EN

WHITE PAPER

DETECTION OF TRANSPARENT OBJECTS

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1. INTRODUCTION

When it comes to detecting transparent objects, sensors in a wide range of industrial processes repeatedly encounter a variety of challenges. Although solutions such as optical sensors and ultrasonic sensors have proven to be sufficiently useful for such tasks, both technologies still demonstrate their own specific weaknesses in practice. In addition, development is ongoing and there are now alternatives to the technologies used to date, especially in the area of optical sensors. This white paper provides an overview of sensor technologies for detecting transparent objects and explains the problems sometimes encountered when using these solutions in practical applications. This document will also present a technology that is based on UV light and capable of overcoming several key challenges that occur repeatedly, in particular when conventional sensors are used.

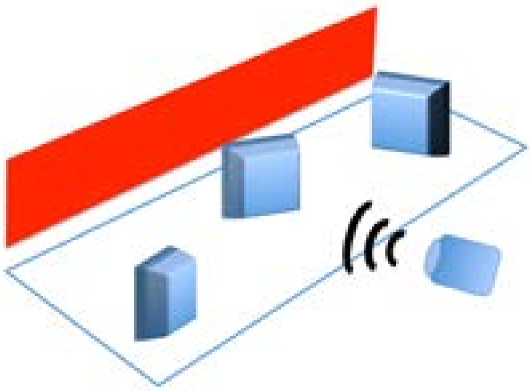
2. WHAT TECHNOLOGIES HAVE BEEN AVAILABLE TO DATE?

As already mentioned in the introduction, ultrasonic sensors and optical sensors are generally suitable for detecting transparent objects and materials. In light of this, the following system variants can be used for both sensor technologies:

- Through-beam systems
- Reflection systems
- Diffuse reflection sensors

Through-beam systems consist of a separate transmitter and receiver. With regard to optical sensors, such systems are also referred to as light barriers; in the case of ultrasonic sensors they are called ultrasonic barriers. If the signal is interrupted or weakened between the transmitter and the receiver by a transparent object in the detection range of the device, the switching output in the receiver changes its signal.

Reflection systems feature a transmitter and a receiver integrated in a single device. Such systems require a reflector, which reflects the transmission signal (red or infrared light and ultrasound). The terms "retro-reflective sensors" (optical sensors) and "ultrasonic retro-reflective sensors" are widely used when referring to such systems. While retro-reflective sensors use a separate reflector as a system component, elements such as machine components can also be used as a reflector in the case of ultrasonic sensors. Reflection systems operate in a similar way to through-beam systems. If a transparent object interrupts or dampens the signal between the transmitter and the receiver, the switching output in the receiver changes its signal.



In the case of ultrasonic retro-reflective sensors, elements such as a machine component (red) can be used as a reflector.
(All images: ipf electronic gmbh)

In contrast, diffuse reflection sensors are systems that operate using the signal reflected off an object. Optical diffuse reflection sensors and ultrasonic diffuse reflection sensors also have a transmitter and a receiver in a single device. However, the signal of the transmitter (red or infrared light, or ultrasound) is reflected by a transparent object to reach the receiver, the switching output of which then changes. The process of detecting transparent objects with ultrasonic sensors and optical sensors, as well as the specific challenges associated with this process, will be examined in greater detail below.

3. ULTRASONIC SENSORS

Ultrasonic sensors are particularly well suited to detecting transparent objects because such systems detect all objects that reflect sound or interrupt an acoustic signal, whether or not they are transparent. The factors that influence the detection of transparent objects, and therefore the possible problems, can vary greatly when using ultrasonic systems. Some of these influencing factors are described in the following chapters. In relation to this, it is important to emphasize that the following influences also affect the detection of non-transparent objects to a certain extent.

3.1 DETECTING PARTICULARLY THIN MATERIALS

Ultrasonic barriers, i.e. through-beam systems or through-beam barrier systems, are used to detect very thin, transparent objects (e.g. transparent films). Such materials always also have a certain amount of natural vibration. Therefore, a very specific problem can occur when using ultrasonic barriers in practice. If a transparent film is not sufficiently tensioned between a transmitter and a receiver, it is possible that the acoustic pulse from the transmitter will also cause the film being detected to vibrate via the air molecules, thereby transmitting the sound to the receiver via the material to be detected. In such cases, the signal passing between the transmitter and the receiver is not interrupted, meaning that the switching output in the receiver does not change its signal. The result: the transparent film is not detected by the ultrasonic barrier. When using ultrasonic barriers to detect particularly thin, transparent or non-transparent objects, it is therefore essential to always ensure that the material is sufficiently tensioned between the transmitter and the receiver.

3.2 FACTORS THAT INFLUENCE AIR AND CONVECTION FLOWS

A classic example of the use of ultrasonic barriers (through-beam systems) is the detection of transparent glass or PET bottles in the beverage industry, where the bottlenecks are generally queried, e.g. using ultrasonic forks. If the objects move through the detection range of an ultrasonic fork at a high speed, the bottleneck may create a stronger air flow. This air flow can sometimes carry away the sound generated by the transmitter, so that the receiver receives only a weak signal or no signal at all. Therefore, the switching signal of the ultrasonic barrier is no longer interrupted in the area between the bottles, resulting in a continuous output signal. However, the influence of air flows on an ultrasonic barrier or ultrasonic fork mainly depends on whether or not an object is transparent.

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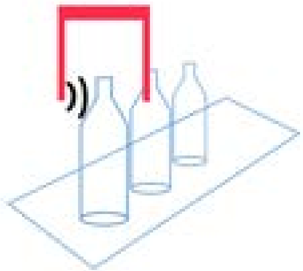

The detection of glass or PET bottles with an ultrasonic fork.

Therefore, the phenomenon described can also be seen in processes such as those where compressed air is used to transport light objects. For example, if an ultrasonic sensor is installed in the area of a workpiece transport for presence checking, the compressed air can also massively influence the acoustic signal and thereby lead to the sensor system in use malfunctioning.

However, in addition to air flows, so-called convection flows can also disrupt the operation of ultrasonic sensors, for example those used in areas with rising warm air. In simple terms, layers of air with different air temperatures are formed in these warm air flows, and these layers create flow vortices (turbulent flows). The propagation velocity of the sound from the ultrasonic sensors is temperature dependent. Therefore, such devices always also measure the ambient temperature and are able to compensate for changes in the room temperature within a certain range. However, if an ultrasonic sensor is positioned close to an object that creates convection flows, e.g. a still warm, transparent film, the turbulent flows or flow vortices can influence the time required by the sound to travel from the sensor to the object and back again. Since the time taken for the acoustic signal to travel can vary greatly, the sensor receives different measured values, and therefore different distance values, with each measurement, meaning that the measurement results cannot be reproduced. In the worst-case scenario, none of the signals are evaluable. Whether or not convection flows are still tolerable for planned measurements with an ultrasonic sensor can essentially only be tested using a test setup on site in a concrete application with the device selected for use.

3.3 THE RANGE OF ULTRASONIC DIFFUSE REFLECTION SENSORS

Finally, whether the range of ultrasonic sensors (e.g. ultrasonic diffuse reflection sensors) is also sufficient for a planned measurement task can likewise only be tested in a concrete application. This may sound like just a formality since the maximum ranges of the devices are usually specified in data sheets and other documentation. However, in practice, users often make miscalculations in this respect because other factors that have a considerable influence on the actual range of a sensor are sometimes not taken into account. The maximum range of an ultrasonic diffuse reflection sensor is always dependent on the size of the object being detected. Therefore, for example, the detection range specification of two ultrasonic sensors, particularly in relation to the maximum ranges of the devices (reliable detection of an object at a distance from the sensor of 300mm or 600mm) always refers to a metal plate with the dimensions 100 x 100mm.

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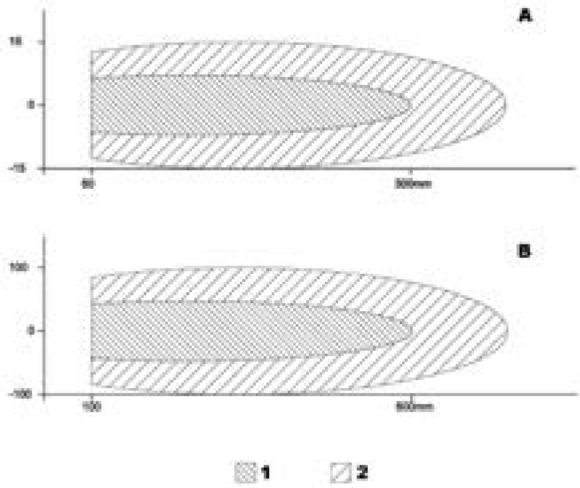

Detection ranges of two ultrasonic diffuse reflection sensors: 1: reliable detection of an object of 100 x 100mm, 2: possible detection of a large object

If the object being detected is smaller, either the distance from the ultrasonic diffuse reflection sensor to the object must be reduced or a device with a larger base range must be selected at the outset. Therefore, if you use the device to detect objects smaller than 100 x 100mm over a maximum range of 300mm (Graphic A), the sensor will not reliably detect the objects with this sensing range. In contrast, the device with a maximum range of 600mm (Graphic B) would be able to detect the object with the sensor at a distance of 300mm from the object because the base range is higher than the operating distance actually desired.

3.4 THE DEAD ZONE OF ULTRASONIC DIFFUSE REFLECTION SENSORS

In addition to the maximum range of the device in relation to object size, it is also important to consider that there is a certain area in front of the sound transducer within which ultrasonic diffuse reflection sensors cannot reliably detect an object. This area is also known as the dead zone. As already described in chapter 2, ultrasonic diffuse reflection sensors feature a transmitter and a receiver integrated in a single device. The sound transducer of such diffuse reflection sensors acts both as the source of the signal and as the receiver. While the device is generating a transmission signal, it cannot receive a signal.

When detecting transparent or non-transparent objects, an ultrasonic diffuse reflection sensor must therefore continually switch between transmitting and receiving. The sound emitted by an ultrasonic diffuse reflection sensor propagates in a funnel shape, meaning that the further an object is from the device, the larger the area that the signal strikes. Conversely, this also means that: the closer an ultrasonic diffuse reflection sensor is to an object, the higher the energy density of the sound that strikes the object.
If an ultrasonic diffuse reflection sensor is very close to an object, the transmitted acoustic signal has a very high energy density when it strikes the object. This can lead to a ping-pong effect within the dead zone: the acoustic signal is reflected by the object being detected and then reflected by the sensor itself due to the high energy density of the signal, thereby reaching the object again. From there, the sound is reflected again and sent back to the sensor.

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The problem regarding the time that the device requires between transmitting and receiving is obvious: the first reflection of the sound reaches the sensor while the sensor is still transmitting. The receiver is therefore unable to detect and process the signal. However, when the signal is reflected by the object for the second time, the ultrasonic diffuse reflection sensor may have switched to receive mode, enabling it to detect an object. Since this depends on the size, reflectivity and distance of an object, reliable detection of the object within this area cannot be ensured. In relation to this, it is also important to mention that ultrasonic diffuse reflection sensors have comparatively low switching frequencies, for example 20Hz. Therefore, through-beam systems are often recommended for high-speed processes, since they have switching frequencies of up to 150Hz. However, even this switching frequency, which is already relatively high for ultrasonic sensors, places certain limits on the detection of objects in applications with extremely high cycle rates.

4. OPTICAL SENSORS

When detecting transparent objects in high-speed processes, it can be sensible to use optical sensors, e.g. retro-reflective sensors, since these devices, which use red or infrared light, reach switching frequencies of between 1,000 and 2,000Hz. Teaching conventional optical retro-reflective sensors is usually a 2-point process in which the devices are taught first without an object between the sensor and the reflector, and then with an object inside the light barrier. The sensor uses the resulting limit values to automatically calculate a switching threshold.

4.1 THE TRANSMITTANCE OF TRANSPARENT OBJECTS

However, in practice, the optical permeability – also known as the transmittance – of transparent objects for visible light makes it difficult to use such solutions. For example, glass has a high transmittance and therefore a high permeability for light in the visible range. Red or infrared light can also permeate transparent objects up to almost 100%, depending on the transmittance of the materials. Therefore, a transparent object results in almost no optical damping of an optical sensor such as a retro-reflective sensor. As a result, the response sensitivity of such a system moves close to the range in which no transparent object is inside the light barrier.

4.2 HIGH SENSITIVITY TO SOILING

Therefore devices with a high response sensitivity are often preferred for detecting transparent objects because they respond to minimal damping of an optical system. However, this feature also means that devices such as optical retro-reflective sensors, or more precisely their optics, are very sensitive to dirt deposits. Depending on how high the calculated switching threshold is, a retro-reflective sensor may be dampened by even a very small amount of soiling on the device optics or reflector (e.g. a layer of dust that is barely perceptible to the human eye), causing it to switch when there is no transparent object in the detection range of the light barrier.

Using such solutions to detect transparent objects can therefore be complex in practice: Either the sensor optics and the reflector must be checked for dirt deposits regularly or these components must be cleaned no later than when the system overtly malfunctions due to soiling.

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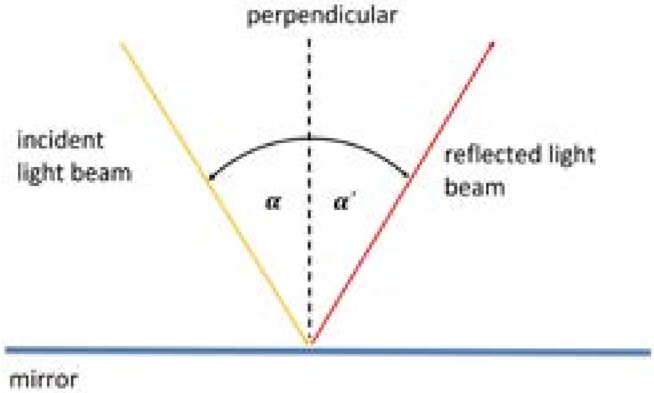
4.3 AN UNFAVORABLE ANGLE OF INCIDENCE

In the case of optical diffuse reflection sensors, problems can occur that are similar to those described under 4.1 and 4.2 for retro-reflective sensors. Another aspect worth mentioning regarding the use of optical diffuse reflection sensors for detecting transparent objects relates to the angular position of such devices in relation to an object. Essentially, the angle in question is the angle from which the signal (red or infrared light) of the diffuse reflection sensor strikes a transparent object. According to the law of reflection, the incident beam, the axis of incidence and the reflected beam lie in the same plane, meaning that the angle of incidence and the angle of reflection are the same size. The mathematical formula for this is: $\alpha = \alpha'$. Therefore, if light is reflected off a surface or an object, its angle of incidence is equal to the angle of reflection.



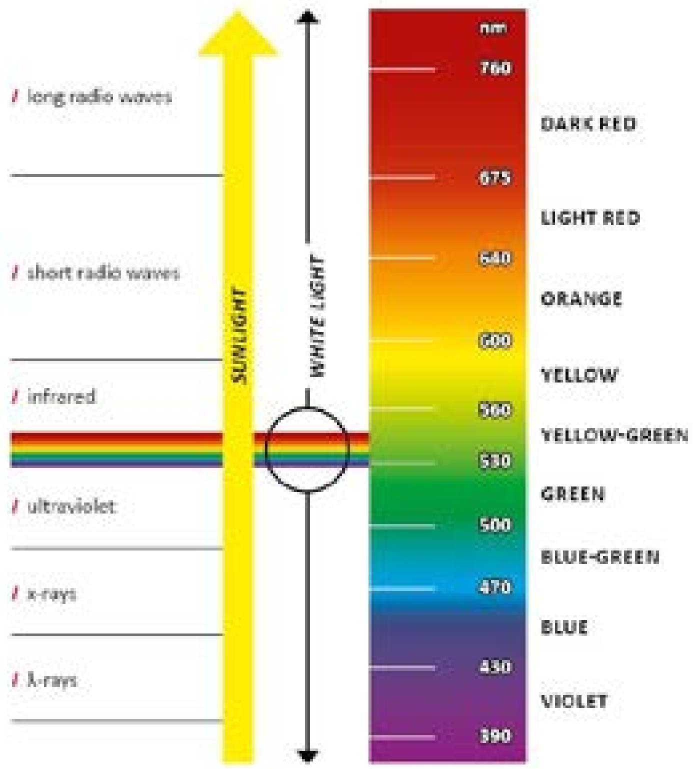
The angle of incidence of a light beam corresponds to its angle of reflection.

As a result, the following problem can occur in practice: suppose that a transparent film is to be detected with an optical diffuse reflection sensor. If the signal of the diffuse reflection sensor strikes the film at a somewhat unfavorable angle, it is possible that the reflected light will not reach the receiver because it is directed in another spatial direction. How wide the angle of a signal in relation to a transparent object can be depends largely on the level of gloss of the object. The glossier the object surface, the narrower the angle of the transmission signal in relation to this surface must be. For this reason, an optical diffuse reflection sensor should be aligned so that it is as perpendicular as possible to the transparent object being detected so that when its signal strikes the object surface they are likewise perpendicular to one another. As the earlier explanations show, reliable detection of transparent objects and materials is associated with very complex challenges both for conventional optical sensors and for ultrasonic sensors. Ultimately, these challenges indicate the need for an alternative to the previously described technologies.

5. RETRO-REFLECTIVE SENSORS WITH UV LIGHT

In the introduction to this white paper, it was mentioned that the technical development of sensors is constantly progressing. One of these pioneering developments is the **OR270478** retro-reflective sensors from ipf electronic, which use extremely short-wave polarized UV light. Whereas the visible red and infrared light of conventional optical diffuse reflection sensors has a wavelength of 700nm to 880nm, the wavelength of the UV light of the **OR270478** is just 275nm.

Development in the area of retro-reflective sensors: unlike conventional retro-reflective sensors, the **OR270478** does not use visible red or infrared light, but rather extremely short-wave polarized UV light.



White light is polychromatic (broad-spectrum) light that consists of various wavelengths in the range between 390nm and 780nm. The red or infrared light of conventional optical sensors has a wavelength of between 700nm and 880nm. In contrast, retro-reflective sensors that use UV light have a wavelength of just 275nm.

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Due to its physical properties, the extremely short-wave UV light cannot permeate transparent materials that are otherwise very difficult to detect because objects made from these materials do not have the attribute of transparency for this type of light; instead, such objects almost have the effect of non-transparent objects. The transmittance of such objects described under 4.1 for the red and infrared light of conventional optical sensors is therefore irrelevant for the **OR270478**. Accordingly, the devices do not require high sensitivity to be able to calculate a clear switching threshold and thereby reliably detect transparent objects or materials.

The transmittance of transparent objects for visible light is irrelevant for the **OR270478**. The figure shows two devices detecting glass panes on a roller conveyor.

This means that if a transparent object is located between the sensor and the reflector, the signal deviation is very high compared to the free light barrier. The **OR270478** have a correspondingly low response sensitivity to soiling and water droplets. Therefore, they can be used even in harsh environmental conditions. Moreover, with the **OR270478** there is no longer multiple switching during detection of the same object. And also the shape and thickness of the object to be detected have no effect on the measurement result.

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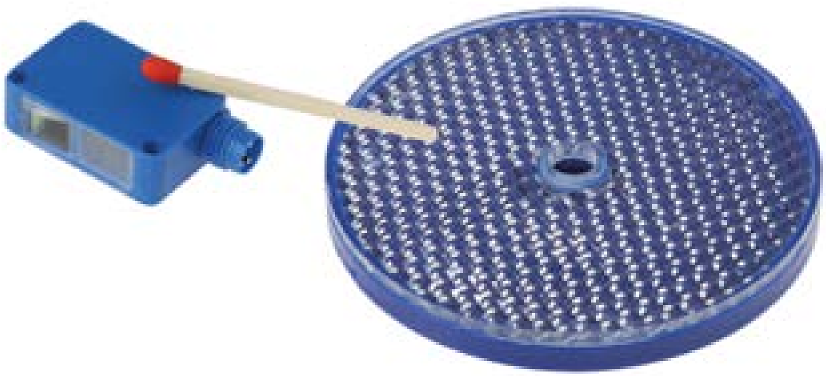
5.1 SYSTEM COMPONENTS

As reflection systems, the **OR270478** feature a transmitter and a receiver integrated in a single device. The transmitting element consists of an LED that emits the polarized UV light. Transmitting and receiving optics are located at the same plane. Special autocollimation optics ensure reliable near-range object detection without blind zone, even through small openings. The principle of the autocollimation optics on another reflection system can be used to explain. In this context, autocollimation refers to a mirror/lens system with which the light from the transmitter hits a semi-transparent mirror from behind, permeates the mirror and thereby reaches the reflector. The light is then reflected and hits the mirror again, where it is deflected by 90° to reach the receiver. As a result, the two beams lie on a single axis, meaning that only a small hole in e.g. a guide rail is required. In addition, such systems naturally also feature integrated lenses, so that the angle of beam spread is not too wide.

In reflection systems with single-lens optics like this device, an autocollimator (mirror/lens system) is used.



System components of the **OR270478**: transmitting and receiving elements (left) are located on a single plane (autocollimation optics). Unlike conventional reflectors, the reflector has a protective cover that can be permeated by UV light.

The reflector of the **OR270478** retro-reflective sensor has special features specifically for use with UV light. Unlike conventional reflectors, the **AO000548** reflector has a protective cover that consists of a coating that can be permeated by UV light.

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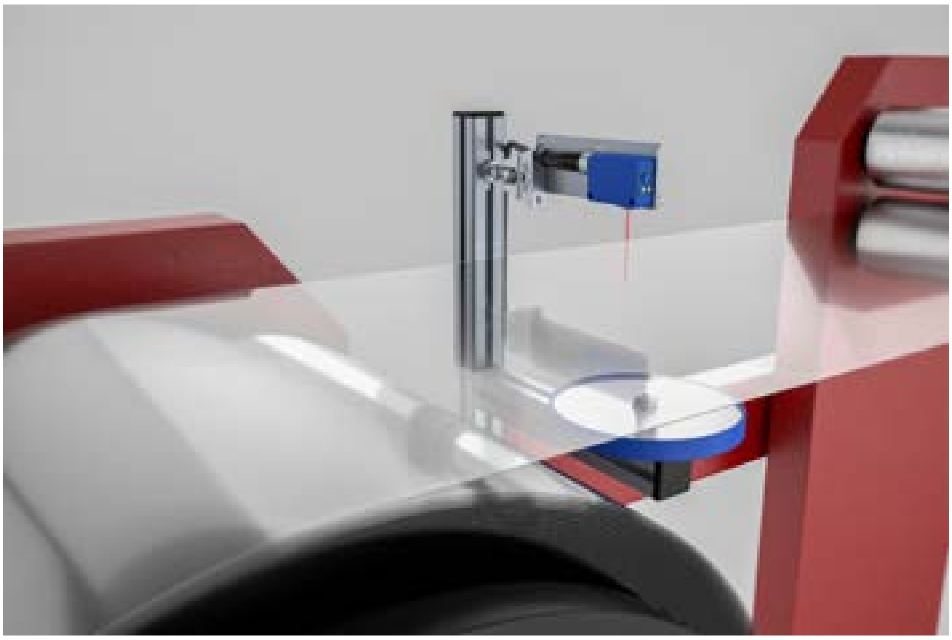
5.2 COMMISSIONING

As with conventional retro-reflective sensors, the **OR270478** can usually be taught with a 2-point process (see chapter 4). This procedure achieves the best results and is always recommended in the case of materials that are particularly difficult to detect (e.g. transparent films) or if dirt or water impede the detection of an object. For detecting thicker transparent objects such as bottles and containers made of glass or plastic, a 1-point teaching process is sufficient. For this purpose, the teach button on the device is pressed once without an object inside the light barrier.



For objects that are difficult to detect, such as a transparent film in this case, a 2-point process is recommended for teaching an **OR270478**.

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5.3 TECHNICAL SPECIFICATIONS

Due to its dimensions of 37mm x 10mm x 20mm (see Figure 9 for a comparison with a match) the **OR270478** are extremely compact solutions that are intended to enable easy installation, especially in applications where space is very constricted. The distance range to the reflector is 40mm to 1,200mm.

To enable easy integration into the industrial Ethernet, the retro-reflective sensors are equipped with an IO-Link interface to make the most of future-oriented features with high added value for the user, for example remote start up, various diagnostics functions, and additional options for configuration. With regard to switching frequency, the **OR270478** switching frequency of ≤1kHz is almost 10 times higher than that offered by ultrasonic sensors, which is already relatively high at up to 150Hz (see chapter 3.4). Therefore, the retro-reflective sensors are particularly well suited for high-speed processes such as the detection of transparent bottles made from glass or PET in the beverage industry.

The retro-reflective sensors are all but predestined for use in high-speed processes due to their high switching frequency of ≤1kHz. This is a typical example from the beverage industry, with the detection of transparent PET bottles.

Other technical properties of the **OR270478** include an output current (max. load) of 100mA and the degree of protection IP67 so that the devices can also be used in hostile industrial environments.

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