. Analog techniques may be used to perform this function, however the recent introduction of high performance ADCs now allows linearization to be done much more efficiently and accurately in software and eliminates the need for tedious manual calibration using multiple and sometimes interactive trimpots.

The application of sensors in a typical process control system is shown in Figure 1.3. Assume the physical property to be controlled is the temperature. The output of the temperature sensor is conditioned and then digitized by an ADC. The microcontroller or host computer determines if the temperature is above or below the desired value, and outputs a digital word to the digital-to-analog converter (DAC). The DAC output is conditioned and drives the *actuator*, in this case - a heater. Notice that the interface between the control center and the remote process is via the industry-standard 4-20mA loop.

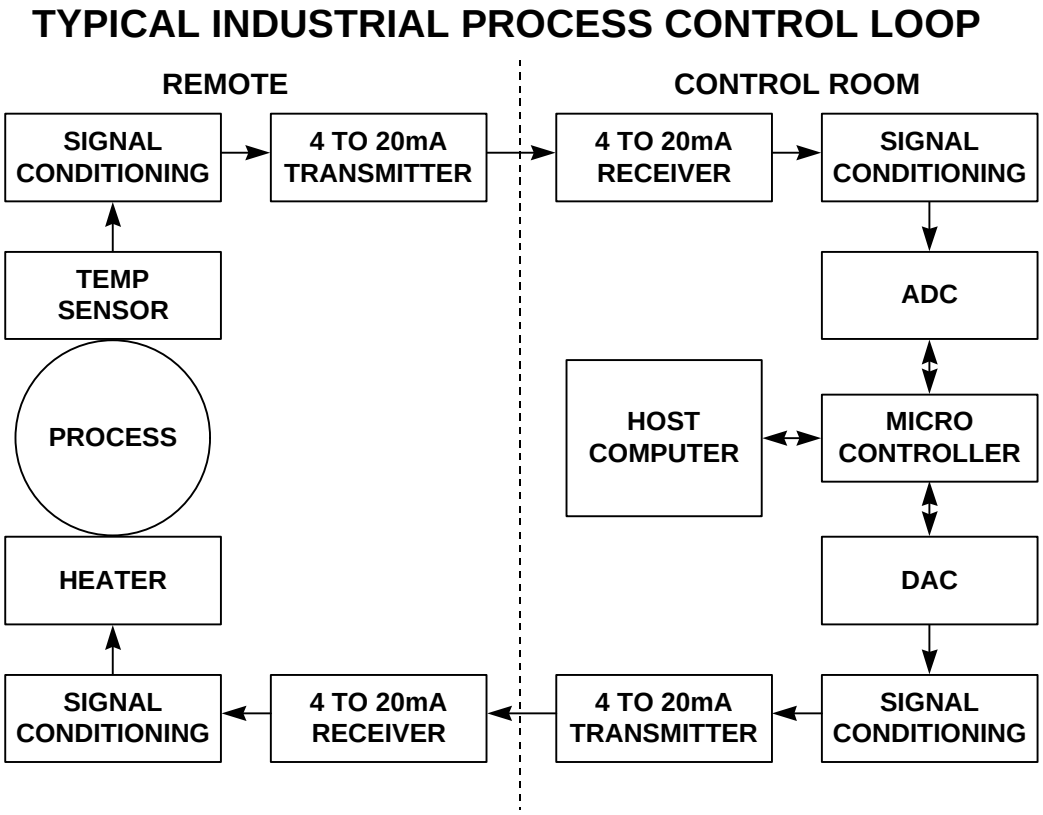

Figure 1.3

Digital techniques are becoming more and more popular in processing sensor outputs in data acquisition, process control, and measurement. 8-bit microcontrollers (8051-based, for example) generally have sufficient speed and processing capability for most applications. By including the A/D conversion and the microcontroller programmability on the sensor itself, a "smart sensor" can be implemented with self contained calibration and linearization features among others. A smart sensor can then interface directly to an industrial network as shown in Figure 1.4.

The basic building blocks of a "smart sensor" are shown in Figure 1.5, constructed with multiple ICs. The Analog Devices MicroConverter™ -series products includes on-chip high performance multiplexers, ADCs, and DACs, coupled with FLASH Memory and an industry-standard 8052 microcontroller core, as well as support circuitry and several standard serial port configurations. These are the first integrated circuits which are truly smart sensor data acquisition systems (high-performance data conversion circuits, microcontroller, FLASH memory) on a single chip (see Figure 1.6).

STANDARDIZATION AT THE DIGITAL INTERFACE USING SMART SENSORS

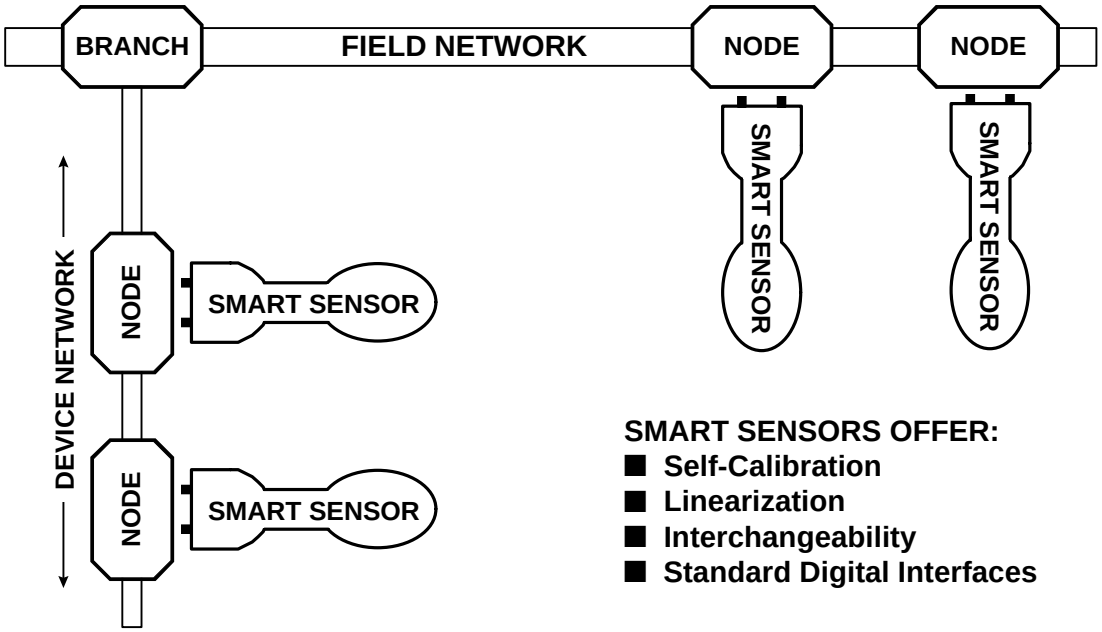

Figure 1.4

BASIC ELEMENTS IN A "SMART" SENSOR

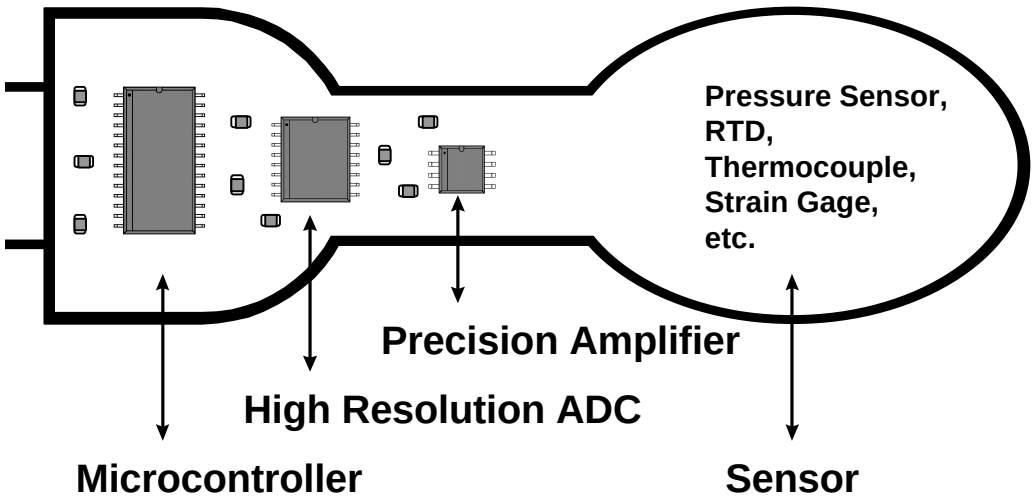

Figure 1.5

THE EVEN SMARTER SENSOR

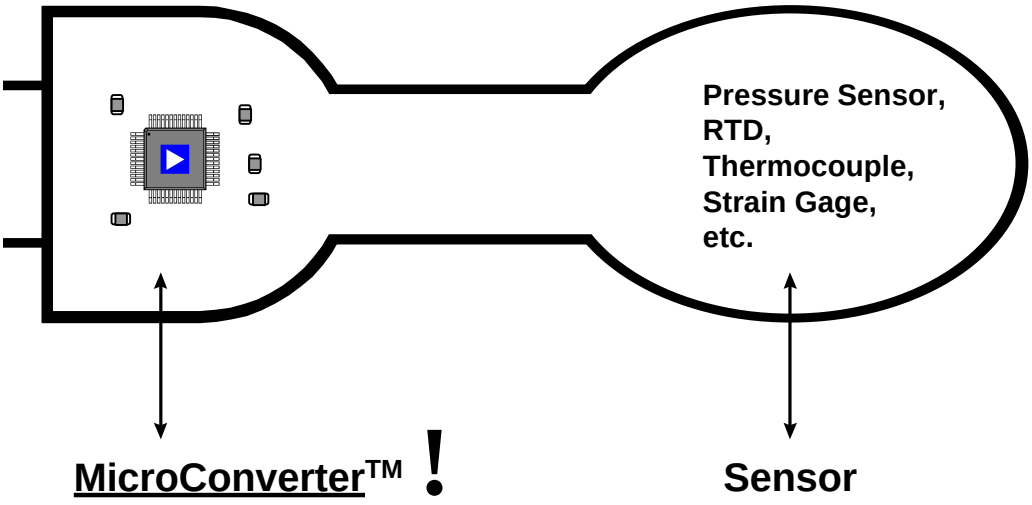

Figure 1.6