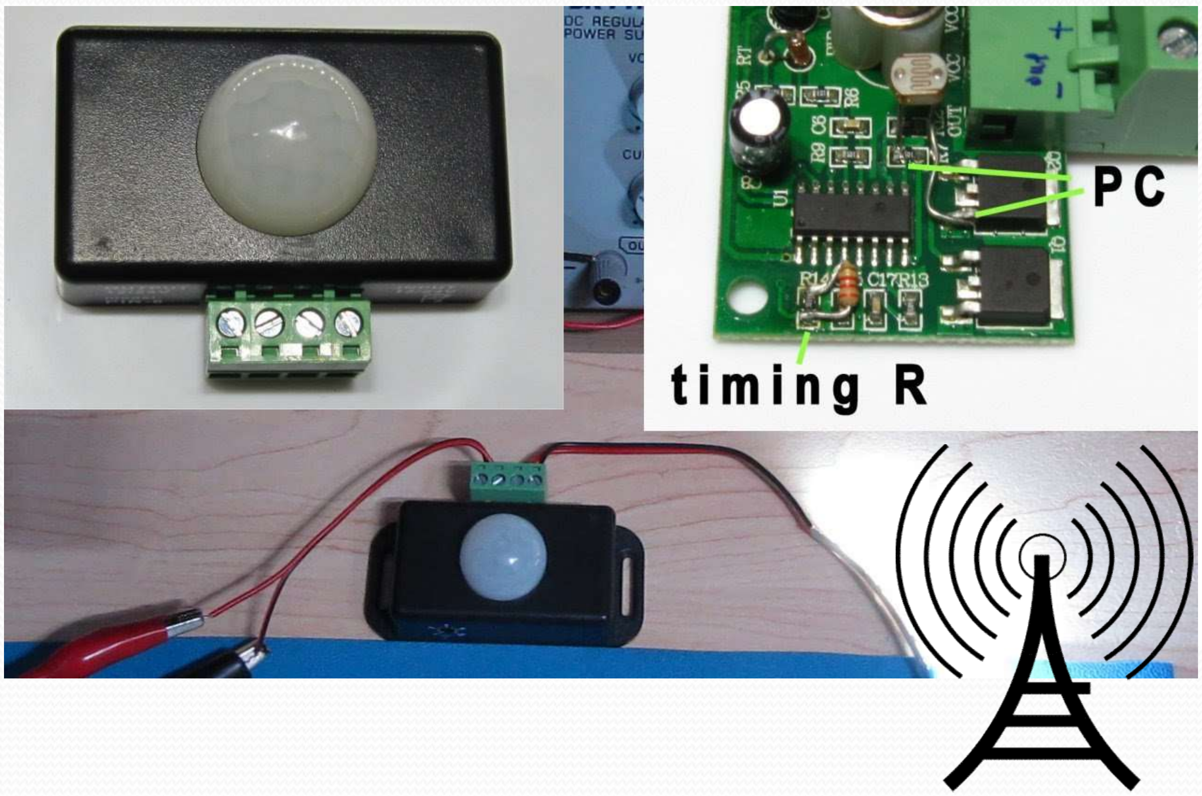
Internet of Things and Applications
Course Code: EE6434D

Module 3



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Introduction : Sensor Networks

Sensor networks are no longer expensive industrial constructs. You can build a simple sensor network from easily procured, low-cost hardware. All you need are some simple sensors and a microcontroller or computer with input/output capabilities. The Arduino and Raspberry Pi are ideal platforms for building sensor networks.

If it is require to monitor your garden pond, track movement in your home or office, monitor the temperature in your house, monitor the environment, or even build a low-cost security system, the above processors are more suitable one.

As inviting and easy as that sounds, don't start warming up the soldering iron just yet. There are a lot of things you need to know about sensor networks. It's not quite as simple as plugging things together and turning them on. If you want to build a reliable and informative sensor network, you need to know how such networks are constructed.

Anatomy of a Sensor Network

Examples of Sensor Networks

Automotive

Almost every modern automobile has a network of sophisticated sensors that monitor the performance of the engine and its subsystems.

Some cars have additional sensors for monitoring external air temperature, tire pressure, and even proximity to objects and other vehicles.

If you take a late-model car in for service and get a chance to look in the garage area, you may notice several machines that resemble computer terminals on wheels (the newest ones are handheld units).

These are diagnostic machines designed to connect to your car and read all the data the sensors and computer have stored.

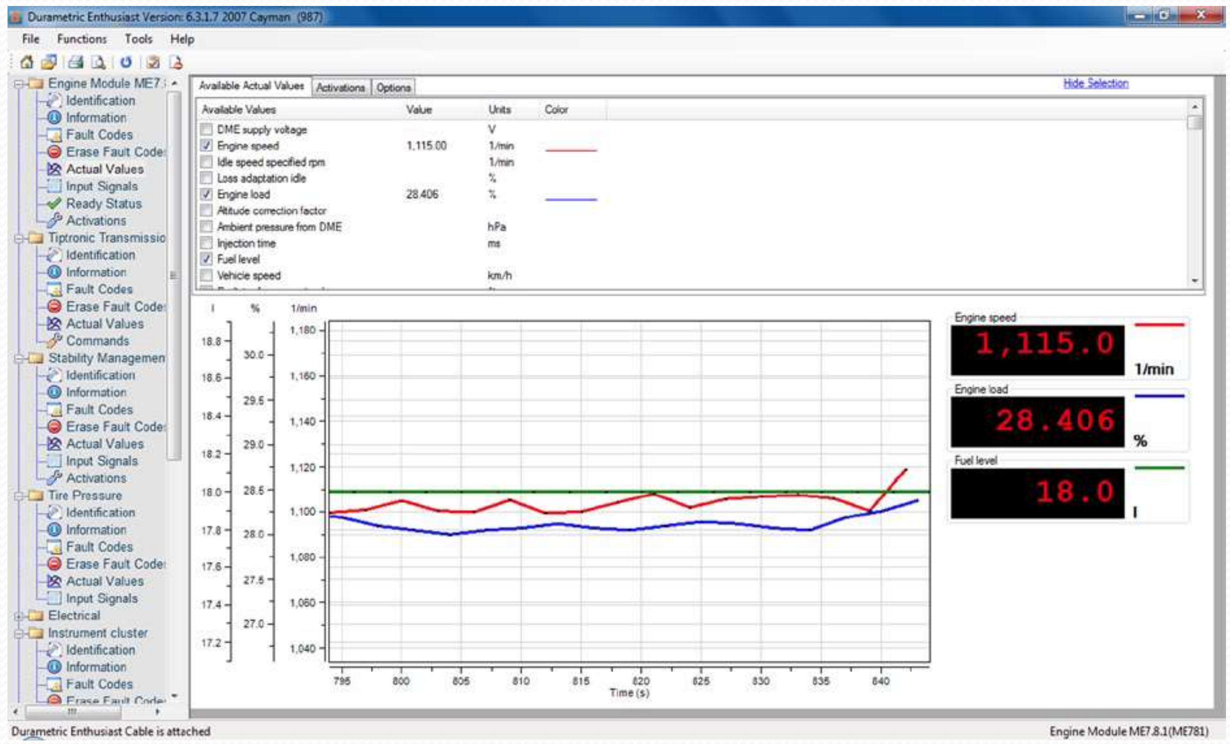
Some manufacturers use the industry standard interface called on-board diagnostics (OBD). There are several versions of this interface and its protocols; most dealerships have equipment that supports all the latest protocols.

Anatomy of a Sensor Network

Examples of Sensor Networks

Automotive

Notice the level of detail displayed. The image shows three metrics in the trace, but if you look at the top of the screen you will see many more metrics that can be monitored. The data shown in the graph was gathered in real time and displayed using the sophisticated sensor networks Porsche employs.



The use of sensors in automobiles has begun to spill over into related machinery such as motorcycles, boats, and even the venerable farm tractor. Many modern farm machines such as combines have sophisticated sensors that enable autopilot mode.

Anatomy of a Sensor Network

Environment

The environment sensor networks include those used to monitor air pollution, detect and track forest fires, detect landslides, provide earthquake early warnings, and provide industrial and structural monitoring.

A clean-room environment often requires very precise temperature and humidity control as well as extremely low levels of contaminants (loose particles floating in the air). Sensors can be used to measure these observations at key locations (windows, doors, air vents, and so on); the data is sent to a computer that records it and generates threshold alerts. Most sophisticated clean rooms tie the filtration, heat, and cooling systems into the same computer system (through the use of their own sensors) to control the environment based on the data collected from the sensor network.

Environmental sensors aren't limited to temperature, humidity, dew point, and air quality. Sensors for monitoring electromagnetic interference and radio frequencies may be used in hospitals to protect patients who rely on sensitive electronic medical equipment. Sensors for monitoring water purity, oxygen level, and contaminants may be used in fish farms to maximize crop yield.

Anatomy of a Sensor Network

Atmospheric

As in environment sensor networks, there are specialized sensors to measure all forms of air quality including free gases, particle contamination, smoke, humidity, and so on. Other motivations for building atmospheric sensor networks include measuring pollution from factories and automobiles, ensuring clean drinking water from water treatment plants, and measuring the effects of aerosols.

Fortunately for the hobbyist and aspiring atmospheric scientist, gas sensors are plentiful, and many are inexpensive. Better still, many example projects available on the Internet demonstrate how to construct atmospheric sensor networks.

Security

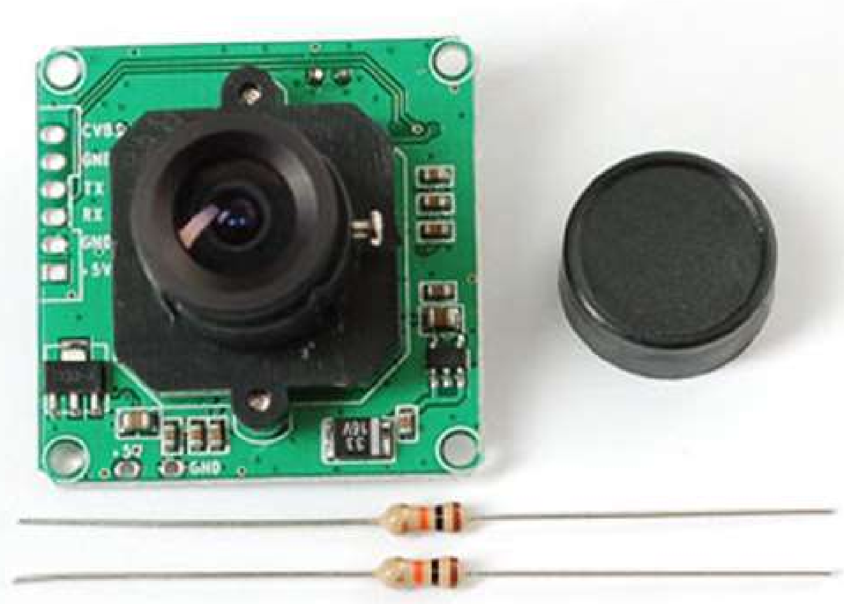
A basic security system is designed to record and alert whenever a door or window is opened. The sensors in such a network are switches (the simplest of all sensors) that detect when a door or window is opened or closed. A central processor or microcontroller can be used to monitor the sensors and take action: for example, generating a signal with a buzzer or bell.

A surveillance system includes more than just a set of switches. Typically, such a system includes video sensors (cameras) and even audio sensors (microphones). The system may also include some form of monitor that records the data and enables users to view that data (see when doors were opened, listen to audio, and view video).

Anatomy of a Sensor Network

Security

Security sensor network: home surveillance system from Harbor Freight



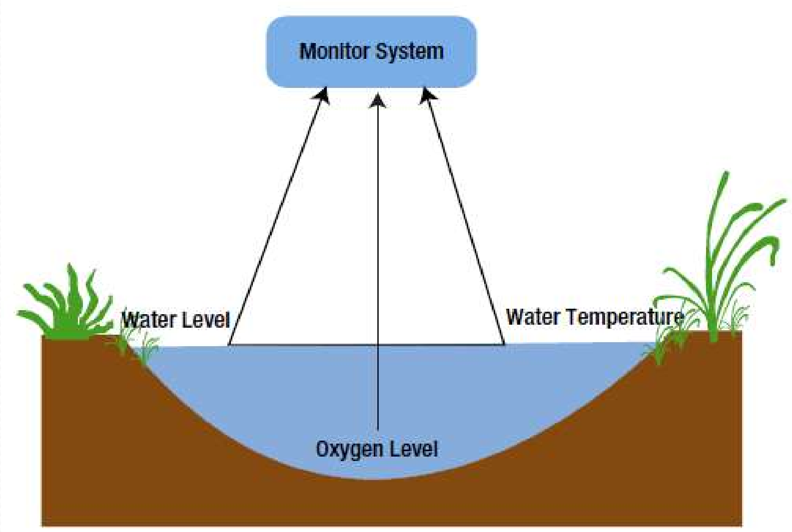
Camera sensor from Adafruit Industries

Surveillance systems used in businesses are similar to home surveillance systems but typically include additional sensors and data tracking such as employee badging, equipment monitoring, and integration, along with offsite support services such as night watchmen and data archiving. Many security sensor networks are available for the consumer. They range from simple audio/visual monitoring to remote monitored systems that integrate into your home, tracking everything from movement to portal breaches, and even temperature and lighting.

The Topology of a Sensor Network

The motivation is to ensure a safe environment for the fish. This means the water temperature should be within tolerance for the species of fish, the water depth should be maintained to avoid over- or under-filling, and the oxygen level of the water should be monitored to ensure that there is sufficient oxygen for the fish to survive.

Most pond owners have learned to build their ponds with the cycle of life in mind, to be sure the pond can sustain its environment. There are many ways to get two Arduino to communicate or share data, but this book limits the discussion to media that permit long-distance communication—wired or wireless.



Typical fishpond monitoring system

Types of Sensor Nodes

Sensor nodes are composed of one or more sensors and a communication device to transmit the data. As mentioned, the communication device can be a microcontroller like an Arduino, an embedded system, or even a small-footprint computer like a Raspberry Pi.

Typically, sensor nodes are designed for unattended operation; they're sometimes installed on mobile objects or in locations where wired communication is impractical. In these situations, sensor nodes can be designed to operate without being tethered to a power or communication source.

Basic Sensor Nodes

At the lowest (or *leaf*) level of the sensor network is a basic sensor node. This is the type of node described thus far—it has a single sensor and a communication mechanism. These nodes don't store or manipulate the captured data in any way—they simply pass the data to another node in the network.

Types of Sensor Nodes

Data Nodes

The next type of node is a data node. Data nodes are sensor nodes that store data. These nodes may send the data to another node, but typically they're devices that send the data to a storage mechanism such as a data card; to a database via a computer; or directly to a visual output device like an LCD screen, panel meter, or LED indicators.

Data nodes require a device that can do a bit more than simply pass the data to another node. They need to be able to record or present the data. This is an excellent use for a microcontroller. Digi, the makers of the XBee, has dedicated sensor nodes that measure temperature, humidity, and light information and transmit the data on the network.

Data nodes can be used to form autonomous or unattended sensor networks that record data for later archiving. Returning to the fishpond example, many commercial pond-monitoring systems employ self-contained sensor devices with multiple sensors that send data to a data node; the user can visit the data node and read the data for use in analysis on a computer.

Types of Sensor Nodes

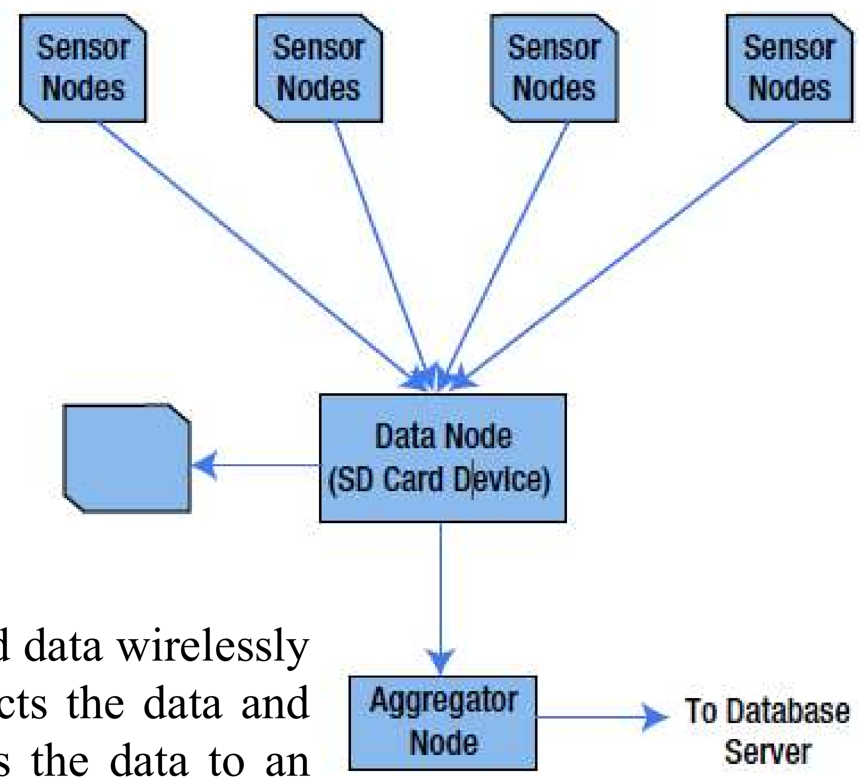
Aggregator Nodes

Another type of node is an aggregate node. These nodes typically employ a communication device and a recording device (or gateway) and no sensors.

They're used to collect data from one or more data or sensor nodes.

In the examples discussed thus far, the monitoring system would have one or more aggregator nodes to read the data from the sensors.

Figure shows how each type of nodes would be used in a fictional sensor network.



In this example, several sensor nodes at the top send data wirelessly to a data node in the middle. The data node collects the data and saves it to a secure digital card, which then sends the data to an aggregator node that communicates with a database server via a wired computer network to store the data.

Mixing data nodes with aggregator nodes ensures that you won't lose any data if your aggregator node fails or the recording and monitoring system fails or goes offline.

Sensor and Its working

Sensors

With all this talk of sensors and what sensor networks are and how they communicate data, you may be wondering what exactly sensors are and what makes them sense.

A *sensor* is a device that measures phenomena of the physical world. These phenomena can be things you see, like light, gases, water vapour, and so on. They can also be things you feel, like temperature, electricity, water, wind, and so on. Humans have senses that act like sensors, allowing us to experience the world around us.

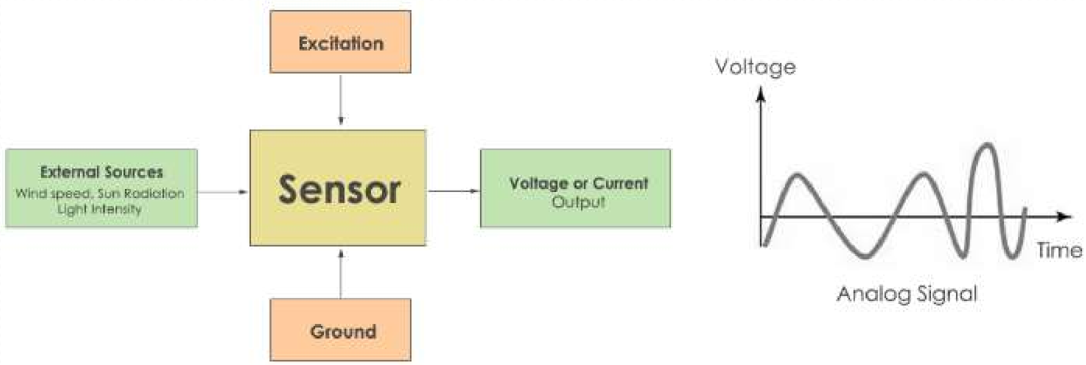
However, there are some things your sensors can't see or feel, such as radiation, radio waves, voltage, and amperage. Upon measuring these phenomena, it's the sensors' job to convey a measurement in the form of either a voltage representation or a number.

Notice the blue module with *XBee* written on it. This is a wireless module that permits the sensor board to send its data to another node or multiple nodes.

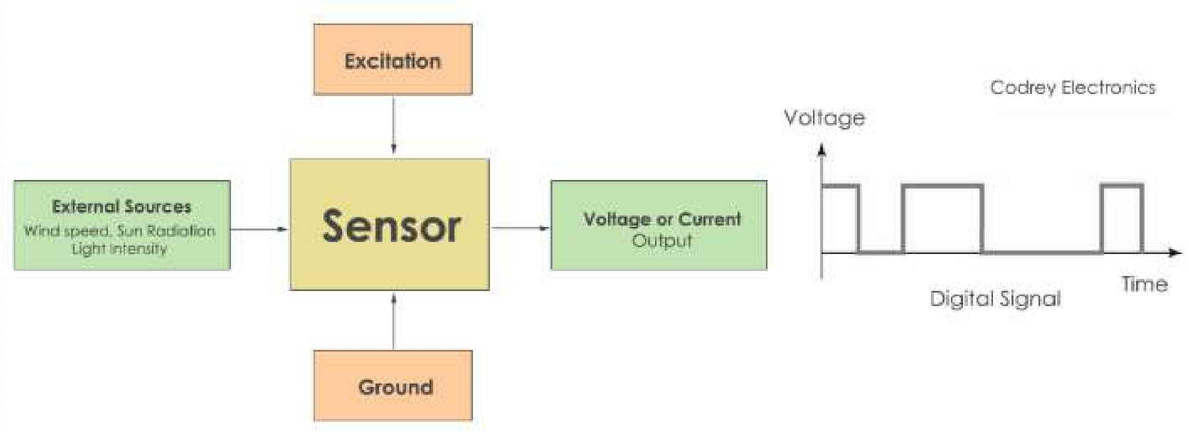
USB Weather Board (courtesy of SparkFun and Juan Pena)

Classification of Sensors

Analog sensor senses the external parameters (wind speed, solar radiation, light intensity etc.) and gives analog voltage as an output. The output voltage may be in the range of 0 to 5V. *Logic High* is treated as “1” (3.5 to 5V) and *Logic Low* is indicated by “0” (0 to 3.5 V).



Unlike analog sensor, **Digital Sensor** produce discrete values (0 and 1’s). Discrete values often called digital (binary) signals in digital communication.



Sensor and Its working

Analog Sensors

Analog sensors are devices that generate a voltage range, typically between 0 and 5 volts.

Analog sensors work like resistors and, when connected to microcontrollers, often require another resistor to "pull up" or "pull down" the voltage to avoid spurious changes in voltage known as *floating*.

Pull-up and pull-down resistors ensure that you have one of these two states. It's the responsibility of the A/D converter to take the voltage read from the sensor and convert it to a value that can be interpreted as data.

When sampled (when a value is read from a sensor), the voltage read must be interpreted as a value in the range specified for the given sensor. Remember that a value of, say, 2 volts from one analog sensor may not mean the same thing as 2 volts from another analog sensor.

When you use a microcontroller like the Arduino, the A/D converters conveniently change the voltage into a value that uses 10 bits, resulting in an integer value between 0 and 1,023.

The Arduino in this case can be programmed to convert the value read from the A/D converter into a value on the sensor's scale.

Sensor and Its working

Digital Sensors

Digital sensors like the DHT-22 are designed to produce a string of bits using serial transmission (one bit at a time). However, some digital sensors produce data via parallel transmission (one or more bytes 8 at a time).

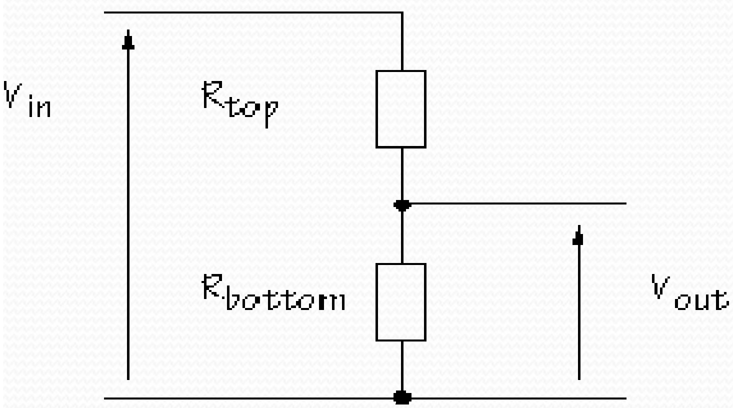
As described previously, the bits are represented as voltage, where high voltage (say, 5 volts) or ON is 1 and low voltage (0 or even -5 volts) or OFF is 0. These sequences of ON and OFF values are called *discrete values* because the sensor is producing one or the other in pulses—it's either ON or OFF.

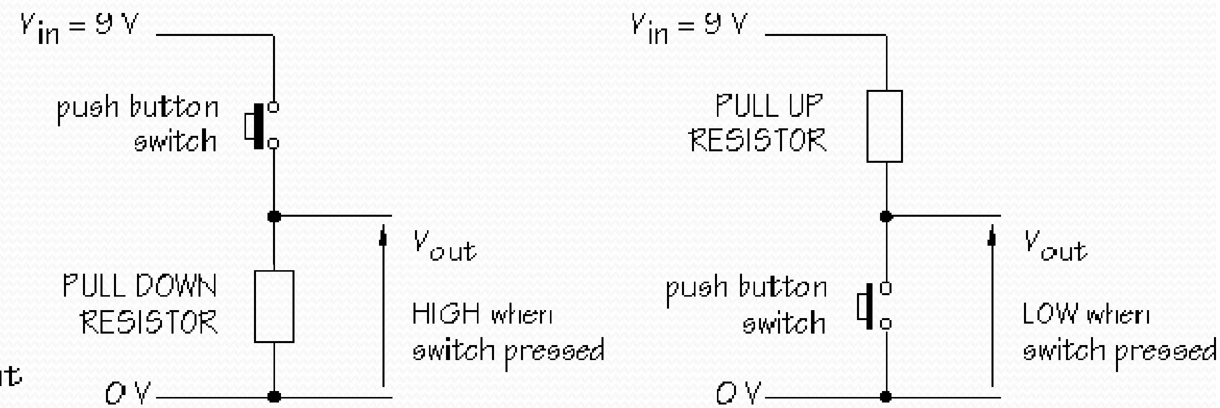
Digital sensors can be sampled more frequently than analog signals because they generate the data more quickly and because no additional circuitry is needed to read the values (such as A/D converters and logic or software to convert the values to a scale). As a result, digital sensors are generally more accurate and reliable than analog sensors. But the accuracy of a digital sensor is directly proportional to the number of bits it uses for sampling data.

In automatic temperature control system, the analog output voltage range is 0 to 5V. What will be the digital output and conversion time if an analog output of 3.2 V is applied to the successive approximation type 3-bit ADC operating at 10 MHz.

Nature of Sensor Technique (use a voltage divider)

Once the output of the voltage divider is known, we can calculate the resistance of the sensor. The resistor and sensor can be swapped over to invert the action of the Voltage divider. The circuit can be built in either of two ways:





$$V_{out} = V_{in} \times \left(\frac{R_{bottom}}{R_{top}+R_{bottom}}\right)$$

Figure 1: Voltage divide circuit

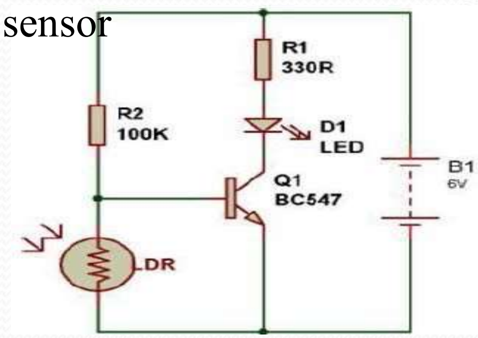
The sensor can be at the top (R_{top}) or at the bottom (R_{bottom}) of the voltage divider. The pull down resistor in the first circuit forces V_{out} to become zero except when the push button switch is operated. This circuit delivers a maximum voltage when the switch is pressed. In the second circuit, the pull up resistor forces V_{out} to maximum except when the switch is operated. Pressing the switch connects V_{out} directly to 0 V.

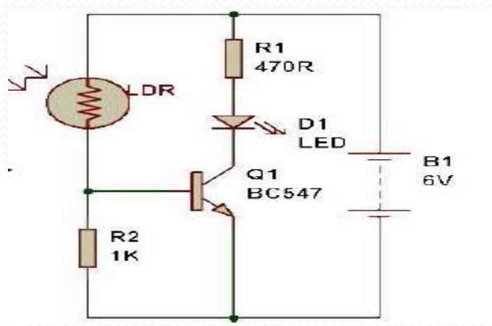
Nature of Sensor Technique (use a voltage divider)

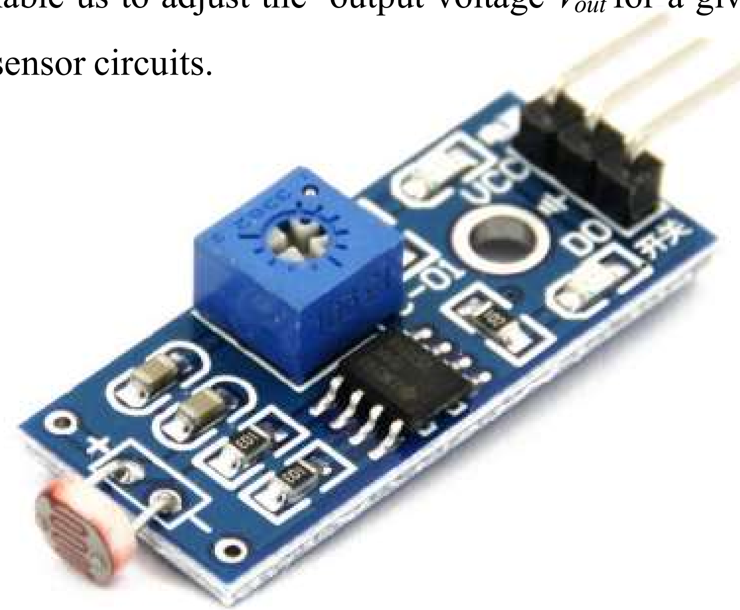
1. <u>Variable resistors sensors</u>:

Force-sensitive resistors, and thermistors are variable resistors, also photocell is a variable resistor, which produces a resistance proportional to the amount of light it senses. The variable resistor (L*ight-Dependent Resistor LDR*) which has a high resistance when dark and a low resistance when brightly lit will enable us to adjust the output voltage V_{out} for a given resistance of the sensor to set the exact brightness level in dark and light sensor circuits.

Automatic dark and light sensor







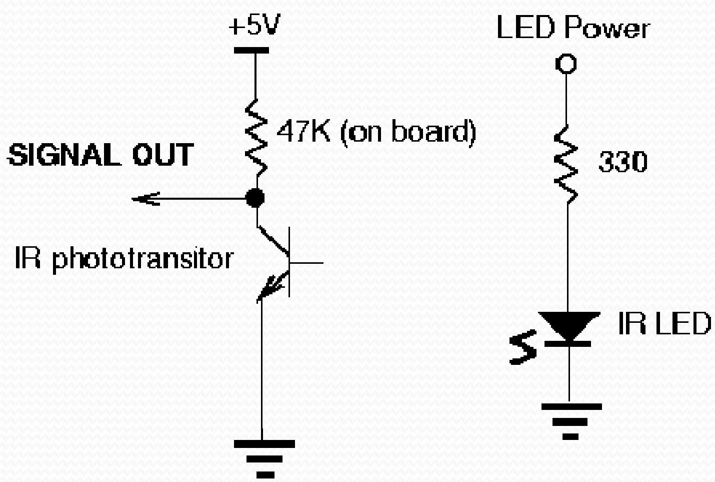
1 If the *LDR* is at the top (near $+V_S$), V_{out} will be low in the dark and high in bright light. As the light level increases and *LDR* meets the lowest threshold resistance the output voltage is large when the resistance of *LDR* is low. This voltage would enough for a transistor to turn on a *LED*. Hence, this circuit automatically turns on the *LED* D_1 and works as Automatic Light sensor.

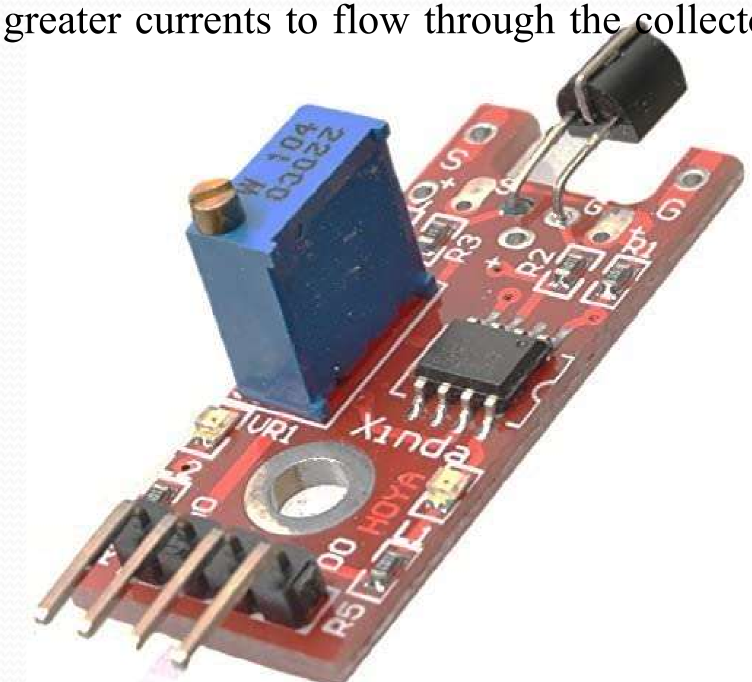
2 If the *LDR* is at the bottom (near 0V), V_{out} will be high in the dark and low in bright light. As the light level decreases and *LDR*

Other Sensors

2. Light sensor (Phototransistor):

The light falling on a phototransistor creates charge carriers in the base region of a transistor, effectively providing base current. The intensity of the light determines the effective base drive and thus the conductivity of the transistor. Greater amounts of light cause greater currents to flow through the collector-emitter leads.





The light emitting element (*LED*) uses a resistor to limit the current that can flow through the device to the proper value of about 10 milliamps. Normally the emitter is always on, but it could be wired to one of the *LED* output ports if we wanted to control it separately. In this way we could use the same sensor to detect the starting light (using the phototransistor with the emitter off) and then to follow a line on the board (normal operation with the emitter on).

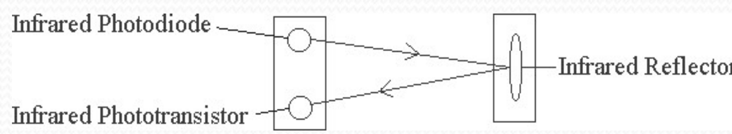
Other Sensors

Motion detectors:

Motion detection is the action of sensing physical movement in a given area. An electronic motion detector contains a motion sensor that transforms the detection of motion into an electric signal.

a) Infra-Red (*IR*) Proximity Sensors

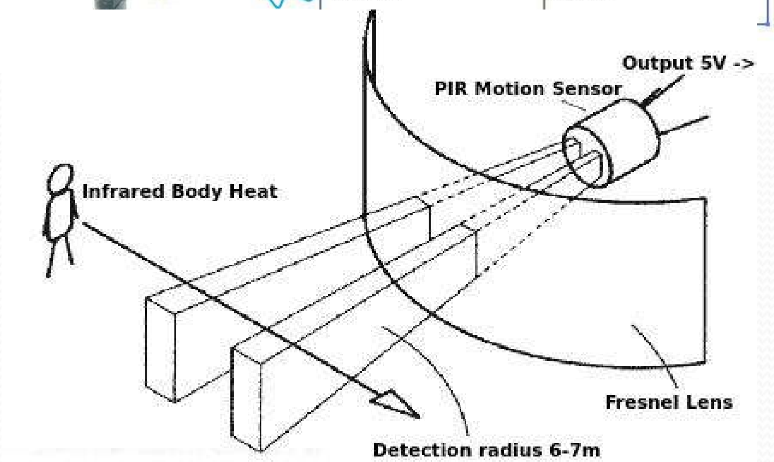
Infrared (*IR*) is an electromagnetic spectrum at a wavelength that is longer than visible light. *IR* sensor works on the principle of emitting *IR* rays and receiving the reflected ray by a receiver. That's mean; there are two-piece elements transmitter (infrared-emitting diode) and receiver (infrared-sensitive phototransistor or photodiode) as shown in Figure.

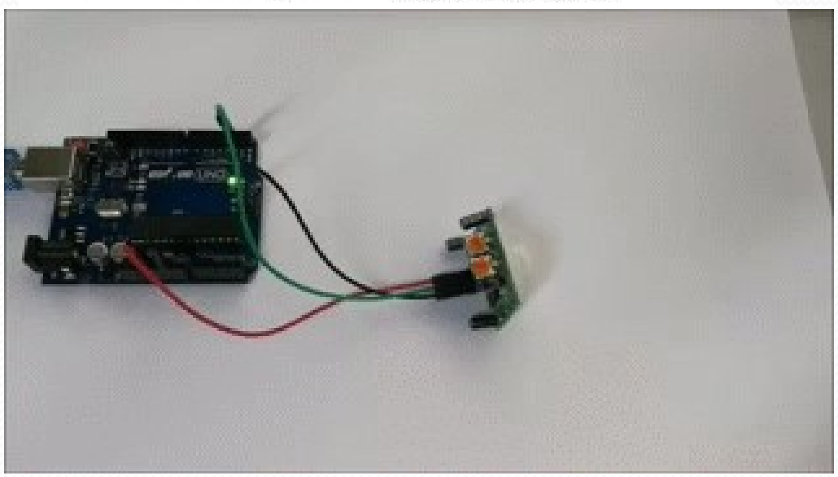


The sensor send infrared light through *IR-LEDs*, then the light reflected by any object in front of the sensor, another *IR-LED* detecting the reflected *IR* light and perform the task of a voltage divider. An electrical property of Light Emitting Diodes (*LEDs*) produces a voltage difference across its leads when it is subjected to light. The greater the intensity of *IR* light hitting *IR* receiver, the lower the resistance of *IR* receiver and hence the output voltage of voltage divider will decreased. The device should be shielded from ambient lighting as much as possible in order to obtain reliable results.

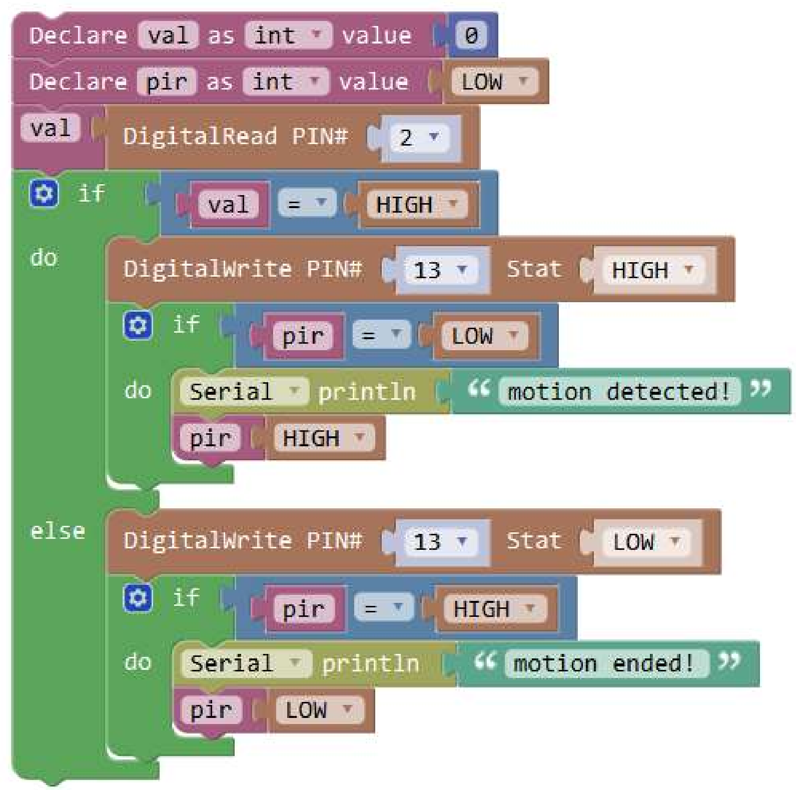
Infra-Red (IR) Proximity Sensors

Counter-Clockwise or Left	Clockwise or Right
Increases Sensitivity. Fully left and the range will be approximately 7 meters.	Decreases Sensitivity. Fully right and the range will be approximately 3 meters.





Counter-Clockwise or Left	Clockwise or Right
Decreases Delay Time. Fully left and the delay will be approximately 5 seconds.	Increases Delay Time. Fully right and the delay will be approximately 5 minutes.



Other Sensors

A reflectance sensor can be used to detect features drawn on a surface or segments on a wheel used to encode rotations of a shaft. It is important to remember that the reflectivity measurement indicates the surface's reflectivity at a particular wavelength of light (the near-visible infrared). In general, surfaces that absorb visible light (making them appear dark to the eye) will absorb infrared light as well.

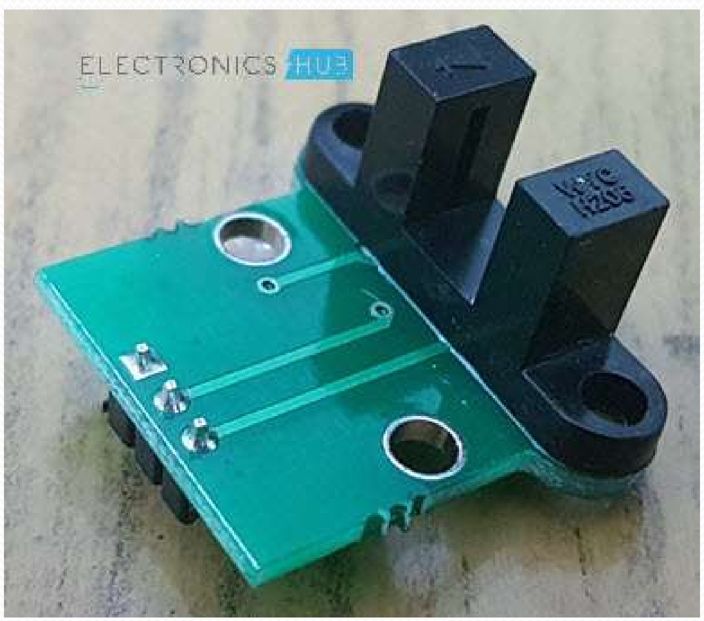
b) Passive Infrared (*PIR*) motion detectors

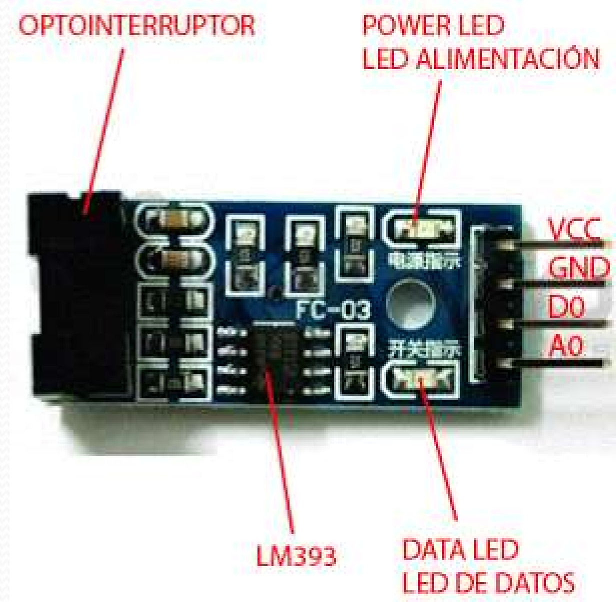
Passive Infrared (*PIR*) motion detectors detect the movements of the objects with identical temperature and measures infrared (*IR*) light radiating from objects in its field of view and automatically activated the systems. A passive infrared (*PIR*) sensor measures infrared light emitted from objects that generate heat, and therefore infrared radiation, in its field of view. The sensor is actually split into two halves so as to detect not the radiation itself, but the change in condition that occurs when a target enters its field. These changes in the amount of infrared radiation on the element in turn change the voltages generated, which are measured by an on-board amplifier.

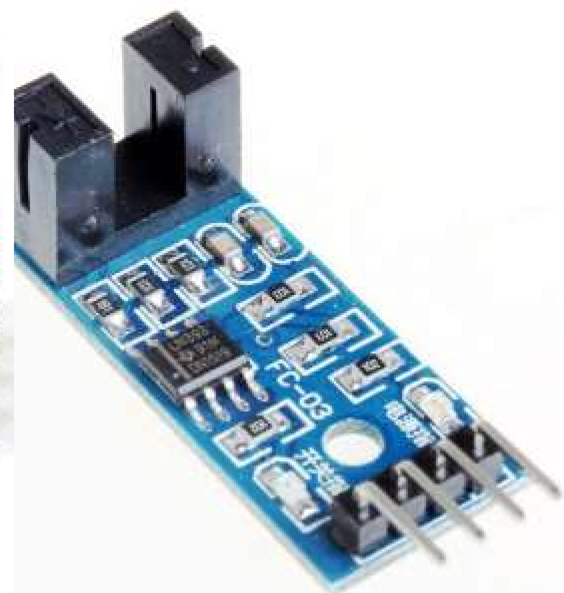
Other Sensors

<u>Speed sensors</u>

<u>Digital</u>: The speed or position of a *dc* motor cannot be controlled accurately without feedback. Digital feedback from the incremental encoder is the most common method in processor systems, since the output from the opto-detector is easily converted into a TTL (transistor-transistor logic) signal. The position relative to a known start position is calculated by counting the encoder pulses, and the speed can then readily be determined from the pulse frequency. This can be used to control the dynamic behavior of the motor, by accelerating and decelerating to provide optimum speed, accuracy and output power.



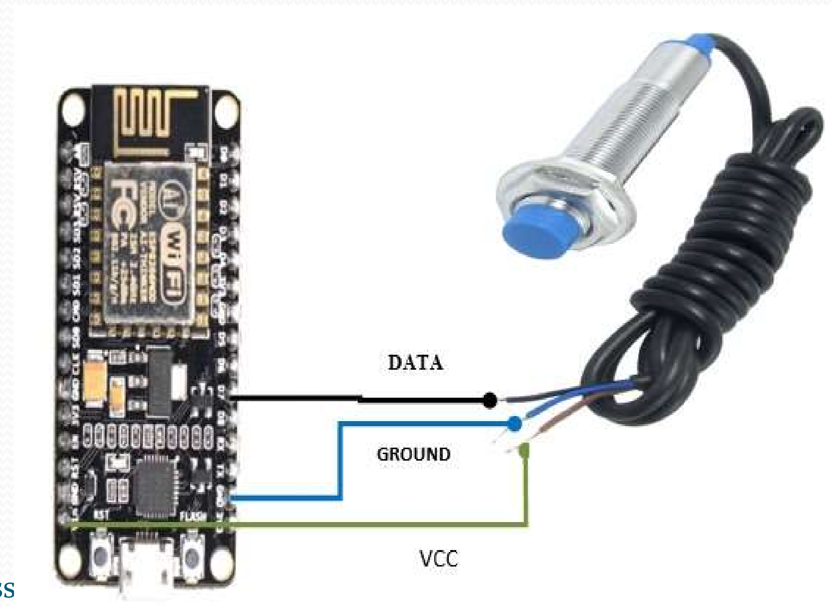




__Analogue__: For analogue feedback of speed, a tacho-generator can be used; this is essentially a permanent magnet *dc* motor run as a generator. An output voltage is generated which is proportional to the speed of rotation. The voltage induced in the armature is proportional to the velocity at which the windings cut across the field.

If the tachometer is attached to the output shaft of a motor controlled using PWM, the tachometer voltage can be converted by the MCU and used to modify the PWM output to the motor, giving closed loop speed control. Alternatively, an incremental encoder can be used, and the motor output controlled such that a set input frequency is obtained from the encoder.

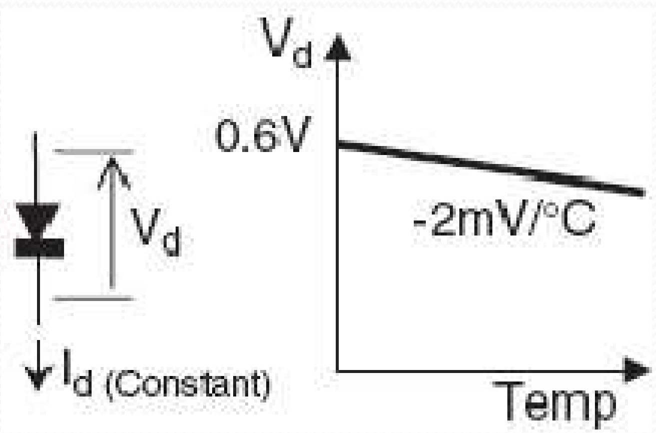
ss

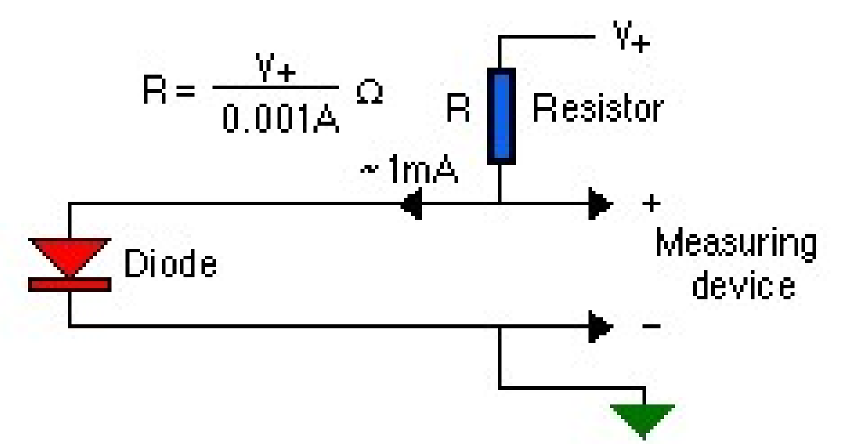


Other Sensors

Temperature sensors

Diode: The forward voltage drop of a silicon diode junction is usually estimated as 0.6 V. However, this depends on the junction temperature; the voltage falls by 2 mV/C° as the temperature rises, as the charge carriers gain thermal energy, and need less electrical energy to cross the junction.





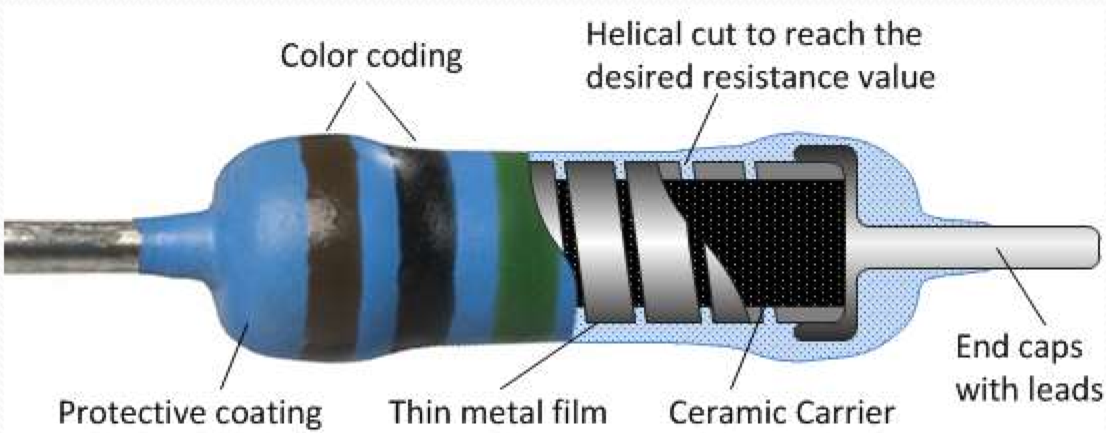
Diode as a Temperature Sensor

Temperature sensors

Metals: Metals have a reasonably linear temperature coefficient of resistance over limited ranges. Metal film resistors are produced which operate up to about 150°C, with platinum sensors working up to 600°C. The temperature coefficient is typically 0.3%/C°.

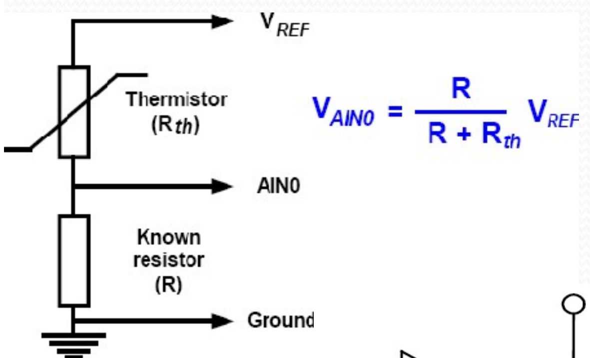
If the resistance at the reference temperature is, say, 1 kΩ, the resistance change over 100°C would be 300-400 Ω. A constant current is needed to convert the resistance change into a linear voltage change.

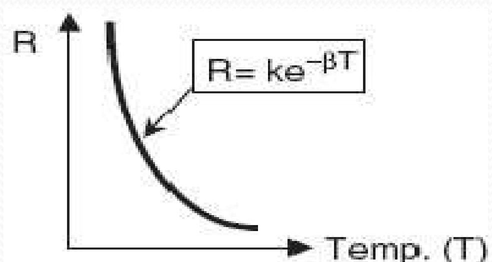
If a 1 kΩ temperature-sensing resistor is supplied with a constant 1 mA, the voltage at the reference temperature, 25°C, would be 1.00 V, and the change at 125°C would be 370 mV, taking it to 1.37 V.

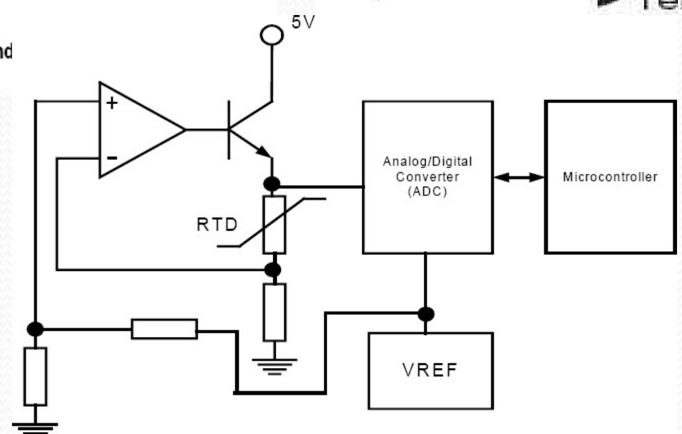


Other Sensors

Thermistor: Temperature dependant semiconductor resistors (Thermistors) are thermally sensitive resistors and have, according to type, a negative (NTC), or positive (PTC) resistance / temperature coefficient. They are made from a single piece of semiconductor material, where the charge carrier mobility, therefore the resistance, depends on temperature. The response is exponential, giving a relatively large change for a small change in temperature, and a particularly high sensitivity. Unfortunately, it is non-linear, so is difficult to convert for precise measurement purposes. The thermistor therefore tends to be used as a safety sensor, to detect if a component such as a motor or transformer .



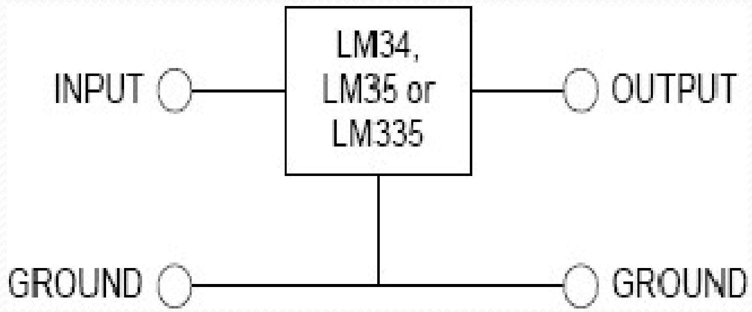




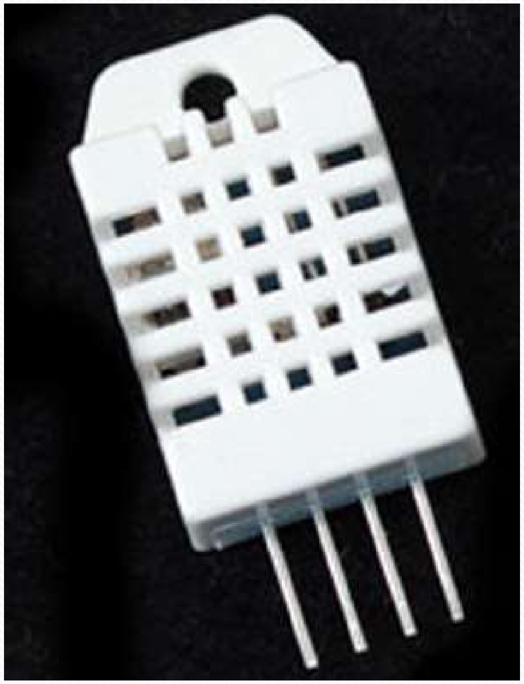
Sensor and Its working

Semiconductor Temperature Sensors:

If measurement or control is needed in the range of around room temperature, an integrated sensor and amplifier such as the LM35 is a versatile device which is easy to interface.

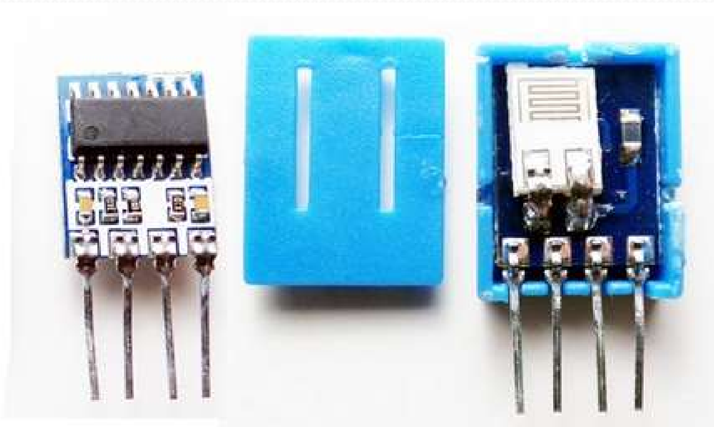


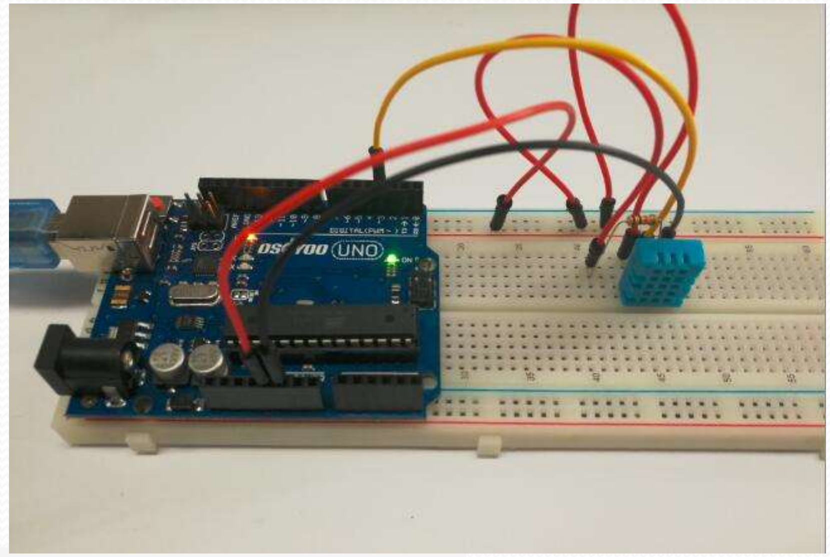
For example, a humidity sensor measures the concentration of water (moisture) in the air. Humidity sensors react to these phenomena and generate a voltage that the microcontroller or similar device can then read and use to calculate a value on a scale.



The DHT-22 is designed to measure temperature as well as humidity. It generates a digital signal on the output (data pin). Although simple to use, it's a bit slow and should be used to track data at a reasonably slow rate (no more frequently than about once every 3 or 4 seconds).

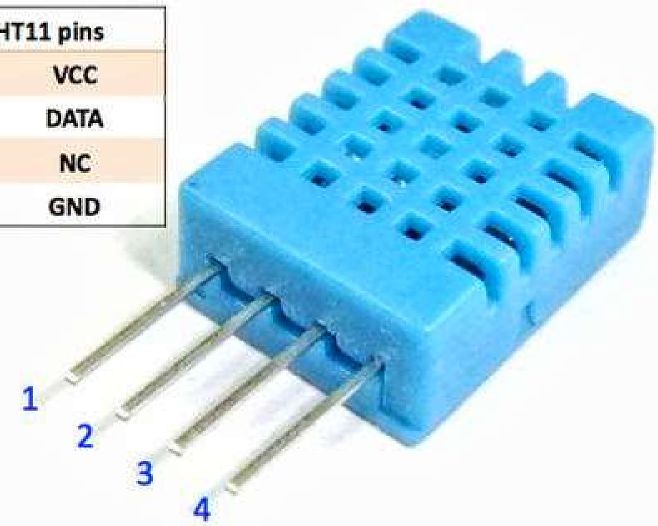
Sensor and Its working





```
#include<dht.h> dht DHT;
// if you require to change the pin number, Edit the pin with your arduino pin.
#define DHT11_PIN 3
void setup() {
Serial.begin(9600);
Serial.println("The real time Temperature and Humidity is :");
}
void loop() { // READ DATA int chk = DHT.read11(DHT11_PIN);
 Serial.print(" Humidity: " );
 Serial.print(DHT.humidity, 1);
 Serial.println('%');
 Serial.print(" Temparature ");
 Serial.print(DHT.temperature, 1);
 Serial.println('C');
 delay(2000);
}
```

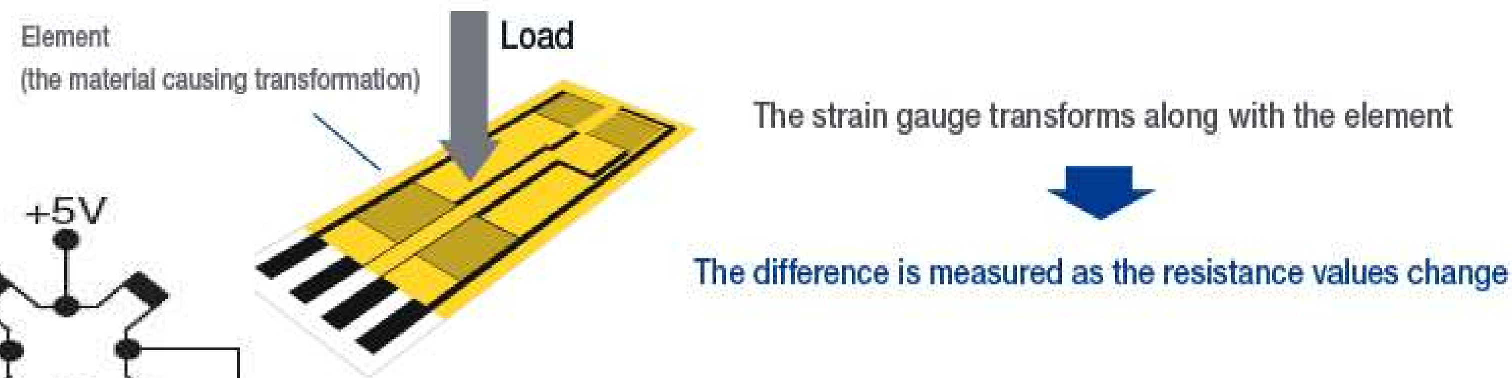
DHT11 pins	
1	VCC
2	DATA
3	NC
4	GND

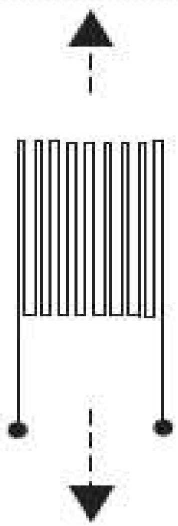


Strain sensors:

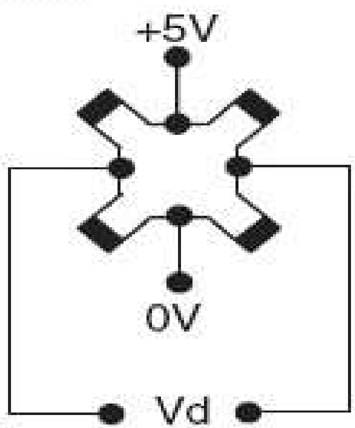
A temperature-stable alloy conductor is folded onto a flexible substrate which lengthens when the gauge is stretched (strained). The resistance increases as the conductor becomes longer and thinner. This can be used to measure small changes in the shape of mechanical components, and hence the forces exerted upon them. The strain gauge can measure displacement by the same means.

General strain gauge mechanism





Strain



Bridge output

Examples of Sensors

Accelerometers: These sensors measure motion or movement of the sensor or whatever it's attached to. They're designed to sense motion (velocity, inclination, vibration, and so on) on several axes. Some include gyroscopic features. Most are digital sensors. A Wii Nunchuck (or WiiChuck) contains a sophisticated accelerometer for tracking movement.

Audio sensors: Perhaps this is obvious, but microphones are used to measure sound. Most are analog, but some of the better security and surveillance sensors have digital variants for higher compression of transmitted data.

Barcode readers: These sensors are designed to read barcodes. Most often, barcode readers generate digital data representing the numeric equivalent of a barcode. Such sensors are often used in inventory-tracking systems to track equipment through a plant or during transport. They're plentiful, and many are economically priced, enabling you to incorporate them into your own projects.

Examples of Sensors

RFID sensors: Radio frequency identification uses a passive device (sometimes called an *RFID tag*) to communicate data using radio frequencies through electromagnetic induction.
For example, an RFID tag can be a credit-card-sized plastic card, a label, or something similar that contains a special antenna, typically in the form of a coil, thin wire, or foil layer that is tuned to a specific frequency. When the tag is placed in close proximity to the reader, the reader emits a radio signal; the tag can use the electromagnet energy to transmit a non-volatile message embedded in the antenna, in the form of radio signals which is then converted to an alphanumeric string.

Biometric sensors: A sensor that reads fingerprints, irises, or palm prints contains a special sensor designed to recognize patterns. Given the uniqueness inherit in patterns such as fingerprints and palm prints, they make excellent components for a secure access system. Most biometric sensors produce a block of digital data that represents the fingerprint or palm print.

Capacitive sensors: A special application of capacitive sensors, pulse sensors are designed to measure your pulse rate and typically use a fingertip for the sensing site. Special devices known as pulse oximeters (called *pulse-ox* by some medical professionals) measure pulse rate with a capacitive sensor and determine the oxygen content of blood with a light sensor. If you own modern electronic devices, you may have encountered touch-sensitive buttons that use special capacitive sensors to detect touch and pressure.

Examples of Sensors

Coin sensors: This is one of the most unusual types of sensors.10 These devices are like the coin slots on a typical vending machine. Like their commercial equivalent, they can be calibrated to sense when a certain size of coin is inserted. Although not as sophisticated as commercial units that can distinguish fake coins from real ones, coin sensors can be used to add a new dimension to your projects. Imagine a coin-operated WiFi station. Now, that should keep the kids from spending too much time on the Internet!

Current sensors: These are designed to measure voltage and amperage. Some are designed to measure change, whereas others measure load.

Flex/Force sensors: Resistance sensors measure flexes in a piece of material or the force or impact of pressure on the sensor. Flex sensors may be useful for measuring torsional effects or as a means to measure finger movements (like in a Nintendo Power Glove). Flex-sensor resistance increases when the sensor is flexed.

Gas sensors: There are a great many types of gas sensors. Some measure potentially harmful gases such as LPG and methane and other gases such as hydrogen, oxygen, and so on. Other gas sensors are combined with light sensors to sense smoke or pollutants in the air.

Examples of Sensors

Light sensors: Sensors that measure the intensity or lack of light are special types of resistors: light-dependent resistors (LDRs), sometimes called photo resistors or photocells. Thus, they’re analog by nature. If you own a Mac laptop, chances are you’ve seen a photo resistor in action when your illuminated keyboard turns itself on in low light. Special forms of light sensors can detect other light spectrums such as infrared (as in older TV remotes).

Liquid-flow sensors: These sensors resemble valves and are placed in-line in plumbing systems. They measure the flow of liquid as it passes through. Basic flow sensors use a spinning wheel and a magnet to generate a Hall effect (rapid ON/OFF sequences whose frequency equates to how much water has passed).

Liquid-level sensors: A special resistive solid-state device can be used to measure the relative height of a body of water. One example generates low resistance when the water level is high and higher resistance when the level is low.

Location sensors: Modern smartphones have GPS sensors for sensing location, and of course GPS devices use the GPS technology to help you navigate. Fortunately, GPS sensors are available in low-cost forms, enabling you to add location sensing to your sensor network. GPS sensors generate digital data in the form of longitude and latitude, but some can also sense altitude.

Examples of Sensors

Magnetic-stripe readers: These sensors read data from magnetic stripes (like that on a credit card) and return the digital form of the alphanumeric data (the actual strings).

Magnetometers: These sensors measure orientation via the strength of magnetic fields. A compass is a sensor for finding magnetic north. Some magnetometers offer multiple axes to allow even finer detection of magnetic fields.

Proximity sensors: Often thought of as distance sensors, proximity sensors use infrared or sound waves to detect distance or the range to/from an object. Made popular by low-cost robotics kits, the Parallax Ultrasonic Sensor uses sound waves to measure distance by sensing the amount of time between pulse sent and pulse received (the echo). For approximate distance measuring, it's a simple math problem to convert the time to distance.

Radiation sensors: Among the more serious sensors are those that detect radiation. This can also be electromagnetic radiation (there are sensors for that too), but a Geiger counter uses radiation sensors to detect harmful ionizing. In fact, it's possible to build your very own Geiger counter using a sensor and an Arduino (and a few electronic components).

Examples of Sensors

Speed sensors: Similar to flow sensors, simple speed sensors like those found on many bicycles use a magnet and a reed switch to generate a Hall effect. The frequency combined with the circumference of the wheel can be used to calculate speed and, over time, distance travelled. Yes, a bicycle computer is yet another example of a simple sensor network: the speed sensor on the wheel and fork provides the data for the monitor on your handlebars.

Switches and pushbuttons: These are the most basic of digital sensors used to detect if something is set (ON) or reset (OFF).

Tilt switches: These sensors can detect when a device is tilted one way or another. Although very simple, they can be useful for low-cost motion-detection sensors. They are digital and are essentially switches.

Touch sensors: The touch-sensitive membranes formed into keypads, keyboards, pointing devices, and the like are an interesting form of sensor. You can use touch-sensitive devices like these for sensor networks that need to collect data from humans.

Examples of Sensors

Video sensors: As mentioned previously, it's possible to obtain very small video sensors that use cameras and circuitry to capture images and transmit them as digital data.

Weather sensors: Sensors for temperature, barometric pressure, rain fall, humidity, wind speed, and so on are all classified as weather sensors. Most generate digital data and can be combined to create comprehensive environmental sensor networks. Yes, it's possible to build your own weather station from about a dozen inexpensive sensors, an Arduino (or a Raspberry Pi), and a bit of programming to interpret and combine the data.

What Is an XBee?

• *Whip or wire antenna*: A simple solution consisting of a single wire soldered onto the Xbee module. These tend to be the cheaper of the antenna options because they do not require any additional hardware to use. They also provide omnidirectional signals, which means they send (radiate) approximately the same signal strength in all directions. This is the module you would use when building sensor nodes whose orientation is unknown and whose antenna wire can be exposed (not enclosed in a case). The wire antenna is not durable and can be easily broken if flexed too often.

• *Chip*: These modules have the antenna mounted as a discrete component on the module. This provides an option without any protrusions, but it does have a limitation. The signal is transmitted in a rough pattern that resembles a heart shape, which means the signal is attenuated in many directions (not omnidirectional). However, because the chip antenna is nearly flush, it makes a good choice for any sensor that will be placed (or worn) in a small space. It's a good alternative to the whip antenna.

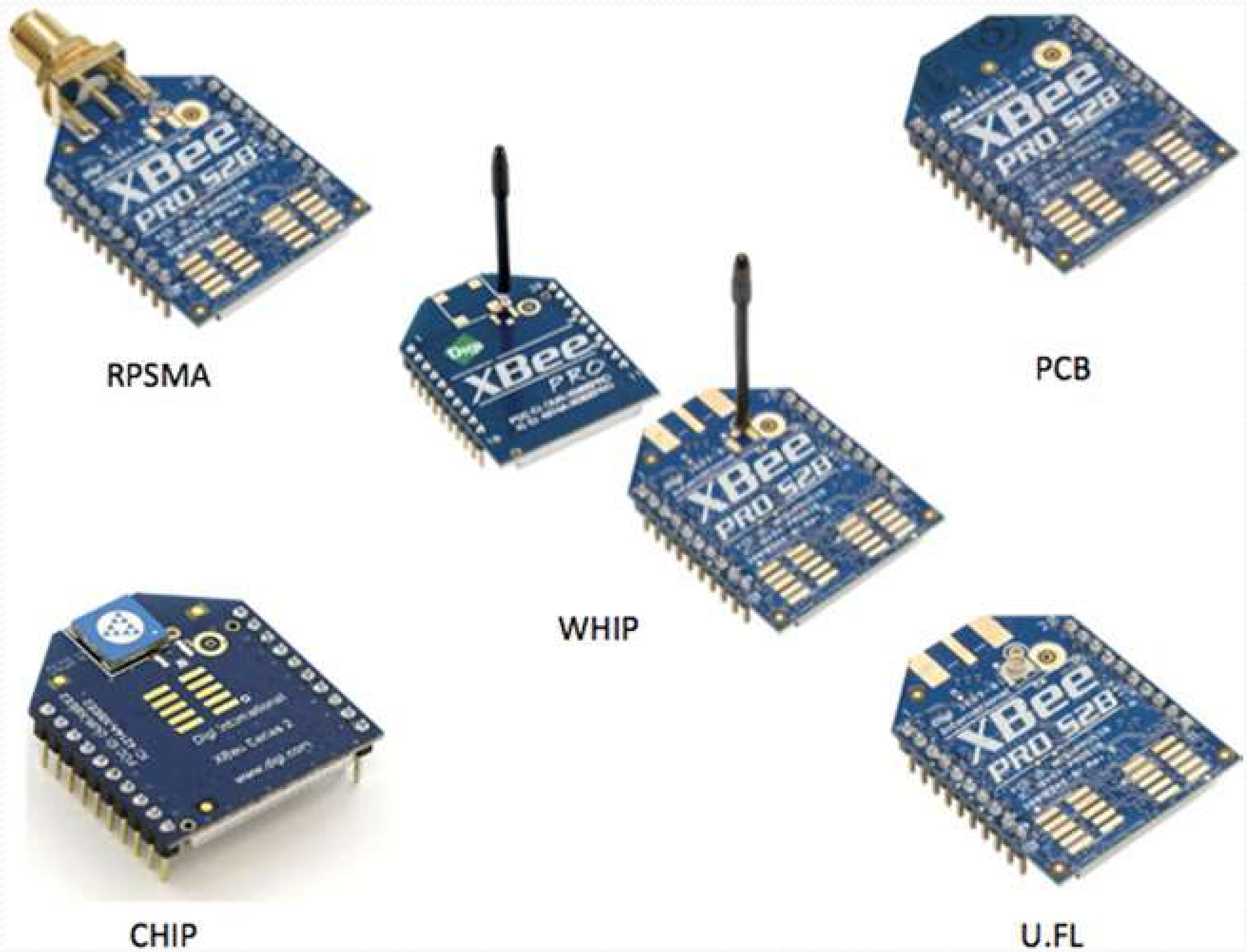
What Is an XBee?

• *U.FL*: This option has a very small connector that requires an adapter cable (called a *pigtail*) to permit the connection to an external antenna. These antennas have the advantage that the XBee module can be enclosed in a casing (even metal) and the antenna mounted to the exterior of the case. These modules tend to cost a few dollars more and require the purchase of the pigtail as well as the antenna.

• *RPSMA*: Like the U.FL option, this one provides for an external antenna; but it uses the much larger Reverse Polarity Sub-Miniature Version (RPSMA) connector. You can mount a swivel antenna to the connector directly, but the risk of stress on the antenna is too great. Thus, you should use an extension cable and mount the antenna externally. Like the U.FL option, these modules cost a bit more and require the purchase of an antenna.

• *PCB*: The antenna is printed or embedded as a wire trace onto the module itself. This type of module is similar to the chip antenna and may be a bit less expensive to manufacture. Currently, only the PRO modules are available with this antenna option.`

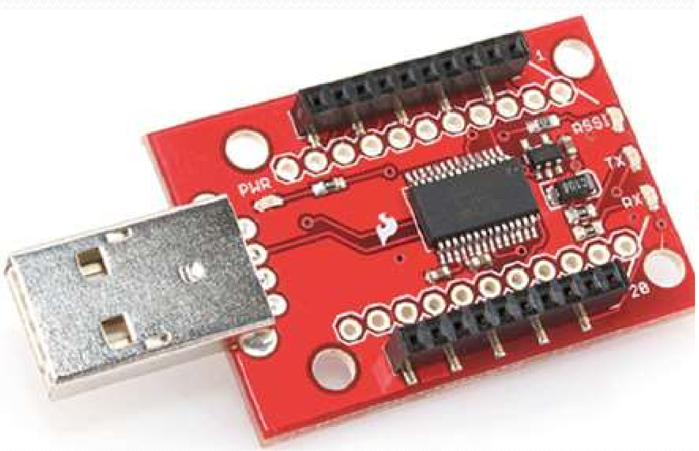
XBee Module Antenna Options

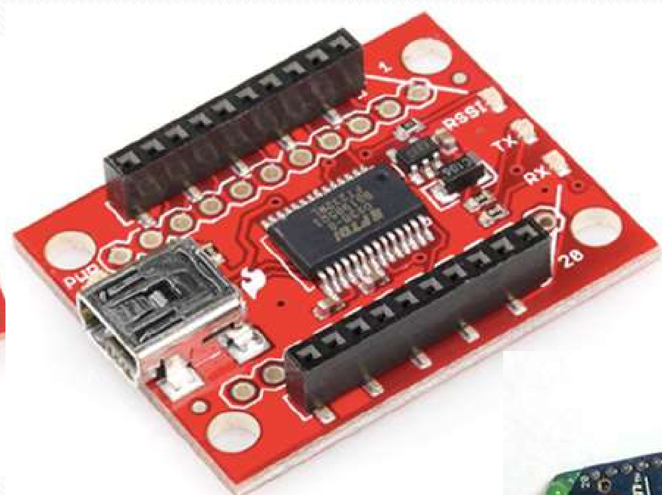


Interacting with an XBee-ZB Module

When you examine the XBee module, the first thing you notice is that the pin layout is much smaller than that of a typical discrete component designed for breadboard use. Furthermore, you cannot connect your computer directly to the XBee.

You need a USB adapter to mount the XBee to allow communication with the module. Fortunately, several variants are available. You use the USB adapter to configure the module.





ZigBee Networks

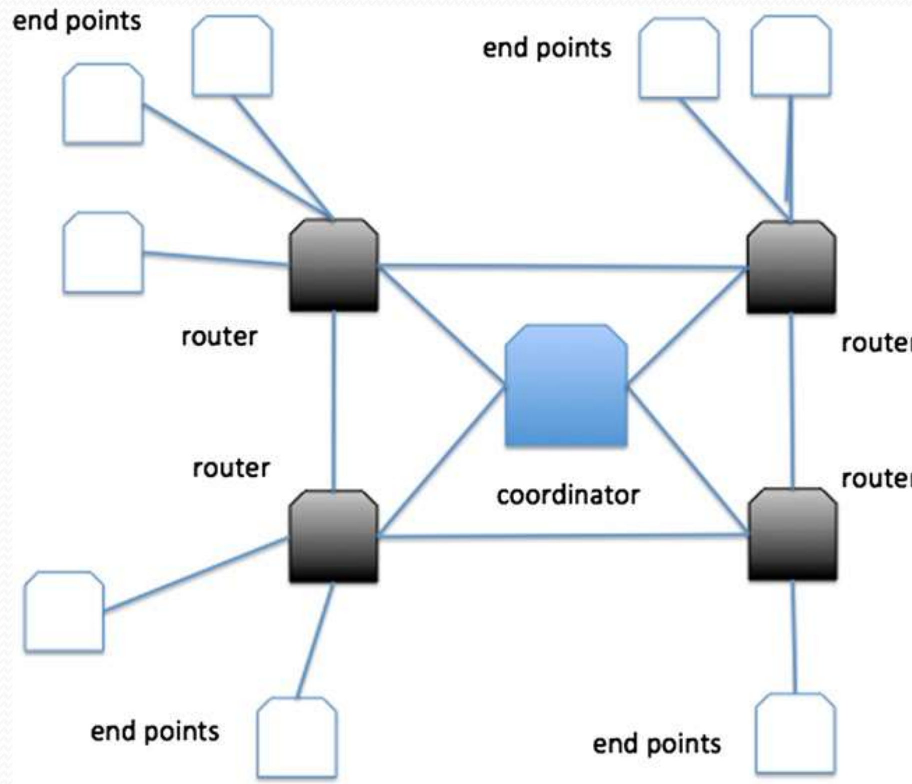
ZigBee networks are based on a predefined network stack where each layer in the stack is responsible for a specific transformation of the data messages. Also like other networks, ZigBee networks support message routing, ad hoc network creation, and self-healing mesh topologies. Thus, the radio address and the PAN address are needed to support these features. Support for mesh topologies is made possible with the addition of different roles that each node (radio) can perform in the network. The following list describes each role in more detail, starting from the most complex.

- *Coordinator*: A single coordinator is needed for each network. This node is responsible for administering addresses and forming and managing the network. All other nodes search for the coordinator and exchange handshake information at start-up.

ZigBee Networks

• *Router*: A node that is configured as a router is designed to pass on (*route*) information to other radios. Routers enable the healing of mesh networks by joining networks and exchanging messages from other nodes. Routers are typically powered with reliable sources because they must be dependable. Thus, a data-aggregation node would be a good choice for the router radio mode.

End device: An end device is a node that sends or receives information to the router nodes and the coordinator. It has an advantage in that less processing is going on, so power consumption is lower. End devices support a sleep mode to reduce power requirements still further. Most of your sensor nodes will be configured as end devices.



ZigBee mesh network