Factory Automation

Fundamental Principles of Smart Sensors

Course Sample

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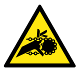
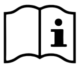
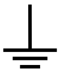
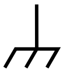
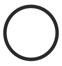
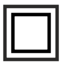
Safety and Common Symbols

The following safety and common symbols may be used in this course and on the equipment:

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk, which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk, which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk, which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the "Caution, risk of danger" sign, indicates a hazard with a potentially hazardous situation, which, if not avoided, may result in property damage.
	Caution, risk of danger. Consult the relevant user documentation.
	Caution, risk of electric shock.
	Caution, lifting hazard.
	Caution, hot surface.
	Caution, risk of fire.
	Caution, risk of explosion.

Symbol	Description
	Caution, belt drive entanglement hazard.
	Caution, chain drive entanglement hazard.
	Caution, gear entanglement hazard.
	Caution, hand crushing hazard.
	Static sensitive contents. Observe precautions for handling electrostatic discharge sensitive devices.
	Notice, non-ionizing radiation.
	Consult the relevant user documentation.
	Radio Equipment Directive (RED) geographical restrictions – consult the relevant user documentation.
⎓	Direct current.
∿	Alternating current.
≂	Both direct and alternating current.
3∿	Three-phase alternating current.

Symbol	Description
	Earth (ground) terminal.
	Protective conductor terminal.
	Frame or chassis terminal.
	Equipotentiality.
	On (supply).
	Off (supply).
	Equipment protected throughout by double insulation or reinforced insulation.
	In position of a bi-stable push control.
	Out position of a bi-stable push control.

Preface

Smart Sensors

In today's complex and increasingly interconnected manufacturing environment, obtaining relevant, timely input from processes is key to higher efficiency and productivity. As the industrial internet of things (IIoT) develops, sensors get smarter and reliance on smart sensor technology increases. It is a building block of Industry 4.0.

Using an open communication protocol, such as IO-Link® or OPC UA, smart sensors become visible through all layers of Industry 4.0 manufacturing networks (machines, PLCs, SCADA, MES, ERP, Cloud). They monitor a variety of physical variables in real time, collect, and transmit data to operators, technicians, and engineers.

Figure 1. Equipment Set TP 1312 Smart Sensors.

Understanding smart sensors

Clever integration of smart sensors in automation equipment provides plant workers with useful, live information about the status of systems and processes, so they can perform predictive maintenance and make improvements to the processes.

Industry 4.0 (I4.0) workers need to understand this technology to reap its full benefits.

Equipment set TP 1312 combines industrial components with project-oriented learning activities to efficiently build proficiency in smart sensor technology for I4.0.

Available smart sensors

All smart sensors are equipped with IO-Link®. The equipment set includes an IO-Link® communication master module and the necessary cables, as well as three common smart sensors:

- Photoelectric sensor
- Inductive proximity sensor
- Ultrasonic sensor

Optional smart sensors can be added depending on training needs:

- RFID sensor
- Laser distance sensor
- Code reader sensor
- Pressure sensor
- Flow proximity sensor
- Temperature sensor

In addition, a Smart IO-Link Interface is available that allows interacting with a sensor using a smart phone or a tablet.

All components are based on the Quick-Fix® mounting system, which allows for quick mounting and alignment of sensors and test objects without any tools. Components can be installed on a profile plate or on the optional Sensor Workstation.

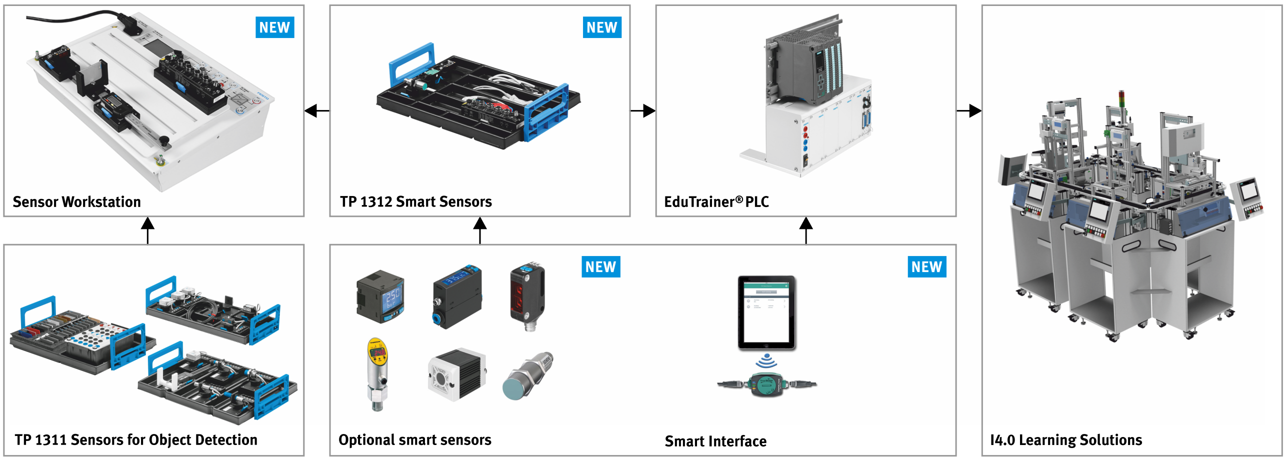


Figure 2. A progressive learning path for sensor technology.

We invite readers to send us their tips, feedback, and suggestions for improving the course.

Please send these to:

services.didactic@festo.com

The authors and Festo Didactic look forward to your comments.

About This Course

Course objectives

When you have completed this course, you will know what Industry 4.0 is, and how smart sensors are an important part of implementing Industry 4.0. You will be familiar with the main differences between smart sensors and regular sensors, and what advantages they offer over regular sensors. You will know the principles of operation of the most common sensor types: inductive proximity sensors, photoelectric sensors, ultrasonic sensors, process sensors, RFID read/write devices, and barcode readers. You will be familiar with the communication protocols used to communicate with smart sensors, such as IO-Link and Profinet.

Safety considerations

Safety symbols that may be used in this course and on the equipment are listed in the Safety and Common Symbols table at the beginning of this course.

Safety procedures related to the tasks you will be asked to perform are indicated in each exercise.

Make sure you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think a manipulation could be dangerous for you or your teammates.

PACTware installation

In this course, the configuration tool used to parameterize the smart sensors is PACTware. Before performing any exercise, make sure PACTware is installed on the host computer on which students perform the manipulations.

You can download the software manager required to install PACTware here:

Turck Software Manager

https://ip.festo-didactic.com/FDCAQRCodes/qrcode0061.html

If necessary, consult the video provided at the following link. It shows the necessary steps to install PACTware on a computer.

Installing PACTware

https://ip.festo-didactic.com/FDCAQRCodes/qrcode0040.html

For more information on how to download and install PACTware, refer to Appendix A of this course.

Prerequisite

Basic electrical knowledge is a prerequisite to this series of courses. It is assumed that you have a general understanding of these concepts:

- DC and ac voltage, current, and power
- Basic electrical components (resistor/potentiometer, inductor, capacitor, diode, transistor)
- Ohm's law

- Series and parallel circuits
- Electrical measurement

System of units

Units are expressed using the International System of Units (SI) followed by units expressed in the U.S. customary system of units (between parentheses).

To the Instructor

You will find in this instructor version of the course all the elements included in the student version together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to the instructor is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this course should be considered as a guide. Students who correctly perform the exercises should expect to demonstrate the principles involved and to make observations and measurements similar to those given as answers.

Time requirements

At the beginning of each section in this course, you will find an indication of the time required by an average student to perform the section. This time indication is for reference purposes only. The actual time required by students may vary significantly from one class to another, and from one student to another.

To prevent inconsistencies in the times required to complete sections, it is recommended that the instructor perform the tasks in the section beforehand to obtain a general idea of the time required to complete the section. The instructor can then better estimate the time required for his or her class to perform the tasks.

Sample

Extracted from

Instructor Guide

Smart Photoelectric Sensors

Photoelectric sensors

16 min.

Competencies

- *Know what photoelectric sensors are.*
- *Be familiar with the basic principles of operation of the following types of photoelectric sensors: through-beam sensors, retro-reflective sensors, diffuse light sensors, and distance sensors.*

Photoelectric sensors are a type of sensor that detect the presence or absence of objects without physical contact. Therefore, they can meet a wide range of control needs: sense height, size, or position, count, monitor operating speed, and much more.

Photoelectric sensors consist of a light emitter and a light receiver. The emitter is a light emitting diode (LED) that emits a specific wavelength of light. Most photoelectric sensors use infrared, visible red, green, or blue light sources. Visible and infrared lights are tiny parts of the electromagnetic spectrum. Infrared LEDs are used when a maximum light output is required for an extended sensing range. Visible light beams ease the setup or help confirm sensor operation.

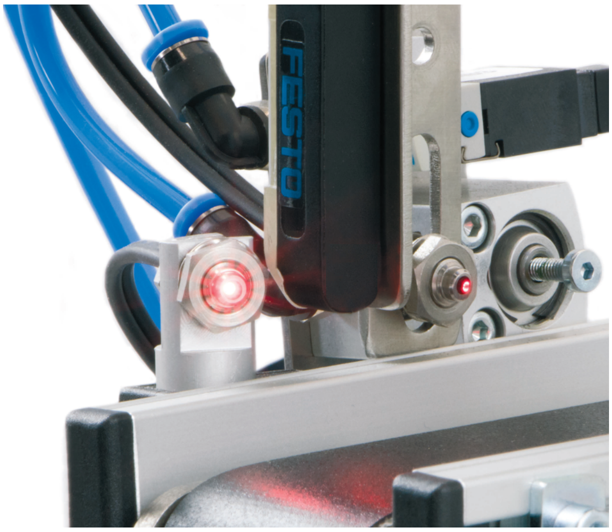


Figure 56. Red light at the emitter/receiver unit of the diffuse light sensor.

The receiver is a photodiode, or phototransistor, that provides a change in conducted current depending on how much light is detected. Photodiodes and phototransistors are more sensitive to certain wavelengths of light. To improve efficiency, the light emitter and receiver must be spectrally matched. The following figure shows the three basic types of photoelectric sensors: through-beam, retro-reflective, and diffuse photoelectric sensors.

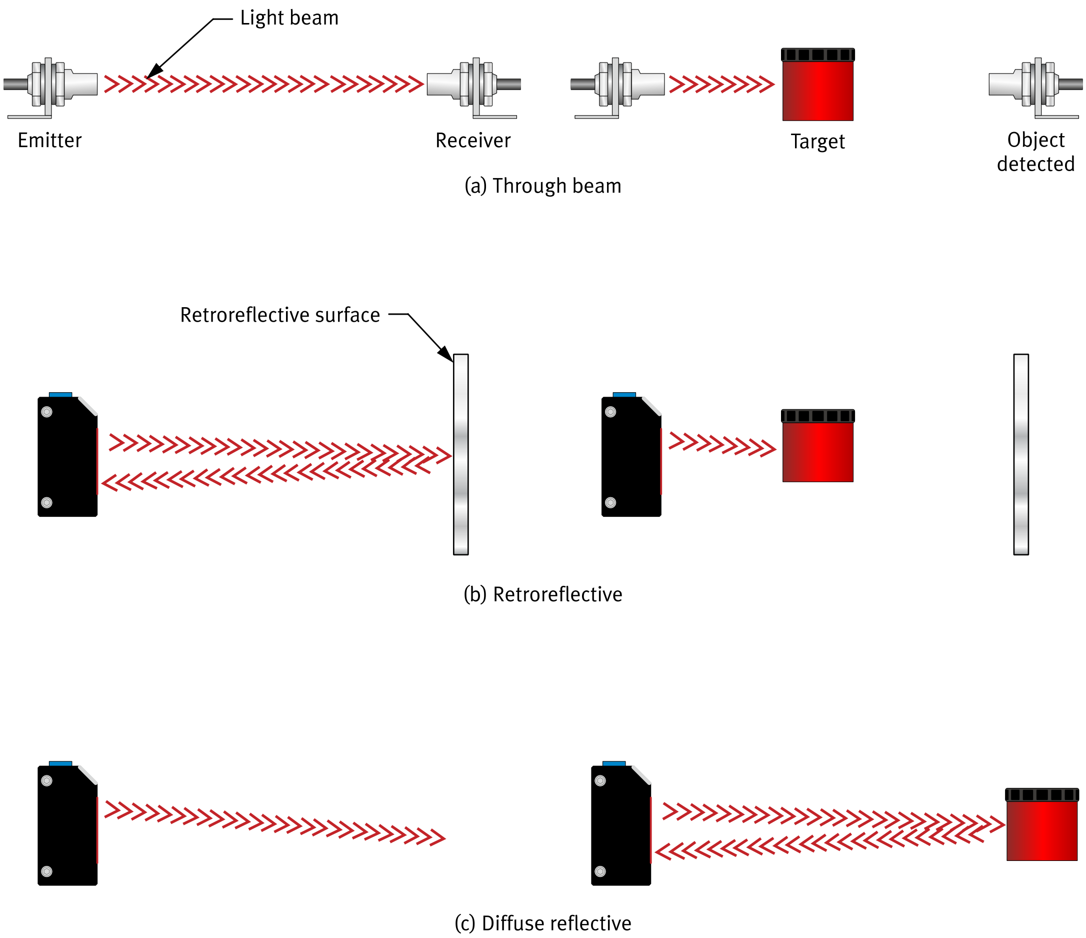


Figure 57. Through-beam, retro-reflective, and diffuse photoelectric sensors.

Photoelectric sensors with fiber-optic cable are often used in difficult-to-access or exposed locations where there is no room for an emitter and/or a receiver, or where harsh environmental conditions prevail. In the case of fiber-optic units, the emitter and the receiver can both be located in one housing. A single cable can combine the fiber-optic cables of both the emitter and the receiver.

The circuit diagram symbol for a photoelectric sensor with a normally open output is shown below.

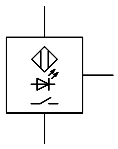


Figure 58. Photoelectric sensor symbol (IEC).

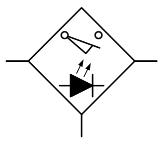
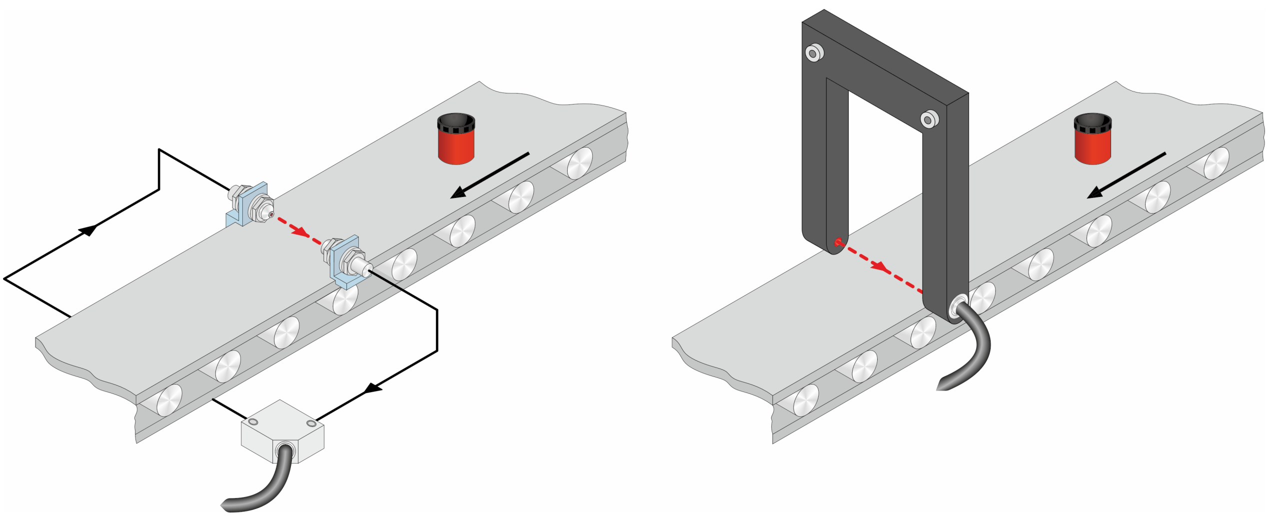


Figure 59. Photoelectric sensor symbol (ANSI).

Through-beam sensors

In most through-beam sensors, the emitter and receiver are in separate housings. The emitter projects a light beam directed toward the receiver, as shown in (a) of the following figure. The target object interrupts the beam and the receiver senses the absence of the light beam, detecting the presence of an object. Through-beam sensors designed to detect objects as soon as the object passes through the beam are often referred to as light barriers.



(a) Through-beam sensor with the emitter and receiver in separate housings

(b) Fork sensor

Figure 60. Through-beam sensor and fork sensor.

A common subtype of through-beam sensor is the fork sensor (also called fork light barrier), as shown in (b) of the above figure. In such sensors, the light emitter and receiver are located in the same housing in the form of a fork, hence the name. The control device for the sensor is also usually in the same housing. The main advantage of fork sensors over other types of through-beam sensors is that, due to the fixed housing, sensor alignment is not an issue.

Through-beam sensors provide the longest sensing ranges. These sensors are well suited to operate in very dusty or dirty industrial environments. They may not be suitable to detect translucent or transparent targets since the receiver will see through this type of target.

Retro-reflective sensors

The emitter of retro-reflective sensors projects a light beam toward a reflector, which directs the beam back to the receiver contained in the same housing, as shown in the following figure. The presence of a target object interrupts the reflected light beam and indicates the sensor detects an object.

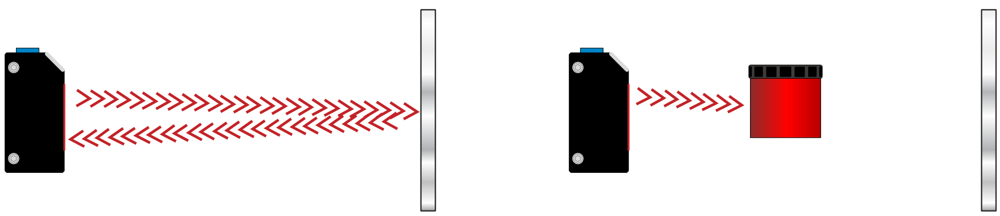


Figure 61. Retro-reflective sensor.

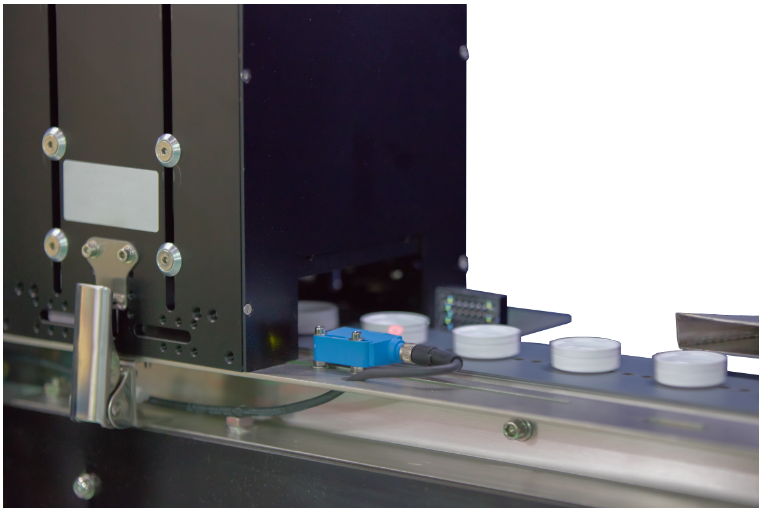


Figure 62. Retro-reflective sensor used for object detection on a belt conveyor.

Diffuse light sensors

In diffuse light sensors, the emitter and receiver are also contained in the same housing, without the use of a reflector (see the following figure). The emitter projects a light beam. When a target object enters the beam, light reflects off the object and back to the receiver. The primary advantage of a diffuse-reflective sensor is its simplicity.

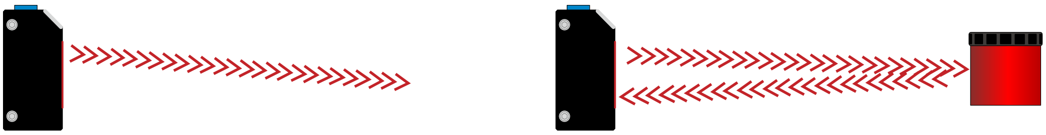


Figure 63. Diffuse light sensor.

The sensing range of diffuse light sensors depends on several factors. The most important factors are:

- Object size. The larger the object detected, the more it reflects light. Thus, sensors detect large objects at a longer sensing distance than small objects for a given sensitivity of the sensor.
- Object material. Certain materials (light-colored materials, metals) reflect more light than other materials (e.g., dark-colored materials, fiber glass). The amount of light reflected by a material can be rated using the reflection factor, a relative measure of a material's reflectivity. The following table shows the reflection factor of different materials. Sensors detect materials with a high reflection factor at a longer sensing distance than materials with a low reflection factor for a given sensitivity. Note that transparent objects such as glass and plastic sheets usually have a smooth, reflective surface. This allows their detection by diffuse light sensors.

Table 14. Reflection factor of different materials.

Kodak neutral card	
White side (reference medium)	100%
Gray side	20%
Paper	
Typewriting paper	94%
Newspaper paper	97%
Black on white typewriting papier	
Drawing ink	4-6%
Photocopy	7%
Plotter pen	
HP fiber-tip pen (0,3 mm)	84%
Ink (Pelikan)	100%
Pencil, HB	26%

Plastics, glass	
White PVC	90%
Blue, green, yellow, red PVC	40-80%
White polystyrene	120%
Fiber glass board material	
Without copper coating	9%
Glass, 1 mm thick	9%
Metals	
Aluminium, bright	110%
Copper, matt (not oxidized)	110%
Gold plating, matt	150%
White cotton	110%
Black velvet	1.5%

- Object shape and orientation. Flat surfaces reflect light in a more direct way than curved surfaces, as shown in (a) of the following figure. Curved surfaces deflect most emitted light away from the sensor's receiver, as shown in (b). Furthermore, object surfaces oriented toward the sensor reflect more light than object surfaces oriented away, as shown in (c).

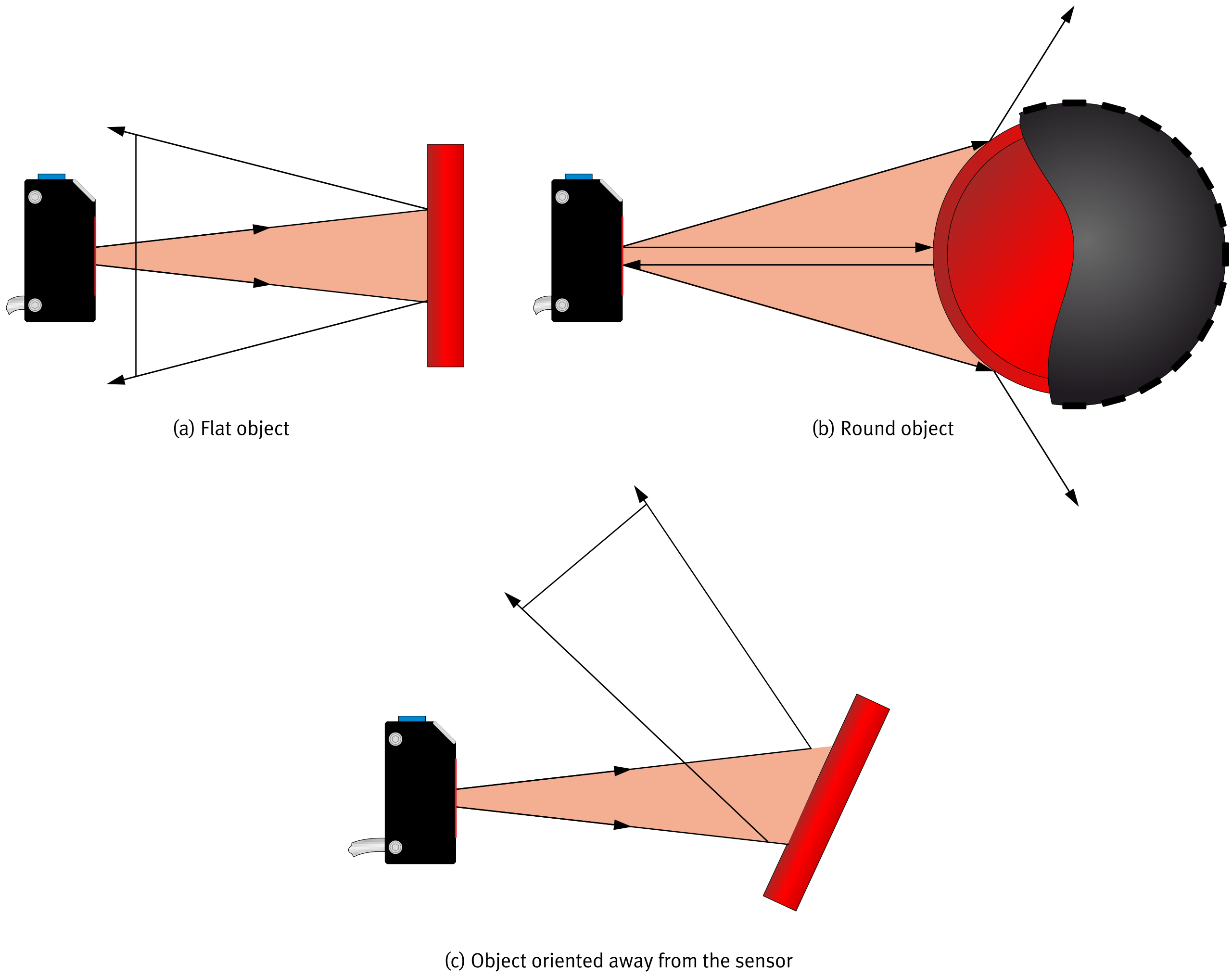


Figure 64. Effects of object shape and orientation on the sensing range of a diffuse light sensor.

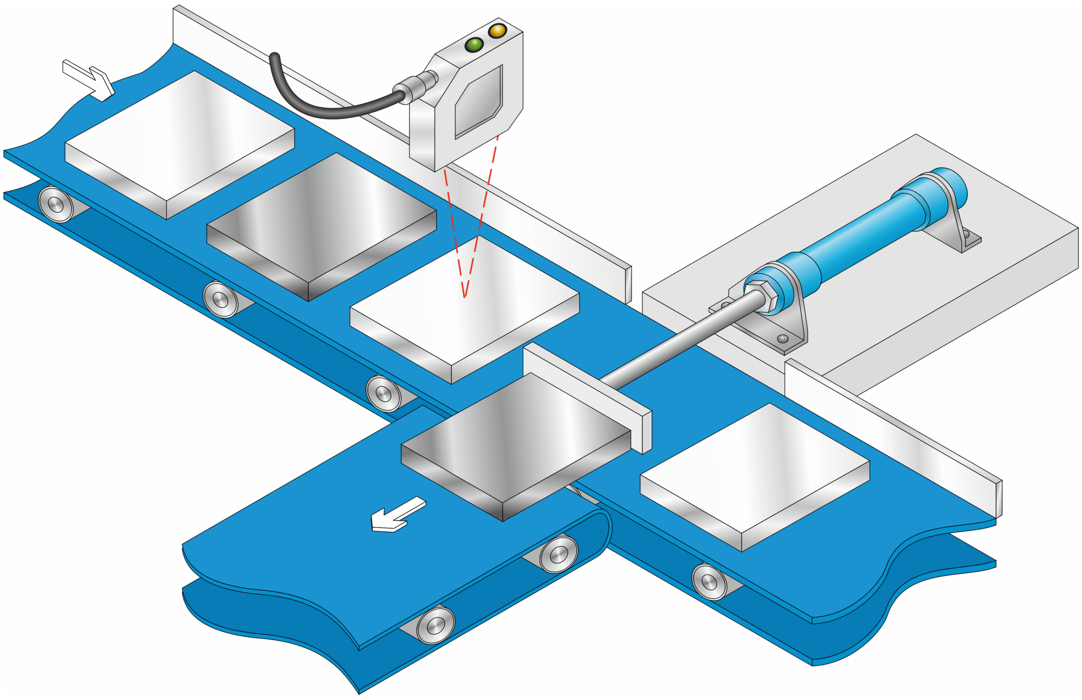


Figure 65. Diffuse light sensor used in a sorting application that distinguishes between the different reflection factors of the workpieces.

Distance sensors are a type of diffuse light sensor that allow distance measurement. They operate in the same way (i.e., the emitter projects a light beam and, when a target object enters the beam, light reflects off the object and back to the receiver). However, in distance sensors, the receiver measures the intensity of the reflected light, which correlates with the distance of the object. The nearer an object is, the more intense the reflected light.

The following figure illustrates this principle of operation in an application where the distance sensor determines if a workpiece is upright or upside down.

- In (a), the workpiece is upright. The reflected light travels a comparatively long distance, reducing its intensity.
- In (b), the workpiece is upside down. The reflected light travels a comparatively short distance, increasing its intensity.

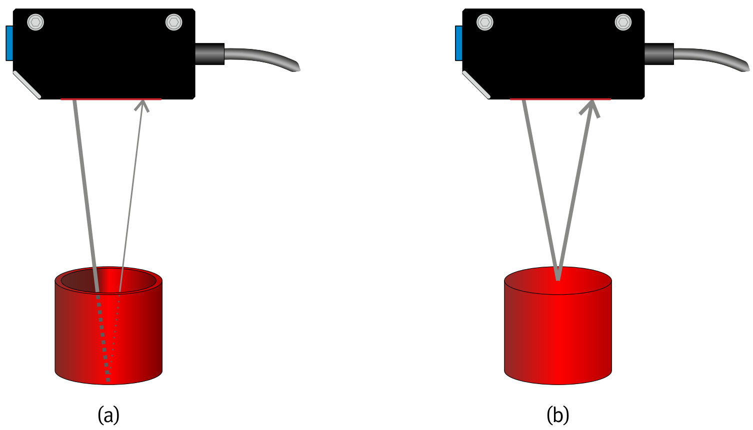


Figure 66. Distance sensor operation.

Most distance sensors must be installed at an angle (such as between 5° and 10°) from the target to ensure a diffuse reflection of the light. Diffuse reflection allows distance measurement based on the intensity of the light reflected on the sensor. If a distance sensor were installed perpendicular to the target, a phenomenon called total reflection would occur. In such a case, almost all light is reflected on the sensor, no matter the distance of the target. Total reflection prevents distance measurement.

Photoelectric sensor selection

6 min.

Competency

- *Know which parameters are considered when selecting a photoelectric sensor for an application.*

Due to their wide variety of operating modes and functions, photoelectric sensors are among the most common sensors used in the industry. However, photoelectric sensors are not suited for all applications. Therefore, it is important to consider the following parameters when determining which sensor to use for an application.

- **Function:** the function most suited for photoelectric sensors is object detection. In this function, the operating principles of photoelectric sensors make their detection of objects accurate, reliable, and versatile.
- **Cost:** photoelectric sensors, particularly diffuse light sensors, are generally low cost and, for this reason, are often preferred to other sensors offering a similar effectiveness.
- **Ease of setup:** photoelectric sensors are easy to set up. This is due to their relatively simple operating principles and the fact that the light they emit is usually visible by technicians.
- **Number of components:** depending on the application, it may be necessary to limit the number of components required for sensor operation. In this case, retroreflective sensors, which require a reflector, and through-beam sensors, which require an emitter unit and a receiver unit, are to be avoided. On the other hand, the emitter and receiver of diffuse sensors are in the same housing, which makes them preferrable when limiting components is crucial.
- **Environmental conditions:** photoelectric sensors can operate in most environmental conditions. However, the presence of smoke, mist, or any light-blocking substance between the sensor and the target severely hampers their efficiency.
- **Sensing distance:** diffuse light sensors are usually designed for detection at relatively small distances (1–60 mm). Retrofflective sensors, on the other hand, can operate at distances up to 10 m, while through-beam sensors offer the longest sensing distance at more than 25 m.

Photoelectric sensor applications

5 min.

Competency

- *Be familiar with typical applications of photoelectric sensors.*

Photoelectric sensors are often used in automated industrial applications and assembly lines. In such applications, color is often a criteria for detection, sorting, or inspection, making diffuse light sensors ideal. Furthermore, in such applications, object detection at certain points of a belt conveyor is a perfect application for through-beam sensors and retro-reflective sensors.

Figure 67. Diffuse light sensor used to detect the presence of caps on plastic containers in a production line.

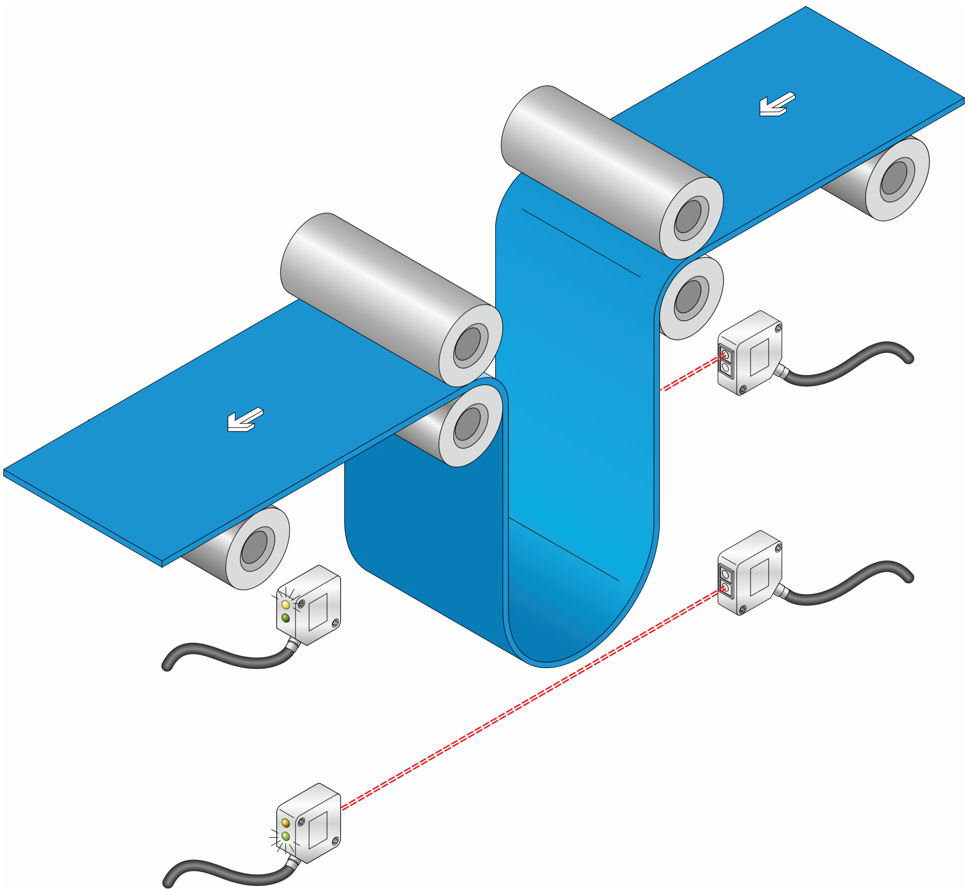


Figure 68. Through-beam sensors used to apply the proper tension to a conveyor belt. For the conveyor belt to be properly tensioned, both sensors must detect no target.

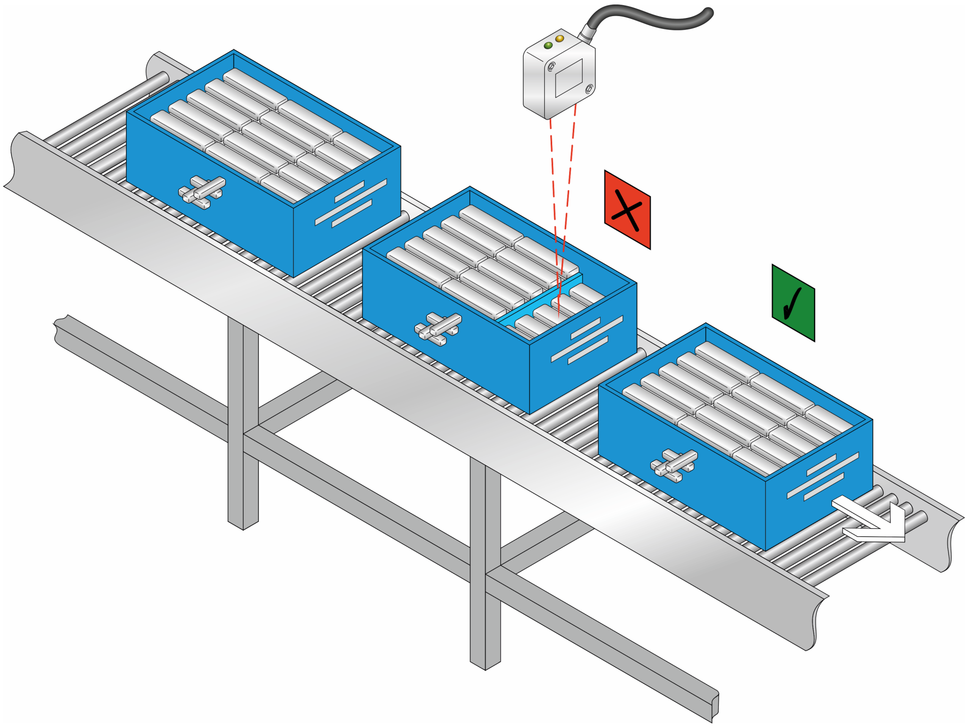


Figure 69. Diffuse light sensor application in which the sensor is used to detect if the crates contain the correct number of bars.

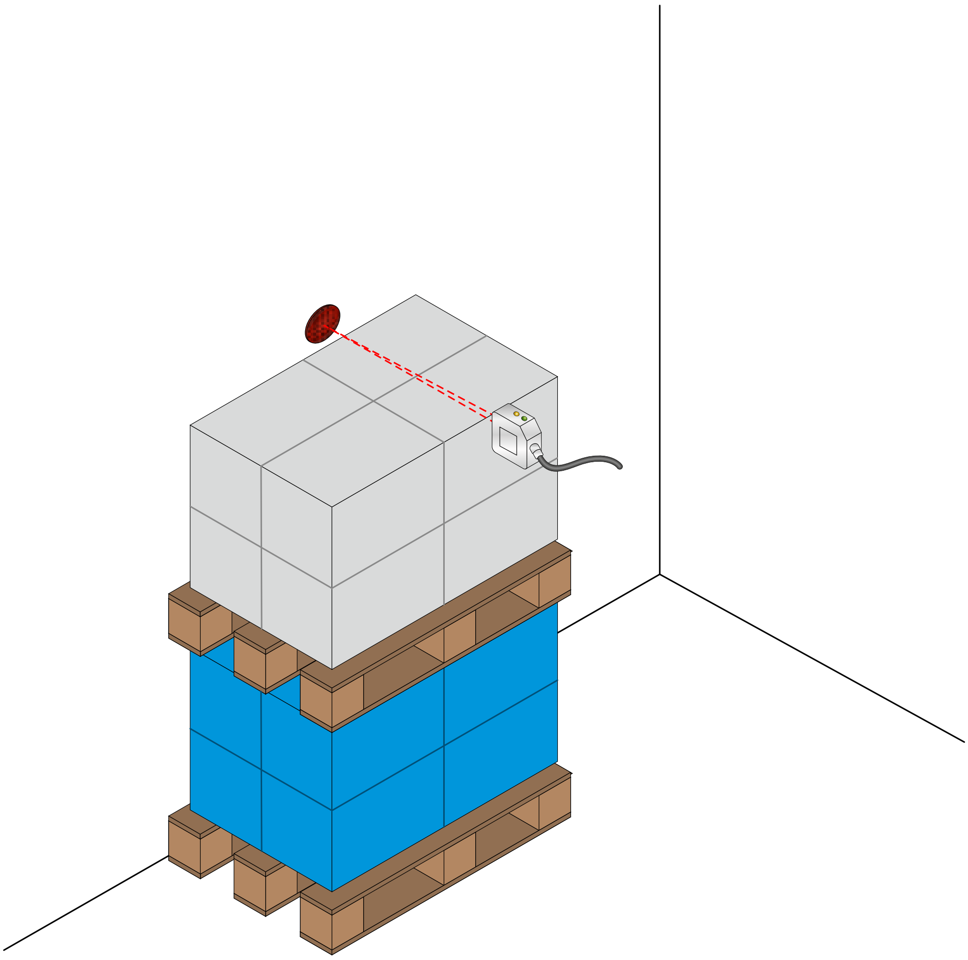


Figure 70. Storage monitoring using a retro-reflective sensor.

Other common applications of photoelectric sensors include machine tools, metal working, and the automotive industry. Diffuse light sensors are particularly suited for this purpose since their background suppression ability allow them to detect even reflective material such as greasy metal surfaces.

Photoelectric sensors can also be used in the food industry, such as in breweries or in dairy product processing plants. This is because photoelectric sensors, contrary to some other types of sensors, operate well in wet conditions, and resist cleaning agents and high pressures.

Figure 71. Diffuse light sensor used for the detection of potato chips on a belt conveyor.

Finally, photoelectric sensors are also found in household applications. Notably, through-beam sensors are commonlu used in garage door motion detectors. Some smoke detectors also include photoelectric sensors, whose emitted light is blocked when smoke is present. Finally, certain self-driving vehicles and robots use of photoelectric sensors to detect their surrounding environment.

Figure 72. Garage door motion detectors are common applications of photoelectric sensors.

Configurable parameters of diffuse light sensors

12 min.

Competency

- *Be familiar with the configurable parameters of diffuse light sensors in PACTware.*

Diffuse light sensors have many configurable parameters, depending on the sensor manufacturer as well as the software used to connect to the sensor. The following figure shows an example of a sensor parameter window for a diffuse light sensor in PACTware.

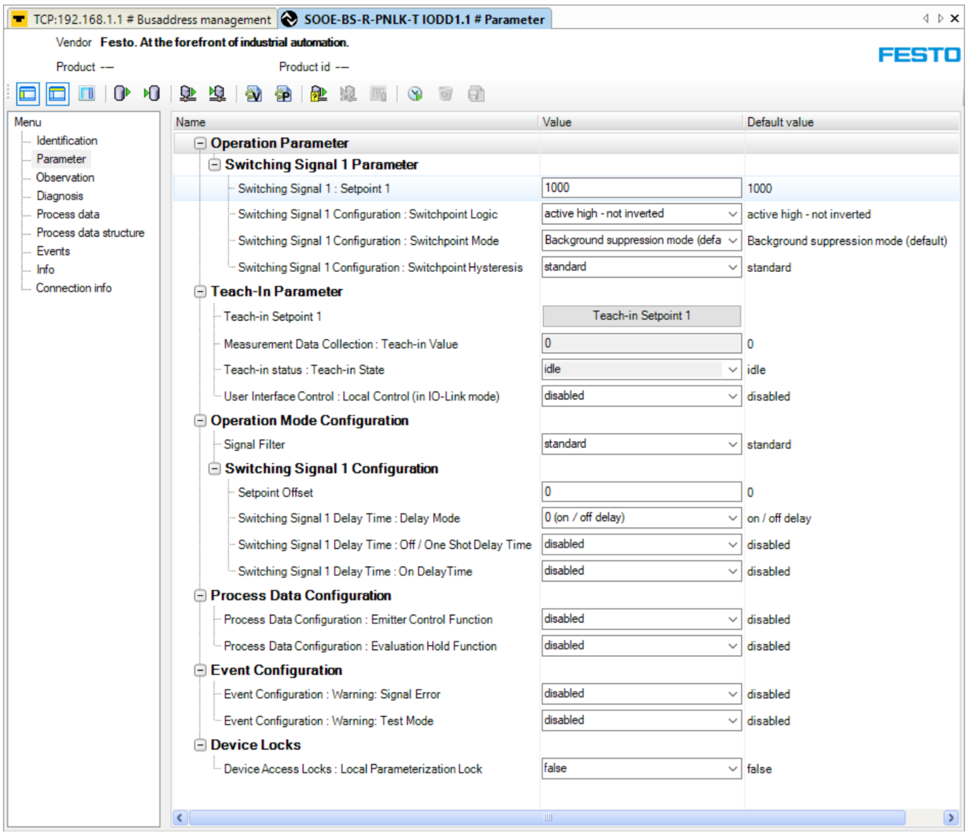


Figure 73. Example of a sensor parameter window for a diffuse light sensor in PACTware.

The main parameters from the PACTware sensor parameter window for a diffuse light sensor are listed in the following table.

Table 15. Description of main parameters from the PACTware sensor parameter window for a diffuse light sensor.

Parameter	Sub-parameter	Description
Operation parameter	Switching Signal 1 : Setpoint 1	Determines the switching signal setpoint (sensibility) of the sensor. The higher the sensibility, the longer the distance at which the sensor signal switches from one state to another (by default, from off to on).
	Switching Signal 1 Configuration : Switchpoint Logic	Determines whether the sensor is normally open or closed. Active high is NO, while active low is NC.
	Switching Signal 1 Configuration : Switchpoint Mode	Determines the evaluation behavior of the switching signal and derived output signal.

Parameter	**Sub-parameter**	**Description**
	Switching Signal 1 Configuration : Switchpoint Hysteresis	Determines the whether the hysteresis level is standard or high. A high hysteresis level may increase stability in certain applications.
Teach-In Parameter	Teach-in Setpoint 1	Clicking on the *Teach-in Setpoint 1* button starts a teach-in process on the sensor. This updates the *Switching Signal 1 : Setpoint 1* parameter according to the currently measured value, for the current target material and distance.
	Measurement Data Collection : Teach-in Value	Displays the measured value of the last performed teach-in command. This value is only updated once you read the parameters from the device.
	Teach-in Status : Teach-in State	Displays the state of the last performed teach-in command. It can indicate, for example, whether the teach-in was performed successfully or an error occurred. This value is only updated once you read the parameters from the device.
	User Interface Control : Local Control (in IO-Link Mode)	Enabled or disabled. When enabled, it allows temporary adjustment or teach-in over local control elements.
Operation Mode Configuration	Signal Filter	Determines whether a standard or low signal filter is applied to the sensor. A higher signal filter can improve stability in certain applications.
	Setpoint Offset	Introduces an offset on the *Switching Signal 1 : Setpoint 1* parameter.
	Switching Signal 1 Delay Time : Delay Mode	Determines whether the sensor operates in on/off delay mode or in a one-time switching delay. *On / off delay*: When a switching signal delay is added, the sensor takes the specified length of time before switching on or off. *On delay / One shot*: When the switching signal turns on, it remains in this state for the specified length of time before switching off, no matter the sensor status.
	Switching Signal 1 Delay Time : Off / One Shot Delay Time	Determines the length of time before the switching signal turns off. This corresponds to an off-delay timer.
	Switching Signal 1 Delay Time : On Delay Time	Determines the length of time before the switching signal turns on. This corresponds to an on-delay timer.

Parameter	Sub-parameter	Description
Process Data Configuration	Emitter Control Function	Enabled or disabled. When enabled, the emitter is controlled via process data output.
	Evaluation Hold Function	Enabled or disabled. When enabled, the signal evaluation process is controlled via process data output.
Event Configuration	Warning : Signal Error	Enabled or disabled. When enabled, an event is generated when the sensor signals are invalid (e.g., when there is heavy interference).
	Warning : Test Mode	Enabled or disabled. When enabled, an event is generated if the sensor is set to test mode by a remote signal.
Device locks	Device Access Locks : Local Parameterization Lock	Prevents the local (i.e., directly on the device) configuration of the sensor. This feature can be important to prevent unauthorized personnel from accessing the sensor in dangerous applications, for example.

Diagnosis information of diffuse light sensors

8 min.

Competency

- *Be familiar with the diagnosis information of diffuse light sensors in PACTware.*

Diffuse light sensors have a large quantity of diagnosis information, depending on the sensor manufacturer as well as the software used to connect to the sensor. The following figure shows an example of a sensor diagnosis window for a diffuse light sensor in the PACTware software.

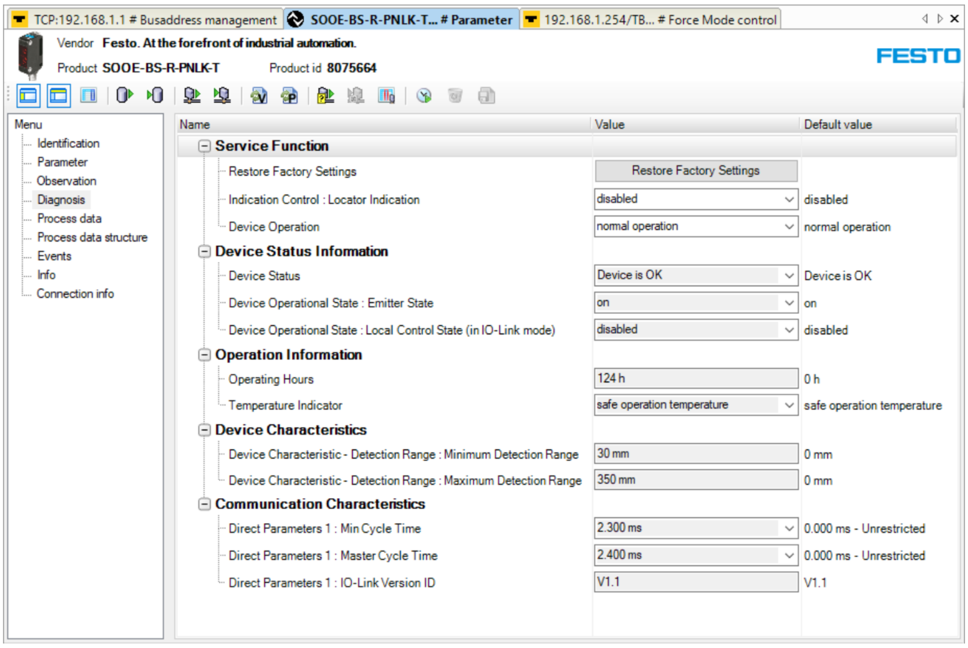


Figure 74. Example of a sensor diagnosis window for a diffuse light sensor in PACTware.

The main information from the PACTware sensor diagnosis window for a diffuse light sensor is listed in the following table.

Table 16. Description of the main information from the PACTware sensor diagnosis window for a diffuse light sensor.

Main identification	Identification	Description
Service function	Restore Factory Settings	This function causes all sensor parameters to revert to their factory (default) settings.
	Indication Control : Locator Indication	This function makes the sensor blink with a certain pattern, which allows its easier location in an industrial environment.
	Device Operation	This function allows the emitter of the sensor to be turned off.
Device Status Information	Device Status	Indicates various device status. In normal conditions, the indication "Device is OK" should appear.
	Device Operational State : Emitter State	Indicates whether the sensor emitter is operational or not.
	Device Operational State : Local Control State (in IO-Link Mode)	Enabled or disabled. When enabled, local control is temporarily enabled for adjustment or teach-in in IO-Link.
Operation Information	Operating Hours	Indicates the current number of operating hours of the sensor.

Main identification	Identification	Description
	Temperature Indicator	Indicates whether the sensor operates within the normal temperature range or not.
Device Characteristics	Detection Range : Minimum Detection Range	Indicates the minimum value of the specified detection range.
	Detection Range : Maximum Detection Range	Indicates the maximum value of the specified detection range.
Communication Characteristics	Direct Parameters 1 : Min Cycle Time	Defines the minimum cycle time to acquire input data or to process output data.
	Direct Parameters 1 : Master Cycle Time	Defines the actual cycle duration the master device uses to communicate with the sensor.
	Direct Parameters 1 : IO-Link Version ID	Indicates the sensor's current IO-Link version.

Assignments

In this exercise procedure, you will perform the following tasks:

- Set up the diffuse light sensor.
- Gather all the technical information available about the diffuse light sensor.
- Set the diffuse light sensor to a certain sensibility in reference to a Kodak gray target, then observe which targets of other material types can be detected.
- Change the operating mode (NO or NC) of the diffuse light sensor, and observe what happens to sensor operation.
- Add on-delay and off-delay timers to the diffuse light sensor, and observe what happens to sensor operation.

Project – Diffuse light sensor

Bottle sorting application

2 min.

In this exercise, you have to set up an application that allows for the sorting of bottles according to the material covering their surface. Three bottle types are available:

- Bottles with an aluminum finish
- Bottles with a red PVC finish
- Bottles with a black PVC finish

To help sort these bottles, you must set up a diffuse light sensor that can differentiate between both types of finish, according to their reflection factor. You will see in this procedure how you can do so.

Setup and connections

23 min.

Competencies

- *Be able to set up and connect an IO-Link master and a smart sensor.*
- *Be able to connect to a smart sensor using an IO-Link master and a configuration application.*

1. On the slot plate, install the IO-Link master, diffuse light sensor, and sliding target base as shown in the following figure. The equipment required for the exercise is indicated in the following table. It is recommended to orient the target base at a 15° angle from the sensor.

The following video shows the Sensors Workstation setup you need to perform in this procedure. Refer to it if necessary.

Equipment setup with the diffuse light sensor

https://ip.festo-didactic.com/FDCAQRCodes/qrcode0041.html

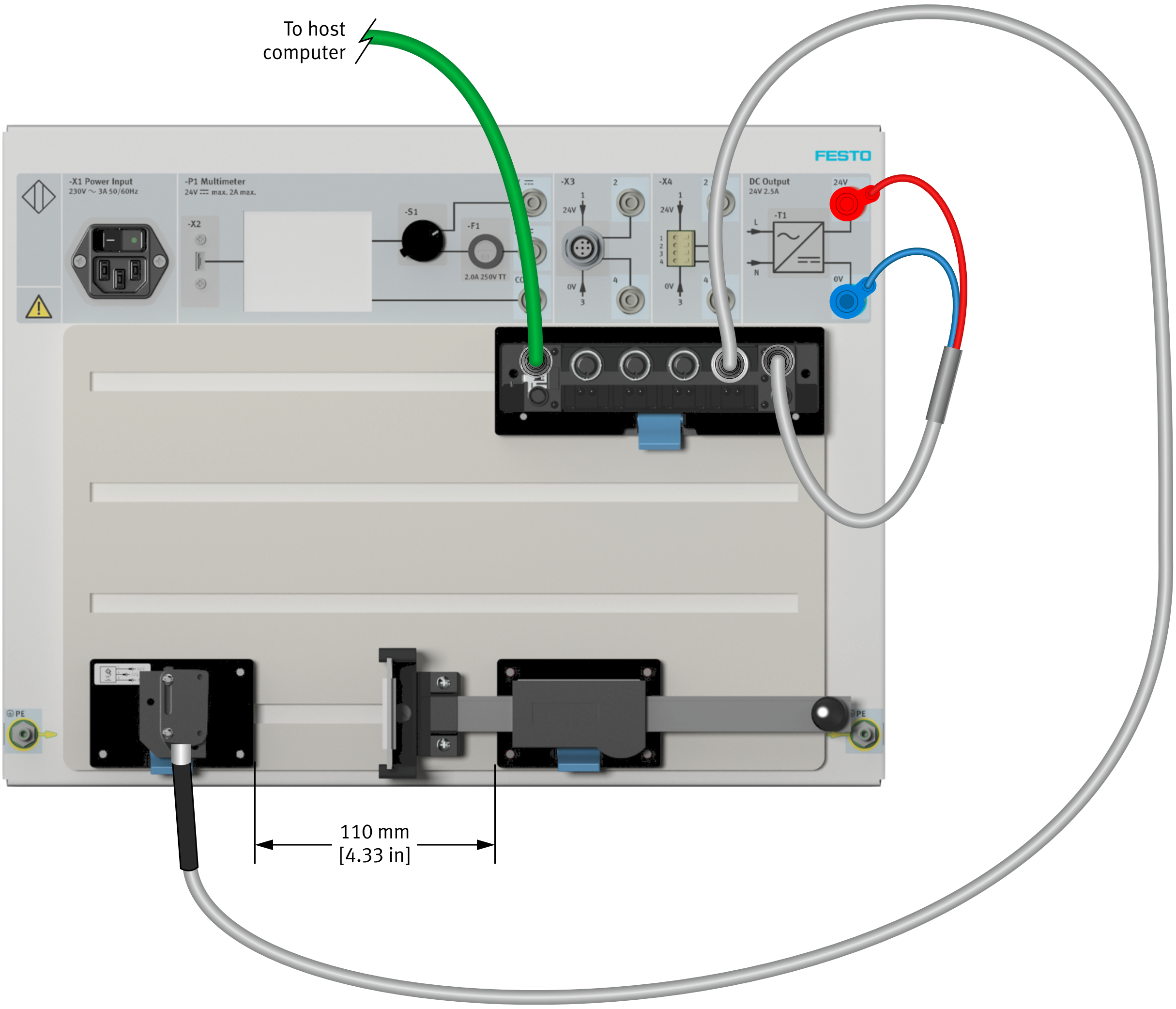


Figure 75. Setup for studying the operation of the diffuse light sensor.

Table 17. Equipment required to perform this exercise.

Equipment	Part number
Workstation (can be replaced by any standard Festo Didactic slot plate)	8110723
IO-Link master	8110729
Diffuse light sensor	8110725
Slide unit	572740
Set of test objects	549830
24 V DC power supply (not required when using the workstation)	N/A
Host computer	N/A

Communication and power connections

2. Using an M12-to-jacks cable, connect the X1 terminal on the IO-Link master to a 24 V ac power supply.

3. Using an M12-to-Ethernet cable, connect the ETH1 terminal on the IO-Link master to an Ethernet port on the host computer.

4. Using an M12-to-M8 cable or an M12-to-M12 cable, connect the Port 1 terminal on the IO-Link master to the sensor you will use in this exercise.

5. Using a power cable, connect the main power connector of the workstation (or any module you use as the 24 V ac power supply) to a suitable power outlet.

6. On the workstation (or any module you use as the 24 V ac power supply), set the main power switch to ON.

PACTware setup

7. On the host computer, make sure of the following:
   - PACTware is installed.
   - The IODD files for the sensor you will use in this exercise are imported on the host computer and added to PACTware.

If necessary, refer to Appendix A to know how to install PACTware, and to import the IODD files.

Connection to the IO-Link master

In this subsection, you will configure the IO-Link master and host computer so they can communicate together. Then, in PACTware, you will connect to the IO-Link master.

If necessary during the connection to the master and sensor procedures, consult the video provided at the following link. It shows the necessary steps to install PACTware on a computer.

Connecting to the master and sensor in PACTware

https://ip.festo-didactic.com/FDCAQRCodes/qrcode0040.html

8. On the host computer, configure the local area network connection so that its IP address is on the same subnet as the IO-Link master. By default, the IP address of the master is 192.168.1.254. It is therefore recommended to set the parameters of the local area network connection as follows using TCP/IPv4:
   - IP address: 192.168.1.1
   - Subnet mask: 255.255.255.0

At this point, it is recommended to make sure the host computer can communicate with the master. To do so, use the command prompt to ping the IP address of the master. If you do not receive any response, there may be communication problems. Ask your instructor for help.

9. In PACTware, click the **Add device** button to add an Ethernet connection to the project.

10. In the window that appears, select **BL Service Ethernet**. This adds the local area network connection you set up previously to the project. Make sure the displayed IP address corresponds to the one you set up.

11. In the Project window, double-click on the Ethernet connection you just added. This causes the window for this Ethernet connection to appear.

12. In the window for the Ethernet connection, click the **Search** button. The available master should appear, as the following figure shows.

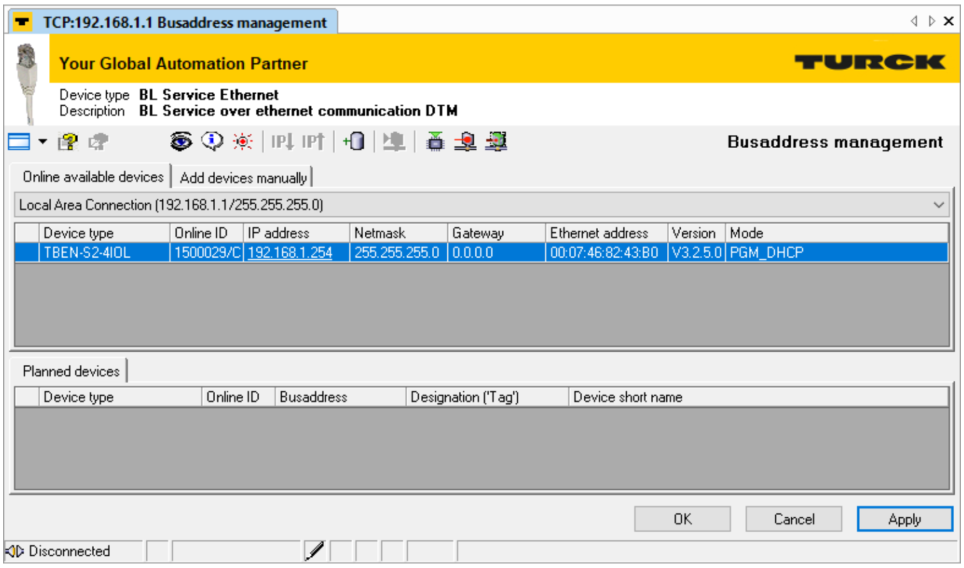


Figure 76. The available master should appear on screen.

13. In the window for the Ethernet connection, click on the master, then click the **Add device/DTM to project** button to add the master to the project. Notice that the project window becomes populated with the master and the number of IO-Link ports corresponding to the device. This is shown in the following figure.

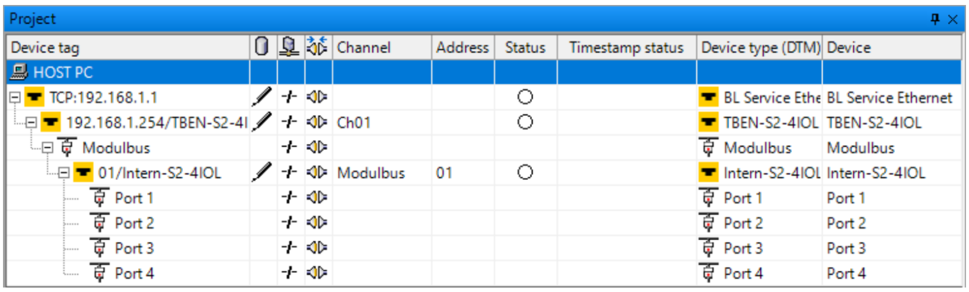


Figure 77. Project window populated with the IO-Link master.

Connection to the sensor

14. In the Project window of PACTware, right-click on the port to which the sensor you want to study is connected, then select **Add device**.

15. In the device selection window that appears, select the sensor to which you want to connect, then click **OK**. If the IODD file(s) for the sensor you want to connect to have been correctly installed on the host computer, the sensor should appear in the list.

If the desired sensor does not appear in the list, it may be due to the sensor's IODD files not being correctly installed on the host computer. Refer to Appendix A of this course to know how to install IODD files.

16. In the Project window, right-click on the sensor you just added. Select **Connect** to connect to the sensor. The sensor's status should change to indicate that PACTware is not connected to it.

17. In the Project window, right-click on the connected sensor. Select **Parameter** to make the sensor's screen appear. You can now configure the sensor(s). This is shown in the following figure.

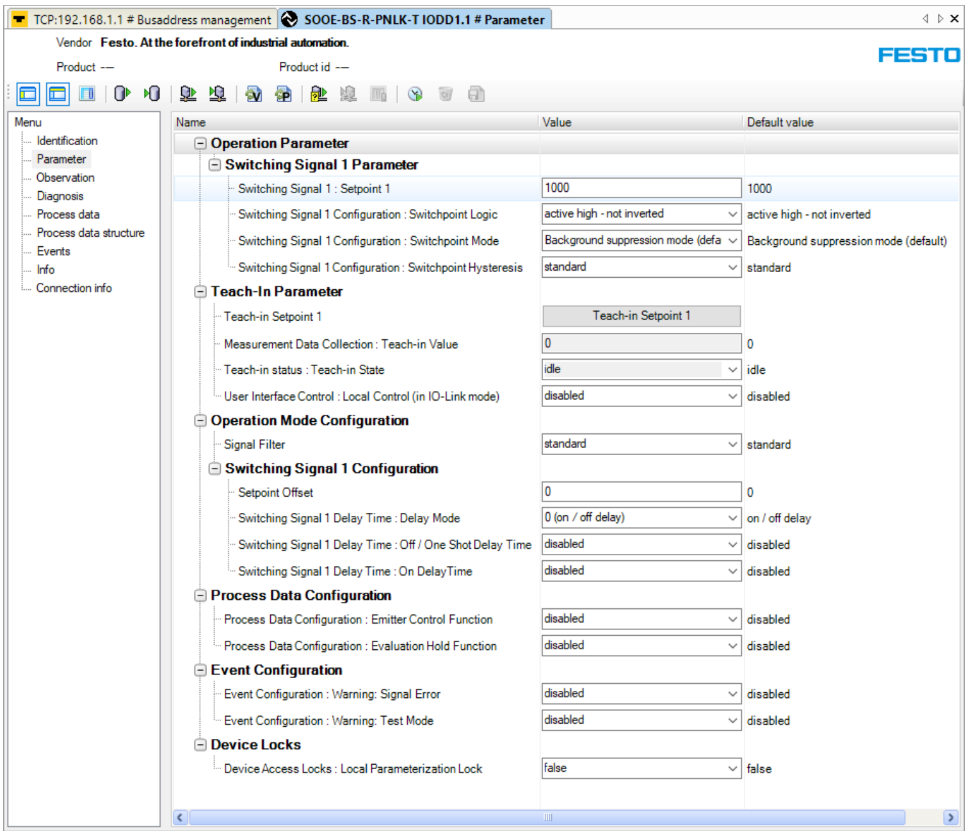


Figure 78. Example of a sensor parameter window.

18. In the sensor parameter window of PACTware, click on the **Read from device (upload)** button to upload the current sensor settings to the software.

Whenever you make modifications to any parameter of the sensor, make sure to click on the ***Write to device (download)*** *button to download the current application settings to the sensor. When doing so, if you are asked if you want to go in force mode, click* ***OK****.*

Technical specifications of the diffuse light sensor

12 min.

Competency

- *Be able to gather the information available about a smart sensor.*

In this section, you will gather the information available on the diffuse light sensor you will use in this exercise.

19. Consult the manufacturer's documentation on the diffuse light sensor. Using the information, complete the following table of the sensor's technical specifications.

The manufacturer, sensor name and part number, as well as some technical specifications of the sensor, are indicated in the ***Identification*** *window of PACTware.*

Table 18. Technical specifications of the diffuse light sensor (SOOE-BS-R-PNLK-T by Festo).

Parameter	Sub-parameter	Value (SI units)	Value (U.S. customary system of units)
Input signal/ measuring element	Measuring principle		
	Light type	_____ LED / Laser	
	Operating range	Min: Max:	Min: Max:
	Minimum object diameter		
	Ambient temperature	Min: Max:	Min: Max:
Signal processing	Max. black-white difference		
Switching output	Default operating mode (NO or NC)		
	Hysteresis		

Parameter	Sub-parameter	Value (SI units)	Value (U.S. customary system of units)
	Max. switching frequency		
	Max. output current		
	Voltage drop	Min: Max:	
Electronic system	Operating voltage range	Min: Max:	
	Residual ripple		
	Idle current		
LED status	Sensor ready for operation	______ (red / Green / Orange) LED	
	Target detected	______ (red / Green / Orange) LED	

Table 18. Technical specifications of the diffuse light sensor (SOOE-BS-R-PNLK-T by Festo).

Parameter	**Sub-parameter**	**Value (SI units)**	**Value (U.S. customary system of units)**
Input signal/ measuring element	Measuring principle	Optoelectronic	
	Light type	LED	
	Operating range	Min: 5 mm Max: 350 mm	Min: 0.197 in Max: 13.780 in
	Minimum object diameter	10 mm	0.394 in
	Ambient temperature	Min: -40 °C Max: 60 °C	Min: -40 °F Max: 140 °F
Signal processing	Max. black-white difference	15 %	
Switching output	Default operating mode (NO or NC)	NO	
	Hysteresis	21 %	
	Max. switching frequency	500 Hz	
	Max. output current	100 A	
	Voltage drop	Min: 0 V Max: 1.5 V	
Electronic system	Operating voltage range	Min: 10 V Max: 30 V	
	Residual ripple	10 %	

Parameter	Sub-parameter	Value (SI units)	Value (U.S. customary system of units)
	Idle current	25 mA	
LED status	Sensor ready for operation	Green LED	
	Target detected	Orange LED	

Object detection using a diffuse light sensor

18 min.

Competencies

- *Be able to set up a smart diffuse light sensor for object detection.*
- *Be able to test the detection of various materials using a smart diffuse light sensor set to a certain sensitivity.*

In this section, you will set the diffuse light sensor for a particular detection sensitivity. Then, you will test its operation on targets of different materials and determine which materials it detects.

20. In the window for the diffuse light sensor in PACTware, go to the **Diagnosis** submenu. Click on the **Restore Factory Settings** button to restore the sensor parameters to their default values.

    Click the **Write to device (download)** button to send the parameters to the sensor.

    Finally, click the **Enable or disable cyclic read from device for process data** icon. This causes PACTware to update cyclically and automatically the sensor's process data displayed in the window, and it allows you to observe the sensor's process data in real-time.

21. On the sliding target base, insert the gray target. Slide the target base until the target is 100 mm from the sensor. This target is used as a reference.

22. Set the diffuse light sensor so it detects the gray target (object 11). To do so, several methods are available:

    - IO-Link

a. In the window for the diffuse light sensor in PACTware, go to the **Parameter** submenu.

b. In the **Parameter** submenu, click on **Teach-in Setpoint 1**. Wait for the process to end. This sets the sensor so that it detects the target at the current distance.

The teach-in function automatically writes the changes to the device. However, if you want to see what those changes are, you need to read the parameters from the device.

c. Click the **Read from device (upload)** button to read the parameters from the device. While the system does so, observe that the **Switching Signal 1 : Setpoint 1** parameter changes. This confirms the new setpoint has been set.

- Sensitivity screw

  a. On the diffuse light sensor, use a small screwdriver to turn the sensitivity screw in the counterclockwise direction. Do so until you hear a click.

  b. Turn the sensitivity screw in the clockwise direction until the target is detected. This is indicated by the LEDs on the sensor lighting up. The detection point is set.

- Sensor button

  a. On the diffuse light sensor, press and hold the button until both LEDs blink simultaneously. This takes about 3 seconds. Release the button.

  b. Press and hold the teach-in button until the green LED blinks. This takes about 1 second. Release the button. The detection point is set.

23. Successively insert on the sliding target base the targets of different materials indicated in the following table. For each target, observe if the sensor detects the target, and note your observation in the table.

The following table assumes the sensor's switching logic is set to its default value (normally open).

If necessary, refer to Appendix C for the list of content of the Set of Detection Objects.

Table 19. Detection of different target materials.

Material	Detection (checkmark if yes)
Galvanized steel (5)	☐
Stainless steel (6)	☐

Material	Detection (checkmark if yes)
Aluminium (7)	☐
Brass (8)	☐
Copper (9)	☐
Drawing cardboard (10)	☐
Plastic, transparent (12)	☐
Plastic, red (13)	☐
Plastic, blue (14)	☐
Plastic, gray (15)	☐
Plastic, black (16)	☐

Table 19. Detection of different target materials.

Material	Detection (checkmark if yes)
Galvanized steel (5)	☑
Stainless steel (6)	☑
Aluminium (7)	☑
Brass (8)	☑
Copper (9)	☑
Drawing cardboard (10)	☑
Plastic, transparent (12)	☐
Plastic, red (13)	☑
Plastic, blue (14)	☐
Plastic, gray (15)	☑
Plastic, black (16)	☐

Questions on the measurement results

24. Observe the results you entered in this table. Which of the following statements correctly describes the materials not detected by the sensor? Indicate all correct statements.

a. The undetected materials reflected less light at the sensor than the reference target.

b. The undetected materials reflected more light at the sensor than the reference target.

c. One or more undetected material was metallic; it reflected too much light at the sensor.

d. One or more undetected material was transparent and let light pass through without reflecting enough at the sensor.

e. One or more undetected material was dark and absorbed too much light without reflecting enough at the sensor.

a, d, and e

25. Using the table listing the reflexivity of different materials given in this exercise discussion (this table), match each of the following target materials (some were used in the previous procedure) with the corresponding reflexivity level.

20%	97%	100%	1.5%
110%	120%	150%	90%

Copper, matt	Gold plating, matt	Kodak gray card	Kodak white card

PVC, white	Paper, newspaper	Polystyrene, white	Velvet, black

Copper, matt	Gold plating, matt	Kodak gray card	Kodak white card
110%	150%	20%	100%

PVC, white	Paper, newspaper	Polystyrene, white	Velvet, black
90%	97%	120%	1.5%

26. Considering the results you noted in this table and the reflexivity of each target material you established in the previous question, what can you say about the reflexivity of the undetected materials?

   a. All undetected materials had a reflexivity above that of the kodak gray card.

   b. All undetected materials had a reflexivity below that of the kodak gray card.

   c. All undetected materials had a reflexivity very near that of the kodak gray card.

b

Bottle-sorting application question

27. In the bottle-sorting application mentioned previously in the project section, bottles are sorted according to the material covering their surface. You want to set up a smart diffuse light sensor so it detects all bottle types but one. Which of the three available bottle types must be the one that remains undetected?

   a. Bottles with an aluminum finish

   b. Bottles with a red PVC finish

   c. Bottles with a black PVC finish

c

28. Which of the three available bottle types would you use to set the sensitivity of the smart sensor so it detects all bottle types but one?

   a. Bottles with an aluminum finish

   b. Bottles with a red PVC finish

   c. Bottles with a black PVC finish

b

NO/NC logic of a diffuse light sensor

9 min.

Competency

- *Be able to change the switching logic (NO/NC) of a diffuse light sensor.*

In this section, you will change the switching logic (NO/NC) of the diffuse light sensor, and observe what happens to sensor operation.

29. Observe the technical specifications of the diffuse light sensor you recorded in Table 18. With which switching logic (NO or NC) does the diffuse light sensor operate by default?

a. NO

b. NC

a

30. Explain your answer to the previous question by indicating which of the following statements is correct.

a. The sensor is "on" when a target is detected and "off" the rest of the time.

b. The sensor is "off" when a target is detected and "on" the rest of the time.

a

31. Set the diffuse light sensor to the other switching logic. To do so, several methods are available:

- **IO-Link**

  a. In the window for the diffuse light sensor in PACTware, go to the **Parameter** submenu.

  b. In the **Parameter** submenu, change the **Switching Signal 1 Configuration : Switchpoint Logic** parameter to the desired setting. Active high corresponds to the normally open logic, while active low corresponds to the normally closed logic.

- **Sensor button**

  a. On the diffuse light sensor, press and hold the button until both LEDs blink simultaneously. This takes about 3 seconds. Release the button.

  b. Press and hold the teach-in button until the green LED blinks. This takes about 1 second. Release the button. The detection point is set.

Sensor operation with the new switching logic

32. Now that the switching logic of the diffuse light sensor is changed, successively insert the targets of different materials indicated in this table. Observe the operation of the sensor and compare it to the results obtained with the other switching logic.

How is the operation of the diffuse light sensor different with this new switching logic?

a. The sensor is now "on" when a target is detected and "off" the rest of the time.

b. The sensor is now "off" when a target is detected and "on" the rest of the time.

b

Does this indicate that the switching logic of the diffuse light sensor has been changed?

☐ Yes ☐ No

Yes

Off-delay and on-delay operation

Parameter settings

18 min.

Competency

- *Be able to add off-delay and on-delay timers to a smart sensor.*

In this subsection, you will make the parameter settings to add off-delay and on-delay timers to the diffuse light sensor.

33. In the window for the diffuse light sensor in PACTware, go to the **Parameter** submenu.

    You want to add off-delay and on-delay timers to the sensor. Which of the following parameters must you set for on / off delay operation?

    a. Emitter Control Function

    b. Switching Signal 1 Delay Time : Delay Mode

    c. Measurement Data Collection : Teach-in Value

    d. Switching Signal 1 Configuration : Switchpoint Mode

    b

34. In the **Parameter** submenu, set the parameter you determined in the previous question to *On / off delay*.

35. Observe the *Switching Signal 1 Delay Time : Off / One Shot Delay Time* and *Switching Signal 1 Delay Time : On Delay Time* parameters. Are both of these parameters set to *disabled* (or 0 ms), indicating that no on-delay and off-delay timers are set?

☐ Yes ☐ No

Yes

36. Test the operation of the diffuse light sensor by performing the following steps. While doing so, observe what happens to the switching signal sent by the sensor in the **Process data** submenu of PACTware.

a. Approach the gray target so it is in the sensor's detection range.

b. Once the target is detected, wait a few seconds.

c. Remove the target from the sensor's detection range, then wait a few seconds.

d. Repeat this procedure if required.

37. Based on the test of the diffuse light sensor operation you just performed, can you conclude that target detection and non-detection are almost instantaneous, indicating that no off-delay or on-delay timers are added to the sensor?

☐ Yes ☐ No

Yes

Off-delay timer

In this subsection, you will add an off-delay timer to the diffuse light sensor, and you will observe what happens to sensor operation.

Off-delay timers are often used in the industry to delay the de-actuation of a sensor. This can be useful in applications in which the workpiece goes by the sensor at a high speed, while the sensor needs to remain on for a minimal length of time. Another example would be if, even though the workpiece is no longer detected by the sensor, an actuator needs to remain on (e.g., a sorting gate) for the workpiece to continue along a conveyor.

38. In the window for the diffuse light sensor in PACTware, go to the **Parameter** submenu. Perform the following:

- Set the **Switching Signal 1 Delay Time : Off / One Shot Delay Time** parameter to 10 000 ms.
- Click the **Write to device (download)** button to send the parameters to the sensor.

39. Test the operation of the diffuse light sensor by performing the following steps. While doing so, observe what happens to the switching signal sent by the sensor in the **Process data** submenu of PACTware.

    a. Approach the gray target so it is in the sensor's detection range.

    b. Once the target is detected, wait a few seconds.

    c. Remove the target from the sensor's detection range, then wait a few seconds.

    d. Repeat this procedure if required.

40. Based on the test of the diffuse light sensor operation you just performed, what is the effect of modifying the **Switching Signal 1 Delay Time : Off / One Shot Delay Time** of the sensor?

    When the target ______ (enters / leaves) the sensor's detection range, the sensor waits 10 000 ms, then its signal switches to ___ (on / off).

    When the target leaves the sensor's detection range, the sensor waits 10 000 ms, then its signal switches to off.

On-delay timer

In this section, you will add an on-delay timer to the diffuse light sensor, and you will observe what happens to sensor operation.

On-delay timers are often used in the industry to delay the actuation of a sensor. This can be useful in applications in which false positives (i.e., a sensor actuating by accident due to a temporary condition) must be prevented. Other applications include assembly lines in which the workpiece must not remain stationary longer than a given length of time.

41. In the window for the diffuse light sensor in PACTware, go to the **Parameter** submenu. Perform the following:

    - Set the **Switching Signal 1 Delay Time : Off / One Shot Delay Time** parameter to **disabled**.
    - Set the **Switching Signal 1 Delay Time : On Delay Time** parameter to 10 000 ms.
    - Click the **Write to device (download)** button to send the parameters to the sensor.

42. Test the operation of the diffuse light sensor by performing the following steps. While doing so, observe what happens to the switching signal sent by the sensor in the **Process data** submenu of PACTware.

a. Approach the gray target so it is in the sensor's detection range.

b. Once the target is detected, wait a few seconds.

c. Remove the target from the sensor's detection range, then wait a few seconds.

d. Repeat this procedure if required.

43. Based on the test of the diffuse light sensor operation you just performed, what is the effect of modifying the **Switching Signal 1 Delay Time : On Delay Time** of the sensor?

When the target _______ (enters / leaves) the sensor's detection range, the sensor waits 10 000 ms, then its signal switches to ___ (on / off).

When the target enters the sensor's detection range, the sensor waits 10 000 ms, then its signal switches to on.

44. Consult the manufacturer's documentation for the diffuse light sensor. Can you find any way to manually set an off-delay or an on-delay timer in the sensor, without using its smart sensor capabilities through the master device?

☐ Yes ☐ No

No

45. Does this indicate that the smart sensor capabilities of the diffuse light sensor give access to additional functions unavailable to standard sensors?

☐ Yes ☐ No

Yes

Off-delay and on-delay applications

46. Consider the bottle-sorting application mentioned in the project section of this procedure. You need to make sure the system does not allow any bottle to remain at the filling station for more than five seconds; otherwise, liquid will spill. To implement this, you will use an NO smart diffuse light sensor. Will you set it up with a five-second off-delay or on-delay function?

a. Off-delay function

b. On-delay function

b

47. In the same bottling application, you need to make sure the conveyor belt operates for three extra seconds after each bottle leaves the filling station, in order for it to reach the capping station. To implement this, you will use an NO smart diffuse light sensor. Will you set it up with a three-second off-delay or on-delay function?

a. Off-delay function

b. On-delay function

a

Ending the exercise

48. Save your current PACTware project on the host computer, then close the PACTware.

49. If applicable, perform each the following manipulations:

- Remove all cable connections and return the cables to their appropriate storage place.
- Remove the sensor from the workstation or the slot plate, and place it in its appropriate location of the storage trays.
- Return all detection objects to the storage tray of the set of detection objects, at their appropriate locations.
- Remove all remaining components from the workstation or slot plate, and place them in their appropriate locations of the storage trays.

50. Turn off the workstation, then return it or the slot plate to its appropriate storage place.

Review questions

1. Which of the following devices are types of photoelectric sensors?

a. Through-beam sensors

b. Inductive proximity sensors

c. Retro-reflective sensors

d. Darklight sensors

e. Diffuse light sensors

a, c, and e

2. How does a through-beam sensor operate?

   a. The emitter projects a light beam toward a reflector, which directs the beam back to the receiver. When reflection is prevented, an object is detected.
   b. The emitter projects a light beam of a great force that heats up the particles of an object, whose activity is then detected by a thermonuclear receiver.
   c. The emitter projects a light beam directed toward the receiver. When the light beam is interrupted, an object is detected.
   d. The emitter projects a light beam, and when a target object enters the beam, light reflects off the object and back to the receiver.

c

3. How does a retro-reflective sensor operate?

   a. The emitter projects a light beam toward a reflector, which directs the beam back to the receiver. When reflection is prevented, an object is detected.
   b. The emitter projects a light beam of a great force that heats up the particles of an object, whose activity is then detected by a thermonuclear receiver.
   c. The emitter projects a light beam directed toward the receiver. When the light beam is interrupted, an object is detected.
   d. The emitter projects a light beam, and when a target object enters the beam, light reflects off the object and back to the receiver.

a

4. How does a diffuse light sensor operate?

   a. The emitter projects a light beam toward a reflector, which directs the beam back to the receiver. When reflection is prevented, an object is detected.
   b. The emitter projects a light beam of a great force that heats up the particles of an object, whose activity is then detected by a thermonuclear receiver.
   c. The emitter projects a light beam directed toward the receiver. When the light beam is interrupted, an object is detected.
   d. The emitter projects a light beam, and when a target object enters the beam, light reflects off the object and back to the receiver.

d

5. Using the reflection factors provided in Table 14, order the following materials, in terms of detection by a diffuse light sensor, from the easiest (1) to the hardest (4).

1 (easiest)	2	3	4 (hardest)
Kodak neutral card, gray side	White PVC	Gold plating, matt	Drawing ink on white typewriting paper

Kodak neutral card, gray side	White PVC	Gold plating, matt	Drawing ink on white typewriting paper
3	2	1 (easiest)	4 (hardest)