## iKnow® Guide to Sensing

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A photoelectric sensor is an optical control used in a variety of automated processes. It works by detecting a visible or invisible beam of light, and responding to a change in the received light intensity.

**Effective beam:** “Working” part of a photoelectric beam.

**Radiation pattern:** Total area of sensing energy emission.

**Field of view:** Area of response.

Components of a Sensor

**Emitter** contains the light source, usually an LED, and an oscillator which modulates the LED at a high rate of speed. The emitter sends a modulated light beam to the receiver.

**Receiver** decodes the light beam and switches an output device that interfaces with the load.

Types of Sensors

1. **Self-contained sensors:** One-piece photoelectric sensors that contain both the optics and the electronics. These sensors perform their own modulation, demodulation, amplification and output switching.

2. **Remote systems:** Sensing systems in which the amplification and the optical sensing are divided. The opto-elements contain only the optical components, allowing the sensing heads to be extremely small. The amplifier module contains the power input, amplification and output switching. This allows the sensitive electronics to be located away from the sensing event.

3. **Fiber optic systems:** Sensing systems in which fiber optic cables are used with either remote or self-contained sensors. Fiber optic devices have no electrical circuitry and no moving parts, and can be used to safely pipe light into and out of hostile environments.

Sensing Modes

One way to tell sensors apart is by their sensing mode, the method in which a sensor sends and receives light. Photoelectric sensors are divided into three basic sensing modes: opposed, retroreflective and proximity.

- **Opposed mode:** The sensor’s emitter and receiver are housed in two separate units. The emitter is placed opposite the receiver. An object is detected when it breaks the effective beam.

- **Retroreflective mode:** The sensor contains both the emitter and receiver elements. The effective beam is established between the emitter, the retroreflector and the receiver. As with an opposed-mode sensor, an object is sensed when it interrupts or breaks the effective beam.

- **Proximity mode:** These sensors contain both emitter and receiver elements. A proximity-mode sensor detects an object when emitted light is reflected off the object, back to the sensor.

Range

The range is the specified operating distance of a sensor or sensing system.

- **Opposed mode:** The distance from the emitter to the receiver.
- **Retroreflective mode:** The distance from the sensor to the retroreflector.
- **Proximity mode:** The distance from the sensor to the object being sensed.

Contrast

Contrast is the ratio of the amount of light falling on a receiver in the “light” state, compared to the “dark” state. Increasing contrast in any sensing situation will increase the reliability of the sensing system.

Beam Pattern

A beam pattern is plotted on a 2-dimensional graph to illustrate how the sensor responds to its emitter or sensing target. Use the beam pattern to estimate placement of the sensing system with respect to adjacent objects.

Excess Gain

Excess gain is a measurement of the amount of light falling on a receiver, over and above the amount of light required to operate the sensor.
### Sensing Modes

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Features</th>
<th>Excess Gain</th>
<th>Beam Pattern</th>
</tr>
</thead>
</table>
| **Opposed**   | • Most reliable mode for opaque targets  
                • High excess gain results in long sensing range  
                • Good performance in contaminated environments  
                • High tolerance to misalignment | ![Excess Gain](chart1) | ![Beam Pattern](chart2) |
| **Retroreflective** | • Convenient when space is limited  
                        • High excess gain results in long sensing range | ![Excess Gain](chart3) | ![Beam Pattern](chart4) |
| **Diffuse**   | • Convenient when space is limited  
                • Used in applications requiring reflectivity monitoring | ![Excess Gain](chart5) | ![Beam Pattern](chart6) |
| **Divergent** | • Convenient when space is limited  
                   • Good performance in detecting clear materials at close range  
                   • Used in applications requiring reflectivity monitoring  
                   • Reliable in detection of shiny or vibrating surfaces | ![Excess Gain](chart7) | ![Beam Pattern](chart8) |
| **Convergent** | • Used for accurate positioning  
                         • Excellent in small colormark or small object detection applications  
                         • Used for accurate counting of radiused objects  
                         • High excess gain allows detection of objects having low reflectivity | ![Excess Gain](chart9) | ![Beam Pattern](chart10) |
| **Background Suppression** | • Definite range limit used to ignore backgrounds  
                                  • High excess gain allows detection of objects having low reflectivity  
                                  • Good at detecting targets of varying reflectivity | ![Excess Gain](chart11) | ![Beam Pattern](chart12) |
FIBER OPTICS

Fibers are transparent strands of optical quality glass or plastic that can be as thin as a strand of hair. In photoelectric sensing, these fibers are used to transmit and/or receive light from the LED of an attached sensor.

Fiber Optic Sensing System

Glass or Plastic Fibers

Fiber optics are available in glass or plastic. Glass fibers are arranged in bundles and plastic fibers are usually packaged as monofilaments.

Cross-sections of Fibers

Core – Thin glass or plastic center of the fiber through which light travels.

Cladding – Outer optical material surrounding the core that reflects light back into the core.

Jacket – Layer around plastic fiber to protect from damage and moisture.

Sheathing – Layer of stainless steel or PVC tubing to protect glass fiber bundles from damage.

Uses for Fibers

- **Tight sensing locations**: Size and flexibility of fibers allow positioning and mounting in tight spaces.
- **Vibration and shock**: Low mass fibers are able to withstand high levels of vibration and mechanical shock.
- **Extreme environments**: Fibers can be constructed to survive in corrosive or extreme moisture environments.
- **Explosion-proof design**: Fibers can safely pipe light into and out of hazardous areas.
- **High temperatures**: Glass fibers can tolerate extreme temperatures.
- **Custom sensing end design**: Fiber sensing heads can be “shaped” to the physical and optical requirements of a specific application.
- **Noise immunity**: A fiber is a passive mechanical part that is completely immune to electrical noise.

Fiber Optics & Sensing Modes

The configuration of the fiber optic assembly and the type of amplifier used will determine the sensing mode.

**Opposed Mode** - Individual Fiber Optic Cable

Guides light from an emitter to a sensing location, or from the sensing location back to the receiver. Opposed-mode fiber sensing requires two individual fiber optic cables.

**Diffuse Mode** - Bilurcated Fiber Optic Cable

Conducts emitted light and the received light within one fiber optic assembly. This lets a single sensor both illuminate and view an object through the same fiber optic assembly.

Considerations

- Larger bundle or core size leads to longer range and larger effective beam.
- Light signal attenuation occurs with longer fiber lengths.
- Optical fibers that have been ground and polished cannot be shortened, spliced or otherwise modified.
- Range and gain depend on both the amplifier and the fiber.
- Due to light transmission properties, plastic fibers are recommended for use only with visible light sensors.
- Glass fibers should not be subject to bending, pinching, repeated flexing, or high levels of radiation.
**BEAM PATTERNS**

A beam pattern is plotted on a 2-dimensional graph to illustrate how the photoelectric receiver is designed to respond to its emitter. Maximum light energy occurs along the sensor's optical axis. The light energy decreases towards the beam pattern boundaries. The horizontal axis usually shows the range of the sensor.

**Uses for Beam Patterns**
- Predict general radiation pattern given a specific target.
- Predict how multiple sensors can be mounted on a line without generating crosstalk.
- Provide accurate depiction of a light pattern a few feet from the sensor.

**Reading a Beam Pattern**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Description</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opposed Mode</td>
<td>The scale depicts the farthest distance on either side of the sensor's optical axis.</td>
<td>To predict how closely adjacent, parallel opposed-mode sensor pairs can be placed to each other without generating optical crosstalk.</td>
</tr>
<tr>
<td>Retrospective Mode</td>
<td>The scale shows the related distance between the retroreflective sensor and the retroreflector.</td>
<td>To show the area within which the sensor will respond to the retroreflector. The size of the beam pattern is proportional to the size and the reflective efficiency of the retroreflector.</td>
</tr>
<tr>
<td>Proximity Mode</td>
<td>The scale shows the width of the sensor response measured on either side of the optical axis.</td>
<td>To show the boundary within which the edge of a light-colored diffuse surface will be detected as it moves past the sensor. The sensor's optical axis is represented as &quot;0&quot; on the vertical scale.</td>
</tr>
</tbody>
</table>

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**EXCESS GAIN (EG)**

Excess gain is a measurement of the sensing light energy over and above the minimum amount required to operate the sensor’s amplifier. This extra sensing energy is used to overcome signal attenuation caused by contaminants in the sensing environment.

Choose a sensor that will give you the optimal excess gain for your application. In most sensing situations, high excess gain relates directly to sensing reliability.

### Measuring Excess Gain

**Excess Gain** = \( \frac{\text{Light energy falling on receiver element}}{\text{Sensor’s amplifier threshold}} \)

### Reading an Excess Gain Curve

**OPPOSED MODE**

The excess gain of an opposed-mode sensor pair is directly related to sensing distance. If the sensing distance is doubled, the excess gain is reduced by a factor of one-fourth, so the curve is always a straight line, when plotted on a log-log scale.

**RETROREFLECTIVE MODE**

The shape of a retroreflective excess gain curve is significantly influenced by the size of the retroreflector. The larger the retroreflector, the larger the shape and size of the curve.

**PROXIMITY MODE**

Excess gain for proximity-mode sensors is usually lower than that of other photoelectric sensing modes, because proximity modes depend on light reflected off the surface of a target. The curves are plotted using a Kodak 90% reflectance white test card as the reference material. Other materials are ranked compared to the test card in the table below.

### Excess Gain Guidelines

Excess gain of one (1x) describes the measured sensing energy at the amplifier threshold level. These guidelines show how much excess gain is required to overcome environmental conditions.

**E.G.** | **General Conditions** | **Threshold:** The level of sensing energy required to cause the sensor's output to switch “on” or “off.”
---|---|---
1.5x | **Clean air:** No dirt buildup on lenses or reflectors. | Excess gain of one (1x) is the measured voltage at the amplifier threshold level. Excess gain charts are useful when comparing sensors for an application, as direct measurement of amplifier voltage is often impractical.
5x | **Slightly dirty:** Slight buildup of dust, dirt, oil, moisture, etc. on lenses or reflectors. Lenses are cleaned on a regular schedule. |
10x | **Moderately dirty:** Obvious contamination of lenses or reflectors (but not obscured). Lenses cleaned occasionally or when necessary. |
50x | **Very dirty:** Heavy contamination of lenses. Heavy fog, mist, dust, smoke, or oil film. Minimal cleaning of lenses.

### Relative Reflectivity

When using a proximity sensor, refer to the Relative Reflectivity chart to determine how reflectivity of different target surfaces will affect the excess gain requirements. Here are some sample targets.

<table>
<thead>
<tr>
<th>Material</th>
<th>General Reflectivity</th>
<th>Minimum Excess Gain Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel, microfinish</td>
<td>400%</td>
<td>0.2</td>
</tr>
<tr>
<td>Natural aluminum, unfinished</td>
<td>140%</td>
<td>0.6</td>
</tr>
<tr>
<td>Kraft paper, cardboard</td>
<td>70%</td>
<td>1.3</td>
</tr>
<tr>
<td>Clear plastic bottle</td>
<td>40%</td>
<td>2.3</td>
</tr>
<tr>
<td>Tissue paper (1 ply)</td>
<td>35%</td>
<td>2.6</td>
</tr>
<tr>
<td>Rough wood pallet (clean)</td>
<td>20%</td>
<td>4.5</td>
</tr>
</tbody>
</table>
**CONTRAST**

Contrast is also referred to as the light-to-dark ratio. While most sensors do not allow direct measurement of light signals, contrast can be estimated. The higher the contrast ratio, the better and more accurately your sensor will detect its target.

Contrast can be defined as:

\[
\text{Contrast} = \frac{\text{Received light in the light condition}}{\text{Received light in the dark condition}}
\]

Threshold: Point where output change-of-state occurs.

**Hysteresis**: Difference of output switchpoint (threshold) from on-to-off, vs. off-to-on. Prevents output chatter.

**TECHNIQUE PROCESS CONCEPT**

**Potentiometer Adjustment**
Manually adjust sensitivity with the potentiometer.

1. Adjust potentiometer to minimum.
2. Present the light and dark sensing conditions individually, turning the potentiometer slowly clockwise, until the alignment indicator just comes on. Note the settings.
3. Adjust the potentiometer to approximately midway between the two settings.

**SET Mode Adjustment**
Sensor’s microprocessor automates sensitivity adjustment.

Present the dark sensing condition, and press the SET button. The sensor automatically sets the operating sensitivity below the switch point threshold for the dark condition.

**TEACH Mode Adjustment**
Sensor’s microprocessor optimizes sensitivity adjustment between two user-set reference points.

1. Present the light sensing condition, and single-click the TEACH button.
2. Present the dark sensing condition, and (again) single-click the TEACH button.
3. The sensor automatically sets the operating sensitivity.

**Contrast Guidelines**
Follow these contrast guidelines to improve sensing reliability:

1. Choose a sensor or lensing option that will optimize contrast in any photoelectric sensing situation.
2. Adjust alignment and gain for maximum contrast during sensor installation.
3. If light and dark conditions are separated by 1/3 or more of the adjustment range of a sensor’s sensitivity potentiometer, contrast is sufficient. Most Banner sensors intended for low-contrast applications are microprocessor-driven and will provide feedback of relative contrast.

---

**Reference**

Bargraph sensors offer relative feedback in low-contrast applications.

### Contrast Guidelines

<table>
<thead>
<tr>
<th>Bar graph LED Number</th>
<th>Relative Contrast/Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 to 8</td>
<td>Excellent: Very stable operation</td>
</tr>
<tr>
<td>4 to 5</td>
<td>Good: Minor sensing variables will not affect sensing reliability</td>
</tr>
<tr>
<td>2 to 3</td>
<td>Low: Minor sensing variables will affect sensing reliability</td>
</tr>
<tr>
<td>1</td>
<td>Marginal: Consider an alternate sensing scheme</td>
</tr>
</tbody>
</table>

---

**Contrast Guidelines**

Follow these contrast guidelines to improve sensing reliability:

1. Choose a sensor or lensing option that will optimize contrast in any photoelectric sensing situation.
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**Job Aid: Sensitivity Adjustment**

Field-adjust the sensitivity of a sensor in order to maximize the contrast in an application.

---

**Table:**

<table>
<thead>
<tr>
<th>TECHNIQUE</th>
<th>PROCESS</th>
<th>CONCEPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potentiometer</td>
<td></td>
<td><strong>Operating sensitivity setting</strong> (midway between light and dark thresholds)</td>
</tr>
<tr>
<td>Adjustment</td>
<td></td>
<td><strong>Switchpoint threshold for light condition</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Switchpoint threshold for dark condition</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET Mode Adjustment</td>
<td>Present the dark sensing condition,</td>
<td><strong>Operating sensitivity setting</strong> (automatically set by sensor)</td>
</tr>
<tr>
<td></td>
<td>and press the SET button. The sensor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>automatically sets the operating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sensitivity below the switch point</td>
<td></td>
</tr>
<tr>
<td></td>
<td>threshold for the dark condition.</td>
<td></td>
</tr>
<tr>
<td>TEACH Mode</td>
<td>Present the light sensing condition,</td>
<td><strong>Operating sensitivity setting</strong> (automatically set by sensor)</td>
</tr>
<tr>
<td>Adjustment</td>
<td>and single-click the TEACH button.</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>the operating sensitivity.</td>
<td></td>
</tr>
</tbody>
</table>
RESPONSE TIME

Response time is the maximum time required for the sensor to respond to a change in the input signal. It is the time from when the sensor sees its target to when it gives an output signal to the load. Response time is the time between the leading (or trailing) edge of the sensing event and the output's change of state.

Importance

Response time can help determine how long a fast-moving object must stay in the sensor's field of view in order to be detected. It is especially important when your application requires detection of:

- High-speed events
- Small objects moving at high speeds
- Narrow gaps between objects
- Brief intervals between sensing events

Modulation

The speed of response of a modulated photoelectric sensor is limited by its frequency of modulation. There is a direct trade-off between sensor response time and sensing range (excess gain). High-speed sensors are modulated faster, thus yielding shorter range. If an LED is pulsed less often, it can be pulsed with a higher current, thereby producing more light energy.

Repeatability

The repeatability specification is used in applications where customers need to know the precise position of a moving part. The sensor's output is allowed to switch only after a few modulated light pulses are counted. The response time before a modulated sensor turns on is equal to the time required for the sensor to count that number of pulses, and the sensor output changes state as soon as the sensor counts enough light pulses of the correct frequency. Since the sensing event can occur at any time during a modulation cycle, the actual time between the sensing event and the sensor's output change can vary by up to one modulation cycle. This variation is the sensor's repeatability.

Calculating Response Time

You can determine a sensor's required response time when you know the size, speed and spacing of the objects to be detected.

\[
\text{Response Time} = \frac{\text{Object width (or gap between objects)}}{\text{Object velocity}}
\]

Application Example

To calculate the required sensor response time, the production line speed is first converted to the speed of, in this case, a seed packet. When calculating the speed of the seed packet, take into account the space between the packets.

1. Determine how many packets are being processed per second:
   
   \[600 \text{ packets/minute} = 10 \text{ packets per second}\]

2. Determine the distance of linear travel:
   
   \[75 \text{ mm (packet width)} + 25 \text{ mm (space between packets)} = 100 \text{ mm}\]

3. Calculate speed of packet = 100 mm/packet x 10 packets/sec
   
   \[\text{Packet Speed} = 1 \text{ m/sec}\]

Light condition:

Sensing condition characterized by higher level of received sensing energy.

Knowing the speed of the object (1 m/sec), it is possible to calculate the time during which the sensor “sees” a packet of seeds.

\[
\frac{\text{Object width (75 mm)}}{\text{Object velocity (1 m/sec)}} = 0.075 \text{ sec}
\]

Time of each packet passing the sensor = 75 ms

Calculating Light Condition

Dark condition:

Sensing condition characterized by lower level of light energy (or none).

\[
\frac{\text{Space width (25 mm)}}{\text{Object velocity (1 m/sec)}} = 0.025 \text{ sec}
\]

Time of each space passing the sensor = 25 ms

Calculating Dark Condition

In this application, the time between the packets is much less than the time during which the sensor “sees” a packet. As a result, the dark (or “off”) time between packets is the more important consideration.
OUTPUTS

The output circuit is the section of the sensor that interfaces to the external load. Output also refers to the useful energy delivered by the sensor. Knowing the voltage and current requirements of the load is crucial to selecting the best sensor. Sensors with analog outputs always interface to circuits or devices which operate at low levels of dc voltage and current. Sensors with digital outputs interface to either ac or dc loads.

Digital/Analog Output

The output of a sensor is either digital or analog. A digital, or switched, output has only two states: “ON” and “OFF.” On and off commonly refer to the status of the load that the sensor output is controlling.

An analog sensor is one that varies over a range of voltage (or current) and is proportional to some sensing parameter. Analog sensors provide a metered or gradual response.

Response Time

The response time of sensors with digital output depends largely on the sensor’s output switching device. In general, sensors with solid-state outputs provide faster switching.

Sensors with electromechanical relays can only provide slow switching; the relay switching speed is the largest component of the specified sensor response time.

Contact Configuration Types

Solid-State Relays

Switching is accomplished by elements such as a transistor or SCR, without moving parts, heated filament or vacuum gaps.

Complementary outputs: The dual-output configuration of a sensing device, where one output is Normally Open and the other is Normally Closed. In this case, both outputs have the same switchpoint, but only one output conducts at a time.

NPN output (sinking): Output switch configured with its collector open and its emitter connected to ground (dc common). The load is connected between the output (collector) and the positive of the dc supply.

PNP output (sourcing): Output switch configured with its collector open and its emitter connected to the positive of the sensor supply voltage. The load is connected between the output (collector) and ground (dc common).

Bipolar outputs: The dual-output configuration of a sensing device, where one output switch is a sinking device (NPN) and the other output switch is a sourcing device (PNP). Both outputs have the same switchpoint.

E/M Relays

Used when a sensor provides direct control of a load that draws more current than can be handled by a solid-state relay. Double-throw contacts are used in interfaces that require complementary switching. E/M relays are useful when a string of sensor outputs are wired together in series for AND logic. Some E/M relay configurations include SPST, SPDT, DPST and DPDT.

Normally Open (NO): Designation for contacts of a switch or relay that are not connected when at rest. When activated, the contacts close (become connected).

Normally Closed (NC): Designation for contacts of a switch or relay that are connected when at rest. When activated, the contacts open (separate).

Light Operate/Dark Operate

The sensor should be active when the application requires it. With digital photoelectric sensors, the input and the output are characterized by one of two sensing terms: Light Operate and Dark Operate.

Light Operate (LO): A condition where a photoelectric sensor output energizes its load when the sensor “sees” a sufficient amount of its own modulated light.

Dark Operate (DO): The complement of LO, where the sensor output energizes its load when it no longer “sees” the modulated light.

E/M Relays

Relay Switch

Common

(N) (NC) (SC)

Common

(N) (NC) (SC)

Light Operate/Dark Operate

Training Note:

The dual-output configuration of a sensing device, where one output is Normally Open and the other is Normally Closed. In this case, both outputs have the same switchpoint, but only one output conducts at a time.

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**VISION SENSORS**

Vision sensing is electronic imaging, applied in a manufacturing setting for the purpose of control: Process control, machine tool control, robot control or quality control. Vision sensing is used to improve production processes and quality. Vision sensing is comprised of two major elements: A **hardware** element (camera, controller and lighting) and a **software** element (control system, graphical user interface and image algorithms).

**Process**

Visual inspection is a three-step process:

1. The sensor **acquires** an image of the part.

2. The microprocessor **analyzes** the image.

3. Another microprocessor **determines** if the inspection passes or fails, and reports the results to the manufacturing line. The part is then either passed to the next process, or it is rejected and removed.

**Inspection**

“Visual inspection” refers to the process of acquiring an image, analyzing that image based on set parameters and reporting the results. For some Banner vision sensors, inspections are set up using a remote PC. A digital camera captures images and the sensor software analyzes the images using vision tools to pass or fail the product.

Vision tools are specific software algorithms used to analyze an image. Each vision sensor uses a specific **tool set** to extract and isolate certain features within the image in order to determine whether a part passes or fails an inspection.

**Parts**

**Choosing Lighting**

1. **Light Source:** The light source is a critical component of any vision inspection system. Lighting is the most powerful tool for creating contrast to amplify the feature of interest, while minimizing other features of the part. Selecting the best light source depends on the shape, surface texture, color and opacity of the part.

   **Opposed Mode**
   **Proximity Mode**

   - Backlight
   - Ring
   - Dome
   - Directional
   - Low-angle
   - On-axis

2. **Lens:** The lens focuses the light onto the sensor’s imager. The main consideration for selecting a lens is focal length. To determine the focal length, the field of view and working distance must be determined. The field of view is the area of the inspection captured on the sensor’s imager. The working distance is the distance between the back of the lens and the target object.

3. **Sensor:** The sensor contains the imager, microprocessors and I/O.

   The **imager** has an array of tiny light-sensitive cells that converts the target into an image.

   **Microprocessors** analyze the image and make determinations about it based on user-determined tolerances and criteria.

   The sensor exports the inspection results through some type of **I/O**, e.g. Discrete or Ethernet.
VISION TOOLS

Vision tools are software algorithms used to analyze an image.

A vision sensor uses a set of tools to create an inspection. Using one or several tools, a user can extract and isolate certain features of an image in order to determine whether a part passes or fails an inspection. Several inspections involving different vision tools can be performed on a single image.

Locational Tools: Search for a reference point in an image. Once the X,Y coordinates of the reference point are found, the location of subsequent regions of interest can be adjusted for translational and rotational variations of the target.

- **Locate Tool**: Determines translational and rotational movement of a part by detecting relative movement of edges.
- **Pattern Find Tool**: Determines translational and rotational movement of a part by detecting relative movement of a pattern.
- **GEO Find Tool**: Determines translational and rotational movement of a part up to 360° by detecting relative movement of a pattern.

Vision Tools: Analyze an image and extract information to use for judgment criteria.

- **Gray Scale Tool**: Determines the average gray scale value.
- **Blob Tool**: Determines the presence, size, connectivity and location of selected features.
- **Edge Tool**: Determines the presence, number and location of edges.
- **Object Tool**: Determines the presence, number, size and location of the space between edges.
- **Pattern Count Tool**: Determines the presence, number and location of a pattern or patterns.
- **Bar Code Tool**: Finds and decodes DataMatrix, ECC 200, PDF 417 and linear bar codes.
- **Geo Count Tool**: Detects the presence and location of a target pattern within a specified search area regardless of orientation.

Analysis Tools: Measure or evaluate the results of the Vision Tools.

- **Measure Tool**: Measures distance between any two prescribed points.
- **Test Tool**: Evaluates results of selected vision and analysis tools to determine whether an inspection passes or fails. It also performs logical operations and activates outputs.
- **Communication Tool**: Sends results of locational, vision and analysis tools over Ethernet or RS-232 serial communication ports.
VISION LIGHTING

A vision sensor captures and then analyzes an electronic image. The quality of the images depends on the image's contrast. Dedicated lighting can guarantee constant, consistent light conditions that can be manipulated to create a high-contrast image.

Here are some factors to consider when choosing lighting:
1. Lighting geometry
2. Techniques
3. Optical properties of the part

Lighting Geometry

The geometry of propagation refers to how light energy leaves the source. Light can come from a point, diffuse, or collimated source.

When you understand how to manipulate lighting geometry, you can:
- Eliminate glare
- Eliminate hot spots
- Minimize unimportant features

Lighting Techniques

Lighting techniques refer to how the light source is mounted in relation to the target object and the sensor.

Dark-Field: Illuminate objects with indirect light.
- Casts shadows
- Highlights height changes
- Textured surfaces are bright

Bright-Field: Illuminate objects with direct light.
- Detect color change
- Smooth surfaces are bright

Backlight: Transmit light from behind the object.
- Highlights outlines and profiles
- Highest contrast

Optical Properties of a Target

Optical properties of a part can be used in conjunction with lighting to highlight features.

<table>
<thead>
<tr>
<th>Optical Properties</th>
<th>Example Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape</td>
<td>Notches</td>
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<tr>
<td></td>
<td>Stampings</td>
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<td></td>
<td>Embossing</td>
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<td></td>
<td>Highlights</td>
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<td></td>
<td>outlines</td>
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<td></td>
<td>and profiles</td>
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<tr>
<td>Surface Texture</td>
<td>Polished metal</td>
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<td>Sandpaper</td>
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<td>Textured</td>
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<tr>
<td></td>
<td>surfaces</td>
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<tr>
<td></td>
<td>are bright</td>
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<tr>
<td></td>
<td>Smooth surfaces are dark</td>
</tr>
<tr>
<td>Color</td>
<td>Wires</td>
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<td></td>
<td>Printing</td>
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<td></td>
<td>Plastic</td>
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<tr>
<td></td>
<td>UV Coatings</td>
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<tr>
<td></td>
<td>Based on</td>
</tr>
<tr>
<td></td>
<td>target color</td>
</tr>
<tr>
<td>Translucency</td>
<td>Drilled hole</td>
</tr>
<tr>
<td></td>
<td>Plastics</td>
</tr>
<tr>
<td></td>
<td>Solid parts</td>
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<tr>
<td></td>
<td>block light</td>
</tr>
<tr>
<td></td>
<td>clear parts</td>
</tr>
<tr>
<td></td>
<td>transmit light</td>
</tr>
</tbody>
</table>

The main goal of lighting in a vision application is to create contrast between the part and the background.
VISION LENSES

The sensor's lens focuses the reflected light onto the imager chip. The quality of the lens will influence the quality of the image.

Lenses have one main function: To create a 2-D image of the scene, focusing the entire field-of-view (FOV) on the imager chip.

Lens Basics

Focal Length: The distance from the lens to the camera's imager. It is specified in millimeters. Focal length determines the relationship between working distance and the angle of view. Shorter focal length results in wider FOV.

Angle of View: Angle of view indicates how much of the visual scene can be captured by the lens. It is determined by the focal length of the lens and how far away the camera is from the target.

Resolution: The ability of a vision sensor to differentiate between two features that are close together. If the features blur together, a higher resolution lens is required.

Distortion: The lens can influence image quality by how it collects and focuses light on the imager chip. Different lenses have different degrees of optical distortion, or undesired change in the shape of an image.

Depth of Field: The in-focus range of a vision system that includes the areas which remain in focus behind and in front of the target.

Image Quality

A camera that captures a high quality image assures the most accurate information for later analysis. To insure a high image quality, choose a lens that:

- Magnifies the feature of interest to fill the FOV
- Captures required FOV without adding distortion to the image
- Optimizes your FOV based on working distance
- Focuses entire scene of inspection
ULTRASONIC SENSORS

Ultrasonic sensors emit a pulse of energy which travels at the speed of sound. A portion of this energy is reflected off of a target and travels back to the sensor. The sensor measures the total time required for the energy to reach the target and return to the sensor and calculates the distance from the sensor to the target.

Temperature Effect

The speed of sound depends on chemical composition, pressure and temperature of the gas in which it is traveling. In most ultrasonic applications, the composition and pressure of the gas are relatively fixed, while the temperature is not. The speed of sound increases roughly 1% per 10° F (6° C) temperature increase.

Target Angle

A flat target that is perpendicular to the beam axis will reflect the most sound energy back to the sensor. As the target angle increases, the amount of energy received by the sensor decreases. For most ultrasonic sensors, the target angle should be 10° or less.

Air Currents

Air currents due to wind, fans, pneumatic equipment or other sources can deflect or disturb the path of the ultrasonic energy, so a sensor may fail to recognize the correct location of the target.

MEASURING LIGHT SCREENS

Banner light screens have a vertical array of photoelectric emitters and receivers: The emitters in one housing, the receivers in another. An object placed between the emitter and receiver will block the emitted light from reaching the corresponding receivers.

Synchronous Scanning

Identifies which of the beams is blocked, by enabling one emitter channel to pulse light while simultaneously directing its corresponding receiver to look for a signal. The system records which beam channels are blocked and which are clear, and then outputs a signal, either analog or discrete.

Sensor Response Time

The time required for an array system to “see” an object varies depending on which channel is blocked, when the object blocks a particular channel and when that particular channel is scanned. The result is that the minimum response time is equal to 1 ms; the maximum response time is equal to twice the scan time. The scan time, in turn, varies according to array length and scanning mode, and is specified in the product literature.

Minimum Object Detection

The minimum object detection size is a function of the lens diameter for an individual channel and the spacing between channels. The minimum object detection size is defined as the smallest diameter rod that can be detected reliably.

Maximum Part Speed

The maximum speed of a passing part is a function of the part size, the lens diameter and the maximum response time of the system.

Measuring Modes

Banner’s measuring light screens can be configured, with a simple Windows setup program, for several measuring modes for both analog and discrete outputs. For example, the output can be based on the:

- First beam blocked
- Last beam blocked
- Total number of beams blocked
- First beam made
- Last beam made
- Total number of beams made
- Center beam of several blocked beams
- Number of transitions from blocked to made
- Highest number of contiguous beams blocked
LIGHT GAUGING SENSORS

Light gauging sensors utilize either “Time of Flight” or triangulation technology to detect the presence and position of targets.

**Time of Flight:** Measurement of the amount of time that emitted light takes to travel to the target and return to the sensor. This technology is used in long-range sensing applications.

**Triangulation:** An emitter transmits visible light through a lens, towards a target. The beam bounces off the target, returning some light to the sensor’s Position Sensitive Device (PSD) receiver element. The target’s distance from the receiver determines the angle at which the light travels to the receiver element. This angle, in turn, determines where the received light will fall along the PSD receiver element. The position of the light on the PSD receiver element is processed through analog and/or digital electronics to calculate the appropriate output value.

![Triangulation Technology Diagram](image)

**Surface Reflectivity and Texture**

Triangulation sensors depend on the diffuse reflections of light from the target. A diffuse reflection is one in which the light tends to scatter equally in all directions from the target. If the target surface is mirror-like, then light will tend to reflect in only one direction (if this target is not perpendicular to the sensor, the light will be reflected away from the sensor).

Triangulation sensors also require a non-porous, opaque surface for accurate operation. Measurement errors will result from semi-transparent targets such as clear plastic, or from porous materials such as foam.

**Color Effects**

The color of the object being measured can affect the resolution and accuracy of the readings. White, red, yellow and orange targets will reflect more light than green, blue or black targets. The resolution for dark targets may be up to four times less than for white targets.

The graph below shows the relative amount of received light that is reflected from various target colors, using visible red light. The resolution is roughly affected according to the square of the received light. For example, reducing the amount of light by a factor of nine will degrade the resolution by a factor of three.

![Color Effects Graph](image)

**Metal Surfaces**

Bare metal surfaces do not exhibit consistent reflectivity across their surfaces. As a result, the repeatability from one point on a metal surface to another, even at the same distance from the sensor, will degrade. This effect varies from metal to metal and is dependent upon surface finish.

**Total Expected Measurement Error**

Keep in mind that the overall expected accuracy of an analog sensor is the combination of several performance parameters, not simply the sensor’s resolution. Linearity and temperature effect can also affect accuracy.
TEMPERATURE GAUGING SENSORS

Temperature Gauging sensors activate an output when they detect objects that are either hotter or colder than the ambient condition. These passive, non-contact sensors use a thermopile as a receiver element to detect infrared light energy emitted by target objects. The information is measured and analyzed by the sensor, and depending on the thermal contrast, an output is given.

Range

The sensing range is determined by the sensor's field of view and the size of the target object.

Thermal Contrast

The difference between the ambient temperature and the temperature of the target object. High thermal contrast increases switching accuracy.

Field of View

The field of view (FOV) is the area of response, based on the sensor's lens design. The temperature information collected by the sensor will be an average of everything in the sensor's field of view. To increase thermal contrast and reliability of the output, the target object must fill as much of the field of view as possible. If the target object does not fill the sensor's field of view, the sensor will average the temperature of everything in the field of view, thereby reducing the reliability of the output.

MAGNETIC SENSORS

Magnetic devices are passive, non-contact magnetic receivers that detects 3-dimensional changes in the Earth's natural magnetic field caused by the presence of large ferrous objects.

Range

The sensor range depends on three variables:
1. The local magnetic environment (including nearby ferrous material)
2. The magnetic properties of the object to be sensed
3. Sensor settings

The strong disturbance of a large ferrous object decreases as distance from the sensor increases, and the magnitude and shape of the disturbance is dependent on the object's shape and content.

D:S Ratio

Spot size refers to the area where the temperature data is taken. Spot size can be calculated at any distance from the target by using the distance-to-spot ratio.

D:S ratio is inversely related to viewing angle. A sensor with a small viewing angle will have a large D:S ratio.

For a sensor with an 8:1 ratio, the sensor's spot size is a 1” diameter circle at a distance of 8”. As you go out further from the sensor face, the spot size will be larger.

The sensor's distance-to-spot size ratio can be adjusted by lensing the thermopile. This might be necessary depending on the size of the target and the range at which it must be sensed.

Sensing Area

Magnetic sensors are omni-directional; they can detect ambient magnetic field in all directions. They can be used in close proximity to each other without interaction since they are passive devices and individually learn their environment.
# ENVIRONMENTAL CONSIDERATIONS

<table>
<thead>
<tr>
<th>ENVIRONMENT</th>
<th>TYPICAL INDUSTRIES &amp; APPLICATIONS</th>
<th>RECOMMENDATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Temperature</td>
<td>All non-abusive applications from -20° to +55° C</td>
<td>• All sensor types; choice depends on range, excess gain and electrical and</td>
</tr>
<tr>
<td></td>
<td>• Metal processing</td>
<td>performance requirements.</td>
</tr>
<tr>
<td></td>
<td>• Painting applications</td>
<td>• Glass fiber optics: Use when above +100° C; max. to 480° C.</td>
</tr>
<tr>
<td></td>
<td>• Paper manufacturing</td>
<td>• Plastic fiber optics: Use polycarbonate fibers up to +125° C.</td>
</tr>
<tr>
<td></td>
<td>• Outdoor applications</td>
<td>• Remote sensors: Use up to +100° C.</td>
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<tr>
<td>High Temperatures</td>
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<td></td>
<td>• Meat processing</td>
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<td></td>
<td>• Food processing</td>
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<td></td>
<td>• Chemical processing</td>
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<td>• Outdoor applications</td>
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<tr>
<td>Low Temperatures</td>
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<td></td>
<td>• Food processing</td>
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<td>• Car washes</td>
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<td>• Pharmaceuticals</td>
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<td>• Bottling plants</td>
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<td></td>
<td>• Outdoor applications</td>
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<tr>
<td>Moisture</td>
<td>• Semiconductors</td>
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<td></td>
<td>• Chemical</td>
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<td></td>
<td>• Lumber</td>
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<td></td>
<td>• Pulp/paper</td>
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<tr>
<td></td>
<td>• Amusement parks (UV light)</td>
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<tr>
<td>Corrosive Agents</td>
<td></td>
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<tr>
<td></td>
<td>• Lumber</td>
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<td></td>
<td>• Ceramics ovens</td>
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<td></td>
<td>• Paper</td>
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<td></td>
<td>• Steel</td>
<td></td>
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<tr>
<td></td>
<td>• Mining</td>
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<tr>
<td>Dirt, Dust, Fog</td>
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<tr>
<td></td>
<td>• Metal (stamping)</td>
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<td></td>
<td>• Printing (presses)</td>
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<tr>
<td></td>
<td>• Packaging</td>
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<tr>
<td>Vibration &amp; Shock</td>
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<tr>
<td></td>
<td>• Chemicals/Gas/Oil/Refinery</td>
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<td></td>
<td>• Grain elevators</td>
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<td></td>
<td>• Airbag manufacturers</td>
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<tr>
<td>Hazardous Areas</td>
<td></td>
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<tr>
<td></td>
<td>• Sensors with NEMA 6 ratings represent the best moisture seals and can resist occasional</td>
<td>• Condensation can be eliminated by using unlensed fiber optics.</td>
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<tr>
<td></td>
<td>• NEMA 4 and 6 ratings: Can withstand low-pressure washdown.</td>
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<td></td>
<td>• NEMA tests do not take into account the elevated pressures and temperatures of solutions</td>
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<tr>
<td></td>
<td>• See NEMA and IP enclosure ratings chart online.</td>
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<tr>
<td></td>
<td>• Stainless steel sensor housings.</td>
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<tr>
<td></td>
<td>• Glass fiber optic assemblies in stainless steel sheathing.</td>
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<tr>
<td></td>
<td>• Fiber optic assemblies without epoxy (available by special order).</td>
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<tr>
<td>Solvents/Alkalis</td>
<td>• Fiber optic assemblies with PVC jackets.</td>
<td></td>
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<tr>
<td></td>
<td>• Thermoplastic polyester housings; see chart online.</td>
<td></td>
</tr>
<tr>
<td>Bases</td>
<td>• Teflon® sheathing; protect the sensing tip from direct contact with concentrated acids.</td>
<td></td>
</tr>
<tr>
<td>Acids</td>
<td>• Polyethylene jacket of standard plastic fiber optic cables resists acids, but can degrade</td>
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<tr>
<td></td>
<td>• High Excess Gain</td>
<td>• Prolonged contact.</td>
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<tr>
<td></td>
<td>• Excess gain data should be carefully evaluated.</td>
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<tr>
<td></td>
<td>• Opposed-mode sensors with excess gain above 1000x.</td>
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</tr>
<tr>
<td>Lens Size</td>
<td>• Smaller lens concentrates the beam for greater penetrating ability.</td>
<td></td>
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<tr>
<td>Inductive Proximity Sensors</td>
<td>For metal targets and short sensing ranges.</td>
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<tr>
<td></td>
<td>• Larger lenses will yield greater range, but will disperse available sensing energy.</td>
<td></td>
</tr>
<tr>
<td>High Excess Gain</td>
<td>• Lightweight sensing components; smaller sensors.</td>
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<tr>
<td></td>
<td>• Anti-vibration mounts placed between the sensor and mounting bracket.</td>
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<td></td>
<td>• Glass or plastic fiber optic assemblies can withstand more than 100 Gs of acceleration.</td>
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<tr>
<td></td>
<td>• Glass fibers cannot tolerate repeated flexing. Use plastic, hi-flex or coiled fibers.</td>
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<tr>
<td></td>
<td>• Remote sensors can withstand up to 15 Gs of acceleration.</td>
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<tr>
<td></td>
<td>• One-piece self-contained sensors with epoxy-encapsulated circuitry withstand up to 10 Gs of</td>
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<tr>
<td></td>
<td>• One-piece self-contained sensors with epoxy-encapsulated circuitry withstand up to 10 Gs of</td>
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<tr>
<td></td>
<td>• Special sensing equipment must be installed, using measures to avoid sources of ignition.</td>
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<td></td>
<td>• See chart defining Hazardous Location Classifications online.</td>
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<tr>
<td></td>
<td>• NAMUR photoelectric sensors.</td>
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</tr>
<tr>
<td></td>
<td>• Glass and plastic fiber optics. (Plastic fiber optics are preferred, as it is easier to seal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• See chart defining Hazardous Location Classifications online.</td>
<td>around the fiber bundle at the barrier between the hazardous and safe environment).</td>
</tr>
</tbody>
</table>

More information online at [bannerengineering.com/iknow](http://bannerengineering.com/iknow)