Proximity sensors compared: Inductive, capacitive, photoelectric, and ultrasonic

Motion System Design

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Inductive sensors

These non-contact proximity sensors detect ferrous targets, ideally mild steel thicker than one millimeter. They consist of four major components: a ferrite core with coils, an oscillator, a Schmitt trigger, and an output amplifier. The oscillator creates a symmetrical, oscillating magnetic field that radiates from the ferrite core and coil array at the sensing face. When a ferrous target enters this magnetic field, small independent electrical currents called eddy currents are induced on the metal's surface. This changes the reluctance (natural frequency) of the magnetic circuit, which in turn reduces the oscillation amplitude. As more metal enters the sensing field the oscillation amplitude shrinks, and eventually collapses. (This is the "Eddy Current Killed Oscillator" or ECKO principle.) The Schmitt trigger responds to these amplitude changes, and adjusts sensor output. When the target finally moves from the sensor's range, the circuit begins to oscillate again, and the Schmitt trigger returns the sensor to its previous output.

If the sensor has a normally open configuration, its output is an on signal when the target enters the sensing zone. With normally closed, its output is an off signal with the target present. Output is then read by an external control unit (e.g. PLC, motion controller, smart drive) that converts the sensor on and off states into useable information. Inductive sensors are typically rated by frequency, or on/off cycles per second. Their speeds range from 10 to 20 Hz in ac, or 500 Hz to 5 kHz in dc. Because of magnetic field limitations, inductive sensors have a relatively narrow sensing range — from fractions of millimeters to 60 mm on average — though longer-range specialty products are available.

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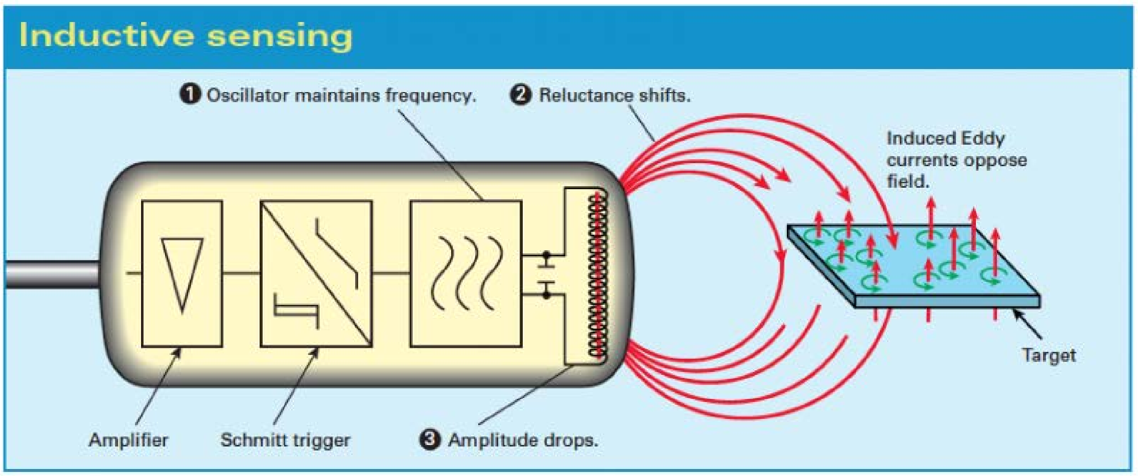
To accommodate close ranges in the tight confines of industrial machinery, geometric and mounting styles available include shielded (flush), unshielded (non-flush), tubular, and rectangular “flat-pack”. Tubular sensors, by far the most popular, are available with diameters from 3 to 40 mm.



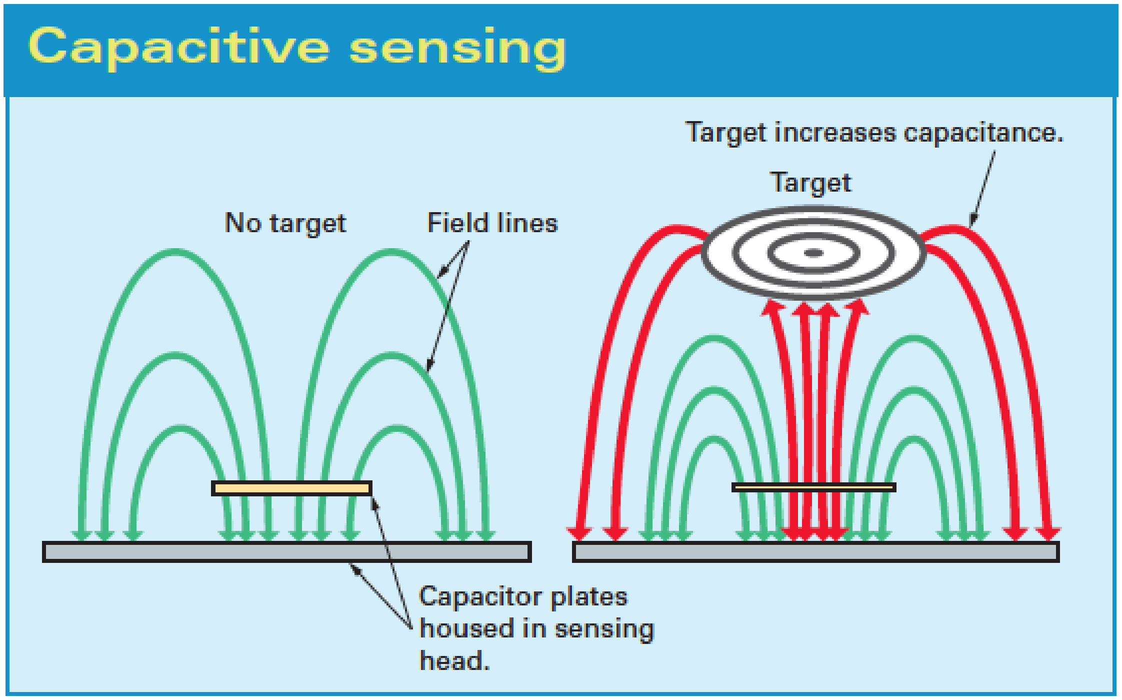
Ferrous targets change the reluctance of the magnetic circuit; system oscillation frequency, which gets left behind when the natural frequency shifts, then loses amplitude.

But what inductive sensors lack in range, they make up in environment adaptability and metal-sensing versatility. With no moving parts to wear, proper setup guarantees long life. Special designs with IP ratings of 67 and higher are capable of withstanding the buildup of contaminants such as cutting fluids, grease, and non-metallic dust, both in the air and on the sensor itself. It should be noted that metallic contaminants (e.g. filings from cutting applications) sometimes affect the sensor’s performance. Inductive sensor housing is typically nickel-plated brass, stainless steel, or PBT plastic.

Capacitive sensors

Capacitive proximity sensors can detect both metallic and non-metallic targets in powder, granulate, liquid, and solid form. This, along with their ability to sense through nonferrous materials, makes them ideal for sight glass monitoring, tank liquid level detection, and hopper powder level recognition.

In capacitive sensors, the two conduction plates (at different potentials) are housed in the sensing head and positioned to operate like an open capacitor. Air acts as an insulator; at rest there is little capacitance between the two plates. Like inductive sensors, these plates are linked to an oscillator, a Schmitt trigger, and an output amplifier. As a target enters the sensing zone the capacitance of the two plates increases, causing oscillator amplitude change, in turn changing the Schmitt trigger state, and creating an output signal. Note the difference between the inductive and capacitive sensors: inductive sensors oscillate until the target is present and capacitive sensors oscillate when the target is present.

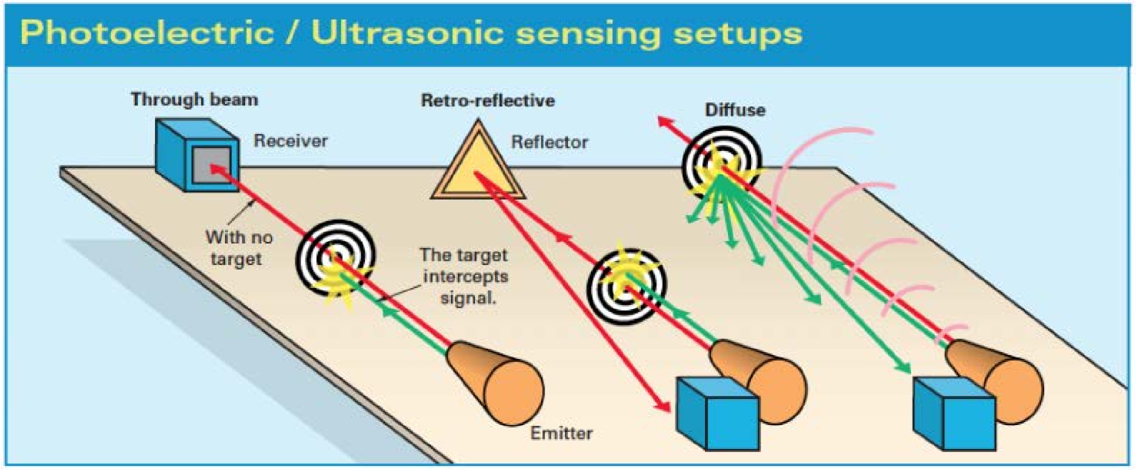


As a ferrous or nonferrous target enters the sensing zone, capacitance increases; circuit natural frequency shifts towards the oscillation frequency, causing amplitude gain.

Because capacitive sensing involves charging plates, it is somewhat slower than inductive sensing … ranging from 10 to 50 Hz, with a sensing scope from 3 to 60 mm. Many housing styles are available; common diameters range from 12 to 60 mm in shielded and unshielded mounting versions. Housing (usually metal or PBT plastic) is rugged to allow mounting very close to the monitored process. If the sensor has normally-open and normally-closed options, it is said to have a complimentary output. Due to their ability to detect most types of materials, capacitive sensors must be kept away from non-target materials to avoid false triggering. For this reason, if the intended target contains a ferrous material, an inductive sensor is a more reliable option.

Photoelectric sensors

Photoelectric sensors are so versatile that they solve the bulk of problems put to industrial sensing. Because photoelectric technology has so rapidly advanced, they now commonly detect targets less than 1 mm in diameter, or from 60 m away. Classified by the method in which light is emitted and delivered to the receiver, many photoelectric configurations are available. However, all photoelectric sensors consist of a few of basic components: each has an emitter light source (Light Emitting Diode, laser diode), a photodiode or phototransistor receiver to detect emitted light, and supporting electronics designed to amplify the receiver signal. The emitter, sometimes called the sender, transmits a beam of either visible or infrared light to the detecting receiver.



Lasers or sound waves serve as the signal in three setups. In through beam and retro-reflective, the signal shoots from the emitter to receiver until the target cuts it off. In diffuse sensing, the signal diverges until a target moves in and reflects some back to the receiver.

All photoelectric sensors operate under similar principles. Identifying their output is thus made easy; darkon and light-on classifications refer to light reception and sensor output activity. If output is produced when no light is received, the sensor is dark-on. Output from light received, and it's light-on. Either way, deciding on light-on or dark-on prior to purchasing is required unless the sensor is user adjustable. (In that case, output style can be specified during installation by flipping a switch or wiring the sensor accordingly.)

Through-beam

The most reliable photoelectric sensing is with through-beam sensors. Separated from the receiver by a separate housing, the emitter provides a constant beam of light; detection occurs when an object passing between the two breaks the beam. Despite its reliability, through-beam is the least popular photoelectric setup. The purchase, installation, and alignment

of the emitter and receiver in two opposing locations, which may be quite a distance apart, are costly and laborious. With newly developed designs, through-beam photoelectric se

nsors typically offer the longest sensing distance of photoelectric sensors — 25 m and over is now commonplace. New laser diode emitter models can transmit a well-collimated beam 60 m for increased accuracy and detection. At these distances, some through-beam laser sensors are capable of detecting an object the size of a fly; at close range, that becomes 0.01 mm. But while these laser sensors increase precision, response speed is the same as with non-laser sensors — typically around 500 Hz.

One ability unique to throughbeam photoelectric sensors is effective sensing in the presence of thick airborne contaminants. If pollutants build up directly on the emitter or receiver, there is a higher probability of false triggering. However, some manufacturers now incorporate alarm outputs into the sensor's circuitry that monitor the amount of light hitting the receiver. If detected light decreases to a specified level without a target in place, the sensor sends a warning by means of a builtin LED or output wire.

Through-beam photoelectric sensors have commercial and industrial applications. At home, for example, they detect obstructions in the path of garage doors; the sensors have saved many a bicycle and car from being smashed. Objects on industrial conveyors, on the other hand, can be detected anywhere between the emitter and receiver, as long as there are gaps between the monitored objects, and sensor light does not "burn through" them. (Burnthrough might happen with thin or lightly colored objects that allow emitted light to pass through to the receiver.)

Proximity sensor comparison

Technology	Sensing range	Applications	Target materials
Inductive 	<4-40 mm	Any close-range detection of ferrous material	Iron Steel Aluminum Copper etc. 
Capacitative 	<3-60 mm	Close-range detection of non-ferrous material	Liquids Wood Granulates Plastic Glass etc. 
Photoelectric 	<1mm- 60 mm	Long-range, smalll or large target detection	Silicon Plastic Paper Metal etc. 
Ultrasonic 	<30 mm- 3 mm	Long-range detection of targets with difficult surface properites. Color/reflectivity insensitive.	Cellophane Foam Glass Liquid Powder etc. 

Retro-reflective

Retro-reflective sensors have the next longest photoelectric sensing distance, with some units capable of monitoring ranges up to 10 m. Operating similar to through-beam sensors without reaching the same sensing distances, output occurs when a constant beam is broken. But instead of separate housings for emitter and receiver, both are located in the same housing, facing the same direction. The emitter produces a laser, infrared, or visible light beam and projects it towards a specially designed reflector, which then deflects the beam back to the receiver. Detection occurs when the light path is broken or otherwise disturbed.

One reason for using a retro-reflective sensor over a through-beam sensor is for the convenience of one wiring location; the opposing side only requires reflector mounting. This results in big cost savings in both parts and time. However, very shiny or reflective objects like mirrors, cans, and plastic-wrapped juice boxes create a challenge for retro-reflective photoelectric sensors. These targets sometimes reflect enough light to trick the receiver into thinking the beam was not interrupted, causing erroneous outputs.

Some manufacturers have addressed this problem with polarization filtering, which allows detection of light only from specially designed reflectors ... and not erroneous target reflections.

Diffuse

As in retro-reflective sensors, diffuse sensor emitters and receivers are located in the same housing. But the target acts as the reflector, so that detection is of light reflected off the dist

urbance object. The emitter sends out a beam of light (most often a pulsed infrared, visible red, or laser) that diffuses in all directions, filling a detection area. The target then enters the area and deflects part of the beam back to the receiver. Detection occurs and output is turned on or off (depending upon whether the sensor is light-on or dark-on) when sufficient light falls on the receiver.

Diffuse sensors can be found on public washroom sinks, where they control automatic faucets. Hands placed under the spray head act as reflector, triggering (in this case) the opening of a water valve. Because the target is the reflector, diffuse photoelectric sensors are often at the mercy of target material and surface properties; a non-reflective target such as matte-black paper will have a significantly decreased sensing range as compared to a bright white target. But what seems a drawback 'on the surface' can actually be useful.

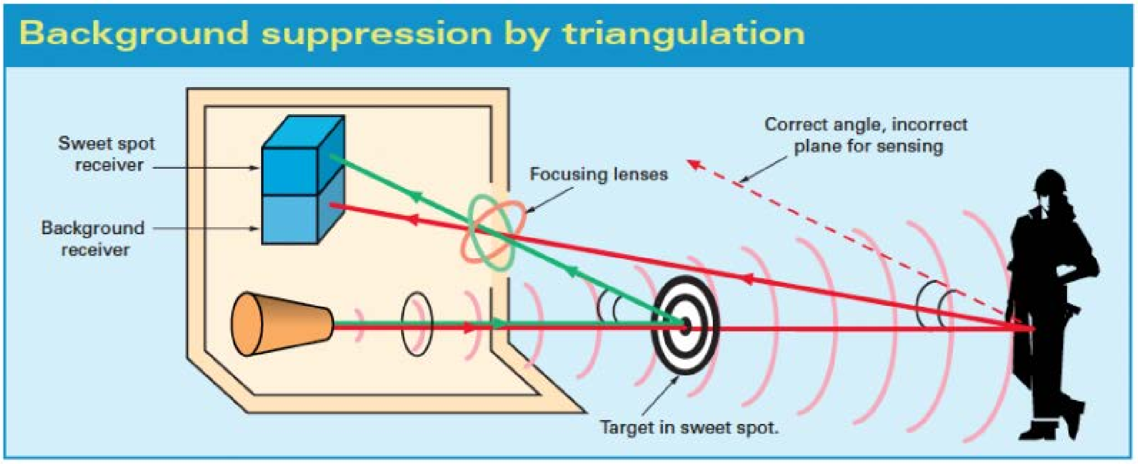
Because diffuse sensors are somewhat color dependent, certain versions are suitable for distinguishing dark and light targets in applications that require sorting or quality control by contrast. With only the sensor itself to mount, diffuse sensor installation is usually simpler than with through-beam and retro-reflective types. Sensing distance deviation and false triggers caused by reflective backgrounds led to the development of diffuse sensors that focus; they "see" targets and ignore background.

There are two ways in which this is achieved; the first and most common is through fixed-field technology. The emitter sends out a beam of light, just like a standard diffuse photoelectric sensor, but for two receivers. One is focused on the desired sensing sweet spot, and the other on the long-range background. A comparator then determines whether the long-range receiver is detecting light of higher intensity than what is being picking up the focused receiver. If so, the output stays off. Only when focused receiver light intensity is higher will an output be produced.

The second focusing method takes it a step further, employing an array of receivers with an adjustable sensing distance. The device uses a potentiometer to electrically adjust the sensing range. Such sensor

s operate best at their preset sweet spot. Allowing for small part recognition, they also provide higher tolerances in target area cutoff specifications and improved colorsensing capabilities. However, target surface qualities, such as glossiness, can produce varied results. In addition, highly reflective objects outside the sensing area tend to send enough light back to the receivers for an output, especially when the receivers are electrically adjusted.

To combat these limitations, some sensor manufacturers developed a technology known as true background suppression by triangulation.



Light reflected off shiny backgrounds might be bright enough to false trigger a sensor. Background suppression sensors avoid this problem by sensing *angles* of light. One receiver is lens-focused on the background; light returning from that focal plane is noted, then ignored. The other receiver is focused on the *sweet spot*; any light returning at its angles will provide an output.

A true background suppression sensor emits a beam of light exactly like a standard, fixed-field diffuse sensor. But instead of detecting light intensity, background suppression units rely completely on the angle at which the beam returns to the sensor.

To accomplish this, background suppression sensors use two (or more) fixed receivers accompanied by a focusing lens. The angle of received light is mechanically adjusted, allowing for a steep cutoff between target and background ... sometimes as small as 0.1 mm. This is a more stable method when reflective backgrounds are present, or when target color variations are an issue; reflectivity and color affect the intensity of reflected light, but not the angles of refraction used by triangulation- based background suppression photoelectric sensors.

Ultrasonic sensors

Ultrasonic proximity sensors are used in many automated production processes. They employ sound waves to detect objects, so color and transparency do not affect them (though extreme textures might). This makes them ideal for a variety of applications, including the longrange detection of clear glass and plastic, distance measurement, continuous fluid and granulate level control, and paper, sheet metal, and wood stacking.

The most common configurations are the same as in photoelectric sensing: through beam, retro-reflective, and diffuse versions. Ultrasonic diffuse proximity sensors employ a sonic transducer, which emits a series of sonic pulses, then listens for their return from the reflecting target. Once the reflected signal is received, the sensor signals an output to a control device. Sensing ranges extend to 2.5 m. Sensitivity, defined as the time window for listen cycles versus send or chirp cycles, may be adjusted via a teach-in button or potentiometer. While standard diffuse ultrasonic sensors give a simple present/absent output, some produce analog signals, indicating distance with a 4 to 20 mA or 0 to 10 Vdc variable output. This output can easily be converted into useable distance information.

Ultrasonic retro-reflective sensors also detect objects within a specified sensing distance, but by measuring propagation time. The sensor emits a series of sonic pulses that bounce off fixed, opposing reflectors (any flat hard surface — a piece of machinery, a board). The sound waves must return to the sensor within a user-adjusted time interval; if they don't, it is assumed an object is obstructing the sensing path and the sensor signals an output accordingly. Because the sensor listens for changes in propagation time as opposed to mere returned signals, it is ideal for the detection of sound-absorbent and deflecting materials such as cotton, foam, cloth, and foam rubber.

Similar to through-beam photoelectric sensors, ultrasonic throughbeam sensors have the emitter and receiver in separate housings. When an object disrupts the sonic beam, the receiver triggers an output. These sensors are ideal for applications that require the detection of a continuous object, such as a web of clear plastic. If the clear plastic breaks, the output of the sensor will trigger the attached PLC or load.

So you've got to pick a proximity sensor ...

1. Prevent duplicating your current problem. What is your current system, and why do you want to change sensors?
2. Narrow sensor candidates. What is the color, shape, and material of the target?
3. How close can you get to the target? For close-range applications, use inductive or capacitive sensors. Otherwise, photoelectric or ultrasonic sensors are better.
4. What is the available voltage supply? Specify whether the sensor will be ac or dc.
5. What will be near the sensor face? If materials are very close, choose flush or non-flush mounted inductive or capacitive sensors.
6. Consider the background's distance, color, shape, and material. Can anything be mounted there? Is background suppression photoelectric sensing needed, or can the background serve as reflector for retroreflective ultrasonic sensing? Close backgrounds can interfere with inductive or capacitive sensors.
7. For reliable detection ... at what speed and frequency do targets pass the sensor?
8. Sensing output styles vary. Do you need an output when the target is present?
9. What is the electrical load you plan to place on the sensor's output powers? A PNP or NPN interface might be required for large loads.
10. Assess the cleanliness, temperature, and moisture of the sensor environment, and from that determine an appropriate environmental rating.

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