



Optical Sensors (Interfaces) – Contents

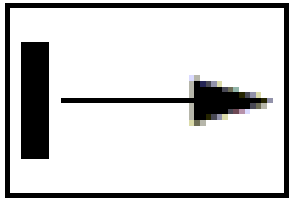
- Types
- Applications
- Encoders – Position Sensors



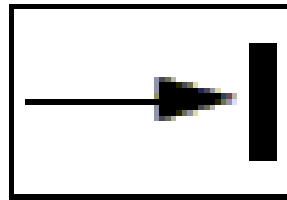
Optical sensors, by operating principle, can be implemented as:

- Transmission (through-beam) sensors
- Reflective sensors
- Diffuse sensors
- Distance-settable sensors (distance estimation)
- Limited-reflective sensors

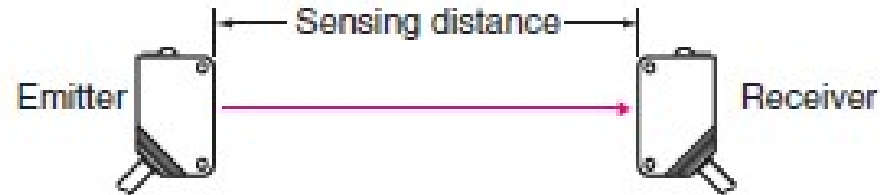
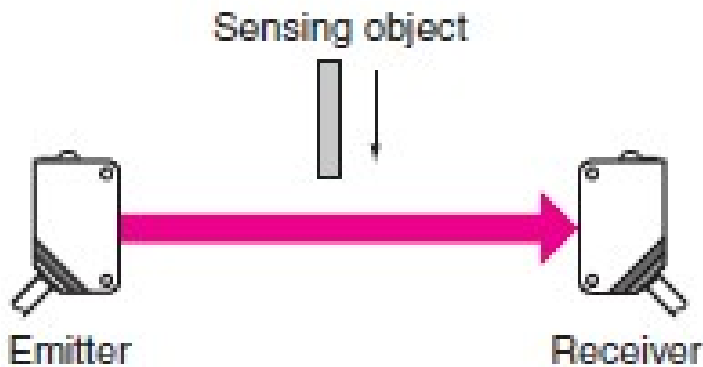
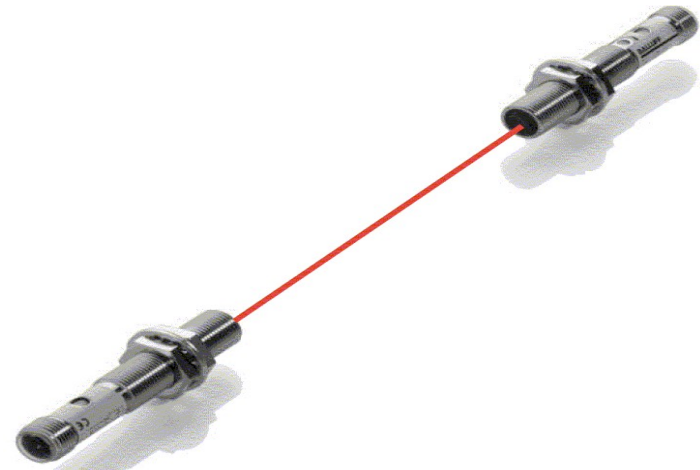
Through-beam (transmission) sensor



emitter



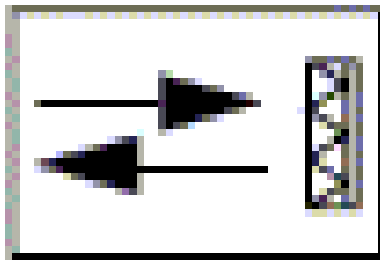
receiver



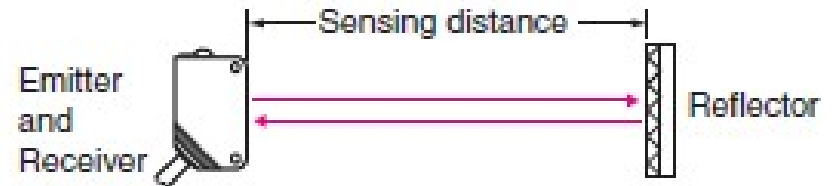
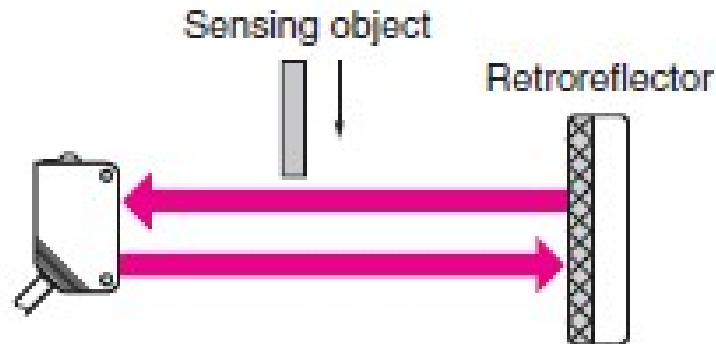
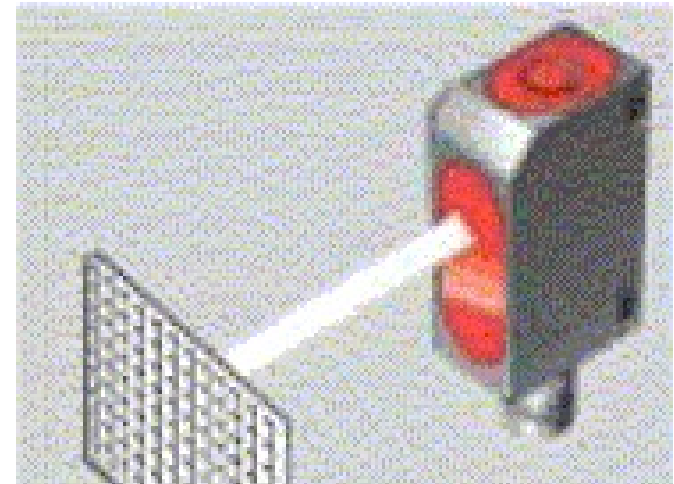
Disadvantages:

- The emitter and receiver must be installed at separate locations.
- Separate cables must be provided for both sides.

Retroreflective sensors

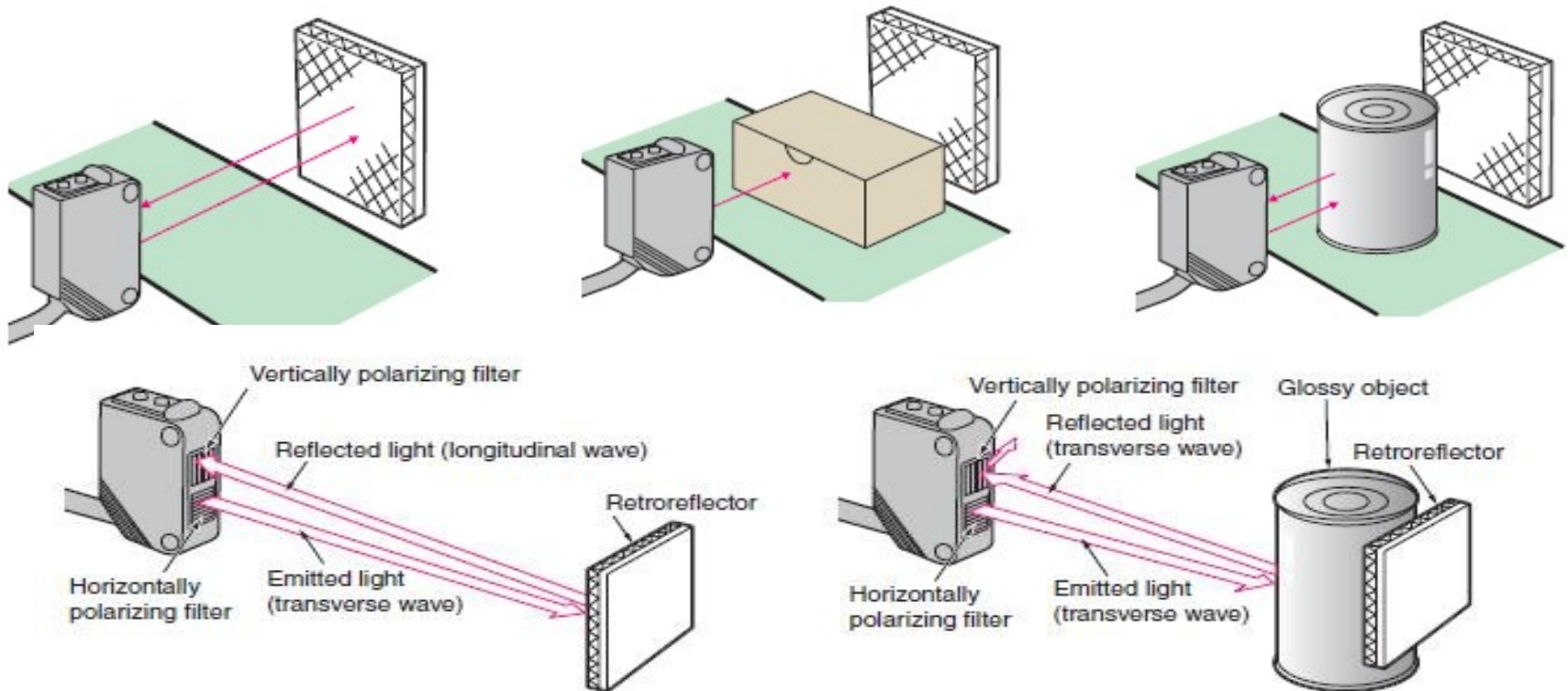


Symbol for a retroreflective sensor



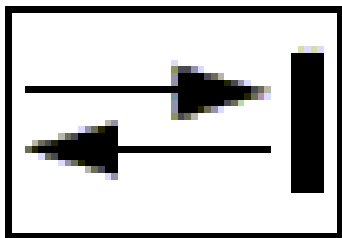
The emitter and receiver are housed together, while a reflector on the opposite side returns the light beam back to the sensor.

Retroreflective sensors

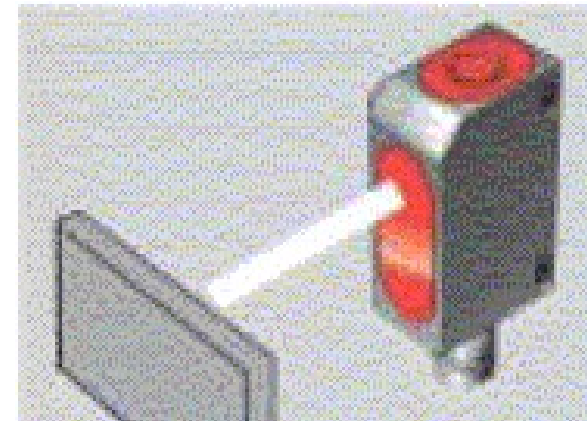


The emitter produces horizontally polarized light. A special retroreflector returns the beam with rotated (vertical) polarization, which the receiver can detect. When the beam is reflected from another object, it returns with horizontal polarization and therefore is not accepted by the receiver.

Diffuse optical sensor

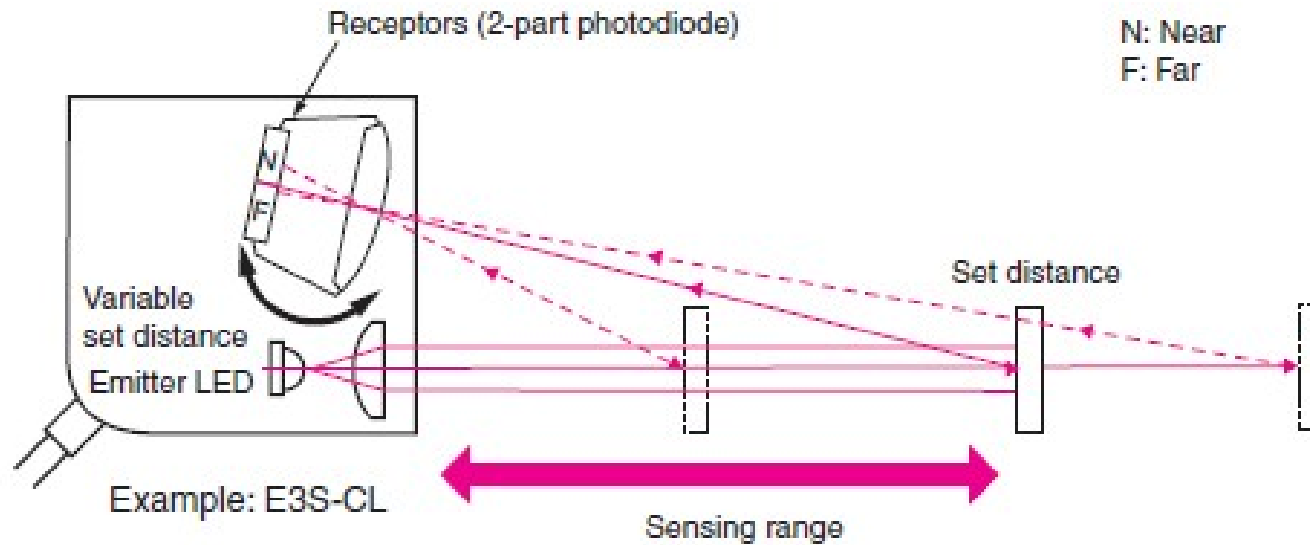


Symbol for a diffuse sensor



It is similar to a retroreflective sensor: the emitter and receiver are housed together. However, no reflector is used here. Light is scattered from the object and detected by the receiver.

Distance-estimation sensor

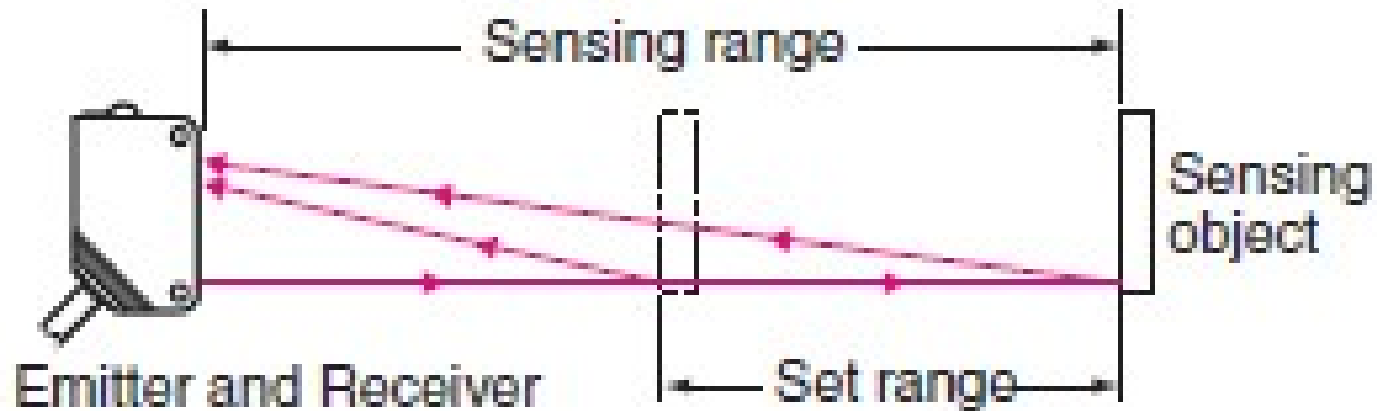


The sensor receiver is a two-part photodiode or a position detector.

The reflected light is focused on part of the receiver.

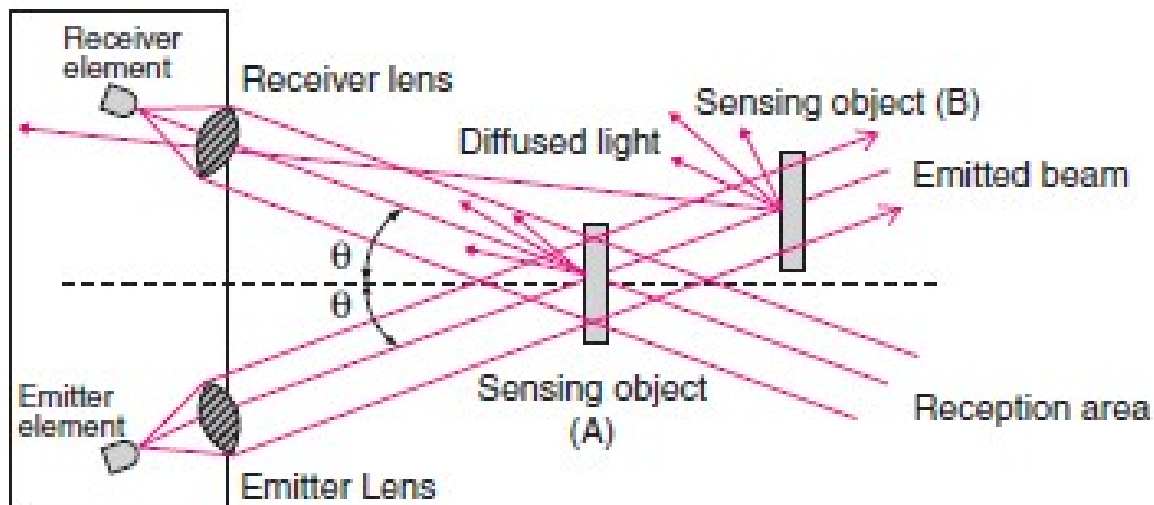
Detection is based on the principle of angle measurement (triangulation). The position at which the reflected light is focused on the receiver depends on the distance to the object.

Distance-estimation sensor



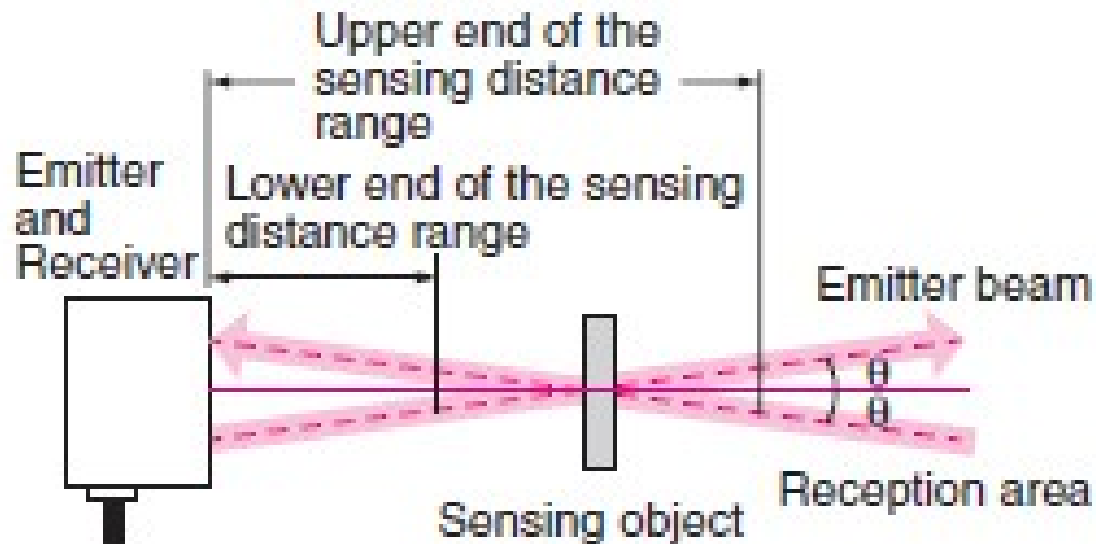
For this type of sensor, the distance range within which an object will be detected can be configured.

Limited-reflective sensor



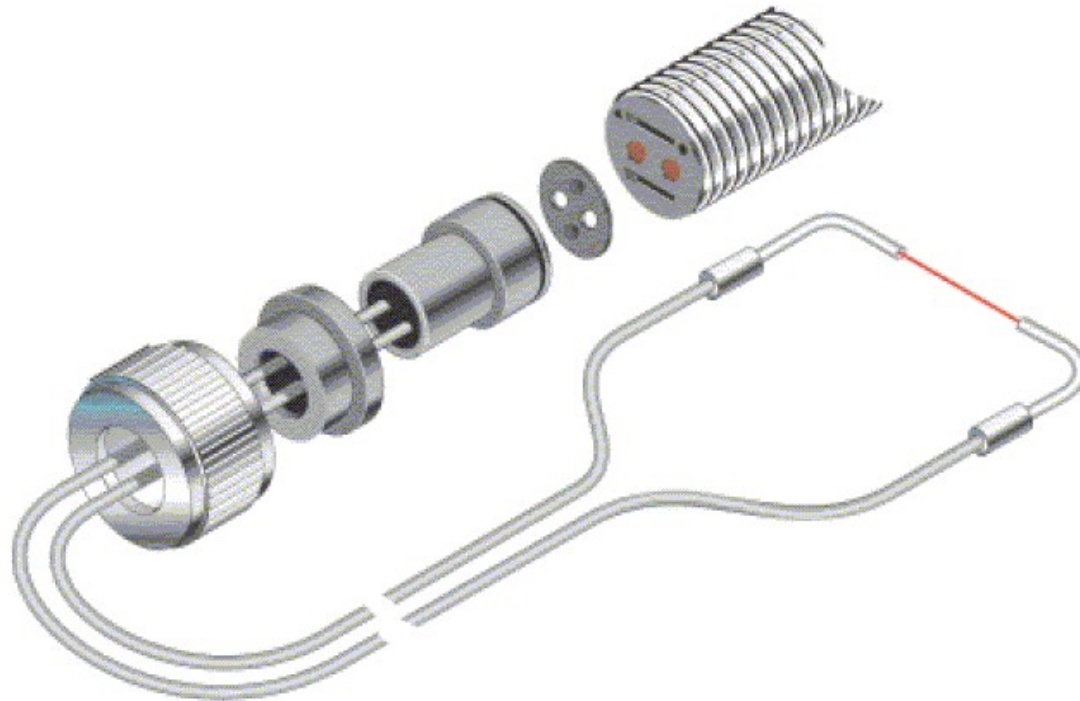
Similar to a diffuse sensor, it detects light reflected from the object. However, its optics are configured to detect objects only at a specific distance — neither closer nor farther.

Limited-reflective sensor





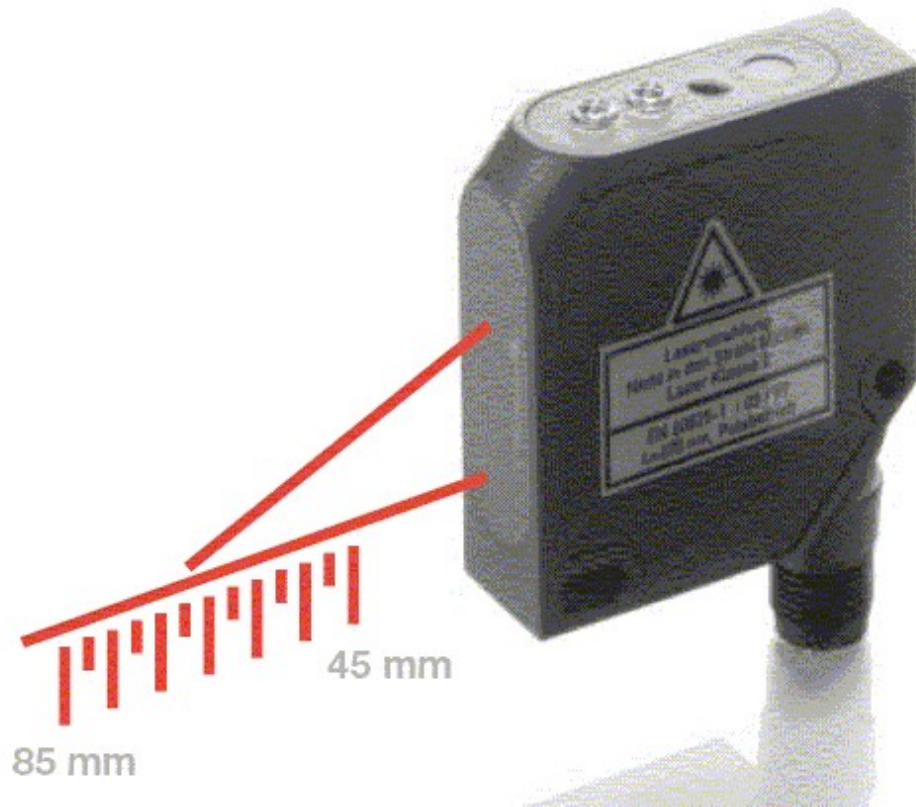
Fiber-optic sensors



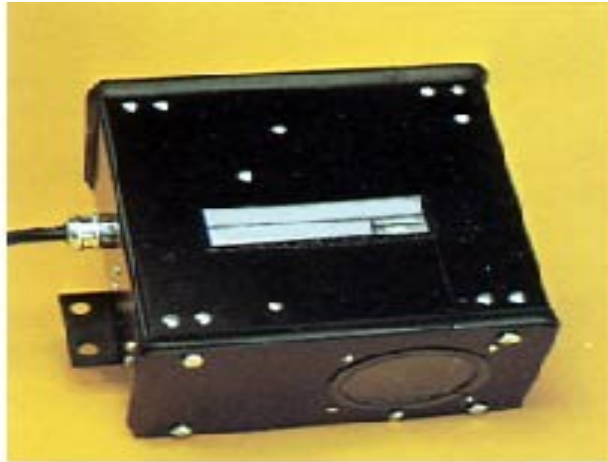
Thanks to optical fibers, the light path can be positioned precisely even in hard-to-reach locations.

Laser distance sensor

The emitter produces a narrow laser beam. The receiver (typically a line-scan camera) observes the illuminated spot on the object under a specific angle. The object distance is computed from that angle.



Examples of packaged sensors



Reflex edge sensor

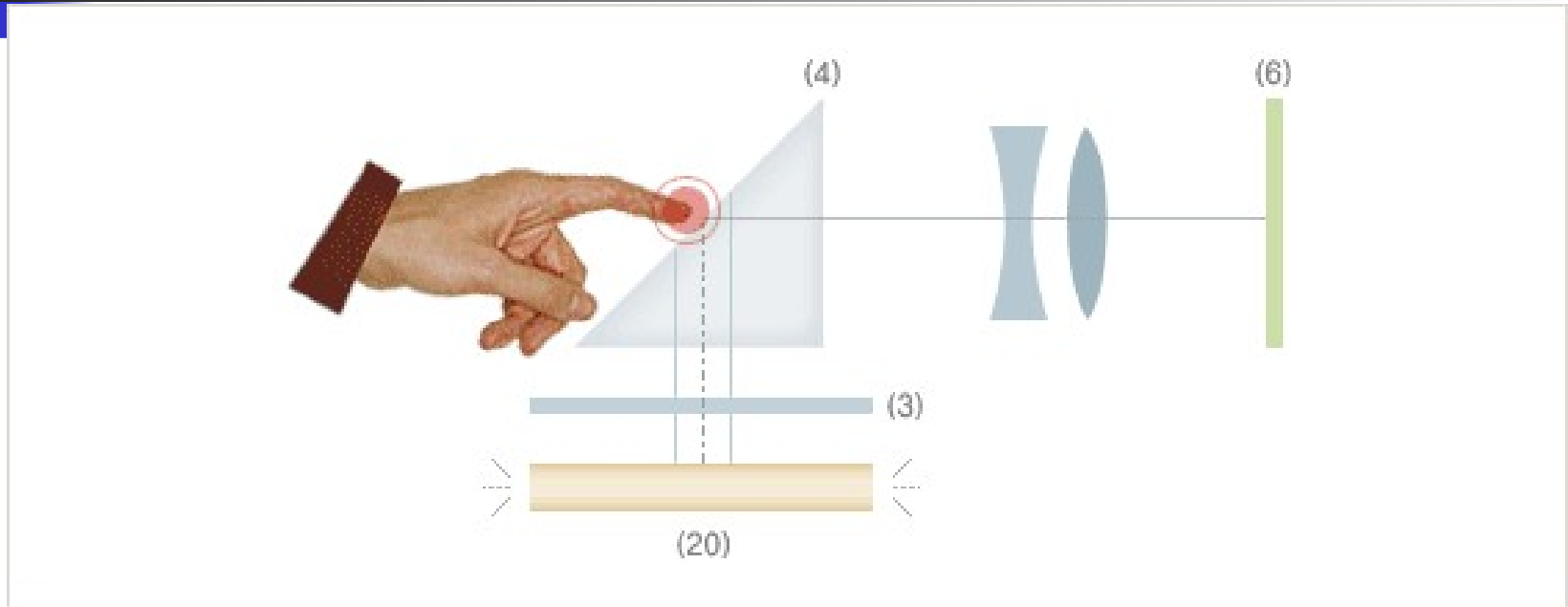


High performance
line/edge sensor



Low cost line/edge sensor

Optical fingerprint scanner



Lens system in optical fingerprint sensors

A finger is placed on the sensing plate and illuminated by an LED light source; through a prism and a lens system, the image is projected onto a camera.

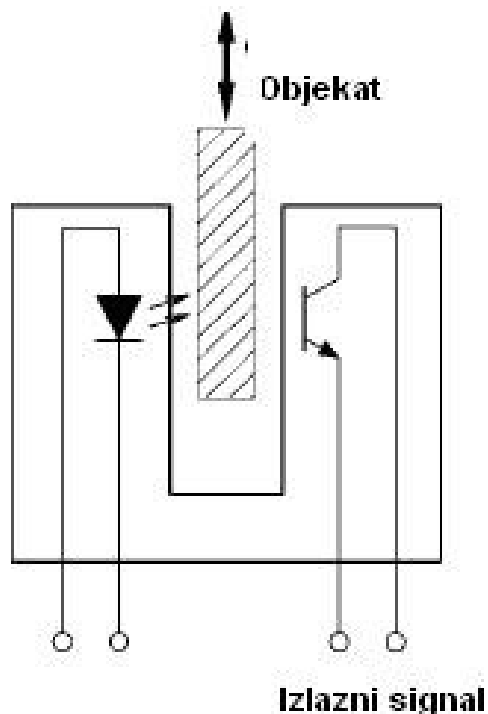
Applications of fingerprint scanners



Used for authorized access to:

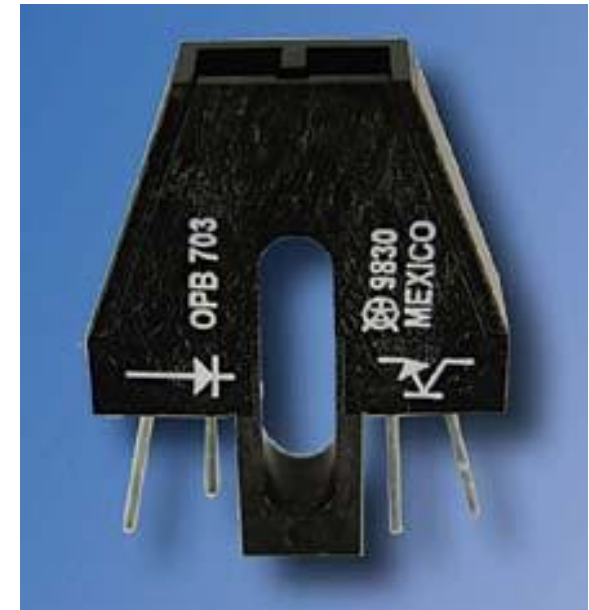
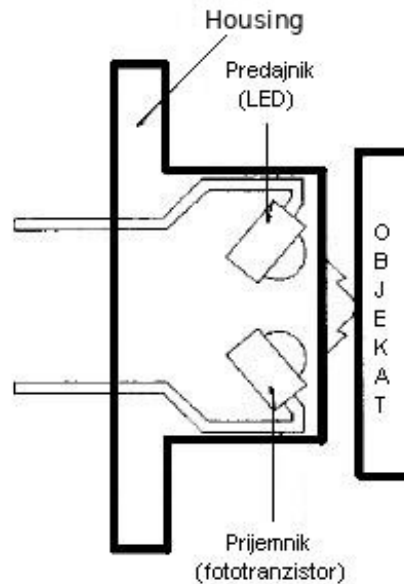
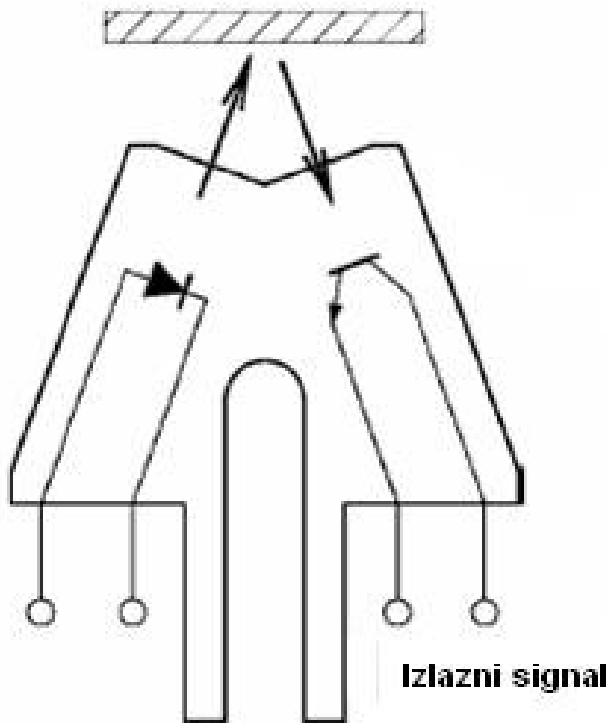
- premises,
- data,
- a computer, or
- other protected content (e.g., a bag).

An optical fork sensor is a through-beam sensor



Operating principle and appearance of an optical fork sensor
Typical fork dimensions are about 1 cm.

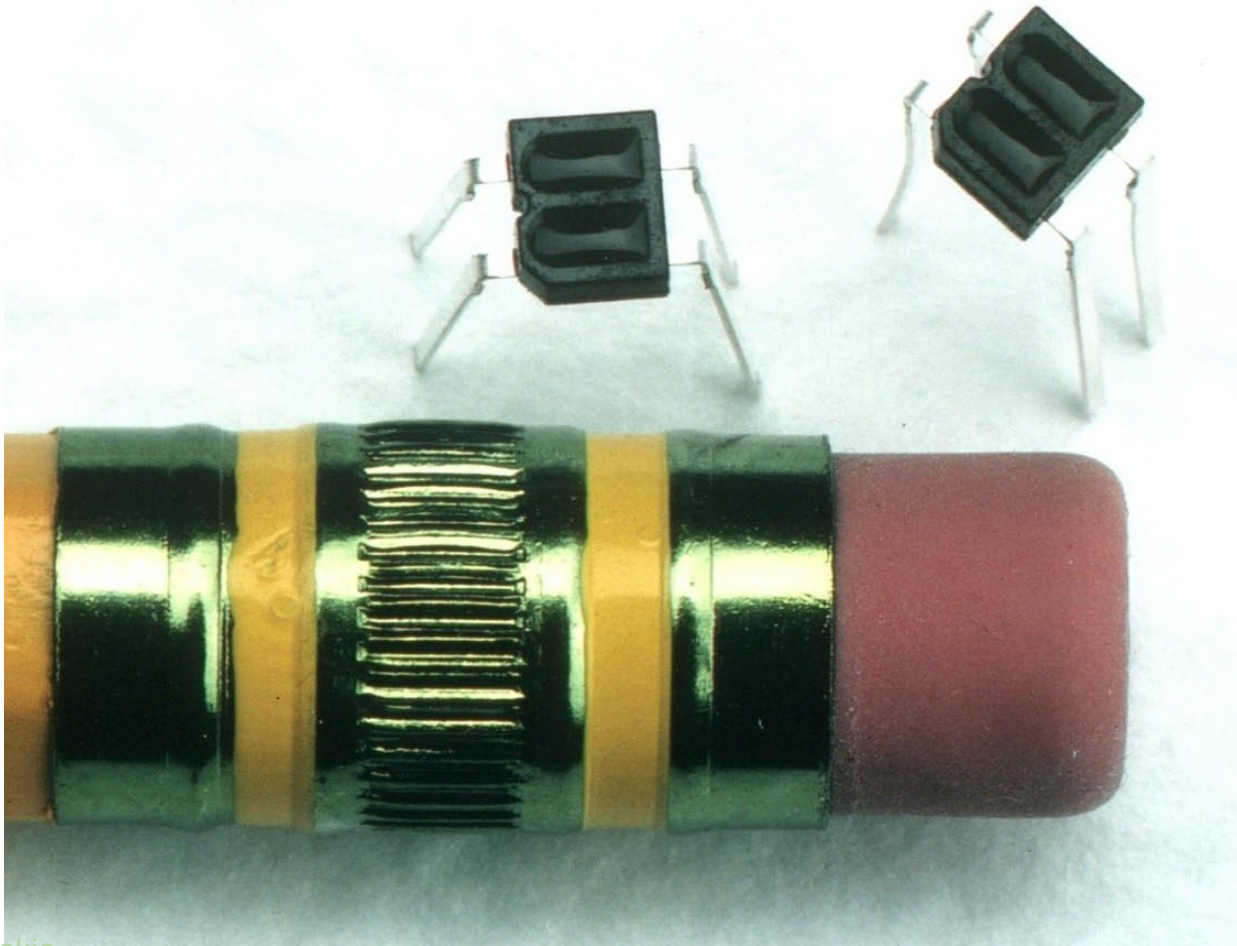
Proximity diffuse sensors



Operating principle and appearance of a proximity diffuse sensor
Typical sensor dimensions are about 1 cm.

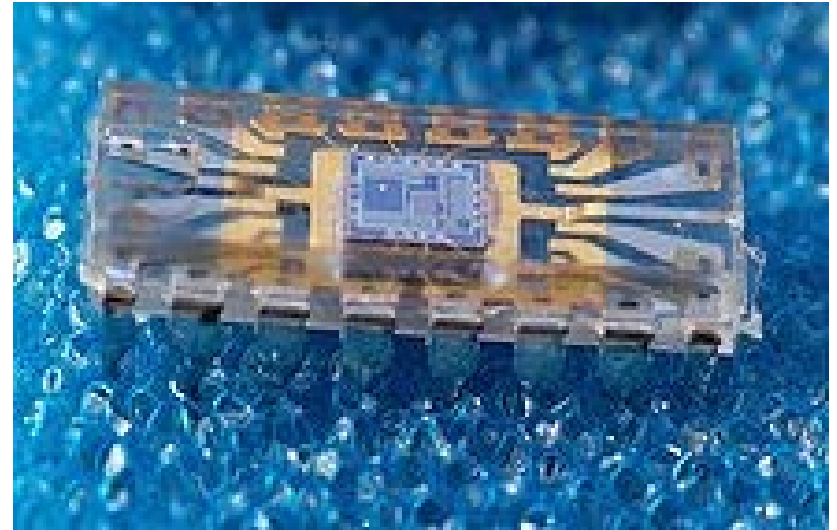


Size of a proximity sensor



Optical mouse

http://en.wikipedia.org/wiki/Optical_mouse#Optical_mice



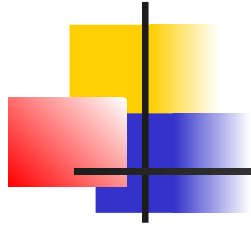
optical sensor IC

An optical mouse consists of:

- an LED (or a laser) to illuminate the surface,
- a miniature camera with an optical sensor IC (optical ~3000 dpi; laser ~6000–15000+ dpi),
- an image-processing and communication controller.

An optical mouse can be repurposed as a scanner. More details:

<http://spritesmods.com/?art=mouseeye>

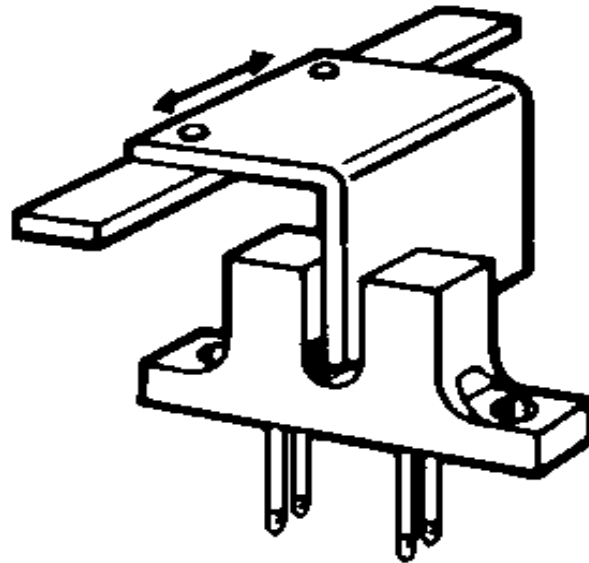


Applications of optical sensors



Detection of a moving opaque flag

1. Sensing of moving sheet metal

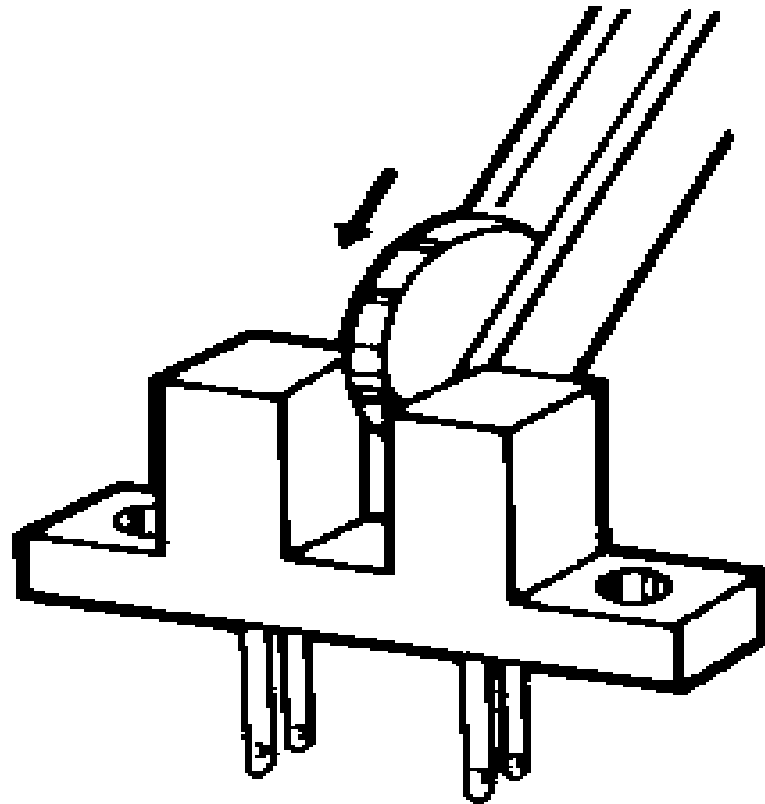


Typically used as an end-of-travel (limit) detector for a mechanism (in printers, plotters, and many other devices).



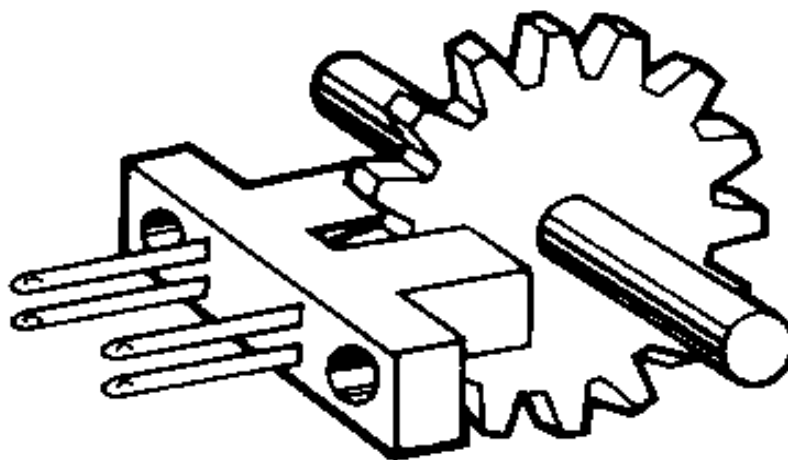
Detection of coins and metal parts

2. Sensing of coin and metal



Detection of gear teeth in transmission mechanisms

3. Sensing of gear tooth

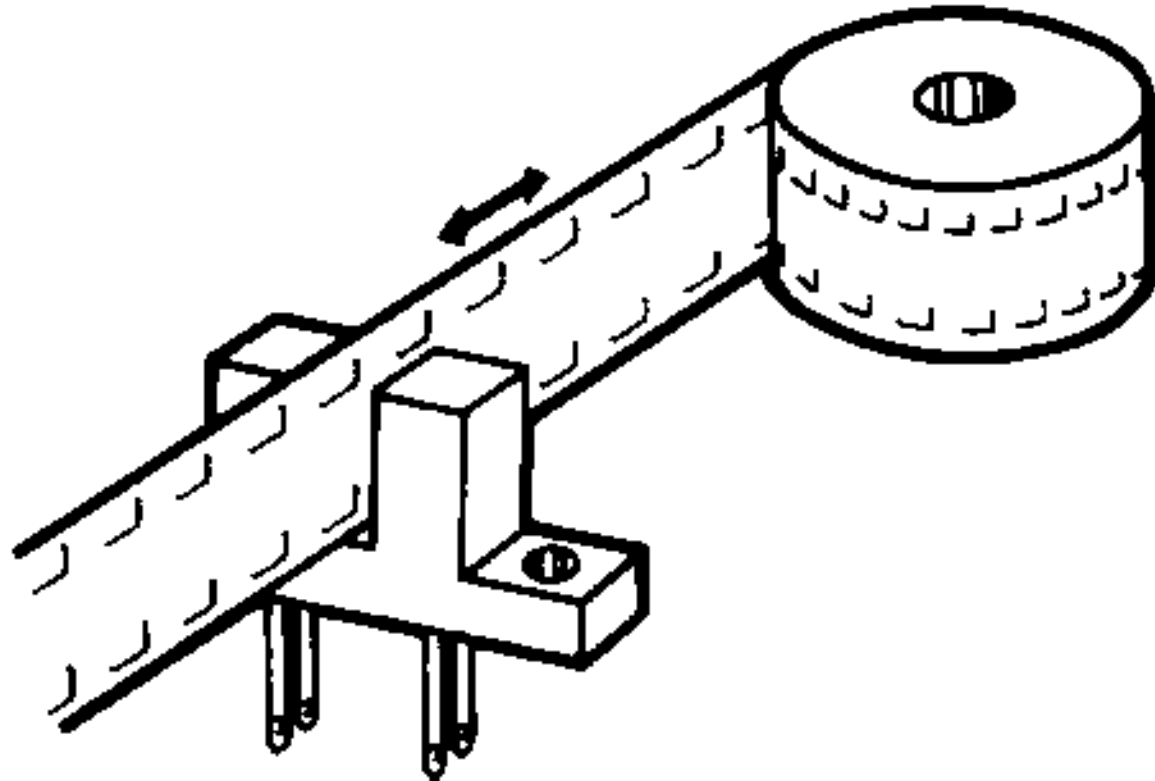


As the gear rotates, pulses are generated at the photoreceiver.
The number of pulses per second is a measure of the gear's rotational speed.



Detection of film position

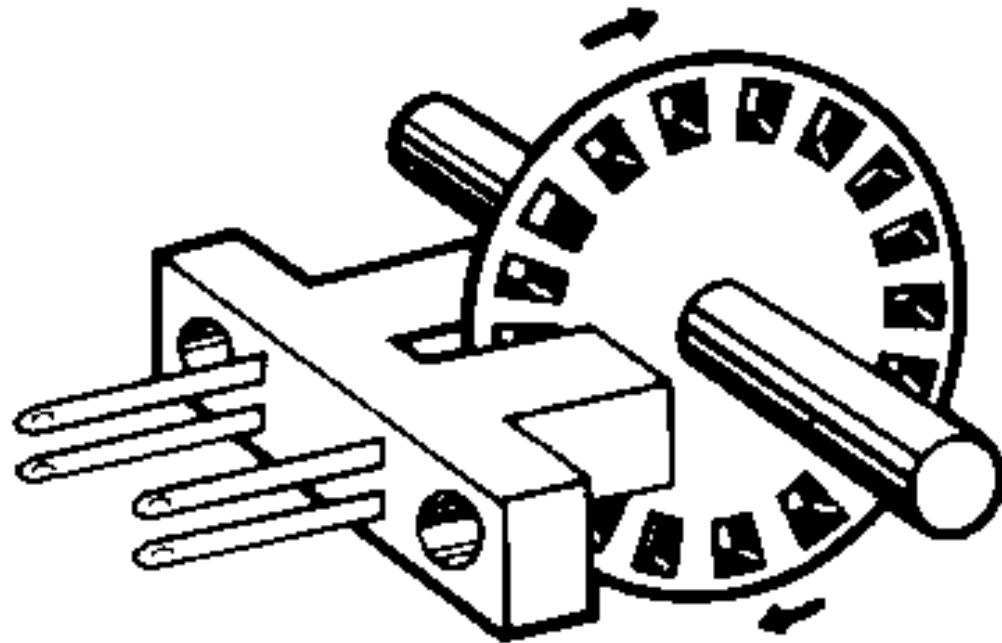
5. Sensing of film position





Detection of the number of revolutions

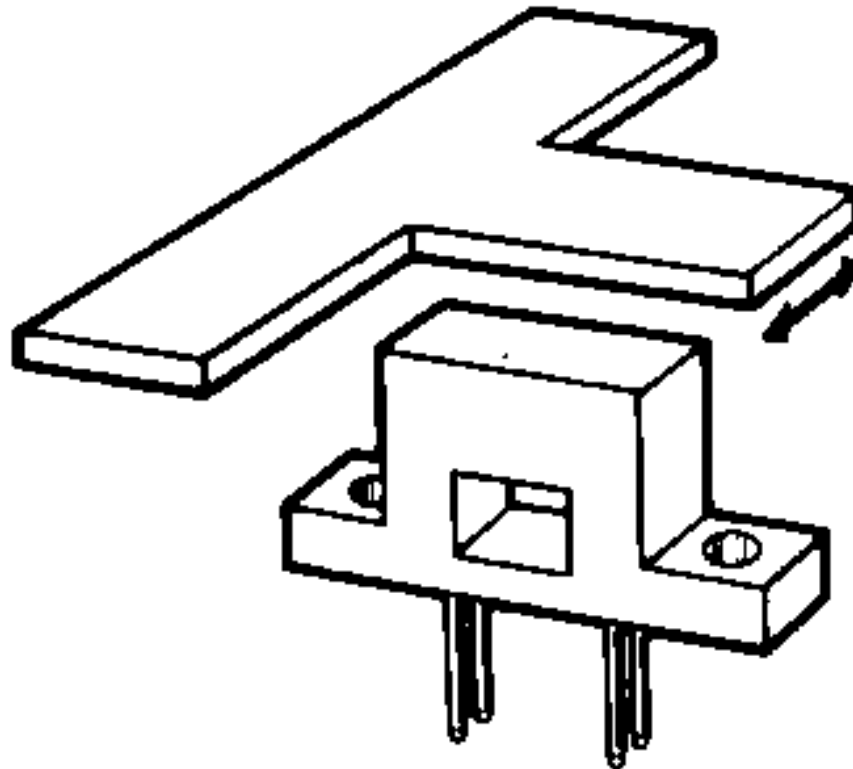
6. Sensing of the number of revolutions





Detection of a reflective flag

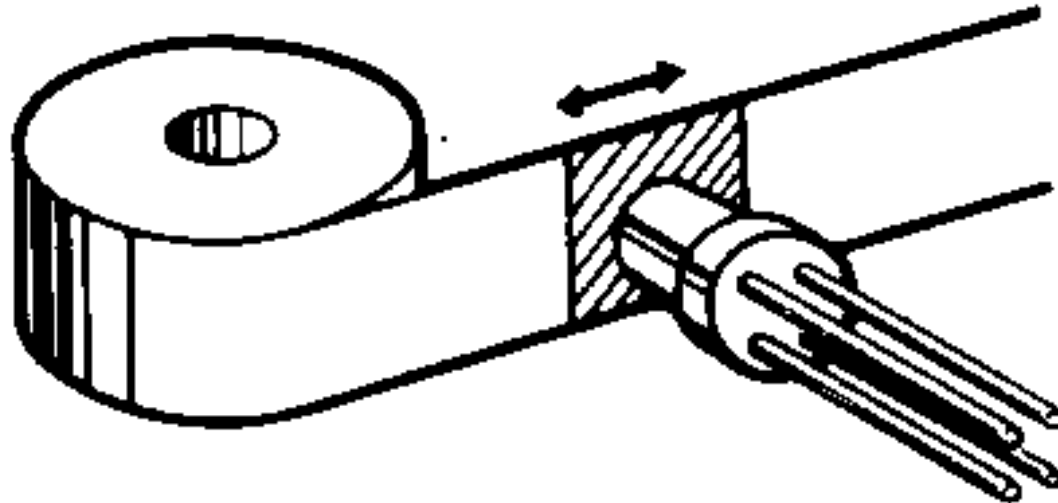
1. Sensing of glossy sheet metal





Detection of the beginning or end of a tape

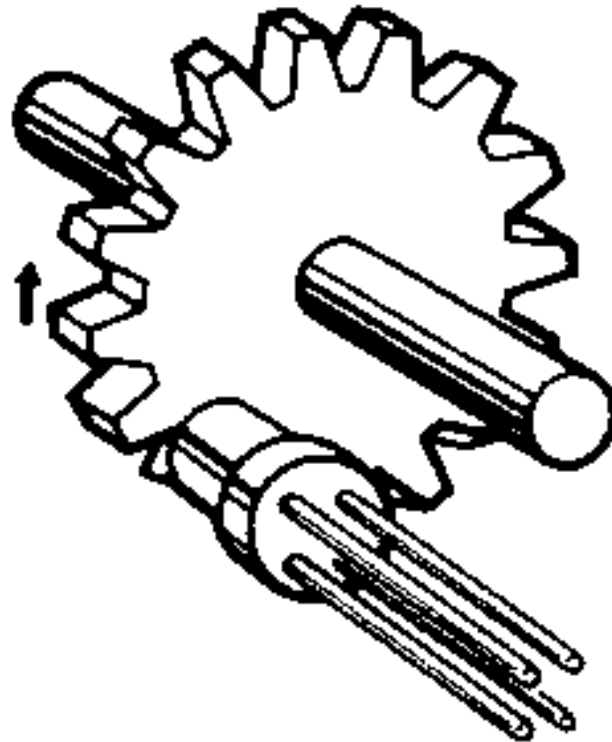
2. Sensing of the end or beginning of tape



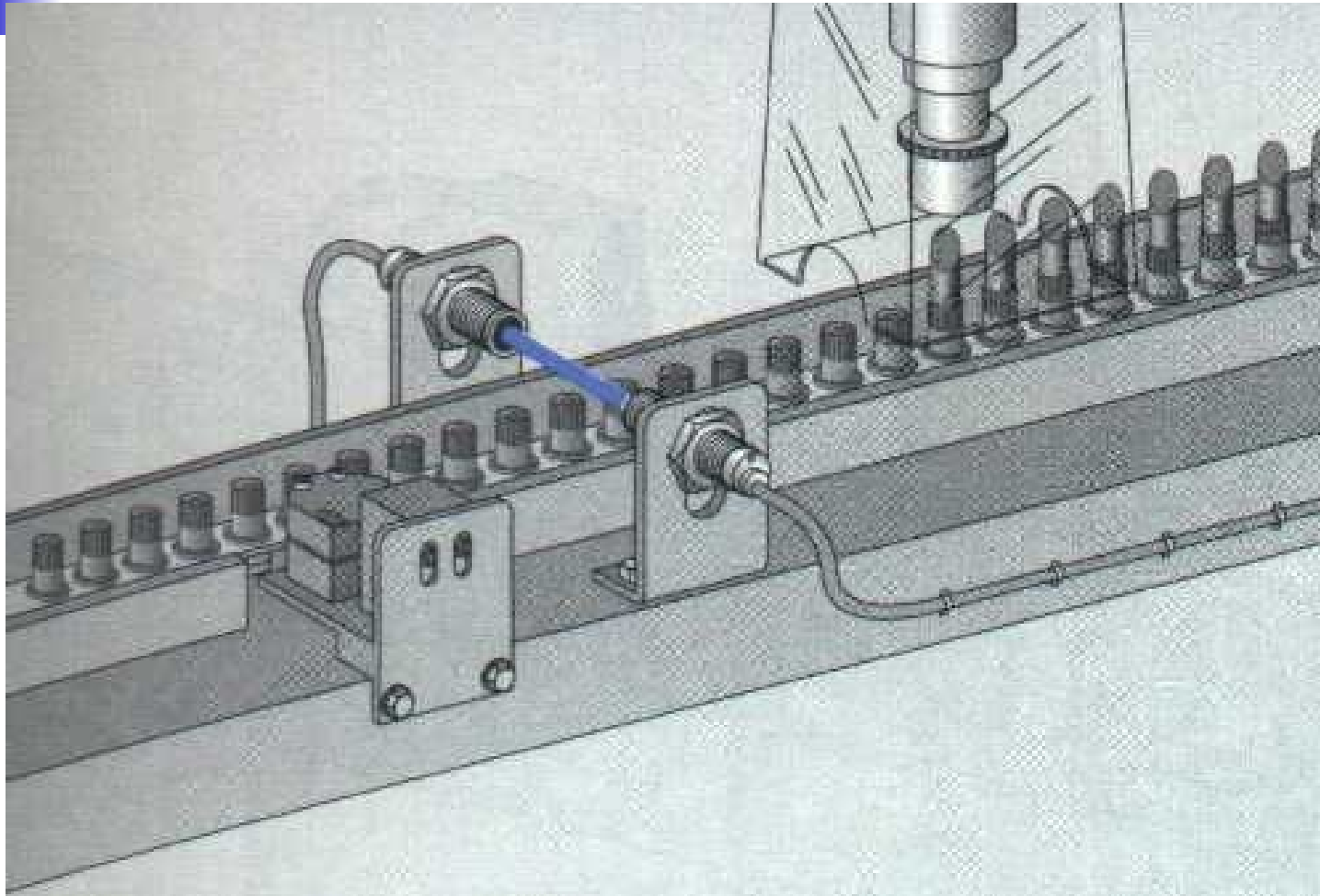


Detection of reflective teeth

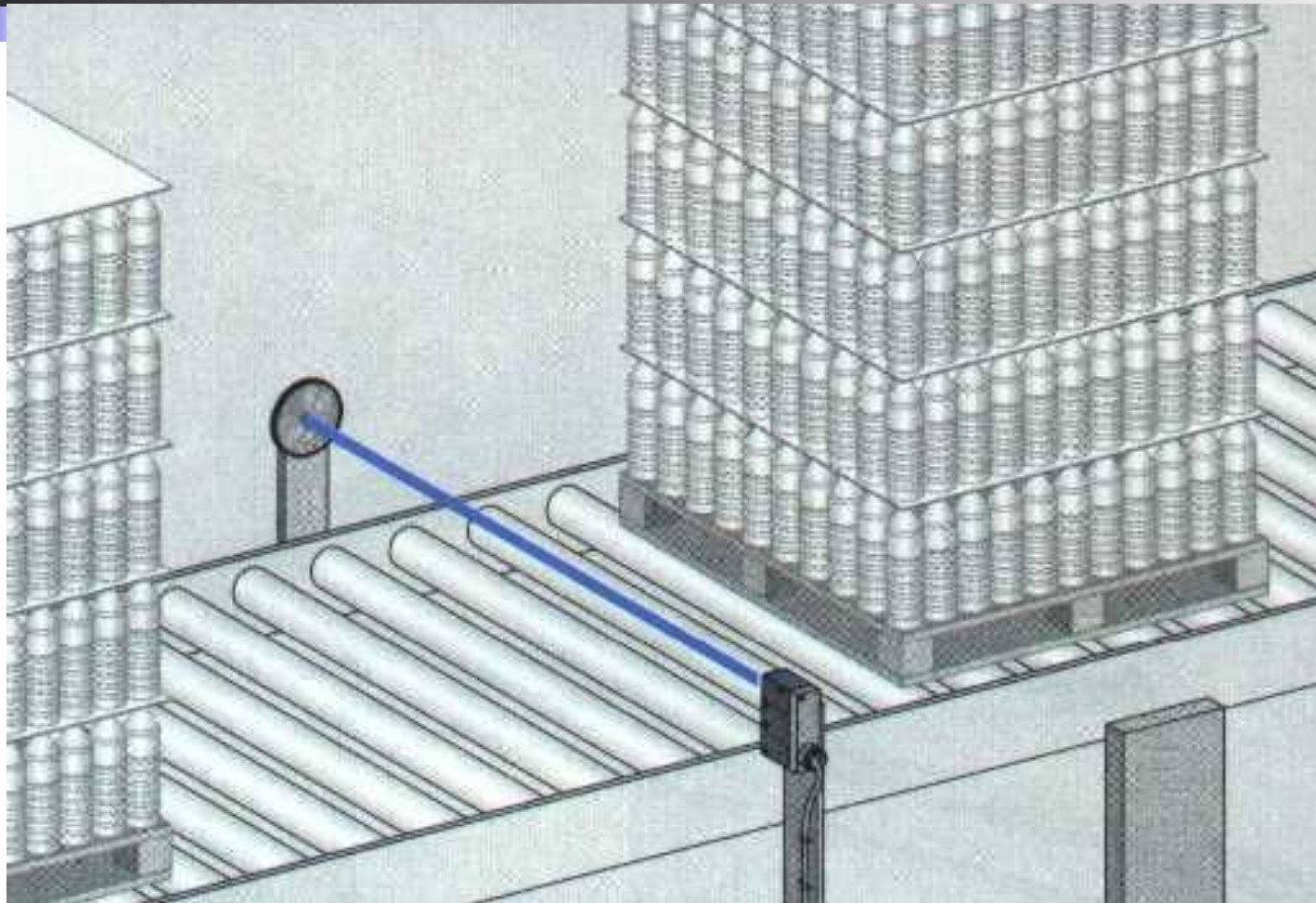
3. Sensing of glossy gear tooth



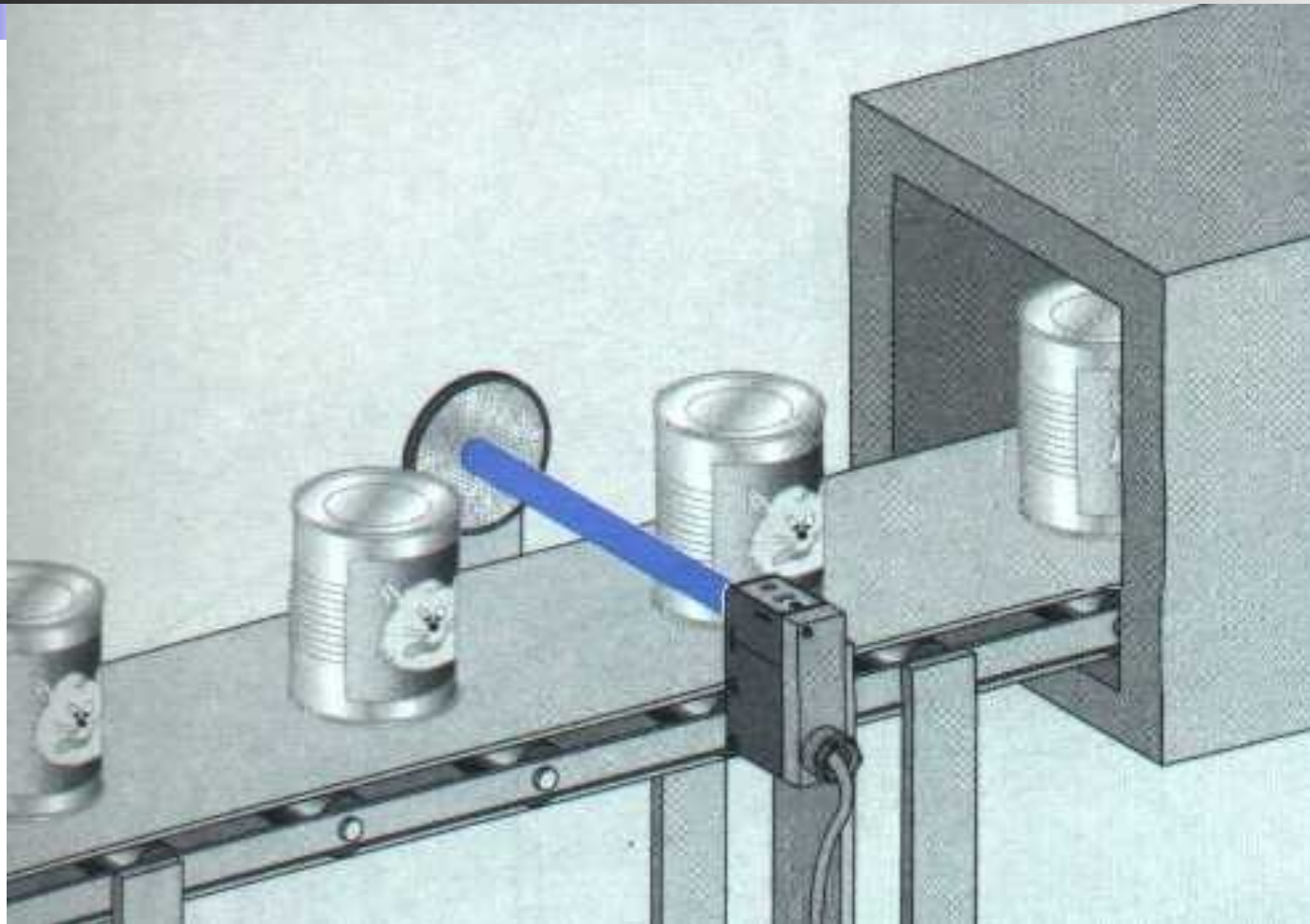
Inspection of lipstick height before placing the cap



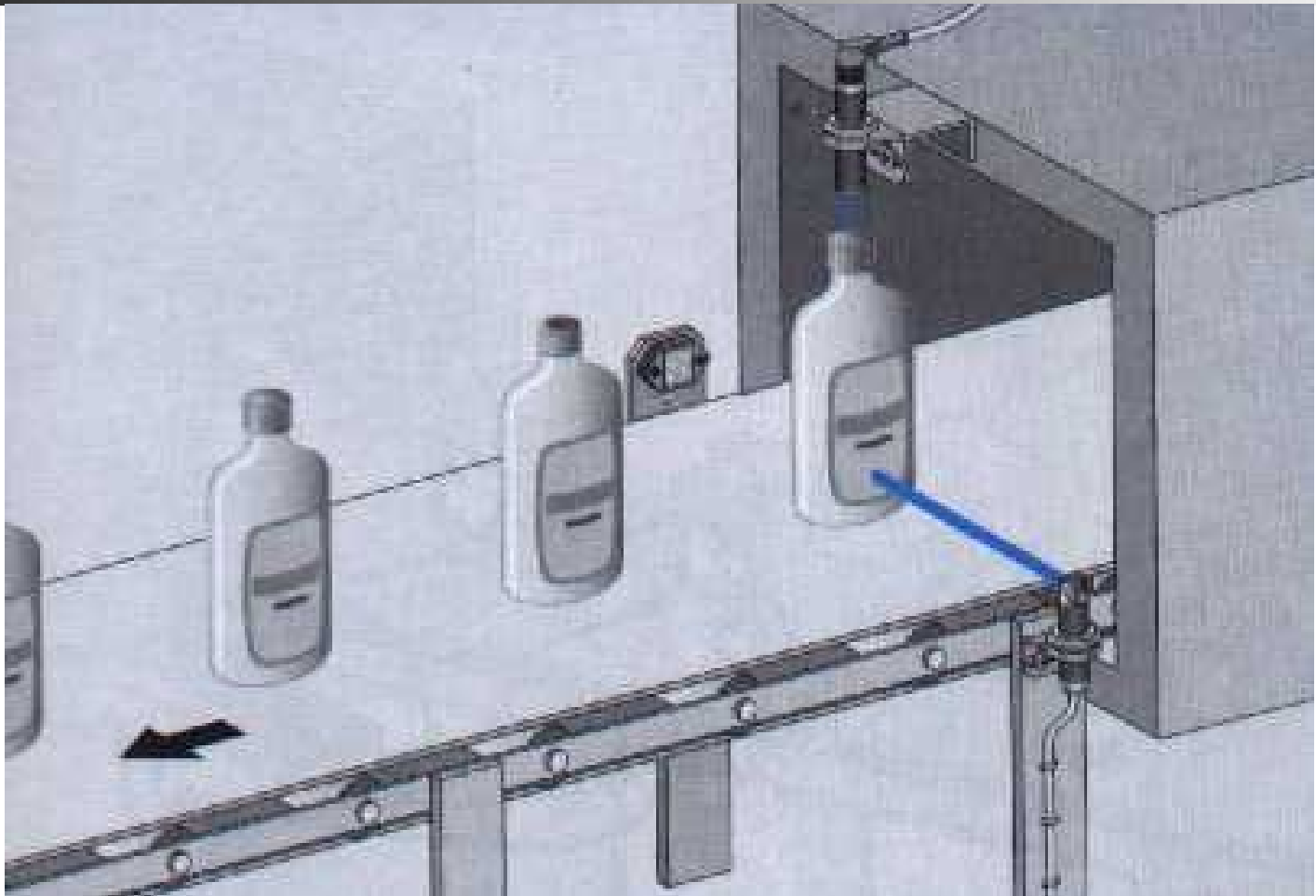
Monitoring the passage of pallets with bottled water



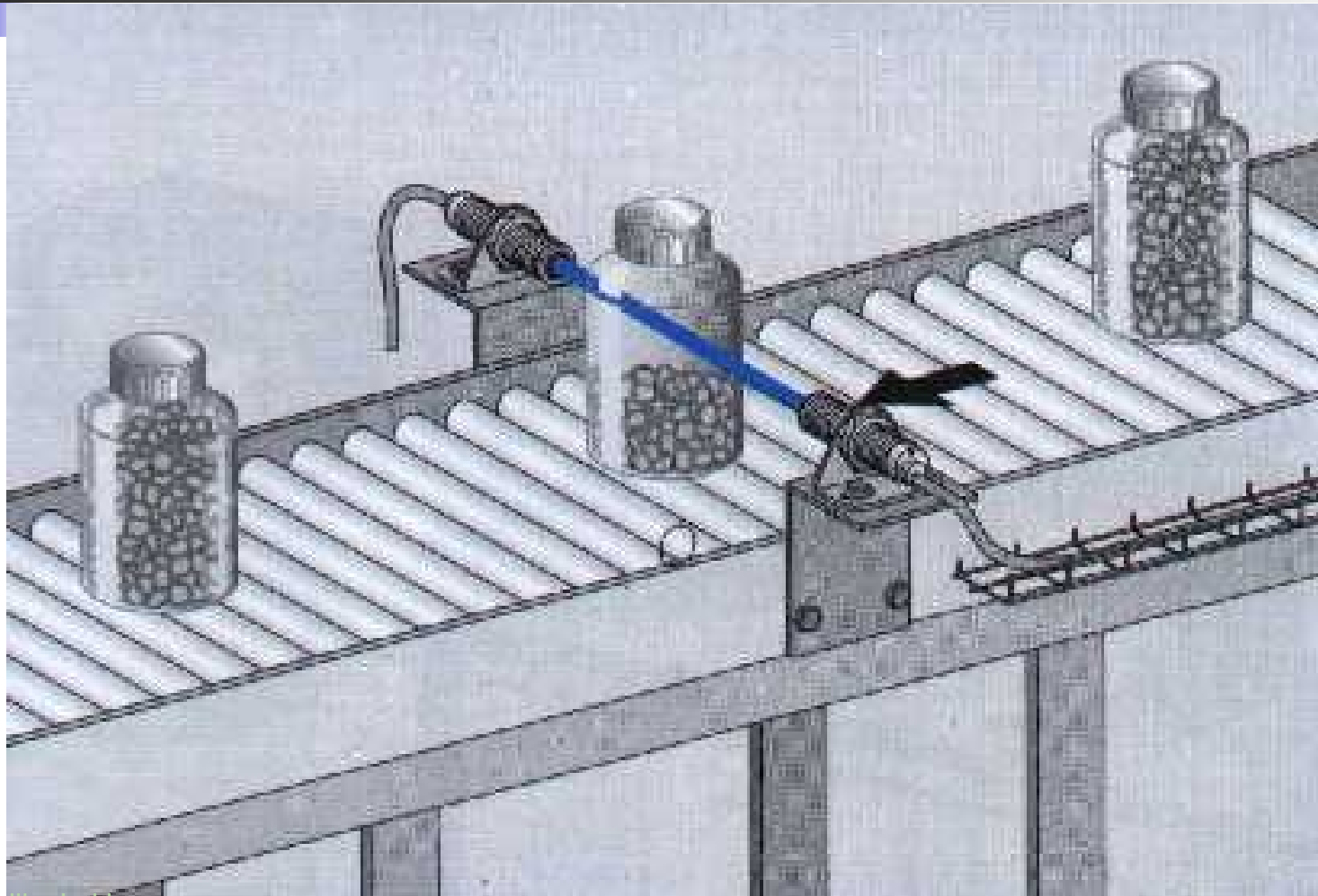
Monitoring the passage of cans (cat food)



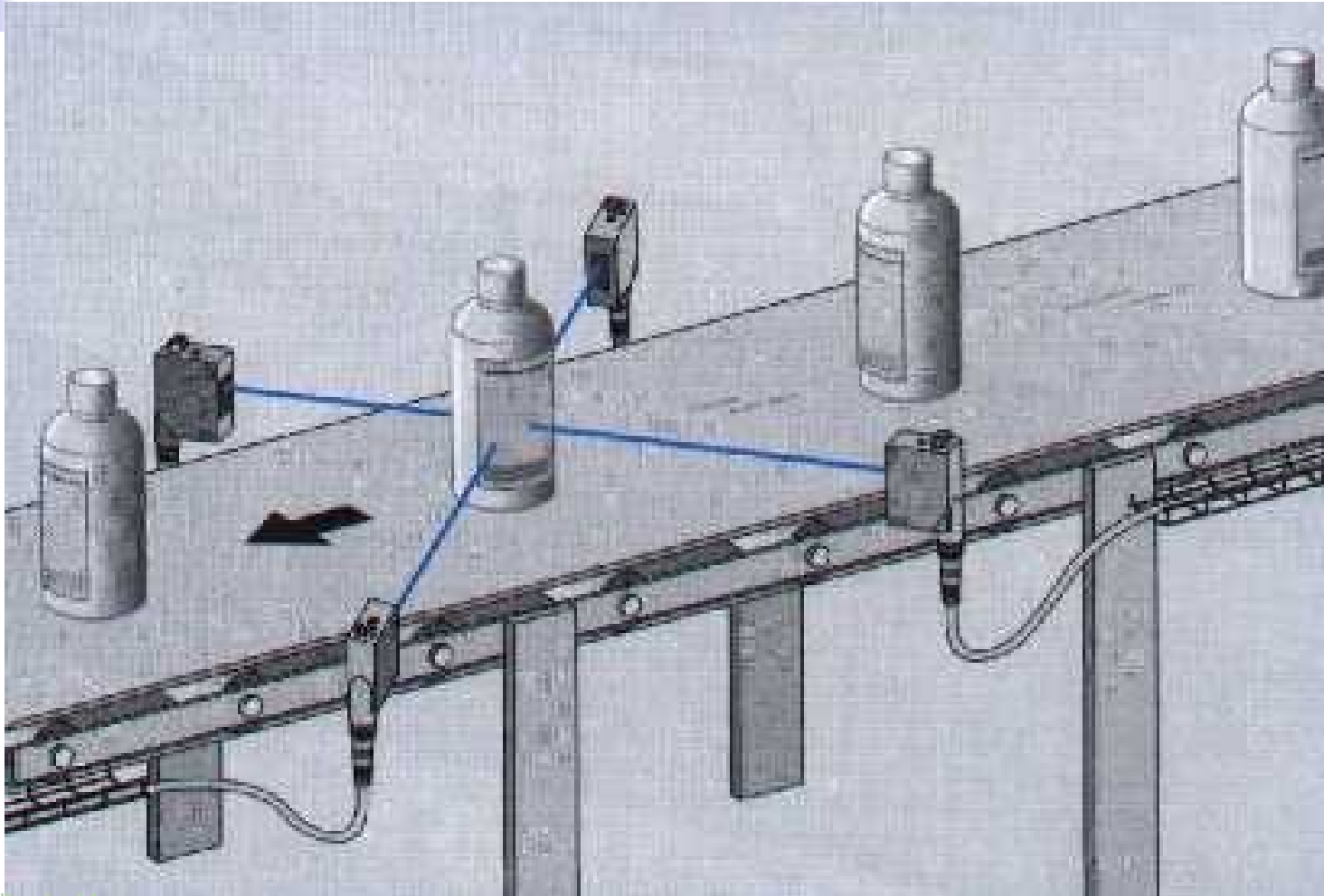
Verification of the presence of a plastic cap



Inspection of tablets in bottles

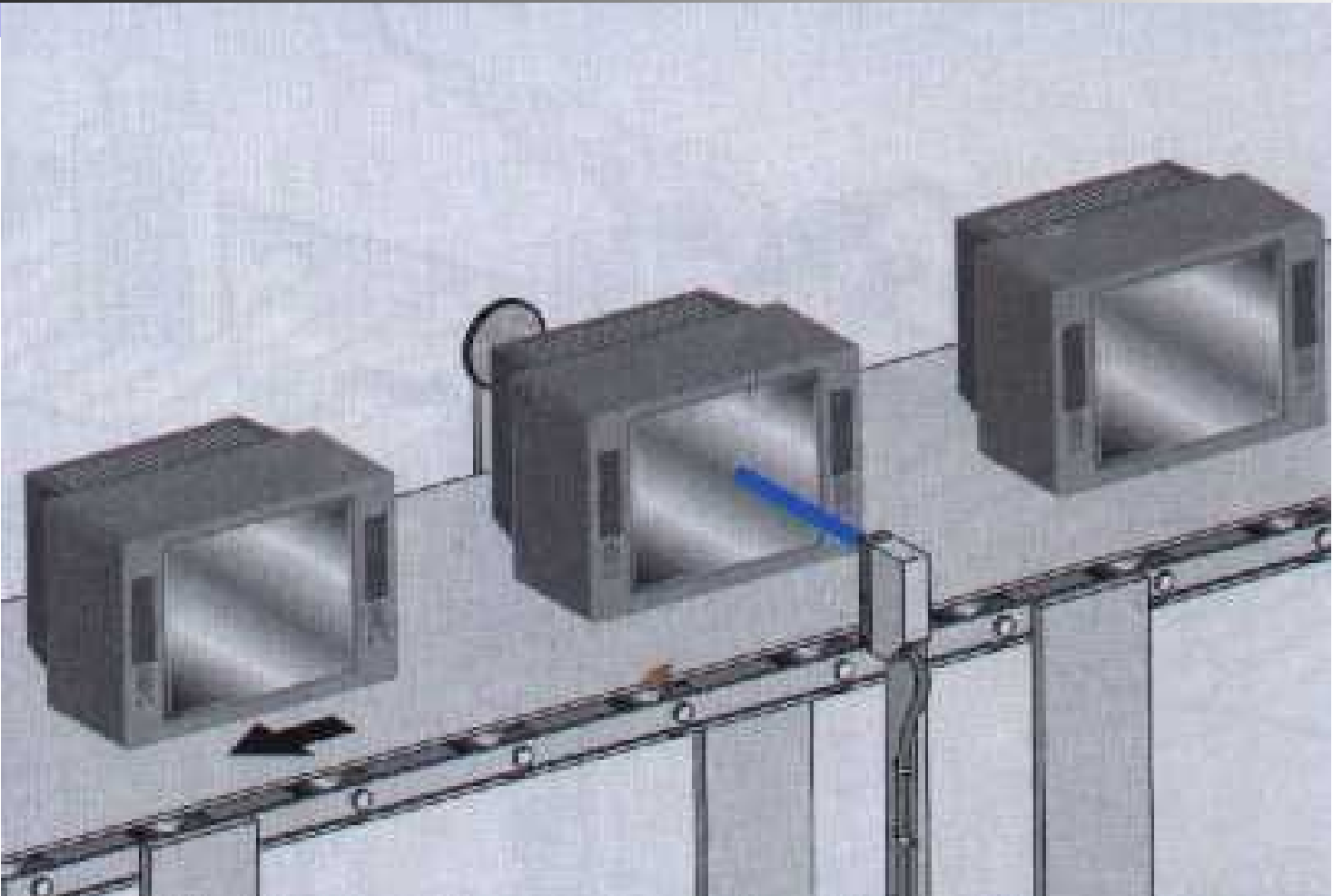


Inspection of labels on bottles

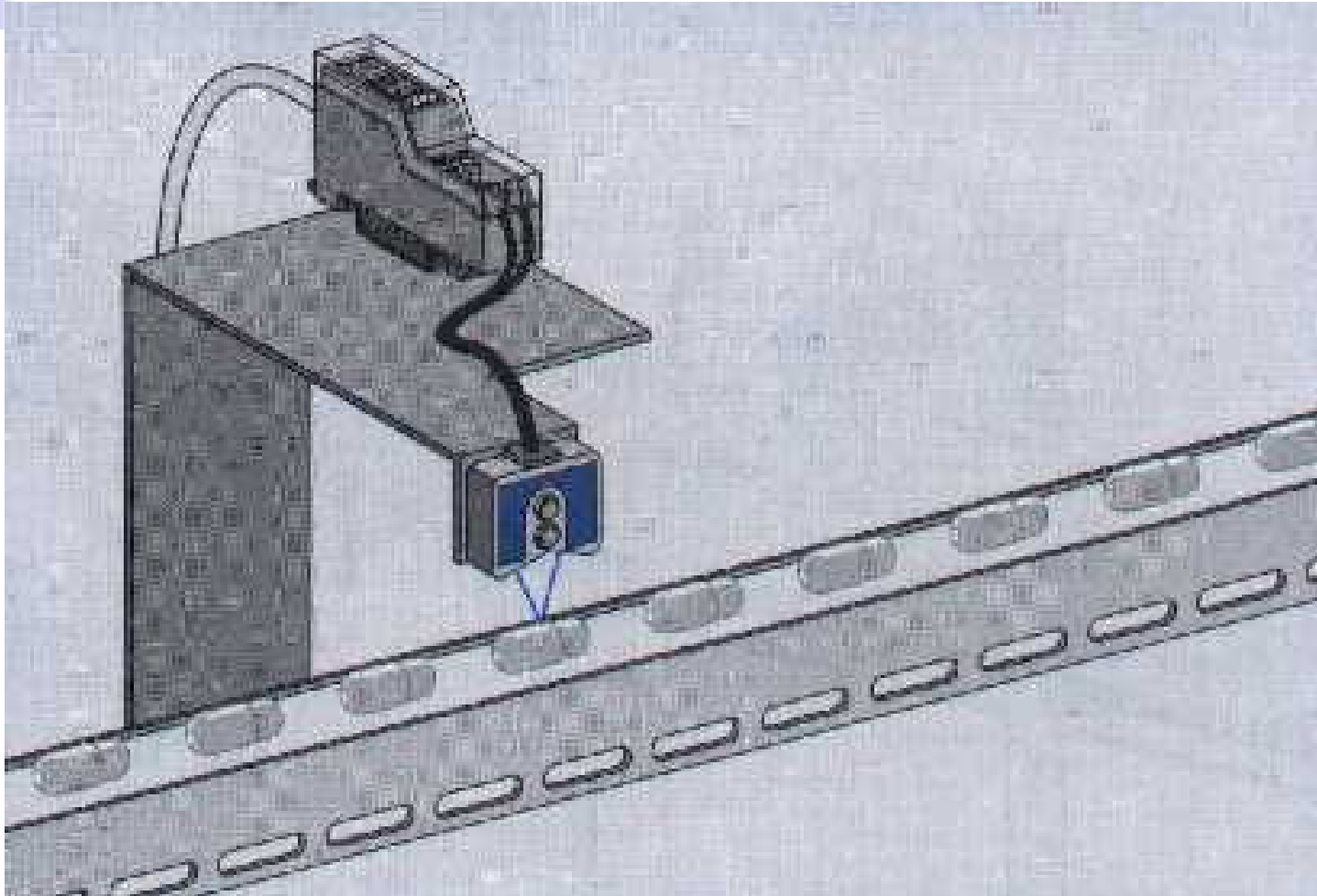




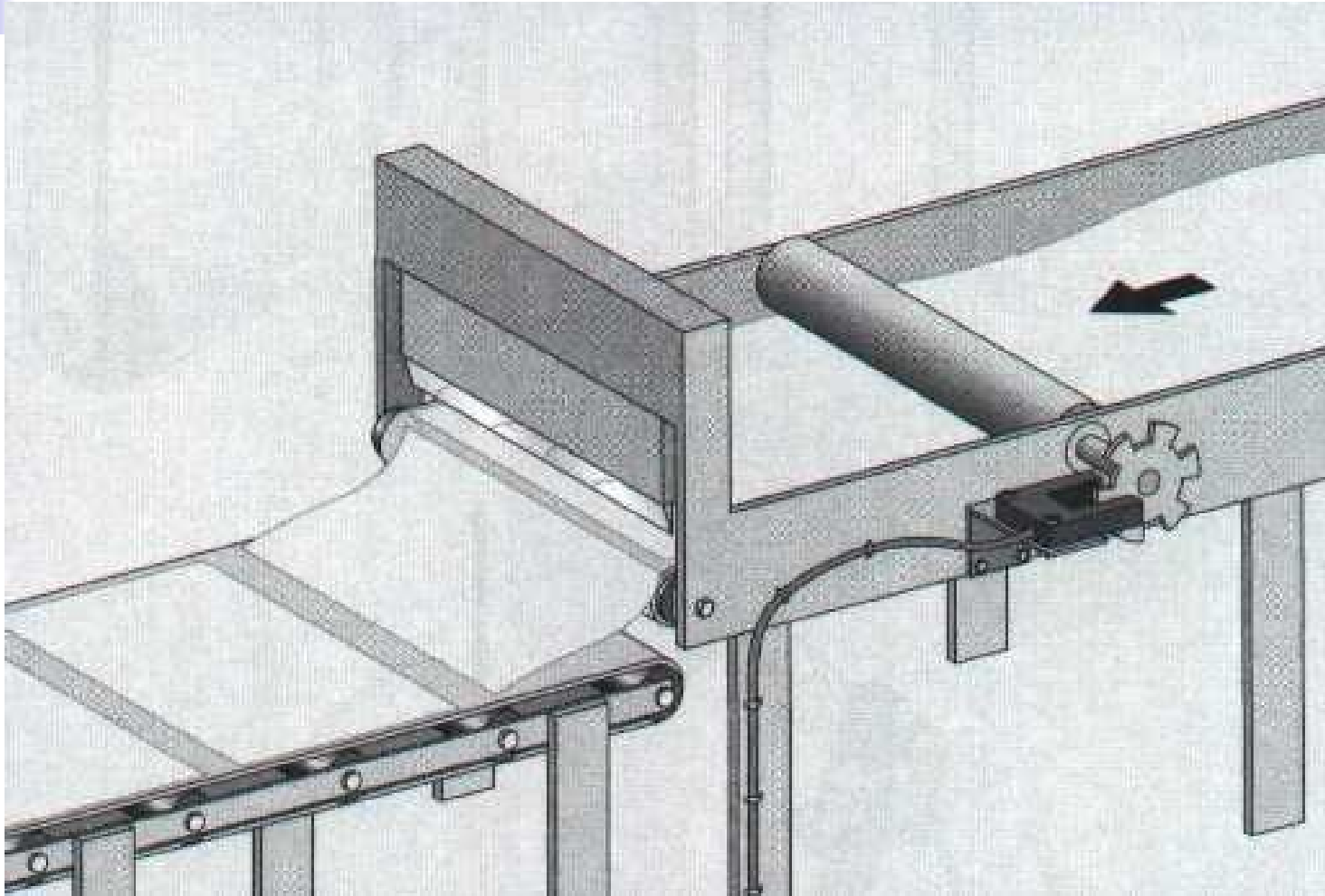
Counting televisions



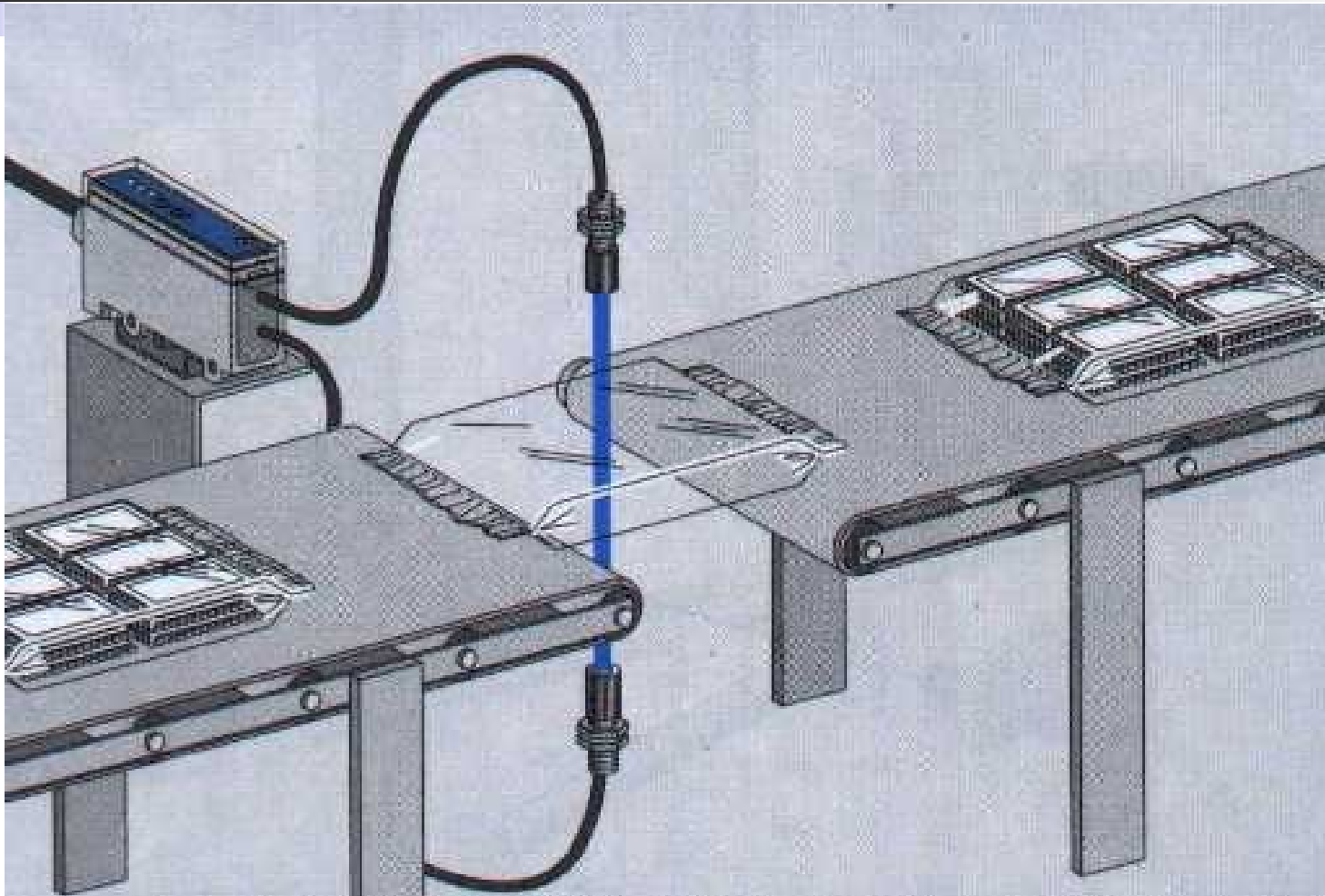
Counting tablets



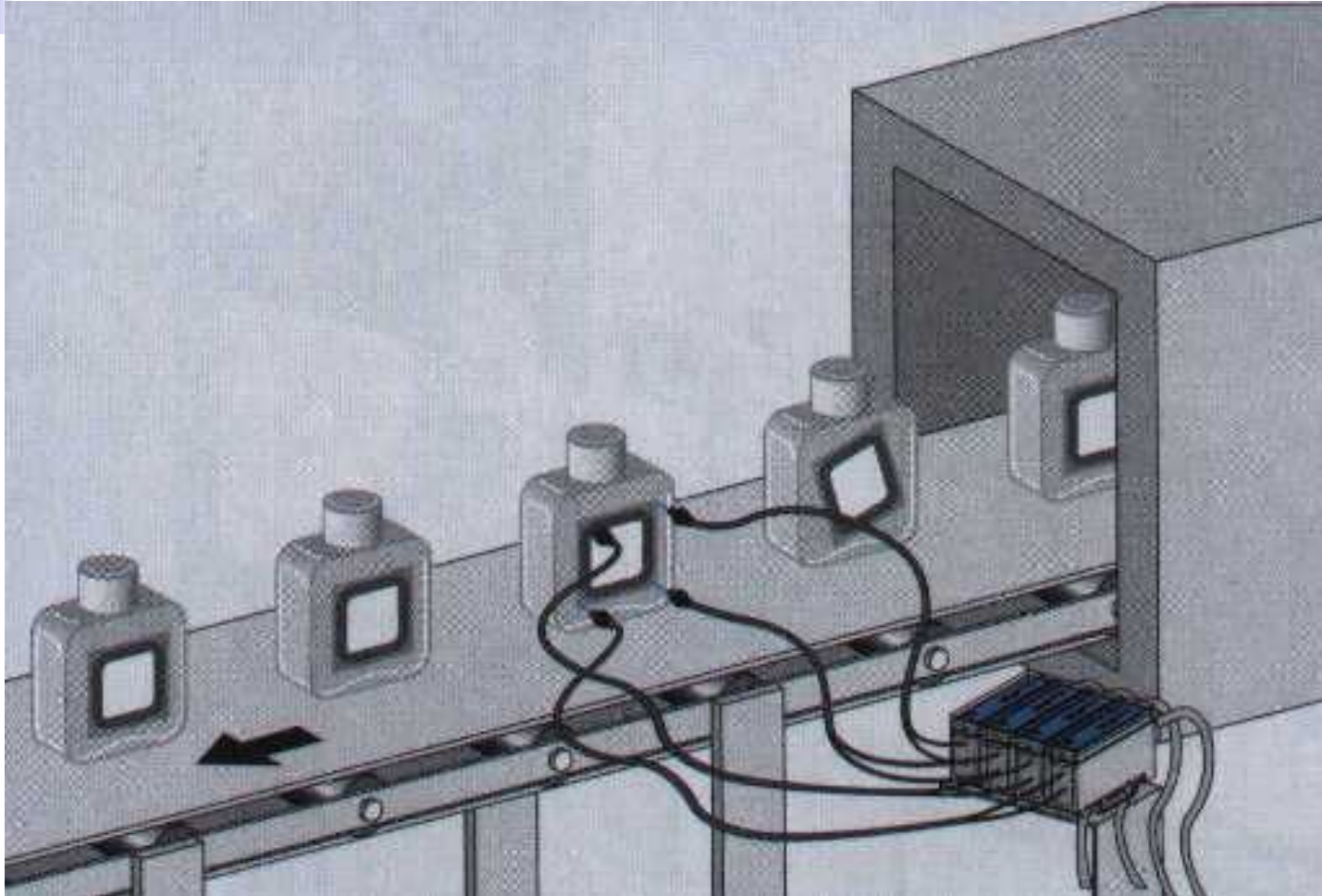
Synchronization of cutting to a specified length



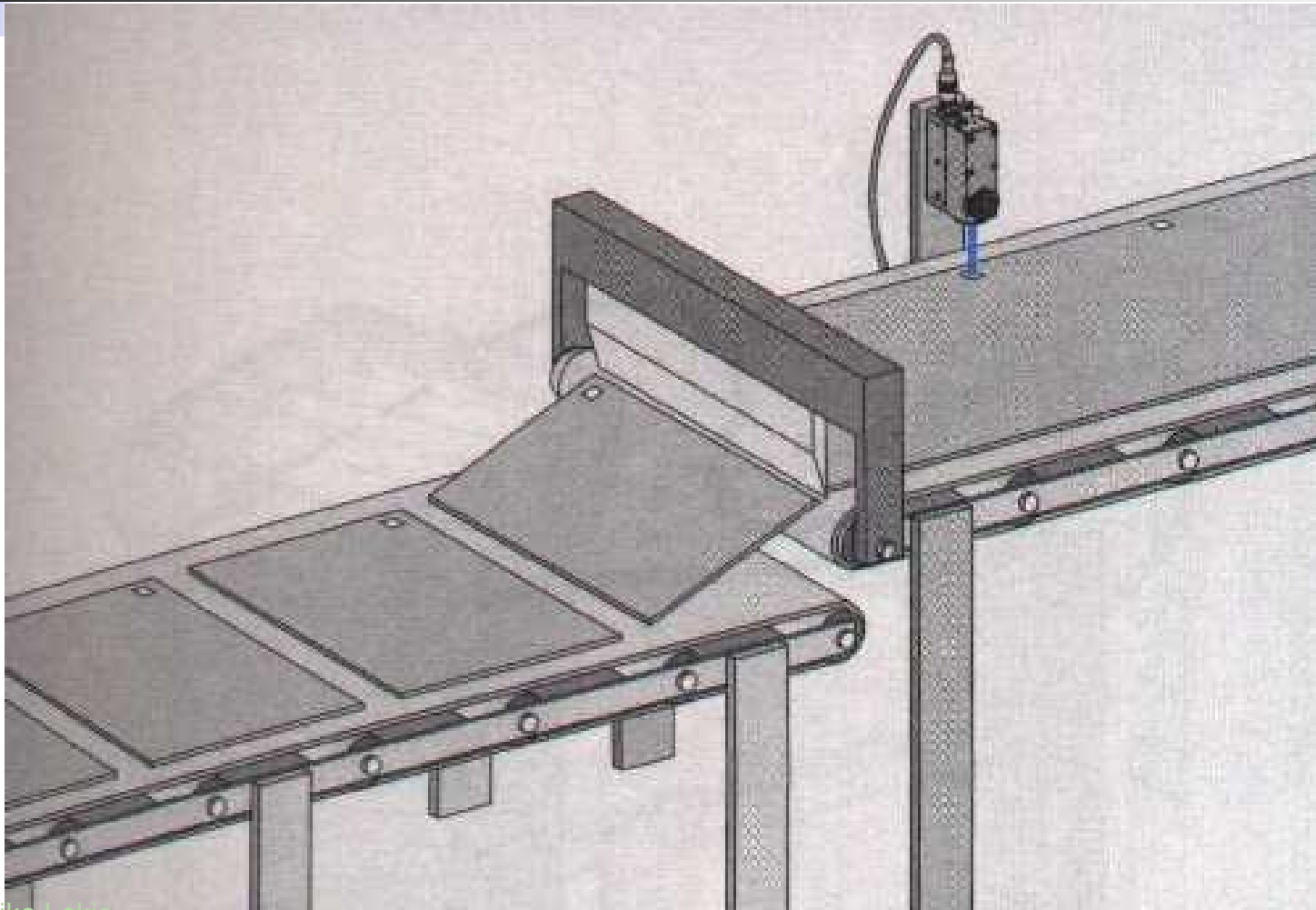
Detection of an empty package



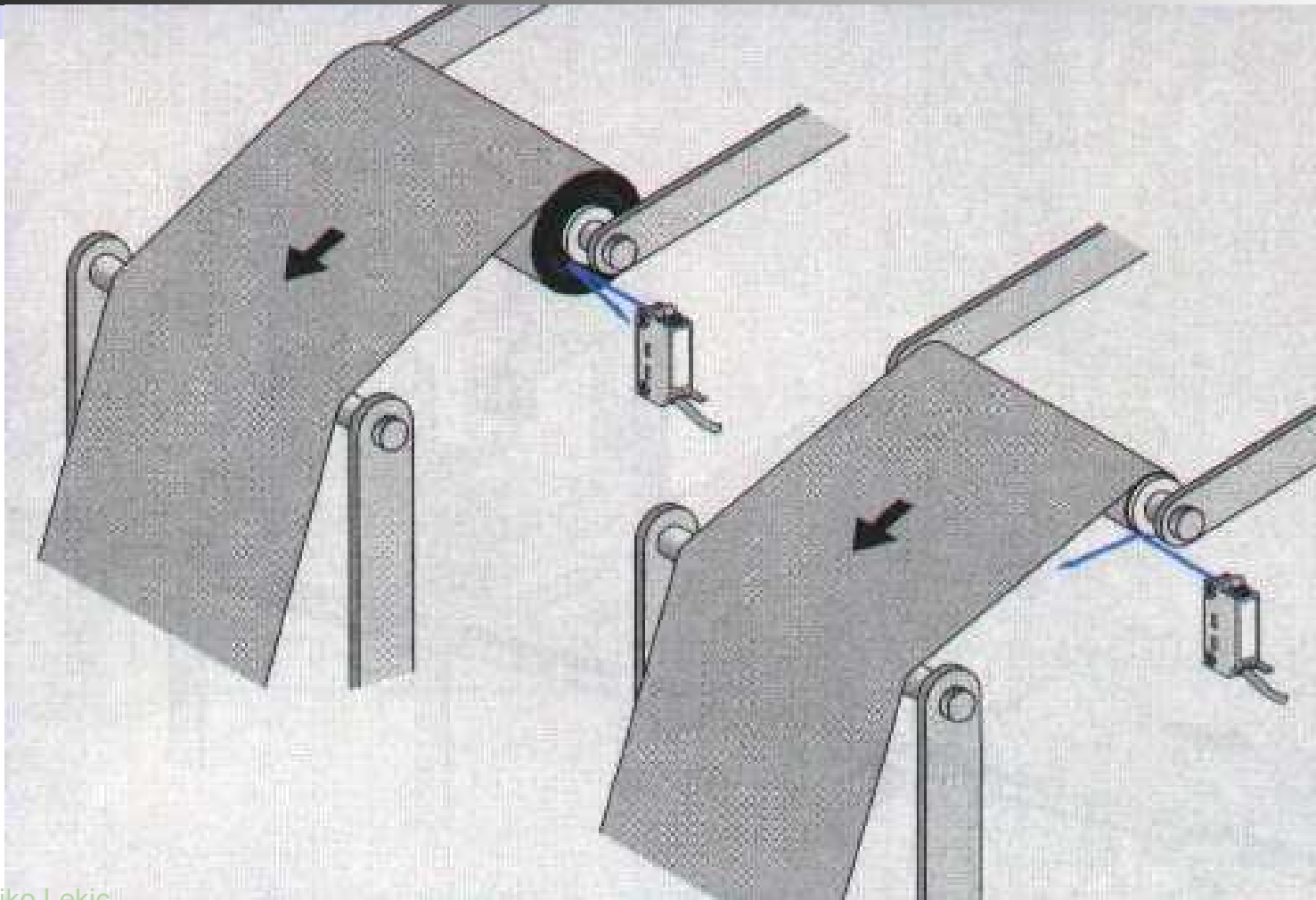
Detection of incorrect label position



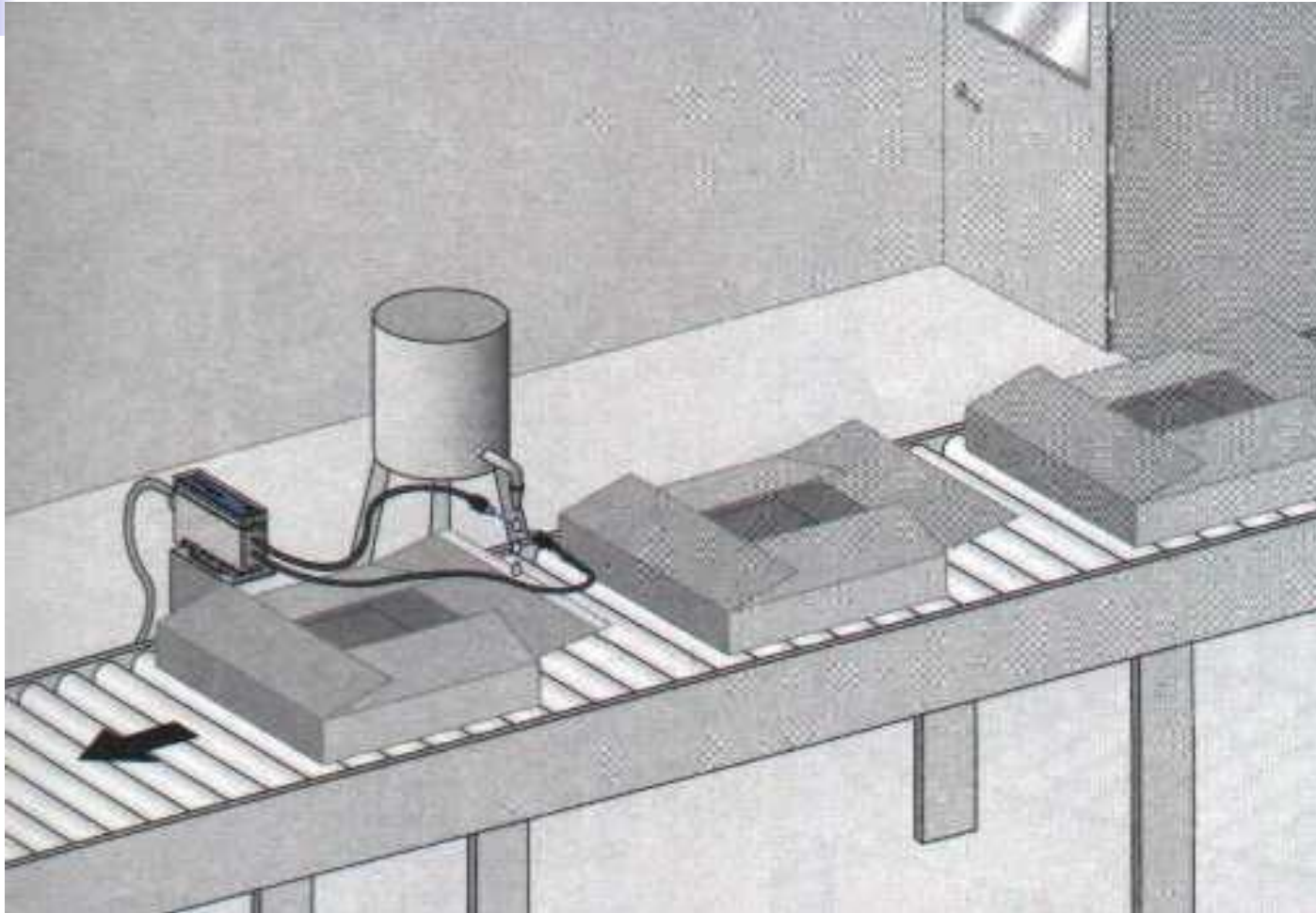
Reading a reference mark for cut-to-length operation



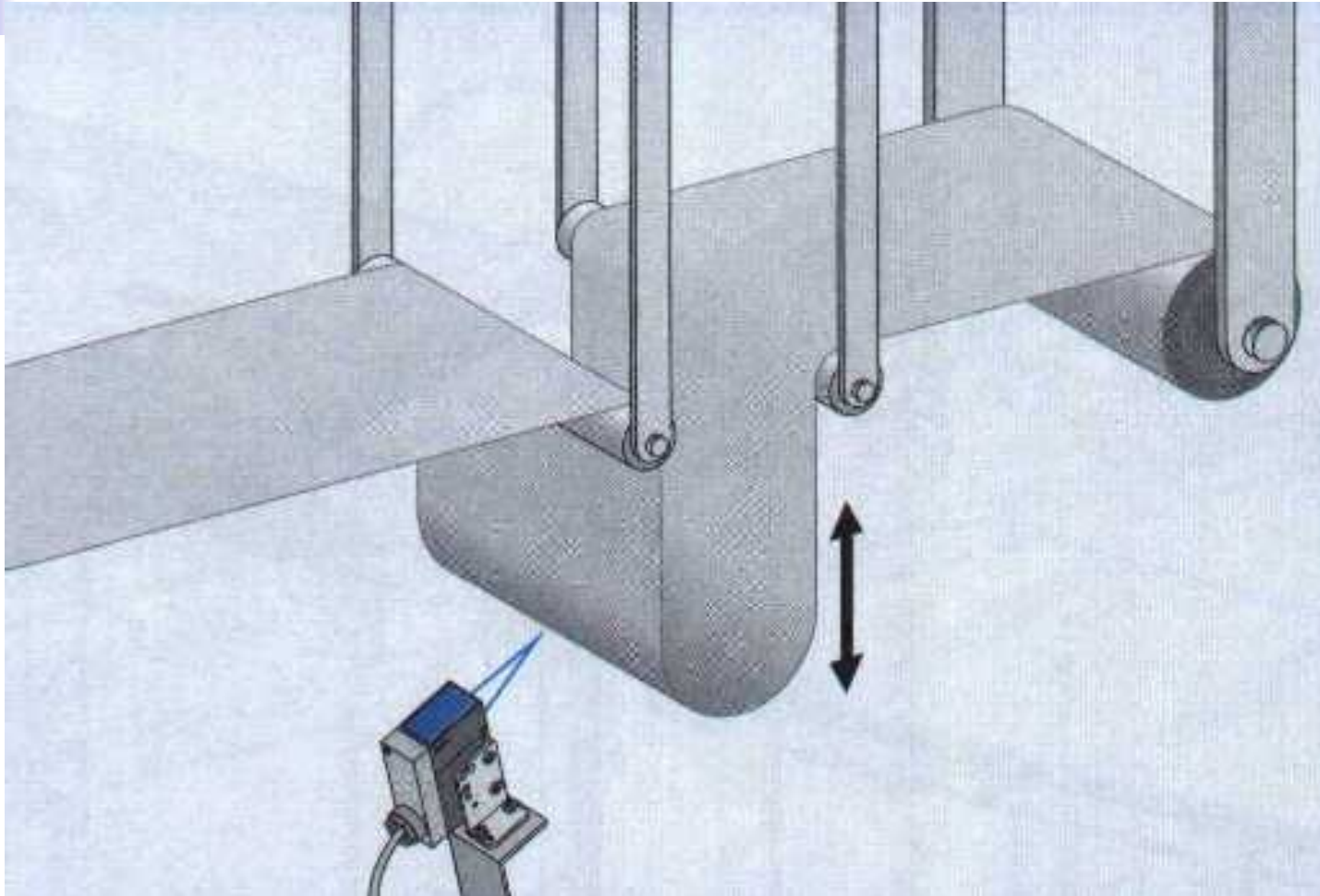
Detection of end-of-roll



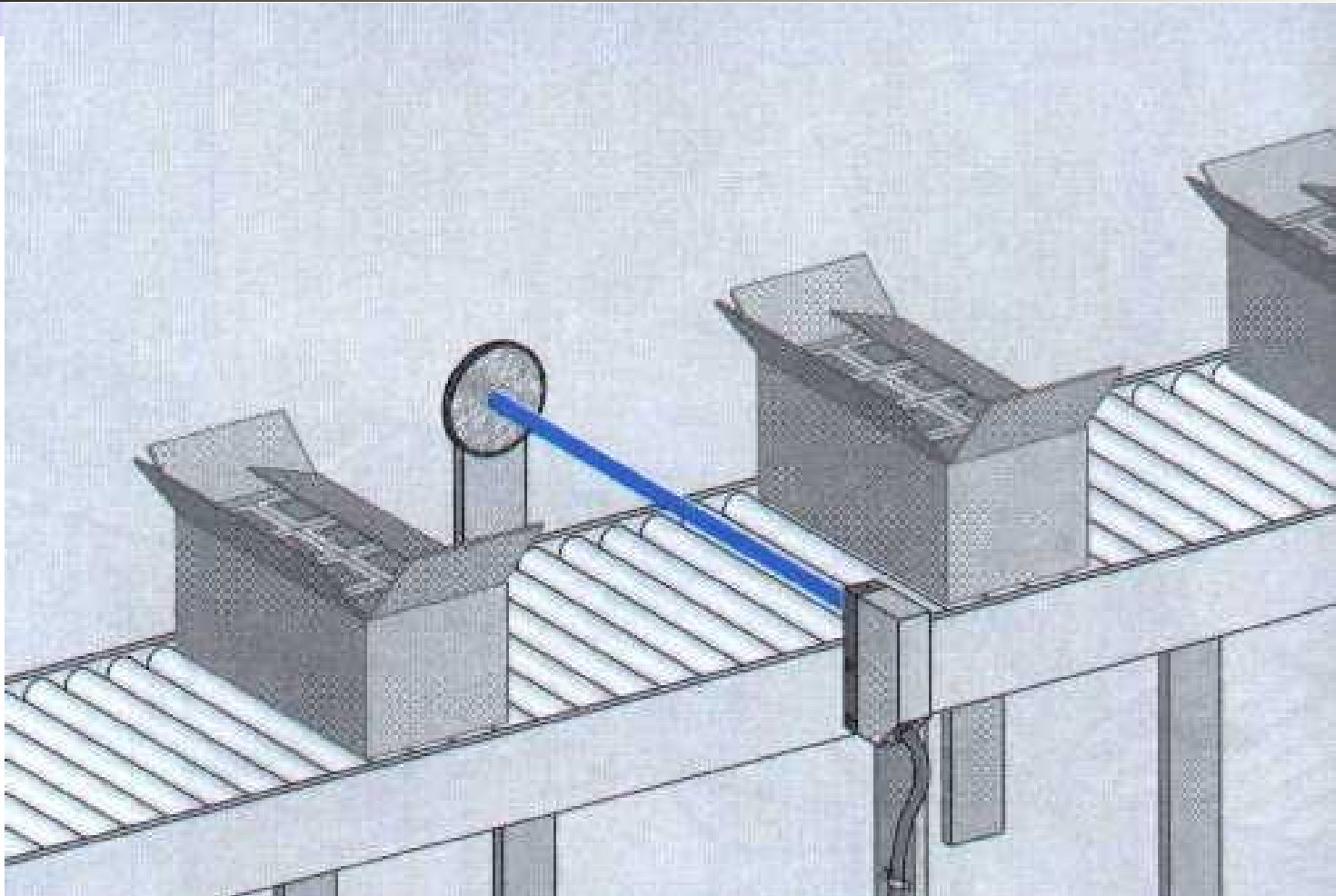
Inspection: “Is there glue present?”



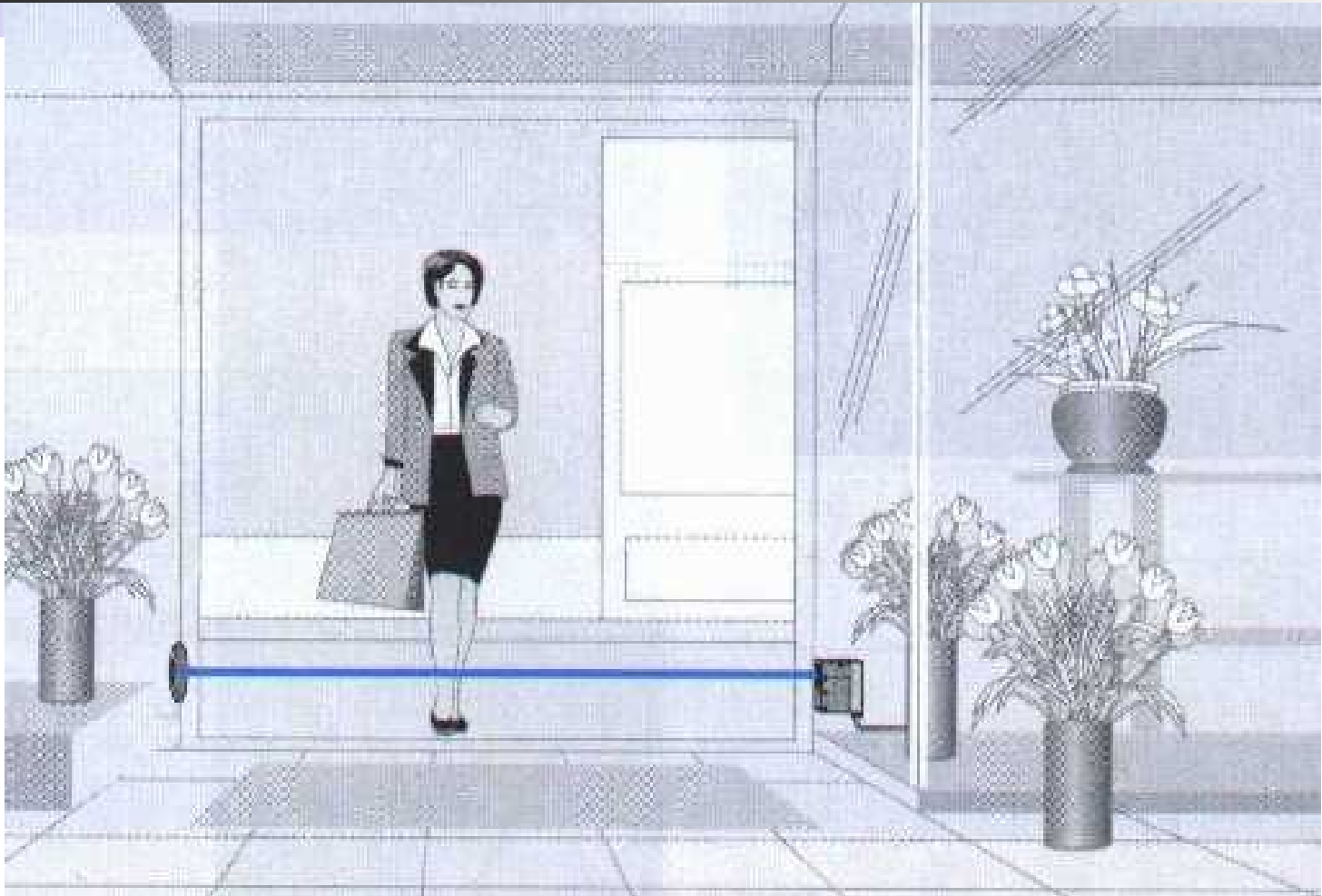
Detection of a loop (material reserve)



Monitoring and counting boxes



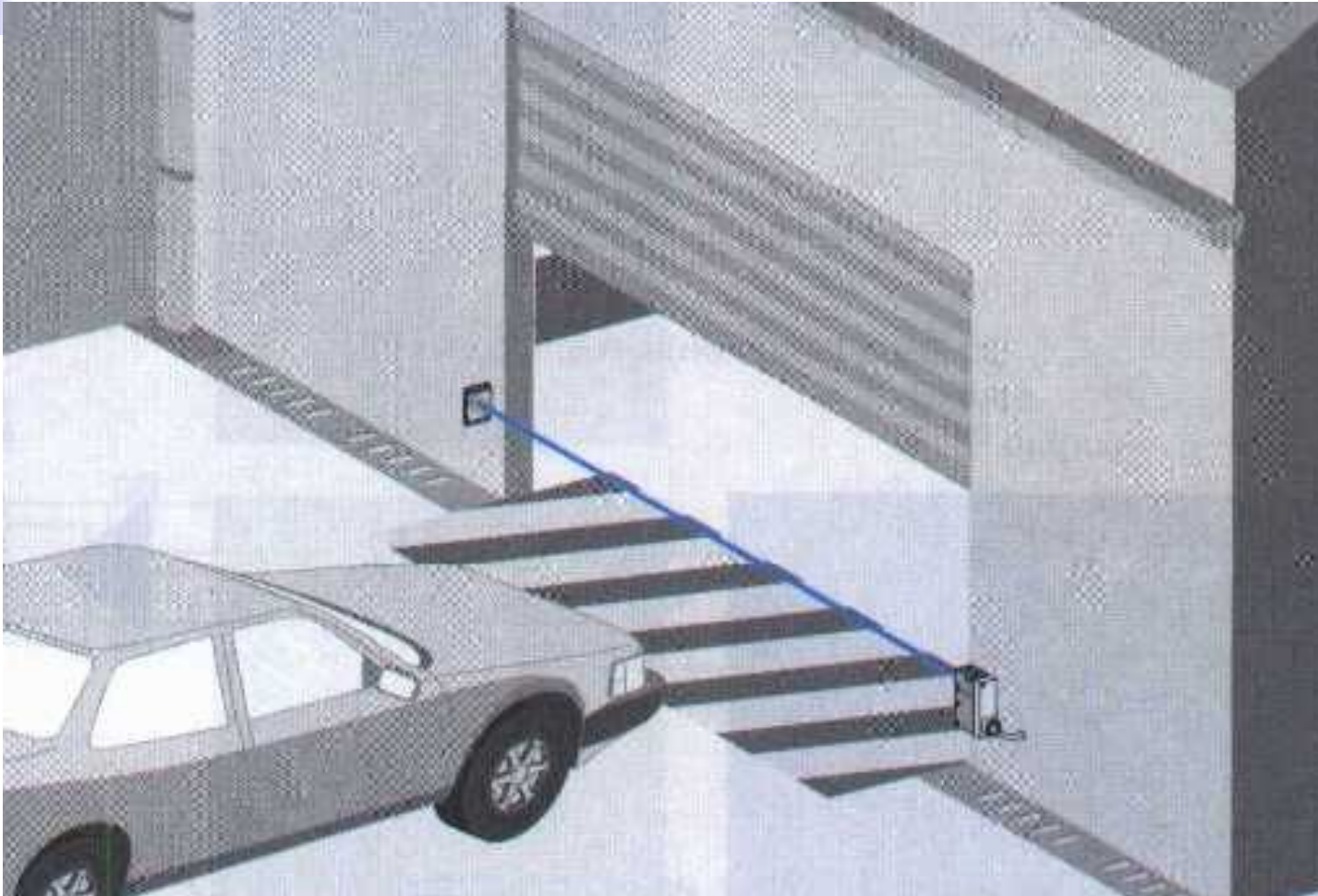
Detection of a person entering the area



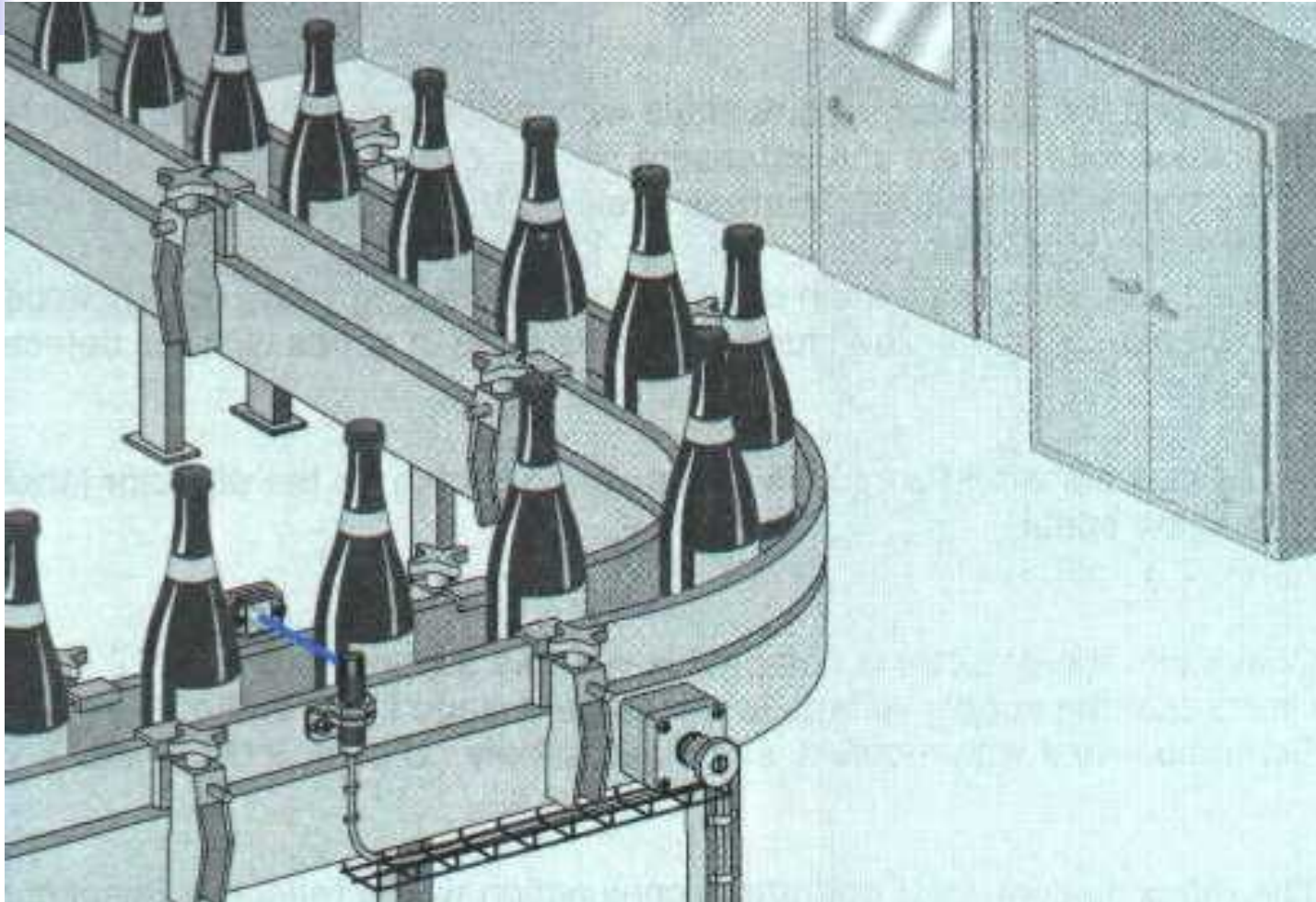
Monitoring (control) zone



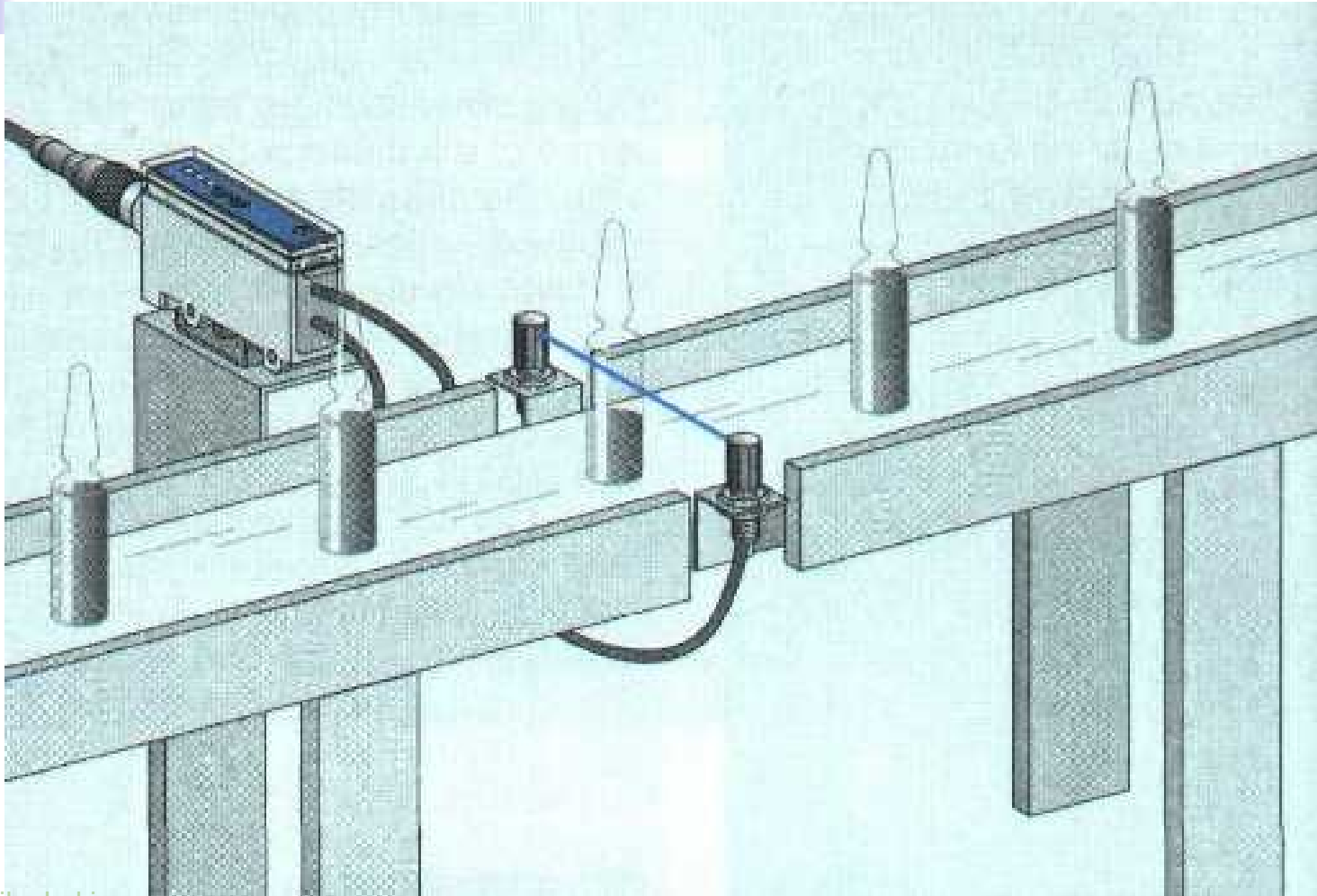
Garage-door control



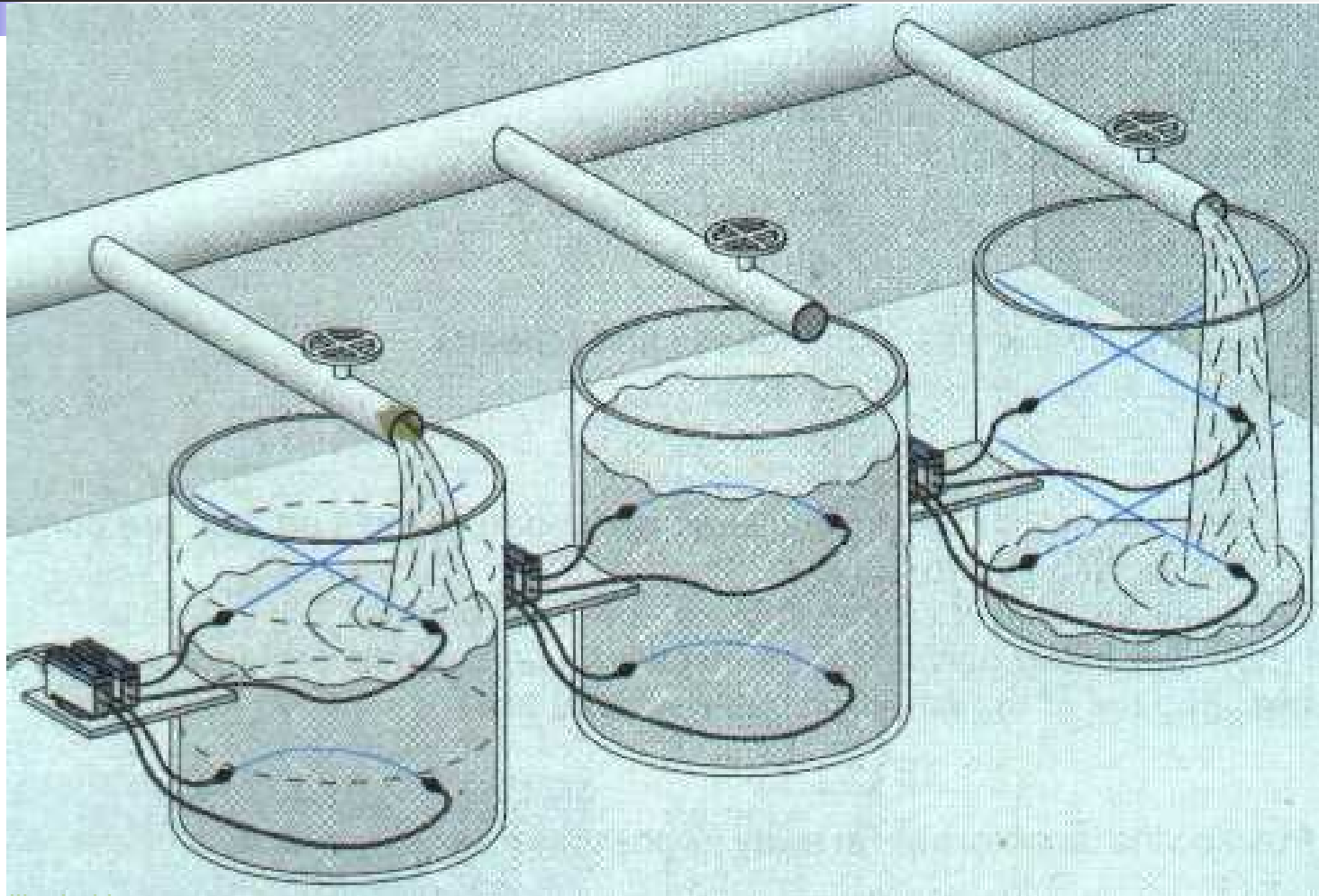
Monitoring and counting bottles



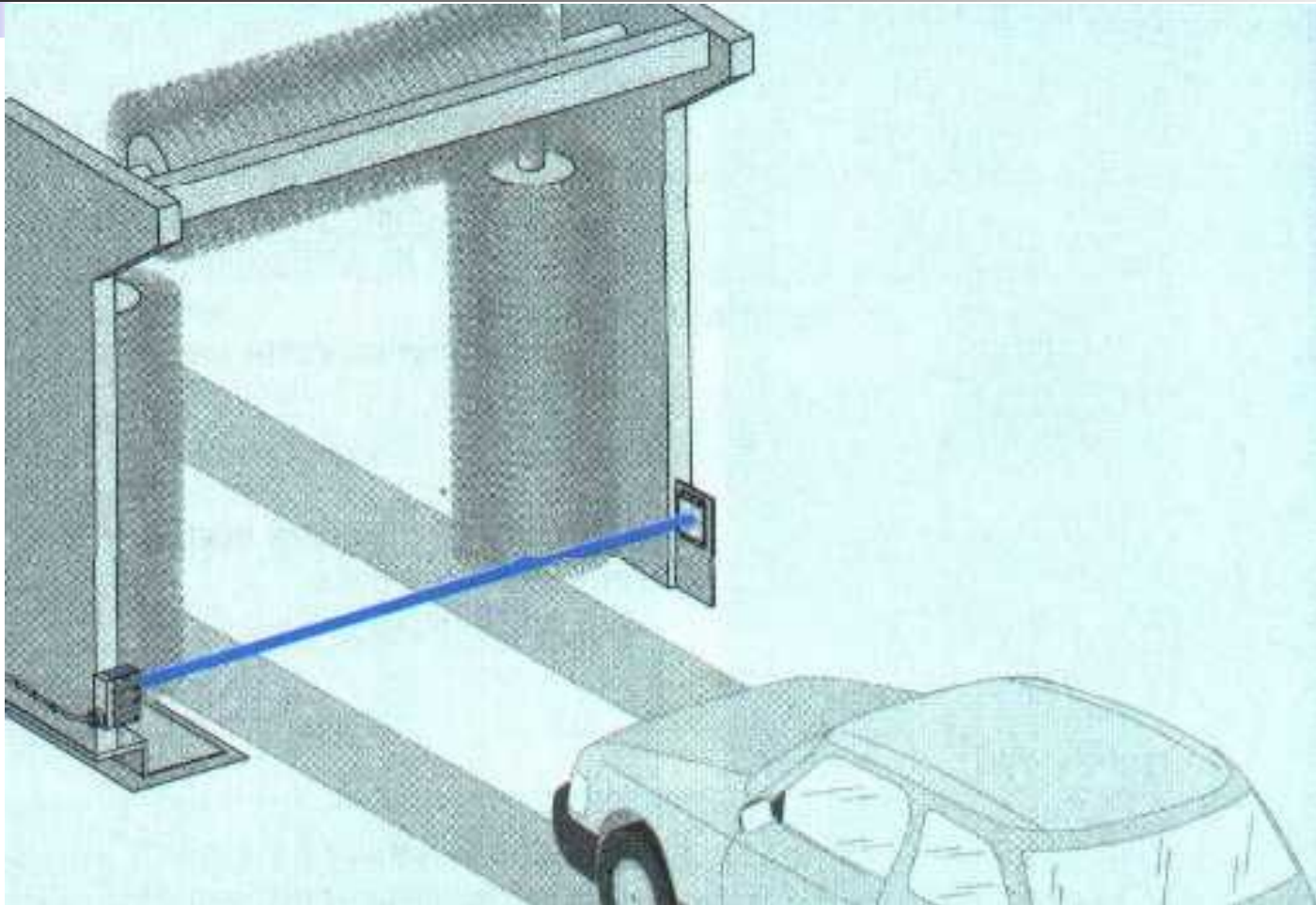
Checking the fill level of ampoules

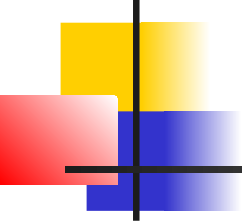


Monitoring water level in containers



Control of actuators in an automated car wash





Digital encoders and position sensors



Digital encoders and position sensors

This is an application area in which optical sensors are dominant.

The two basic types of digital encoders are **absolute** and **incremental**.

According to the type of motion, encoders are classified as **linear** and **rotary**.

According to the direction-of-motion capability:

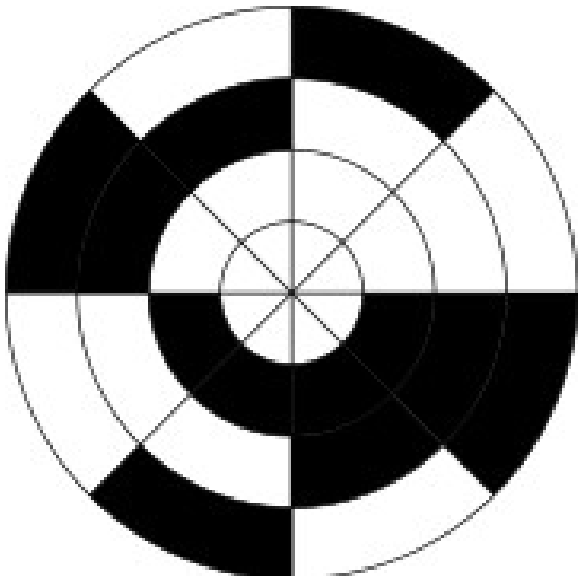
Single-channel (does not indicate the direction of motion);

Two-channel (provides information on the direction of motion).



Absolute encoders

Absolute encoders provide a unique digital code for each distinct position of an object (shaft/spindle).



Sector	Contact 1	Contact 2	Contact 3	Angle
1	off	off	off	0° to 45°
2	off	off	on	45° to 90°
3	off	on	off	90° to 135°
4	off	on	on	135° to 180°
5	on	off	off	180° to 225°
6	on	off	on	225° to 270°
7	on	on	off	270° to 315°
8	on	on	on	315° to 360°

[*Absolute encoder \(video clip 1\)*](#)

[*Absolute encoder \(video clip 2\)*](#)



Gray code (absolute encoders)

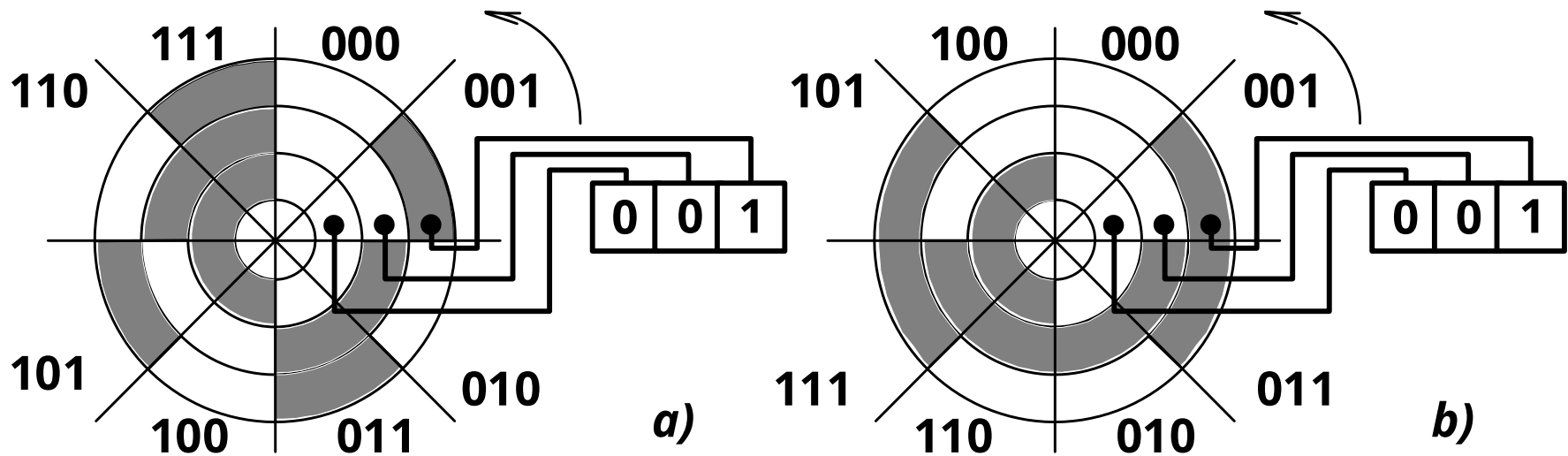
Two adjacent states differ by only one bit.

	<u>B₂</u>	<u>B₁</u>	<u>B₀</u>		<u>G₂</u>	<u>G₁</u>	<u>G₀</u>
<i>a)</i>	0	0	0	<i>b)</i>	0	0	0
	0	0	1		0	0	1
	0	1	0		0	1	1
	0	1	1		0	1	0
	1	0	0		1	1	0
	1	0	1		1	1	1
	1	1	0		1	0	1
	1	1	1		1	0	0

Three-bit combinations: (a) in binary code and (b) in Gray code.

$$G_2=B_2, \quad G_1=B_2+B_1, \quad G_0=B_1+B_0 \quad (\text{bez prenosa}),$$

Gray code



Two disk variants for a 3-bit code:
(a) natural (binary) code; (b) Gray code

a) Prirodni kod; b) Greyov kod



Incremental encoders

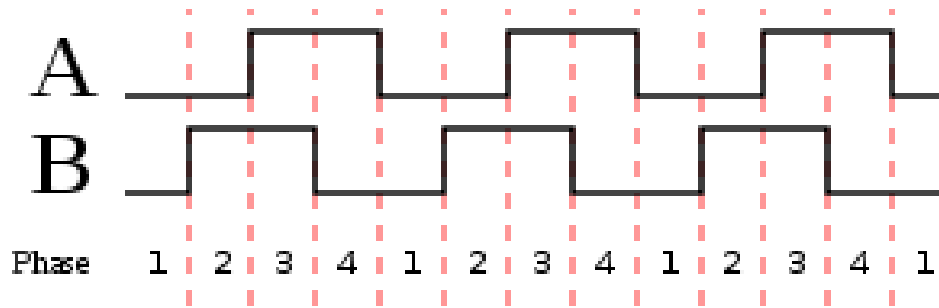
Rotary incremental encoder

Linear incremental encoder



Incremental encoders

Incremental encoders have two outputs.



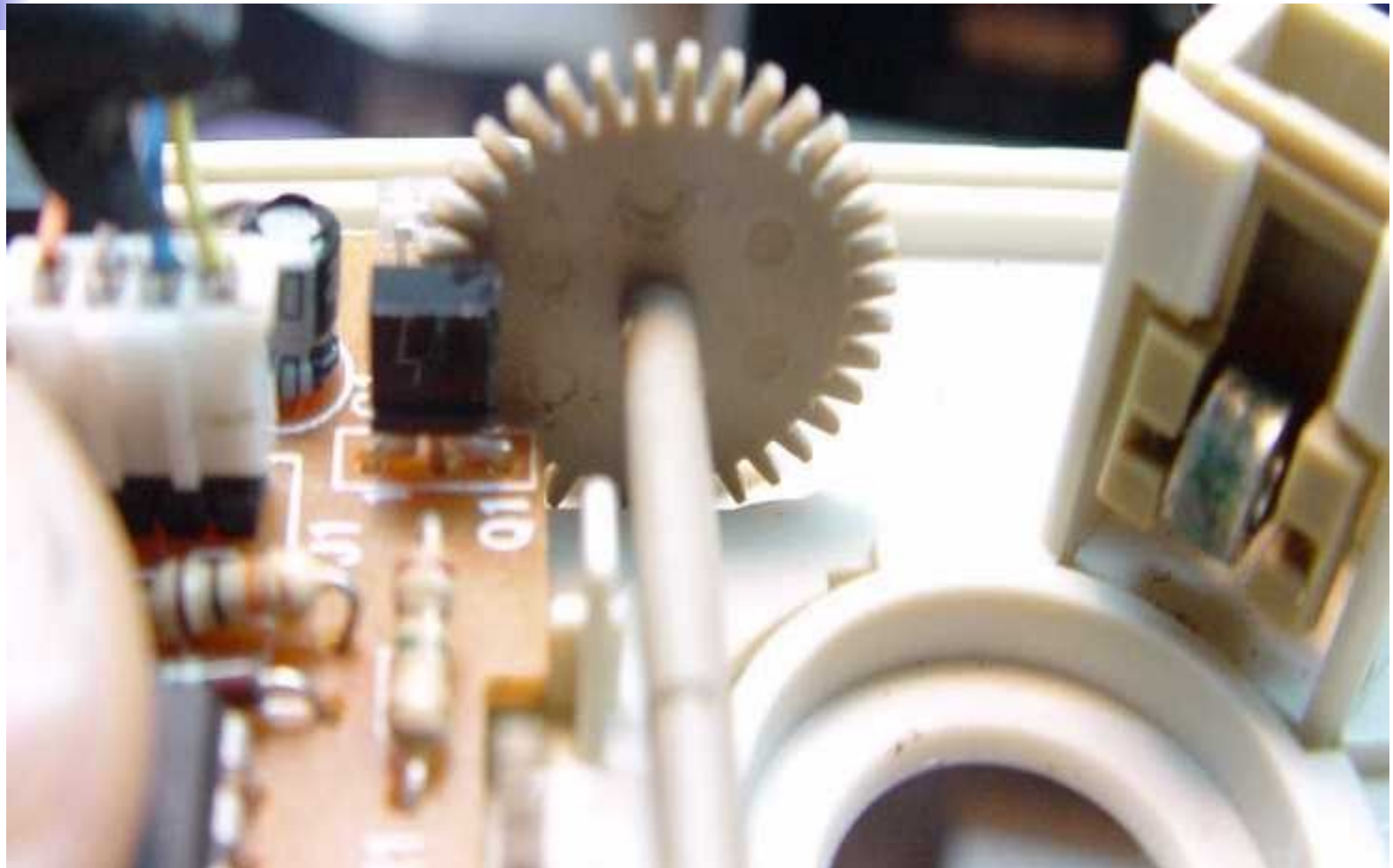
Gray coding for
clockwise rotation

Phase	A	B
1	0	0
2	0	1
3	1	1
4	1	0

Gray coding for
counter-clockwise rotation

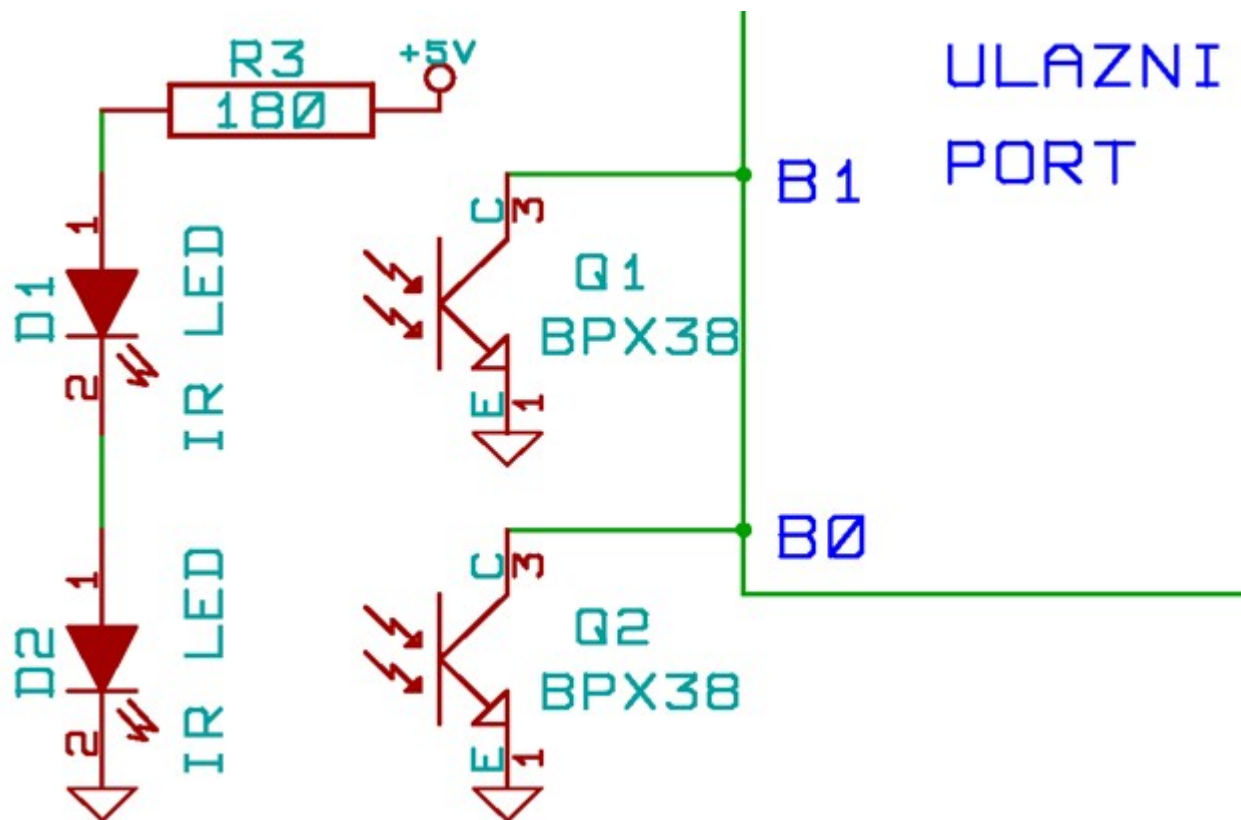
Phase	A	B
1	1	0
2	1	1
3	0	1
4	0	0

Incremental sensor with a toothed disk



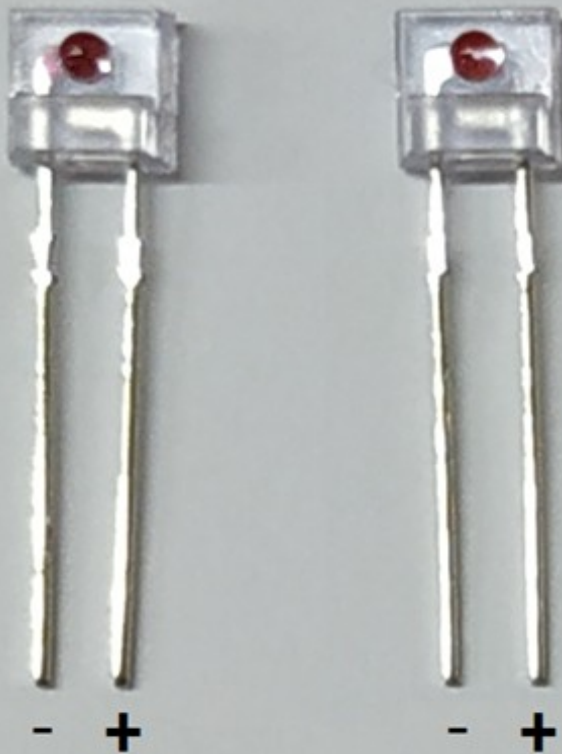
Optical interface (incremental sensor)

```
x=PINB & 3; // read the state of the phototransistors
```



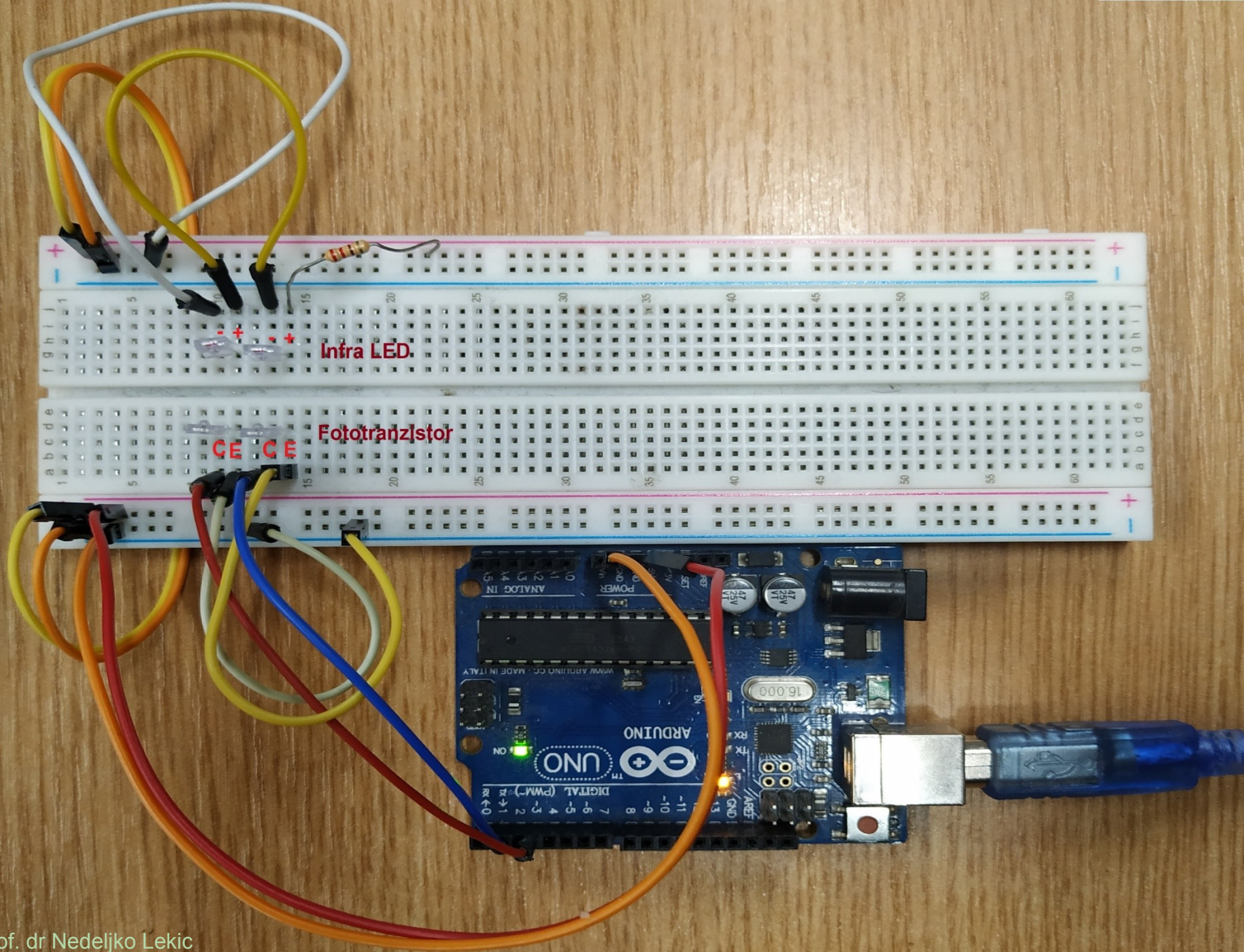
Optical interface (optoelements)

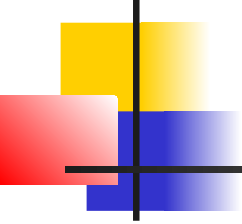
Infra LED



Fototranzistori







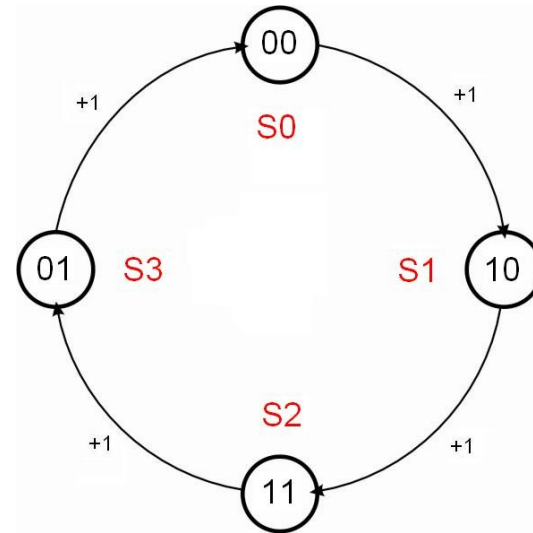
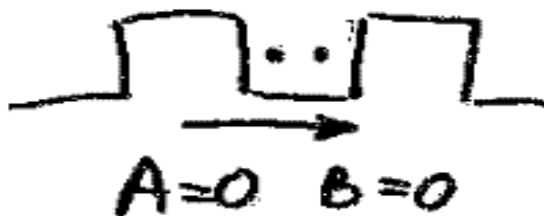
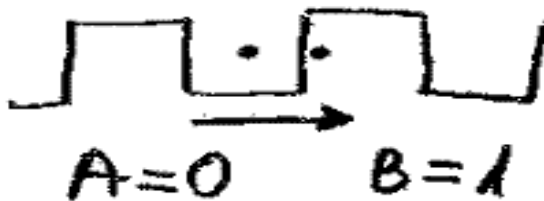
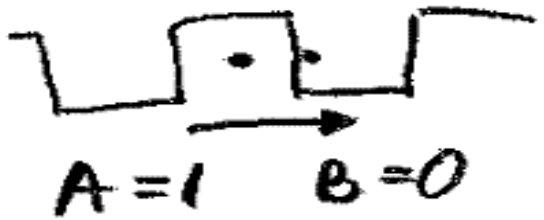
Program for a single-channel incremental position sensor

```
void loop()
{
    int y, staro;
        int novo=0,p=0;

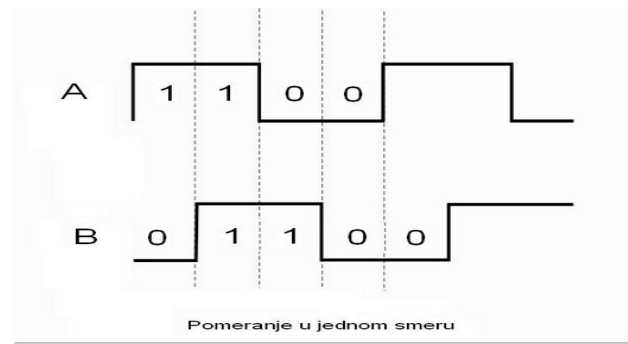
    y = PINB;
    Serial.println(y);

    staro=novo;
    novo=y & 1;
    if (novo==staro) return;
    p++;
    Serial.println(p);
}
```

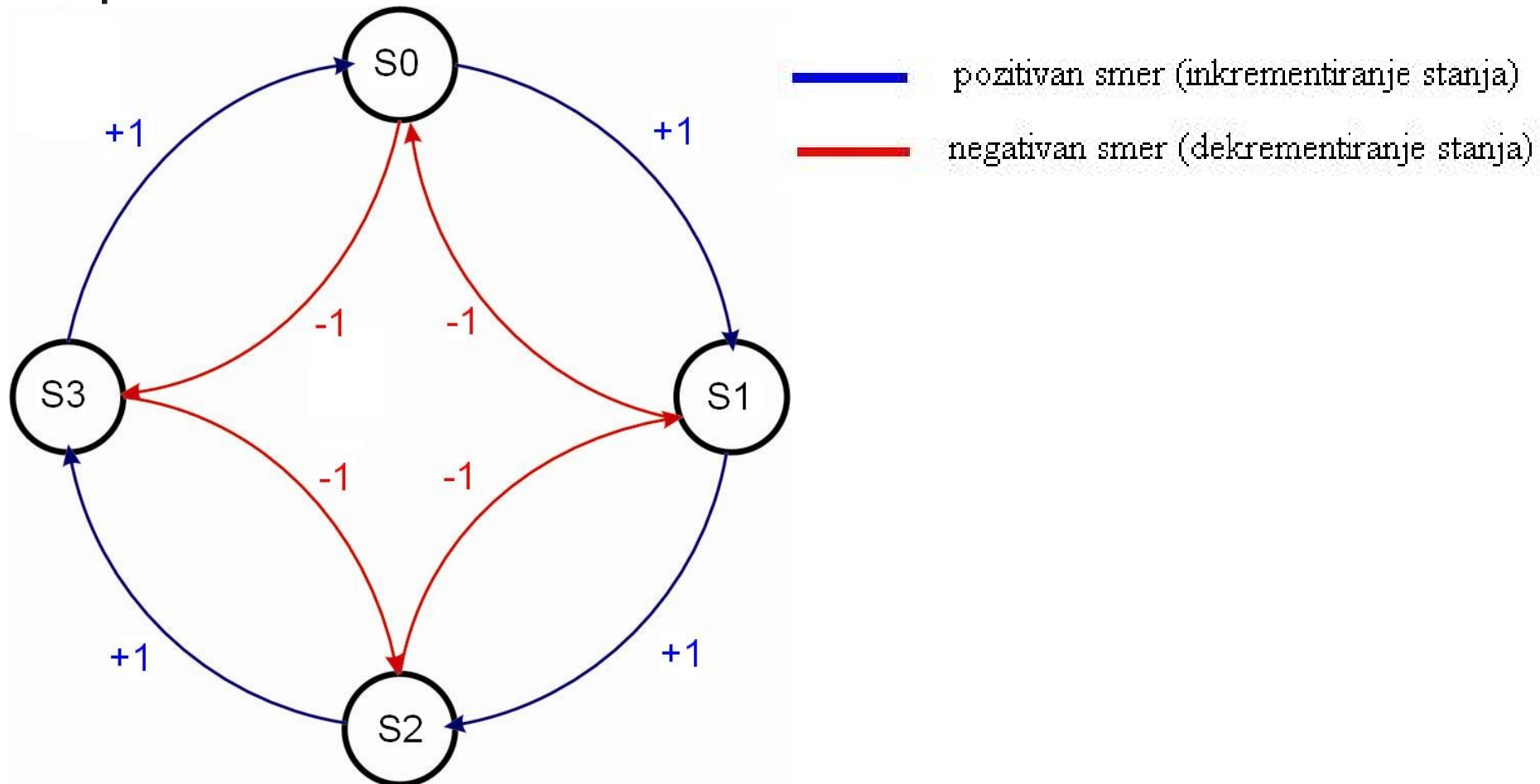
State diagram – one direction of rotation



Motion in the positive direction



State sequence for “+” and “-” directions of rotation



Spacing between optical channels

The spacing between optical channels does not have to be exactly one quarter of the tooth period. Spacings of $3/4$, $5/4$, $7/4$, ... are equally valid.



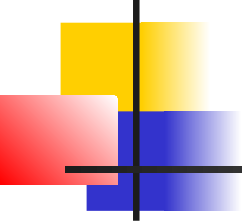
$$A=0 \quad B=1$$



$$A=1 \quad B=1$$



$$A=1 \quad B=0$$



Program for a two-channel incremental position sensor

```
void loop()
{ #define S0 0 /*A=0 B=0*/
  #define S1 8 /*A=1 B=0*/
  #define S2 12 /*A=1 B=1*/
  #define S3 4 /*A=0 B=1*/
```

```
int staro;
static int novo=0, p=0;
```

```
staro=novo;
novo=PIND & 12;
if (novo==staro) return;
```

```
switch(staro){
  case S0: if(novo==S1) p++;
           if(novo==S3) p--; break;
  case S1: if(novo==S2) p++;
           if(novo==S0) p--; break;
  case S2: if(novo==S3) p++;
           if(novo==S1) p--; break;
  case S3: if(novo==S0) p++;
           if(novo==S2) p--; break;
} /* kraj switch petlje */
Serial.println(p);

} /* Kraj programa*/
```



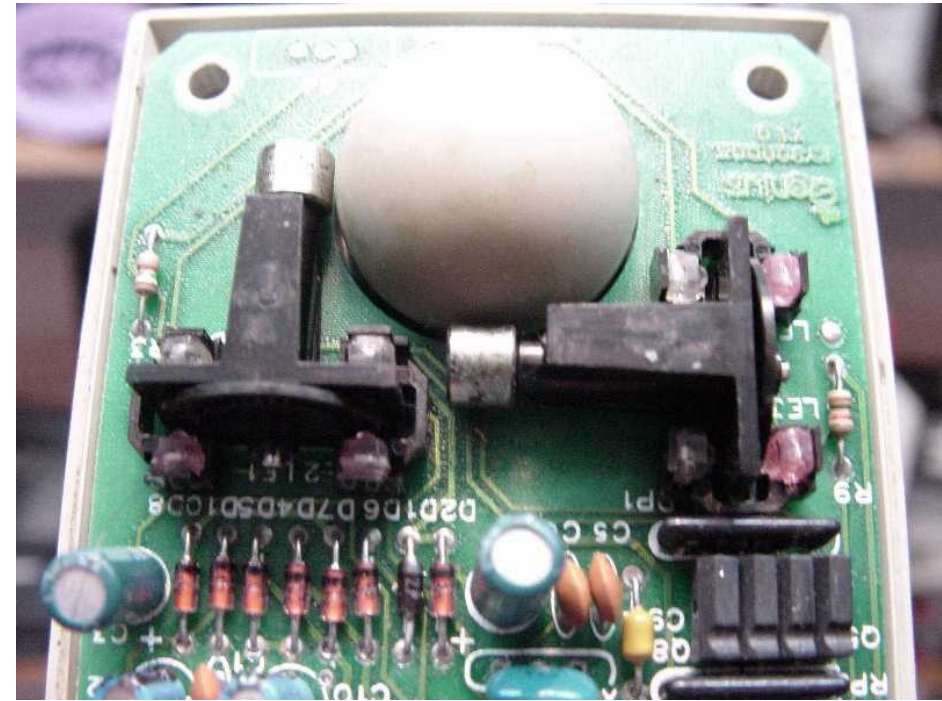
Port sampling rate

The port sampling rate must be set so that every state change on the port is registered.

If the sampling rate is too low relative to the input transition speed, some changes will not be captured.

This leads to missed states and an incorrect position estimate.

X and Y incremental sensors (two two-channel incremental sensors)



Although incremental encoders are no longer used in mice, they remain indispensable in many other applications. They are used to measure position, linear speed, angle, rotational speed, and any quantity that can be converted into displacement (e.g., weight, force, pressure, level, etc.).

Laser measuring instruments with an incremental encoder



vernier caliper



micrometer



tachometer

A laser light source allows an incremental encoder to generate more pulses per unit length, enabling more precise measurement.



Exercises

1. Implement a two-channel incremental position sensor with direction tracking using interrupts on Arduino digital pins 2 and 3. For each movement of the rack in one direction, generate a short audible signal for that direction. The signals for the two directions must be distinguishable. The audible signal must be brief (no longer than 100 ms). (For details on using interrupts on Arduino digital pins, see the referenced page.) (2-1)
2. Counting products by shifts. Use the Serial Monitor message “FIRST” to start counting for the first shift. Use “STOP” to stop counting in the current shift. Use “SECOND” to start the second shift only if the previous shift counting has been stopped. Use “THIRD” to start the third shift only if the previous shift counting has been stopped. Upon receiving “DAY”, report the number of counted products per shift on the Serial Monitor, provided that counting has been stopped. (2–1)
3. Rack motion controls a stepper motor: motion of the rack initiates stepper-motor rotation at a speed set by a potentiometer, in the range 50–450 steps/s. A change in rack direction reverses the motor direction and triggers an audible direction-change signal. When the rack direction changes, print: “Direction change. Direction: {Left/Right}”. For each rack step, print: “Consecutive steps {Left/Right}: {count}”. If the rack performs 12 or more consecutive steps in one direction, stop the stepper motor, emit a stop signal, and print: “Motor stopped until the rack moves in the opposite direction”. Motion in the opposite direction restarts the motor. (2–1 points)