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TECHNICAL SPECIFICATION

Safety of machinery – Safety-related sensors used for the protection of persons –
Part 3: Sensor technologies and algorithms

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INTERNATIONAL
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SAFETY OF MACHINERY – SAFETY-RELATED SENSORS USED FOR THE PROTECTION OF PERSONS

Part 3: Sensor technologies and algorithms

FOREWORD

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IEC TS 62998-3 has been prepared by IEC technical committee TC 44: Safety of machinery – Electrotechnical aspects. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
44/981/DTS	44/1002/RVDTS

Full information on the voting for the approval of this Technical Specification can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

This document is intended to be used in conjunction with IEC TS 62998-1.

A list of all parts in the IEC 62998 series, published under the general title *Safety of machinery – safety-related sensors used for the protection of persons*, can be found on the IEC website.

Future documents in this series will carry the new general title as cited above. Titles of existing documents in this series will be updated at the time of the next edition.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Applications of automated guided vehicles, service robotics used in public areas or human machine interaction in industries show an increasing demand and use of new sensor technologies and new kinds of sensor functions with respect to hazard exposure of persons. A rapidly increasing number of sensors, with different sensor technologies, are used in these applications to achieve a high degree of automation up to autonomy. The systematic capabilities of such sensors are relevant to reduce the risk of personal injury. Other aspects of functional safety related to sensors as part of control systems are covered by e.g. IEC 61508 (all parts), IEC 62061 or ISO 13849 (all parts).

Existing design specific sensor standards set requirements on systematic capabilities for a selected sensor technology and how these can be assessed by analysis and test. The specific requirements are derived from products with limited classes of safety performance and already well-known sensor technology.

IEC TS 62998-1 sets general requirements for the development, integration and maintenance of safety related sensors (SRS) and safety related sensor systems (SRSS) applicable to all sensor technologies with special attention to systematic capabilities. IEC TS 62998-1 is appropriate for the risk reduction in accordance with all classes of safety performance in an identified application.

First assessments of SRS/SRSS in accordance with IEC TS 62998-1 identified the need for additional guidance for the required analysis of sensor technologies and use of algorithms.

Sensor technology is defined by the wavelength range, the measurement method and the arrangement of the sensing unit in an SRS, respectively arrangement of SRS in an SRSS. This document gives guidance for sensor technologies without setting requirements for a specific design or limiting the class of safety performance. If applicable to the sensor technology, additional information is given for physical properties of the objects to be detected or relevant objects that interfere with the detection of such objects.

Algorithms are a core element to achieve safety related functions in an SRS/SRSS, such as signal processing to extract peaks in analogue signals, localization or classification of objects that are important to guide an autonomous or highly automated system in a more or less known surrounding. Platforms such as cloud services provide e.g. algorithms or measures for their automated generation that can be implemented by different integrators of SRS into an SRSS or by the manufacturer of such sensors. This document gives guidance on the correct implementation of algorithms to prevent intolerable risk for persons.

SAFETY OF MACHINERY – SAFETY-RELATED SENSORS USED FOR THE PROTECTION OF PERSONS

Part 3: Sensor technologies and algorithms

1 Scope

This part of IEC 62998, which is a technical specification, gives guidance on:

– analysis of sensor technologies of different wavelength ranges, measurement methods, and the sensing unit arrangement in an SRS, respectively the arrangement of SRSs in an SRSS;
– representative physical properties of safety-related objects with due consideration of their material characteristics and the sensor technology/technologies used in an SRS/SRSS to achieve the detection capability and comparable results during verification and validation;
– analysis of the interference of objects present in the surrounding on the safety related objects and thereby the influence on the dependability of the detection capability;
– use of algorithms during design, development and maintenance to achieve appropriate detection capability and dependability of detection;
– appropriate use of algorithms during the integration of SRS or SRSS by the integrator to improve execution of measurement information or provide decision information derived from measurement information.

If an SRS/SRSS uses sensor technologies not stated in this document, then the generic approach in accordance with IEC TS 62998-1 applies.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60079-29 (all parts), *Explosive atmospheres - Part 29 - Gas detectors*

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems*

IEC TS 62998-1:2019, *Safety of machinery - Safety-related sensors used for the protection of persons*

EN 50402, *Electrical apparatus for the detection and measurement of combustible or toxic gases or vapours or of oxygen – Requirements on the functional safety of fixed gas detection systems*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
acoustic impedance
at a specified surface, quotient of sound pressure by volume velocity through the surface

[SOURCE: IEC 60050-801:1994 [3][1], 801-25-40]

3.2
algorithm
finite set of well-defined rules for the solution of a problem in a finite number of steps

Note 1 to entry: An algorithm can be implemented by software or hardware means or by a combination of both.

[SOURCE: IEC 60050-171:2019 [2], 171-05-07, modified – Note to entry has been added]

3.3
bidirectional reflectance distribution function
function describing how a wave is reflected at a surface of an object

Note 1 to entry: It is employed in the optics of real-world light, in computer graphics algorithms, and in computer vision algorithms.

Note 2 to entry: It is usually applied in case of a mixed reflection.

3.4
cloud service
one or more capabilities offered via cloud computing invoked using a defined interface

[SOURCE: ISO/IEC 20924:2021 [12], 3.1.8]

3.5
concentration
amount of the gas or vapour of interest in a specified amount of the background gas or air

Note 1 to entry: Typical units include volume fraction (V/V); molar (moles per mole – m/m); percentage of the LFL of a particular substance; parts per million by volume (ppm); and parts per billion by volume (ppb).

3.6
depth from focus/defocus
changing of focal setting parameters to estimate distances in a scene

Note 1 to entry: Usually the distances are related to an observed surface of that scene.

Note 2 to entry: The distances are reconstructed from a set of two or more images related to the changed focal parameters of the observing sensor (e.g. light field cameras)

[1] Numbers in square brackets refer to the bibliography.

3.7
diffuse reflectance value
ratio of the diffusely reflected part of a wave and the incoming wave

Note 1 to entry: An ideal diffuse reflecting surface is said to exhibit Lambertian characteristic, meaning that there is equal luminance when viewed from all directions lying in the half-space adjacent to the surface.

3.8
diffuse reflection
scattering by reflection in which, on the macroscopic scale, there is no regular reflection

[SOURCE: IEC 60050-845:2020 [4], 845-24-054, modified – Note to entry has been removed]

3.9
direct time-of-flight
when a pulse is emitted, time difference between outgoing and incoming signals measured as an equivalent of time-of-flight

Note 1 to entry: For the use in an SRS/SRSS, the wavelength range for near infrared radiation is defined between 50 µm and 1 mm.

3.10
illuminated portion
effective echoing area of an object in terms of radar cross section

3.11
indirect time-of-flight
when a continuous amplitude modulated signal is emitted, phase difference between outgoing and incoming signals measured as an equivalent of time-of-flight

3.12
level switching
comparison of a detected signal related to a predefined threshold

3.13
machine learning model
mathematical construct that generates an inference, or prediction, based on input data

EXAMPLE If a univariate linear function ($y = \theta 0 + \theta 1x$) has been trained using linear regression, the resulting model can be $y = 3 + 7x$.

[SOURCE ISO/IEC 22989:2022 [13], 3.2.11, modified –Note to entry has been removed]

3.14
measurement method
generic description of a logical organization of operations used in a measurement

Note 1 to entry: Measurement methods may be qualified in various ways such as: substitution measurement method, differential measurement method, and null measurement method; or direct measurement method and indirect measurement method. See IEC 60050-300 [6].

[SOURCE: ISO/IEC GUIDE 99:2007 [18], 2.5]

3.15
middle infrared radiation
part of the infrared spectrum of optical radiation in which the wavelengths are longer than those of near infrared radiation and shorter than those of long infrared radiation

Note 1 to entry: For the use in an SRS/SRSS, the wavelength range for middle infrared radiation is defined between 3 µm and 50 µm.

3.16
mixed reflection
partly regular and partly diffuse reflection

[SOURCE: IEC 60050-845:2020 [4], 845-24-056]

3.17
near infrared radiation
part of the infrared spectrum of optical radiation in which the wavelengths are longer than those of visible radiation and shorter than those of middle infrared radiation

Note 1 to entry: For the use in an SRS/SRSS, the wavelength range for near infrared radiation is defined between 780 nm and 3 µm.

3.18
passive infrared sensor
sensor that is used to detect temperature changes

Note 1 to entry: Unlike other temperature sensors (e.g. thermography cameras), passive infrared sensors do not respond to a specific temperature level that is constant over time, but only to the change in temperature.

Note 2 to entry: Passive infrared sensors are based on pyroelectricity, a property of some piezoelectric semiconductor crystals.

3.19
practical use
use that involves real situations and events, rather than just ideas, theories or generally understood patterns of usage

EXAMPLE Derivation of real situations, events and scenarios from the application of the SRS/SRSS in the end user environment.

Note 1 to entry: The practical use can be a subset or an expansion of the intended use.

3.20
radar cross section
RCS
equivalent echoing area which is 4 π times the ratio of the power per unit solid angle scattered in a specified direction to the power per unit area in a plane wave incident on the scatterer from a specified direction

Note 1 to entry: The concept of RCS is also applied in case of ultrasound wave radiation.

[SOURCE: ISO 8729-2:2009 [19], 3.3, modified – the Note 1 to entry has been added]

3.21
reflectivity
<of an object> the ability of an object to reflect a wave

EXAMPLE A wave can be of electromagnetic or acoustic type.

3.22
reflection coefficient
ratio of the regular reflected part of a wave and the incident wave

3.23
regular reflection
specular reflection
reflection in accordance with the laws of geometrical optics, without scattering

[SOURCE: IEC 60050-845:2020 [4], 845-24-052]

3.24
tag
human- or machine-readable mark, or digital identity used to communicate information about an entity

Note 1 to entry: A tag can contain information that can be read by sensors to aid in identification of the physical entity.

[SOURCE: ISO/IEC 20924:2018 [12], 3.1.31]

3.25
thermography camera
an imaging method for displaying the surface temperature of objects

Note 1 to entry: The intensity of the infrared radiation emitted by a point is interpreted as a measure of its temperature.

Note 2 to entry: In this document, thermography is applied to passive techniques that do not require active energy emitted by the SRS.

3.26
training data
subset of input data samples used to train a machine learning model

[SOURCE: ISO/IEC 22989:2022 [13], 3.2.22]

4 Sensor technologies

4.1 General considerations

An SRS uses sensor technologies for the detection of safety related objects (persons and hazardous objects) and automation related objects. Objects present in the surrounding can interfere with the safety related object and thereby affect the dependability of the detection capability.

In accordance with 5.3 of IEC TS 62998-1:2019, the type and combination of physical properties of the safety related object with due consideration of the sensor technology/technologies shall be analysed.

During the analysis of the sensor technology of an SRS the manufacturer shall take into consideration:

– wavelength range;
– measurement method; and
– sensing unit(s) arrangement.

In Table 1, examples of well-known sensor types are listed to support the specification of the sensor technology.

NOTE 1 Within an SRS, one or more types of sensors, wavelength or measurement methods can be used.

Table 1 – Specific sensor types used as part of SRS

Examples of sensor types	Wave type	Wavelength range	Frequency range	Measurement method
– Ultrasound	Sound wave	11 µm – 21 mm (normal atmosphere)	16 kHz – 30 MHz	– Pulse-wave, – Continuous wave, – Frequency modulated continuous wave (FMCW)
– Ultra-wideband (UWB), – Radio frequency Identification (RFID), – Wireless local area network, – Wireless personal area network, – 5G	Radio / Millimetre wave	22 mm – 2400 m	125 kHz – 13,56 GHz	– Presence detection or localization of a tag, for details see 4.6.3
– Radar	Millimetre wave	2 mm – 33 mm	9 GHz – 148,5 GHz	– In-range distance, – Doppler, – Angle of arrival,
– Passive infrared sensor, – Thermography camera, – Infrared gas detector	Middle infrared	3 µm – 50 µm	6 THz – 100 THz	– Level switching, – See normative references in 4.4 for infrared gas detector.
– Lidar, – Stereoscopic Camera, – Time-of-flight camera, – Light field camera, – Lightgrid, – Light beam device	Near infrared	780 nm – 3 µm	100 THz – 384 THz	– Direct time-of-flight, – Indirect time-of-flight, – Triangulation, – Level switching, – FMCW, – Depth from focus / defocus
– Lidar, – Stereoscopic Camera, – Time-of-flight camera – Light field camera, – Lightgrid, – Light beam device	Visible	380 nm – 780 nm	384 THz – 789 THz	– Direct time-of-flight, – Indirect time-of-flight, – Triangulation, – Level switching – Depth from focus / defocus.

NOTE 2 Wavelength depends on media and media properties.

NOTE 3 Wavelength ranges can change due to technological improvements or revised regulatory constraints.

The considered wavelength range, measurement method and sensing unit arrangement shall be used for the identification of relevant physical properties of objects and their limits:

– to perform the person detection function within the safety-related zone if applicable;
– to perform the hazardous object function within the safety-related zone if applicable;

– inside the safety-related zone that influences the person detection function or the hazardous object function if applicable;
– outside the safety-related zone but inside the sensing zone that influences the person detection function or the hazardous object function if applicable.

The relevant physical properties and their limits shall be used for analysis, test, or both, of the detection capability and the dependability of the detection capability as stated in 5.8.1 of IEC TS 62998-1:2019.

The objects, their relevant physical properties and their limits:

– shall be derived from the intended use by the manufacturer during design and development as far as reasonably practical; or
– shall be identified in the application by the integrator or end user during integration or installation phase in accordance with procedures provided by the manufacturer, and
– shall not reduce the detection capability and the dependability of the detection capability below the limits as provided in the information for use.

Depending on the specified wavelength range used in an SRS one or more of the following subclauses of Clause 4 shall be considered in addition to the physical properties and their limits given in 5.8.2 of IEC TS 62998-1:2019.

NOTE 4 This includes the identification of relevant physical properties and their limits for objects with active characteristics such as tags in accordance with 4.6.

NOTE 5 It is reminded that environmental influences (e.g. pollution) that are relevant for the dependability of the detection capability are given in IEC TS 62998-1:2019, 5.8.3.

4.2 SRS using visible light

4.2.1 General

If the SRS is using visible light, at least the following object-related physical properties shall be considered:

– geometry and location (see IEC TS 62998-1:2019 ,5.8.2.2);
– velocity and acceleration (see IEC TS 62998-1:2019 ,5.8.2.2);
– material characteristics (see 4.2.2).

The object-related physical properties shall be used for analysis, test, or both, of the detection capability and the dependability of the detection capability. The physical properties may be used, independently or in combination, in testing or analysis. (see Annex A).

4.2.2 Material considerations

The material of the safety related object is relevant to characterize the interaction of visible light with the object. The interaction in a certain direction is determined by the electromagnetic properties which themselves depend on wavelength, polarization, field strength and angle of incidence. To quantify the interaction the reflectivity of the safety-related object shall be used (see Annex A).

4.2.3 Measurement method considerations

Depending on the measurement method, the following effects shall be considered for the analysis, test, or both, of the detection capability and the dependability of the detection capability:

a) direct time-of-flight:
   1) multipath effects of objects interfering within the sensing zone.

b) indirect time-of-flight:
   1) multipath effects of objects interfering within the sensing zone.
   2) non-ambiguity range related to object location within the sensing zone;
c) triangulation:
   1) influence of periodic structure;
   2) effects of low contrast.
d) level switching:
   1) effects increasing or reducing the signal.
e) depth from focus/defocus:
   1) effects of low contrast;
   2) limited sensing zone due to small apertures.

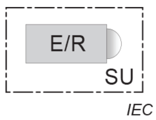
NOTE Small apertures are relevant for monocular cameras using micro lenses.

4.2.4 Sensing unit arrangement considerations

Depending on the sensing unit arrangement, the following object and sensing unit related effects shall be considered for the analysis, test, or both, of the detection capability and the dependability of the detection capability:

a) co-located and stationary (e.g. emitter and receiver in a sensing unit are in close proximity and the sensing unit is in a fixed location, see Figure 1):
   1) obscuration of objects in a line within the safety-related zone.
b) separated and stationary (e.g. emitter and receiver in a sensing unit are separated and the sensing unit is in a fixed location, see Figure 2):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators.
c) multiple and stationary (e.g. more than one sensing unit separated from each other with the sensing units being in a fixed location, see Figure 3):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) similarity of object related physical properties from different perspectives;
   4) interference of sensing units of identical design.
d) co-located and moving (e.g. emitter and receiver in a sensing unit are in close proximity and the sensing unit is moving, see Figure 4):
   1) obscuration of objects in a line within the safety-related zone;
   2) physical properties of the object can change with the location of the sensing unit;
   3) velocity of the sensing unit.
e) separated and moving (e.g. emitter and receiver in a sensing unit are separated and the sensing unit is moving, see Figure 5):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) physical properties of the object can change with the location of the sensing unit;
   4) velocity of the sensing unit.

f) multiple and moving (e.g. more than one sensing unit separated from each other and the sensing units are moving, see Figure 6):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) similarity of object related physical properties from different perspectives;
   4) physical properties of the object can change with the locations of the sensing units;
   5) velocity of the sensing units;
   6) interference of sensing units of identical design.
g) combined stationary and moving (e.g. combination of stationary and moving sensing units separated from each other, see Figure 7):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) similarity of object related physical properties from different perspectives;
   4) physical properties of the object can change with the locations of the sensing units;
   5) velocity of the sensing units;
   6) interference of sensing units of identical design.
h) multiple combined and moving (e.g. combination of sensing units separated from each other and the sensing units are moving independently to each other, see Figure 8):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) similarity of object related physical properties from different perspectives;
   4) physical properties of the object can change with the locations of the sensing units;
   5) velocity of the sensing units;
   6) interference of sensing units of identical design.



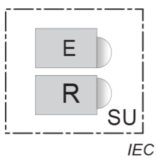
Key

E emitter

R receiver

SU stationary sensing unit

Figure 1 – Co-located and stationary sensing unit arrangement



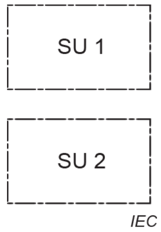
Key

E emitter

R receiver

SU stationary sensing unit

Figure 2 – Separated and stationary sensing unit arrangement

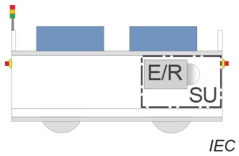


Key

SU 1 stationary sensing unit 1

SU 2 stationary sensing unit 2

Figure 3 – Multiple and stationary sensing unit arrangement



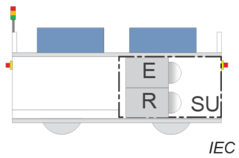
Key

E emitter

R receiver

SU moving sensing unit

Figure 4 – Co-located and moving sensing unit arrangement



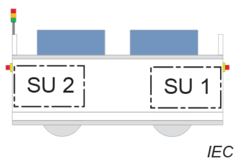
Key

E emitter

R receiver

SU moving sensing unit

Figure 5 – Separated and moving sensing unit arrangement

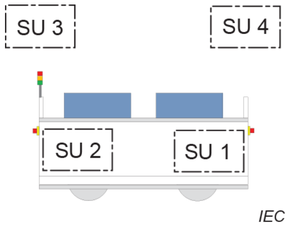


Key

SU 1 moving sensing unit 1

SU 2 moving sensing unit 2

Figure 6 – Multiple and moving sensing unit arrangement



Key

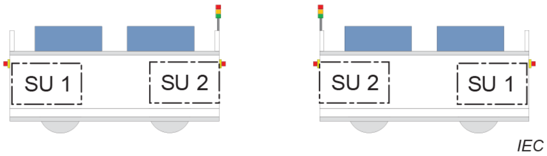
SU 1 moving sensing unit 1

SU 2 moving sensing unit 2

SU 3 stationary sensing unit 3

SU 4 stationary sensing unit 4

Figure 7 – Exemplary combined stationary and moving sensing unit arrangement



Key

SU 1 moving sensing unit 1

SU 2 moving sensing unit 2

Figure 8 – Exemplary multiple combined and moving sensing unit arrangement

4.3 SRS using near infrared radiation

4.3.1 General

If the SRS is using near infrared radiation, at least the following object-related physical properties shall be considered:

– geometry and location (see IEC TS 62998-1:2019, 5.8.2.2);

– velocity and acceleration (see IEC TS 62998-1:2019, 5.8.2.2);

– material characteristics.

The object-related physical properties shall be used for analysis, test, or both, of the detection capability and the dependability of the detection capability. The physical properties may be used, independently or in combination, in testing or analysis. (see Annex A).

4.3.2 Material considerations

The material of the safety related object is relevant to characterize the interaction of near infrared radiation with the object. The interaction is determined by the electromagnetic properties which themselves depend on wavelength, polarization, field strength and angle of incidence. To quantify the interaction the reflectivity of the safety-related object shall be used (see Annex A).

If the physical property temperature is the determining material characteristic of the safety-related object for the detection in the near infrared wavelength range, then 4.4 shall be applied instead of 4.3.

4.3.3 Measurement method considerations

Depending on the measurement method, following effects shall be considered for the analysis, test, or both, of the detection capability and the dependability of the detection capability:

a) direct time-of-flight:
   1) multipath effects of objects interfering within the sensing zone.
b) indirect time-of-flight:
   1) multipath effects of objects interfering within the sensing zone;
   2) non-ambiguity range related to object location within the sensing zone.
c) triangulation:
   1) influence of periodic structure;
   2) effects of low contrast.
d) level switching:
   1) effects increasing or reducing the signal.
e) FMCW:
   1) effects related to multi target situations;
   2) effects related to the coherent detection.
f) depth from focus/defocus:
   1) effects of low contrast;
   2) limited sensing zone due to small apertures.

NOTE Small apertures are relevant for monocular cameras using micro lenses.

4.3.4 Sensing unit arrangement considerations

Depending on the sensing unit arrangement, one or more of the following object and sensing unit related effects shall be considered for the analysis, test, or both, of the detection capability and the dependability of the detection capability:

a) co-located and stationary (e.g. emitter and receiver in a sensing unit are in close proximity and the sensing unit is in a fixed location, see Figure 1):
   1) obscuration of objects in a line within the safety-related zone.
b) separated and stationary (e.g. emitter and receiver in a sensing unit are separated and the sensing unit is in a fixed location, see Figure 2):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators.
c) multiple and stationary (e.g. more than one sensing unit separated from each other with the sensing units being in a fixed location, see Figure 3):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) similarity of object related physical properties from different perspectives;
   4) interference of sensing units of identical design.
d) co-located and moving (e.g. emitter and receiver in a sensing unit are in close proximity and the sensing unit is moving, see Figure 4):
   1) obscuration of objects in a line within the safety-related zone;
   2) physical properties of the object can change with the location of the sensing unit;
   3) velocity of the sensing unit.

e) separated and moving (e.g. emitter and receiver in a sensing unit are separated and the sensing unit is moving, see Figure 5):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) physical properties of the object can change with the location of the sensing unit;
   4) velocity of the sensing unit.
f) multiple and moving (e.g. more than one sensing units separated from each other and the sensing units are moving in their locations, see Figure 6):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) similarity of object related physical properties from different perspectives;
   4) physical properties of the object can change with the locations of the sensing units;
   5) velocity of the sensing units;
   6) interference of sensing units of identical design.
g) combined stationary and moving (e.g. combination of stationary and moving sensing units separated from each other, see Figure 7):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) similarity of object related physical properties from different perspectives;
   4) physical properties of the object can change with the locations of the sensing units;
   5) velocity of the sensing units;
   6) interference of sensing units of identical design.
h) multiple combined and moving (e.g. combination of sensing units separated from each other and the sensing units are moving independently to each other, see Figure 8):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) similarity of object related physical properties from different perspectives;
   4) physical properties of the object can change with the locations of the sensing units;
   5) velocity of the sensing units;
   6) interference of sensing units of identical design.

4.4 SRS using middle infrared radiation

4.4.1 General

If the SRS is using middle infrared radiation for the detection of toxic or explosive gas concentration or vapour, then the IEC 60079-29 series or EN 50402 shall be used in addition to IEC TS 62998-1, and the following requirements of 4.4.1 and Clause 5 of this document do not apply.

NOTE Explosive gases are safety-related objects in accordance with IEC TS 62998-1:2019.

If the SRS is using middle infrared radiation for the detection of objects, at least the following object-related physical properties shall be considered:

– geometry and location (see IEC TS 62998-1:2019 ,5.8.2.2);
– velocity and acceleration (see IEC TS 62998-1:2019 ,5.8.2.2);
– material characteristics.

The object-related physical properties shall be used for analysis, test, or both, of the detection capability and the dependability of the detection capability. The physical properties may be used, independently or in combination, in testing or analysis. (see Annex C).

4.4.2 Material considerations

The material of the safety-related object is relevant to characterize its emitted radiation energy in the middle infrared wavelength range. The radiation energy is quantified by temperature (see Annex C).

4.4.3 Measurement method considerations

Depending on the measurement method, the following effects shall be considered for the analysis, test, or both, of the detection capability and the dependability of the detection capability:

a) level switching:
   1) effects increasing or reducing the signal.

4.4.4 Sensing unit arrangement considerations

Depending on the sensing unit arrangement, one or more of the following object and sensing unit related effects shall be considered for the analysis, test, or both, of the detection capability and the dependability of the detection capability:

a) co-located and stationary (e.g. emitter and receiver in a sensing unit are in close proximity and the sensing unit is in a fixed location, see Figure 1):
   1) obscuration of objects in a line within the safety-related zone.
b) separated and stationary (e.g. emitter and receiver in a sensing unit are separated and the sensing unit is in a fixed location, see Figure 2):
   1) obscuration of objects anywhere in the safety-related zone.
c) multiple and stationary (e.g. more than one sensing unit separated from each other with the sensing units being in a fixed location, see Figure 3):
   1) obscuration of objects anywhere in the safety-related zone;
   2) similarity of object related physical properties from different perspectives.
d) co-located and moving (e.g. emitter and receiver in a sensing unit are in close proximity and the sensing unit is moving, see Figure 4):
   1) obscuration of objects in a line within the safety-related zone;
   2) physical properties of the object can change with the location of the sensing unit;
   3) velocity of the sensing unit.
e) separated and moving (e.g. emitter and receiver in a sensing unit are separated and the sensing unit is moving, see Figure 5):
   1) obscuration of objects anywhere in the safety-related zone;
   2) physical properties of the object can change with the location of the sensing unit;
   3) velocity of the sensing unit.
f) multiple and moving (e.g. more than one sensing units separated from each other and the sensing units are moving in their locations, see Figure 6):
   1) obscuration of objects anywhere in the safety-related zone;
   2) similarity of object related physical properties from different perspectives;
   3) physical properties of the object can change with the locations of the sensing units;
   4) velocity of the sensing units.

g) combined stationary and moving (e.g. combination of stationary and moving sensing units separated from each other, see Figure 7):
   1) obscuration of objects anywhere in the safety-related zone;
   2) similarity of object related physical properties from different perspectives;
   3) physical properties of the object can change with the locations of the sensing units;
   4) velocity of the sensing units.
h) multiple combined and moving (e.g. combination of sensing units separated from each other and the sensing units are moving independently to each other, see Figure 8):
   1) obscuration of objects anywhere in the safety-related zone;
   2) similarity of object related physical properties from different perspectives;
   3) physical properties of the object can change with the locations of the sensing units;
   4) velocity of the sensing units.

NOTE Additional information to define a test plan performed as laboratory test in accordance with IEC TS 62998-1:2019 can be found in IEC 62642-2-2:2010 [10].

4.5 SRS using millimetre wave radiation

4.5.1 General

If the SRS is using radio millimetre wave radiation, at least the following object-related physical properties shall be considered:

– geometry and location (see IEC TS 62998-1:2019, 5.8.2.2);
– velocity and acceleration (see IEC TS 62998-1:2019, 5.8.2.2);
– material characteristics (see examples in IEC TS 62998-1:2019, 5.8.2.1, Note 1).

The object-related physical properties shall be used for analysis, test, or both, of the detection capability and the dependability of the detection capability. Analysis and testing may be performed independently or in combination.

4.5.2 Material considerations

The material of the safety related object is relevant to characterize the interaction of millimetre waves with the object. The interaction in a certain direction is determined by the electrical properties which themselves depend on wavelength, polarization, field strength and angle of incidence. To quantify the interaction the RCS shall be applied (see Annex B).

4.5.3 Measurement method considerations

Depending on the measurement method, the following effects shall be considered for the analysis, test, or both, of the detection capability and the dependability of the detection capability:

a) in-range distance:
   1) multipath effects of objects interfering within the sensing zone;
   2) effects of shadowing of targets by adjacent objects / targets with large RCS;
   3) effects of range resolution on the detectability of the object;
   4) non-ambiguity range related to object location within the sensing zone.
b) doppler:
   1) effects of doppler resolution on the detectability of the object;
   2) non-ambiguity velocity related to object location within the sensing zone.

c) Angle-of-Arrival:
   1) multipath effects of objects interfering within the sensing zone;
   2) effects of shadowing of targets by adjacent objects / targets with large RCS;
   3) effects of angular resolution on the detectability of the object;
   4) non-ambiguity angle related to object location within the sensing zone.

4.5.4 Sensing unit arrangement considerations

Depending on the sensing unit arrangement, one or more of the following object and sensing unit related effects shall be considered for the analysis, test, or both, of the detection capability and the dependability of the detection capability:

– stationary vs moving;
– single vs multiple.

NOTE 1 Separated arrangements (e.g. multistatic radar) are currently not considered.

a) co-located and stationary (e.g. emitter and receiver in a sensing unit are in close proximity and the sensing unit is in a fixed location, see Figure 1):
   1) obscuration of objects in a line within the safety-related zone;
   2) velocity of object;
   3) effects of mounting position (height, pan, tilt, roll):
      i) illuminated portion of the object;
      ii) direction of penetration into the safety-related zone (radial, perpendicular).
b) multiple and stationary (e.g. more than one sensing unit separated from each other with the sensing units being in a fixed location, see Figure 3):
   1) obscuration of objects anywhere in the safety-related zone;
   2) interference of sensing units of identical design;
   3) effects of mounting position (height, pan, tilt, roll):
      i) illuminated portion of the object;
      ii) direction of penetration into the safety-related zone (radial, perpendicular).
c) co-located and moving (e.g. emitter and receiver in a sensing unit are in close proximity and the sensing unit is moving, see Figure 4):
   1) obscuration of objects anywhere in the safety-related zone;
   2) relative velocity of sensing unit and safety related object;
   3) effects of mounting position (height, pan, tilt, roll):
      i) illuminated portion of the object;
      ii) direction of penetration into the safety-related zone (radial, perpendicular).
d) multiple and moving (e.g. more than one sensing units separated from each other and the sensing units are moving in their locations, see Figure 6):
   1) relative velocity of sensing unit and safety related object;
   2) interference of sensing units of identical design;
   3) effects of mounting position (height, pan, tilt, roll):
      i) illuminated portion of the object;
      ii) direction of penetration into the safety-related zone (radial, perpendicular).

NOTE 2 Being able to detect a walking person at 1 m/s (and a static sensing unit) does not necessarily mean being able to detect a static person (and a moving sensing unit at 1 m/s).

4.6 SRS using radio/millimetre wave radiation

4.6.1 General

If the SRS is using radio/millimetre wave radiation as stated in Table 1 and uses a so called tag as part of the measurement method, at least the following tag-related physical properties shall be considered:

– geometry and location (see IEC TS 62998-1, 5.8.2.2);
– velocity and acceleration (see IEC TS 62998-1, 5.8.2.2);
– tag considerations

The tag-related physical properties shall be used for analysis, test, or both, of the detection capability and the dependability of the detection capability. The tag-related physical properties may be used, independently or in combination, in testing or analysis. Following paragraphs consider each tag-related physical property used independently to the others for the detection.

4.6.2 Tag considerations

The following tag-related considerations shall be used for analysis, test, or both, of the detection capability and the dependability of the detection capability:

– orientation dependency due to antenna radiation pattern and polarization of the radiation;
– energy supply by battery (active tag) by “Backscatter radio links” (semi passive, passive tag)
– reasonably foreseeable misuse of the tag (e.g not carrying the tag);
– obscuration by surrounding material or parts of body;
– durability especially as wearable device in case of passive tags;
– interference by other electronic devices;
– multi-tag-reading (Bulk reading).

4.6.3 Measurement method considerations

There are different techniques such as presence detection in which a reader/anchor detects a tag while entering into the readers/anchors field of view or localization in which several readers/anchors detect a tag and determine the distance to the tag by multilateration. These techniques base on a manifold of measurement methods that are covered by existing technology-specific standards or regulations. The SRS shall comply with appropriate technology-specific standards or regulations.

NOTE 1 Exemplary technology specific standards for RFID are ISO/IEC 18000 series [10], for UWB ISO/IEC 26907 [16] and ISO/IEC 26908 [17].

NOTE 2 Tag detection can include tag identification as determination of the value of a physical property, see also IEC TS 62998-1:2019, 3.6.

Depending on the technique, the following effects shall be considered for the analysis, test, or both, of the detection capability and the dependability of the detection capability of the SRS:

– dynamic range of the detector;
– multipath propagation;
– polarization;
– antenna directivity pattern;
– co-located tags and objects that interact with the radio/millimetre wave radiation;

4.6.4 Sensing unit arrangement considerations

Depending on the sensing unit arrangement one or more of the following tag and sensing unit related effects shall be considered for the analysis, test, or both, of the detection capability and the dependability of the detection capability:

a) co-located and stationary (e.g. emitter and receiver in a sensing unit are in close proximity and the sensing unit is in a fixed location, see Figure 1):
   1) obscuration of tags in a line within the safety-related zone.
b) separated and stationary (e.g. emitter and receiver in a sensing unit are separated and the sensing unit is in a fixed location, see Figure 2):
   1) obscuration of tags anywhere in the safety-related zone;
   2) directional characteristic of tag antennas.
c) multiple and stationary (e.g. more than one sensing unit separated from each other with the sensing units being in a fixed location, see Figure 3):
   1) obscuration of tags anywhere in the safety-related zone;
   2) directional characteristic of tag antennas;
   3) similarity of object related physical properties from different perspective.
d) co-located and moving (e.g. emitter and receiver in a sensing unit are in close proximity and the sensing unit is moving, see Figure 4):
   1) obscuration of tags in a line within the safety-related zone;
   2) physical properties of the tag can change within the location of the sensing unit;
   3) velocity of the sensing unit.
e) separated and moving (e.g. emitter and receiver in a sensing unit are separated and the sensing unit is moving, see Figure 5):
   1) obscuration of tags anywhere in the safety-related zone;
   2) directional characteristic of tag antennas;
   3) physical properties of the tag can change with the location of the sensing unit;
   4) velocity of the sensing unit.
f) multiple and moving (e.g. more than one sensing units separated from each other and the sensing units are moving in their locations, see Figure 6):
   1) obscuration of tags anywhere in the safety-related zone;
   2) directional characteristic of tag antennas;
   3) physical properties of the object can change with the locations of the sensing units;
   4) velocity of the sensing units;
   5) interference of sensing units of identical design.
g) combined stationary and moving (e.g. combination of more stationary and moving sensing units separated from each other, see Figure 7):
   1) obscuration of tags anywhere in the safety-related zone;
   2) directional characteristic of tag antennas;
   3) physical properties of the tag can change with the locations of the sensing units;
   4) velocity of the sensing units;
   5) interference of sensing units of identical design.

h) multiple combined and moving (e.g. combination of sensing units separated from each other and the sensing units are moving independently to each other, see Figure 8):
   1) obscuration of tags anywhere in the safety-related zone;
   2) directional characteristic of tag antennas;
   3) physical properties of the tag can change with the locations of the sensing units;
   4) velocity of the sensing units;
   5) interference of sensing units of identical design.

4.7 SRS using ultrasound wave radiation

4.7.1 General

If the SRS is using ultrasound wave radiation, at least the following object-related physical properties shall be considered:

– geometry and location (see IEC TS 62998-1:2019, 5.8.2.2);
– velocity and acceleration (see IEC TS 62998-1:2019, 5.8.2.2);
– material characteristics (see examples in IEC TS 62998-1:2019, 5.8.2.1, Note 1).

The physical properties shall be used for analysis, test, or both, of the detection capability and the dependability of the detection capability. The physical properties may be used, independently or in combination, in testing or analysis (see Annex D).

4.7.2 Material considerations

The material of the safety related object is relevant to characterize the interaction of ultrasound waves with the object. The strength of the interaction in a certain direction is determined by the mechanical properties which themselves depend on wavelength, pressure, and angle of incidence. In order to quantify the interaction the acoustic impedance, the reflection coefficient or the RCS shall be used (see Annex D).

4.7.3 Measurement method considerations

Depending on the measurement method, the following effects shall be considered for the analysis, test, or both, of the detection capability and the dependability of the detection capability:

a) pulse wave:
   1) dynamic range of the detector;
   2) multipath propagation;
   3) multi echo e.g layered material, layered propagation medium, or both (e.g. temperature differences in air);
   4) co-located objects that interact with the ultrasound wave.
b) continuous wave:
   1) dynamic range of the detector;
   2) multipath propagation;
   3) multi echo e.g. layered material, layered propagation medium, or both (e.g. temperature differences in air);
   4) co-located objects that interact with the ultrasound wave;
   5) doppler shift due to relative object velocity;
   6) non-ambiguity.

c) FMCW:
   1) dynamic range of the detector;
   2) multipath propagation;
   3) multi echo e.g. layered material, layered propagation medium, or both (e.g. temperature differences in air);
   4) co-located objects that interact with the ultrasound wave;
   5) doppler shift due to relative object velocity.

4.7.4 Sensing unit arrangement considerations

Depending on the sensing unit arrangement one or more of the following object and sensing unit related effects shall be considered for the analysis, test, or both, of the detection capability and the dependability of the detection capability:

a) co-located and stationary (e.g. emitter and receiver in a sensing unit are in close proximity and the sensing unit is in a fixed location, see Figure 1):
   1) obscuration of objects in a line within the safety-related zone.
b) separated and stationary (e.g. emitter and receiver in a sensing unit are separated and the sensing unit is in a fixed location, see Figure 2):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators.
c) multiple and stationary (e.g. more than one sensing unit separated from each other with the sensing units being in a fixed location, see Figure 3):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) similarity of object related physical properties from different perspectives;
   4) interference of sensing units of identical design.
d) co-located and moving (e.g. emitter and receiver in a sensing unit are in close proximity and the sensing unit is moving, see Figure 4):
   1) obscuration of objects in a line within the safety-related zone;
   2) physical properties of the object can change with the location of the sensing unit;
   3) velocity of the sensing unit.
e) separated and moving (e.g. emitter and receiver in a sensing unit are separated and the sensing unit is moving, see Figure 5):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) physical properties of the object can change with the location of the sensing unit;
   4) velocity of the sensing units.
f) multiple and moving (e.g. more than one sensing units separated from each other and the sensing units are moving in their locations, see Figure 6):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) similarity of object related physical properties from different perspectives;
   4) physical properties of the object can change with the locations of the sensing units;
   5) velocity of the sensing units;
   6) interference of sensing units of identical design.

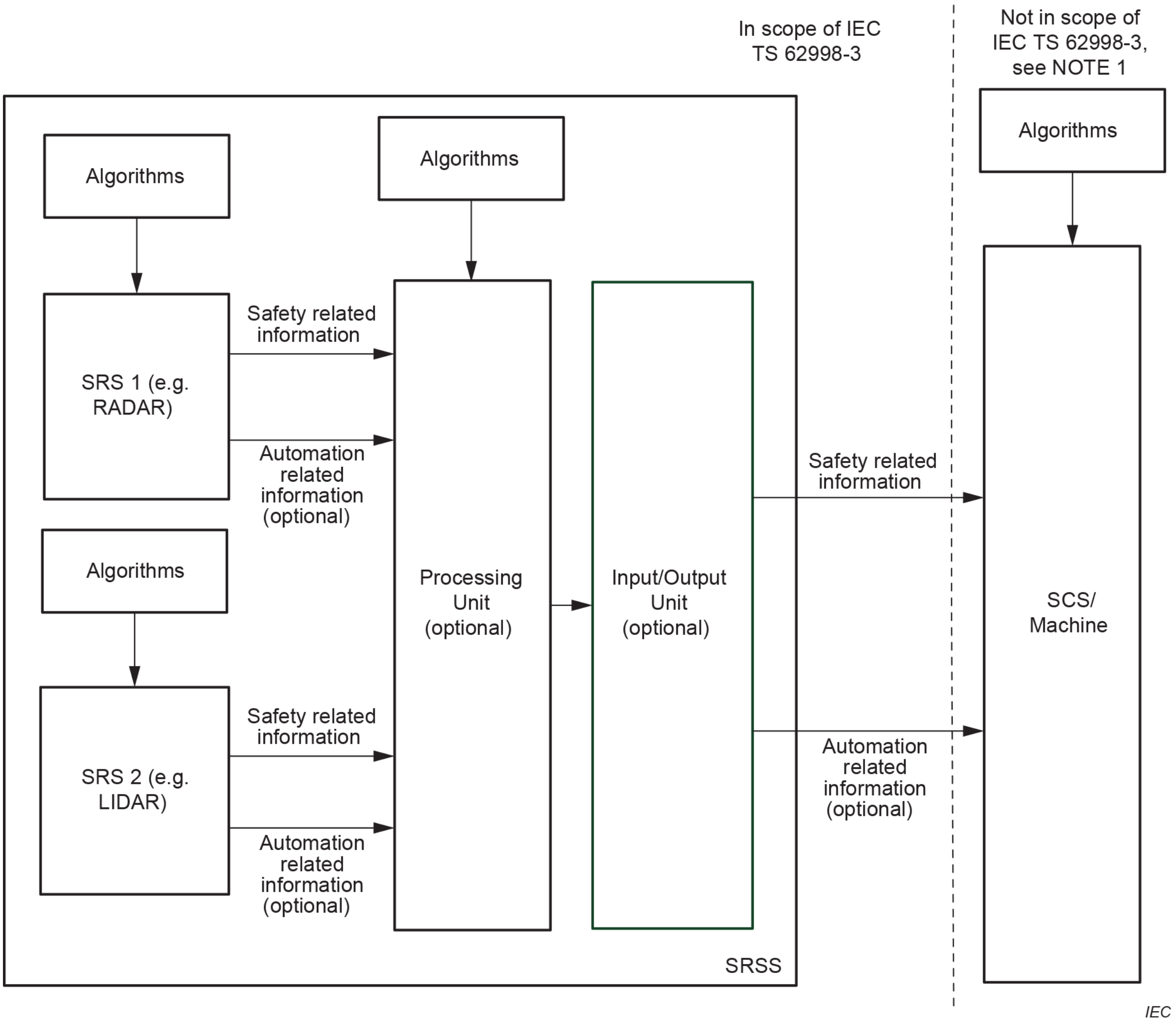
g) combined stationary and moving (e.g. combination of stationary and moving sensing units separated from each other, see Figure 7):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) similarity of object related physical properties from different perspectives;
   4) physical properties of the object can change with the locations of the sensing units;
   5) velocity of the sensing units;
   6) interference of sensing units of identical design.
h) multiple combined and moving (e.g. combination of sensing units separated from each other and the sensing units are moving independently to each other, see Figure 8):
   1) obscuration of objects anywhere in the safety-related zone;
   2) directional characteristic of non-ideal diffuse radiators;
   3) similarity of object related physical properties from different perspectives;
   4) physical properties of the object can change with the locations of the sensing units;
   5) velocity of the sensing units;
   6) interference of sensing units of identical design.

5 Algorithm related considerations

5.1 General

Algorithms shall be considered as part of an SRS or SRSS (see Figure 9) if they affect the detection capability and are implemented during:

– design and development phase of an SRS (see 5.2);
– integration of an SRS into an SRSS (see 5.3);
– maintenance phase of an SRS or SRSS (see 5.4).



NOTE 1 Algorithms as part of an SCS are not in scope of this document (see Figure 9) but the information given in 5.3 and 5.4 (integration and installation phase or maintenance phase of an SRS or SRSS) can be of interest as guideline for further integration of an SRS or SRSS into an SCS respective during their maintenance. Algorithms added and performed in an SCS, or a machine can have an impact on the detection capability or dependability of the detection capability.

NOTE 2 Processing Unit, Input / Output Unit or SRSs of an SRSS can be in different locations.

Figure 9 – Algorithms exemplary applied to an SRS or an SRSS

This document defines two categories of algorithms as follows:

– algorithms based on requirements derived from the intended use not using machine learning models (see Figure 10);

– algorithms based on training data derived from the intended or practical use using machine learning models (see Figure 11).

EXAMPLE A thresholding algorithm can be classified depending on how its threshold value is determined and how the algorithm is implemented. If determined from requirements and implemented not using a machine learning model, it belongs to the first category. If it is determined based on training data and implemented using a machine learning model, it belongs to the second category.

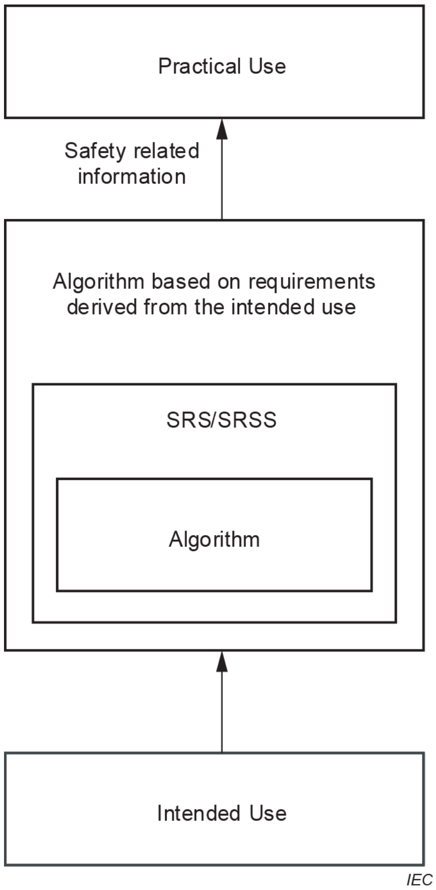
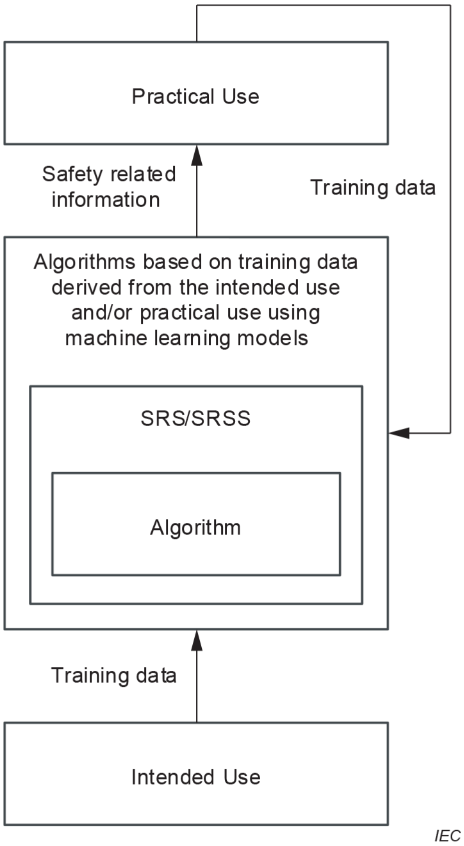


Figure 10 – Flowchart for algorithm based on requirements



NOTE The feedback loop shown in the right part of Figure 11 does not illustrate any statement on continuous learning.

Figure 11 – Flowchart for algorithm based on training data

5.2 Design and development phase

5.2.1 General

Algorithms implemented based on requirements derived from the intended use during design and development of an SRS shall:

– be in accordance with stated level of safety performance for the requirements as stated in standards for functional safety of safety related control system (e.g. the IEC 61508 series; see 4.3 of IEC TS 62998-1:2019);

– be analysed as stated in 5.3 of IEC TS 62998-1:2019 by applying 5.2.1 of this document.

Algorithms implemented based on training data derived from the intended or practical use using machine learning models shall:

– be analysed as stated in 5.3 of IEC TS 62998-1:2019 by applying 5.2.1 of this document; and

– use training data of sufficient quality assured by applying applicable standards for data quality (e.g. ISO/IEC 25012 [15]); and

– be in accordance with stated level of safety performance for the requirements as stated in applicable standards for functional safety of safety related control system (e.g. the IEC 61508 series; see 4.3 of IEC TS 62998-1:2019), or be in accordance with applicable standards for systems and software engineering (e.g. ISO/IEC/IEEE 15026 [20], ISO/IEC 25000 [14]).

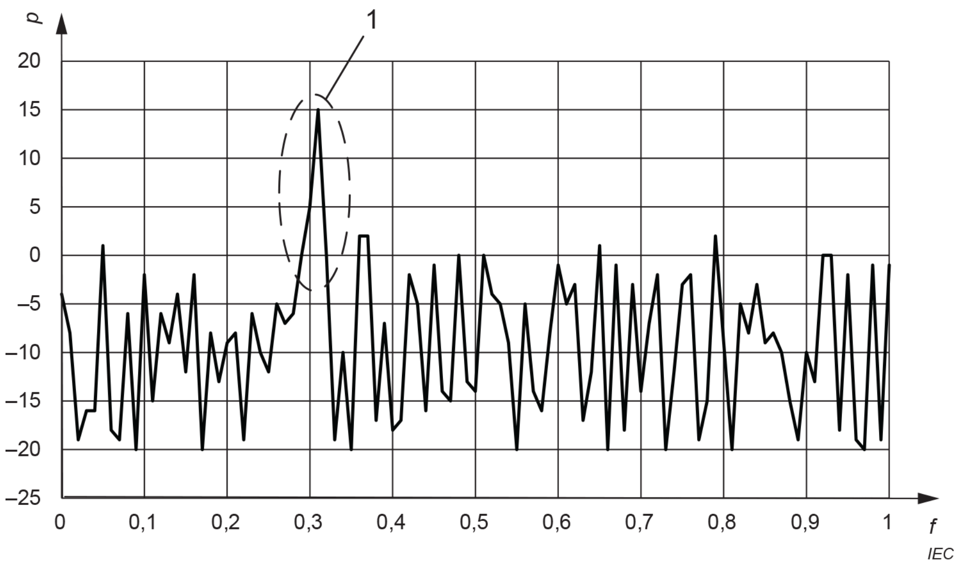
NOTE 1 IEC TS 62998-3 gives specific guidance on algorithms implemented with respect to the detection capability and the dependability of the detection capability. The dependability of the detection capability is detailed in 5.8 of

IEC TS 62998-1:2019 using different attributes to prevent failure to danger conditions. ISO/IEC/IEEE 15026 [20] or ISO/IEC 25000 [14] are examples of standards that give guidance on appliance of dependability attributes.

Algorithms implemented shall be analysed by the manufacturer of an SRS and classified as algorithms used:

- to achieve the detection of objects by:
  - using one or more object-related physical properties to provide measurement information based on the output of the sensing unit (e.g. extraction of peaks in an analogue signal provided as decision information at the output unit, see Figure 12);
  - combining information of one or more sensing units in a processing unit (e.g. to combine signals of 2 sensing units in a multiple stationary or mobile arrangement, see in example Figure 6,and identify agreement or disagreement resulting in a common measurement information at the output unit, see Figure 13);
- to improve the dependability of the detection capability by:
  - using one or more object-related physical properties to provide measurement information based on the output of the sensing unit (e.g. suppressing of signals in an analogue signal provided as decision information at the output unit);
  - combining information of one or more sensing units in a processing unit (e.g. to combine signals of 2 sensing unit in a multiple stationary or mobile arrangement, see in example Figure 6);
- to provide confidence information at the output unit by:
  - identifying measurement accuracy of measurement information;
  - identifying measurement uncertainty of measurement information;
  - identifying decision probability of decision information.

NOTE 2 An algorithm can belong to more than one class.



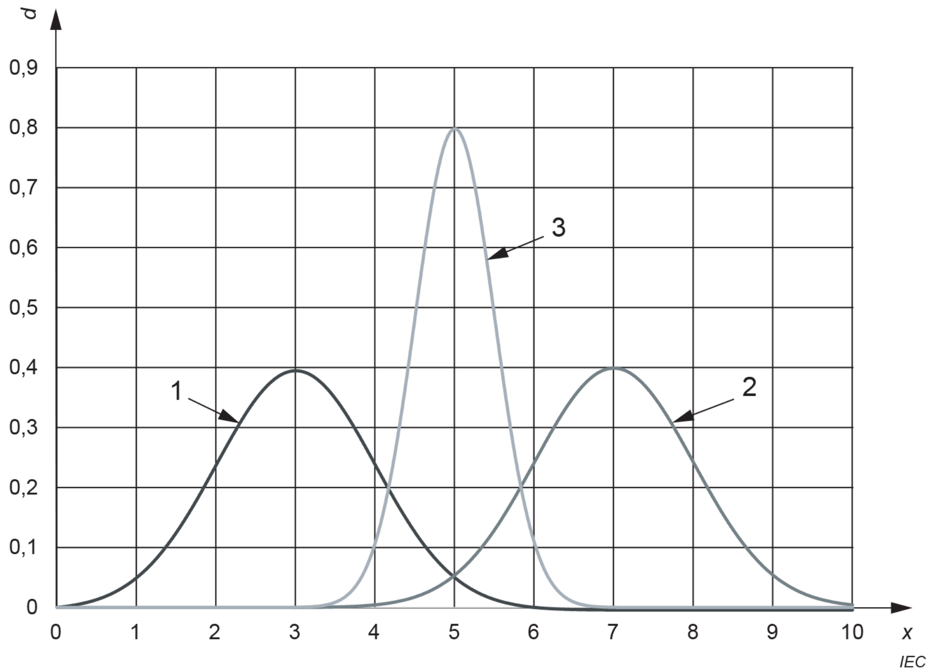
Key

f normalized frequency (x π rad/sample)

p power/frequency (dB(rad/sample))

1 extracted peak in an analogue signal

Figure 12 – Exemplary use of algorithm for peak extraction



Key

x random variable

d density

1 density distribution of the information of sensing unit 1

2 density distribution of the information of sensing unit 2

3 density distribution of the common measurement information using information of sensing unit 1 and sensing unit 2

Figure 13 – Exemplary use of algorithm to combine measurement information

5.2.2 Achieve the detection of objects

Algorithms used to achieve the detection in an SRS shall not reduce the detection capability or increase the response time beyond the limits as specified by the manufacturer.

The manufacturer shall verify:

– the influence of algorithms on the detection capability if applicable;

NOTE 1 The algorithms can be developed by the manufacturer or developed by other parties but integrated by the manufacturer.

– the influence on the response time;

– the influence of the training data on the detection capability if applicable;

The manufacturer shall analyse that test methods and test setup (e.g. synthetic test patterns or type tests with objects) used for verification of algorithms are appropriate representative for the intended use.

Type tests or field tests applied for verification of algorithms shall be based on the applied physical properties of all objects in accordance with 5.8.2.1 of IEC TS 62998-1:2019.

NOTE 2 In accordance with IEC TS 62998-1:2019, type tests are applicable as simulation tests. The use of simulation is described in more detail in Annex D of IEC TS 62998-1:2019.

5.2.3 Improve the dependability of the detection capability

Algorithms used to improve the dependability (e.g. increase of the availability by filtering of objects beyond the limits of properties as stated by the manufacturer) shall not result:

– in a failure to danger condition as specified in 5.8.3.3 of IEC TS 62998-1:2019;

– in a response time beyond the limits as specified by the manufacturer in accordance with 5.9.3.3 of IEC TS 62998-1:2019.

The manufacturer shall verify:

– the influence of algorithms on the dependability of the detection capability if applicable;

NOTE 1 The algorithms can be developed by the manufacturer or developed by other parties but integrated by the manufacturer.

– the influence of the training data on the dependability of the detection capability if applicable;

The manufacturer shall analyse that test methods and test setup (e.g. synthetic test patterns or type tests with objects) used for verification of algorithms are appropriate representative for the intended use.

Type tests or field tests applied for verification of algorithms shall be performed:

– at the limits of the physical properties of safety related objects in accordance with 5.8.2.1 of IEC TS 62998-1:2019;

– within the limits of physical properties of safety related objects in accordance with 5.8.2.1 of IEC TS 62998-1:2019.

NOTE 2 In accordance with IEC TS 62998-1:2019 type tests are applicable as simulation tests. The use of simulation is described in more detail in Annex D of IEC TS 62998-1:2019.

5.2.4 Provide confidence information at the output unit

Algorithms used to provide confidence information related to a decision information or measurement information at the output unit of an SRS shall not result in coverage or decision probability beyond the limits stated in Table 5 of IEC TS 62998-1:2019 or identified in accordance with Formula (1) of IEC TS 62998-1:2019.

The results of the verification in accordance with 5.2.2 and 5.2.3 may be used to identify:

– accuracy of measurement information as part of the confidence information;

– uncertainty of measurement information as part of the confidence information;

– probability of decision information as part of the confidence information.

5.3 Integration and installation phase

5.3.1 General

Algorithms implemented based on requirements derived from the intended use in an SRSS using safety related information provided by two or more SRS shall:

– be in accordance with stated level of safety performance for the software parts in accordance with standards of functional safety of safety related control system (e.g. the IEC 61508 series, IEC 62061; see 4.3 of IEC TS 62998-1:2019);

– be analysed as stated in 5.3. of IEC TS 62998-1:2019 by applying 5.3.1 of this document.

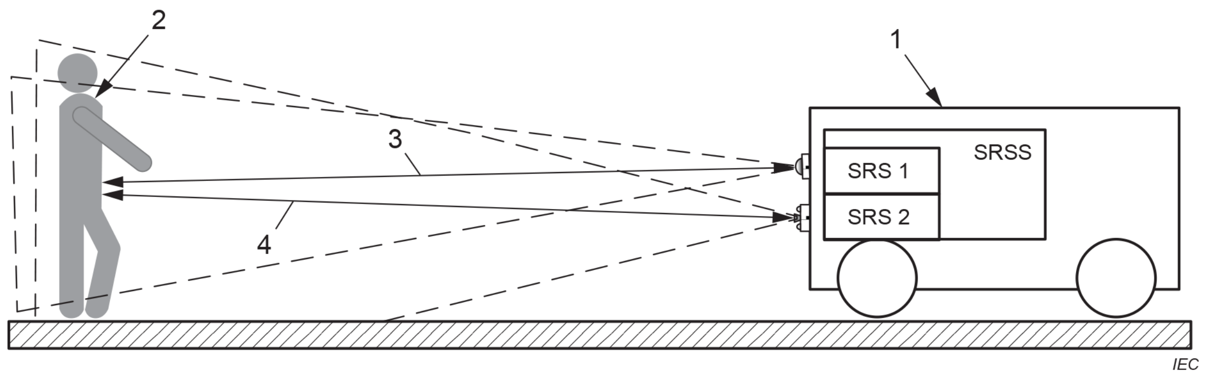
Algorithms implemented based on training data derived from the intended or practical use using machine learning models shall:

– be analysed as stated in 5.3. of IEC TS 62998-1:2019 by applying 5.3.1 of this document; and
– use training data of sufficient quality assured by applying applicable standards for data quality (e.g. ISO/IEC 25012 [15]); and
– be in accordance with stated level of safety performance for the requirements as stated in applicable standards for functional safety of safety related control system (e.g. the IEC 61508 series; see 4.3 of IEC TS 62998-1:2019) or be in accordance with applicable standards for systems and software engineering (e.g. ISO/IEC/IEEE 15026 [20], ISO/IEC 25000 [14]).

Algorithms shall be analysed by the integrator of two or more SRS into an SRSS and classified as algorithms used:

- to achieve improved detection of objects by combining information of 2 or more SRS in a processing unit (e.g. to combine signals of 2 SRS in a multiple stationary or mobile arrangement, see Figure 14, and identify agreement or disagreement resulting in a common measurement information at the output unit, see Figure 15, or combine the sensing zones of 2 SRS);
- to improve the dependability of the detection capability by combining information of 2 or more SRS in a processing unit (e.g. to combine signals of 2 SRS in a multiple stationary or mobile arrangement);
- to provide improved confidence information at the output unit by:
  – identifying measurement accuracy of measurement information based on the measurement information provided by two or more SRS;
  – identifying measurement uncertainty of measurement information based on the measurement information provided by two or more SRS;
  – identifying decision probability of decision information based on the decision information provided by two or more SRS.

NOTE An algorithm can belong to more than one class.



Key

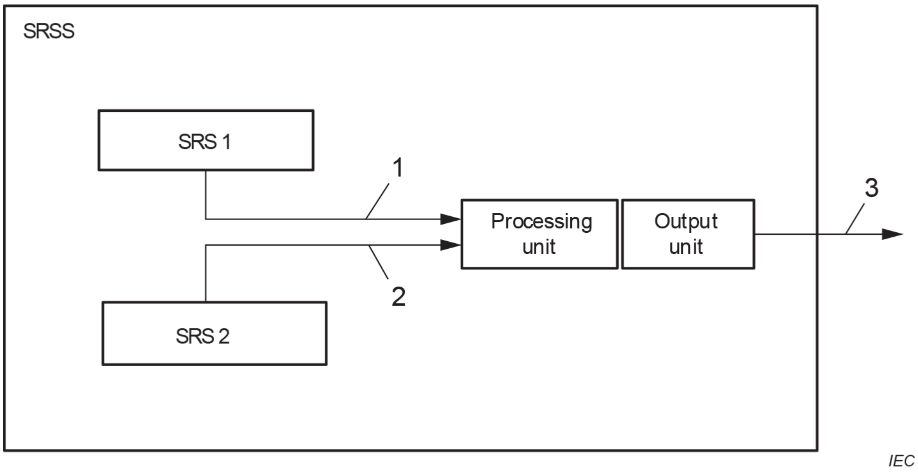
1 SRS1, SRS 2 and an SRSS in a mobile arrangement

2 object

3 distance 1 from SRS 1 to the object

4 distance 2 from SRS 2 to the object

Figure 14 – Exemplary combination of two SRS in an SRSS



Key

1 measurement information of SRS1 representing distance 1 of Figure 14 to the object

2 measurement information of SRS 2 representing distance 2 of Figure 14 to the object

3 measurement information of the SRSS representing commonly agreed distance to the object

Figure 15 – Exemplary integration of SRS measurement information in an SRSS

5.3.2 Achieve improved detection of objects

Algorithms used to achieve an improved detection of objects (e.g. new object properties are detected compared to the ones as stated in the information of use of the SRS) in an SRSS shall not reduce the detection capability or increase the response time beyond the limits as specified by the integrator of two or more SRS into an SRSS.

The integrator shall verify:

– the influence of algorithms on the detection capability if applicable;

NOTE 1 The algorithms can be developed by the integrator or developed by other parties but integrated by the integrator.

– the influence of the training data on the dependability of the detection capability if applicable;
– the influence on the response time;
– the field of application of the SRS as stated by the manufacturer of the SRS;
– the limits of use of the SRS as stated by the manufacturer of the SRS;

The integrator shall analyse that test methods and test setup (e.g. synthetic test patterns or type tests with objects) used for verification of algorithms are appropriate representative for the intended use.

Type tests or field tests applied for verification of algorithms:

– shall be specified by the integrator;
– shall be based on the applied physical properties of all objects in accordance with 6.2.3 of IEC TS 62998-1:2019.

NOTE 2 In accordance with IEC TS 62998-1:2019 type tests are applicable as simulation tests. The use of simulation is described in more detail in Annex D of IEC TS 62998-1:2019.

5.3.3 Improve the dependability of the detection capability

Algorithms used to improve the dependability of the detection capability of an SRSS (e.g. increase of the availability by filtering of objects based on their properties) shall not result:

– in a failure to danger condition as specified in 6.2.5 of IEC TS 62998-1:2019;

– in a response time beyond the limits as specified by the integrator in accordance with 6.2.8 of IEC TS 62998-1:2019.

The Integrator shall verify:

– the influence of algorithms on the dependability of the detection capability if applicable;

NOTE 1 The algorithms can be developed by the manufacturer or developed by other parties but integrated by the manufacturer.

– the influence of the training data on the dependability of the detection capability if applicable;

The integrator shall analyse that test methods and test setup (e.g. synthetic test patterns or type tests with objects) used for verification of algorithms are appropriate representative for the intended use.

Type tests or field tests applied for verification of algorithms shall be performed:

– at the limits of the physical properties of safety related objects in accordance with 6.2.3 of IEC TS 62998-1:2019;

– within the limits of physical properties of safety related objects in accordance with 6.2.3 of IEC TS 62998-1:2019.

NOTE 2 In accordance with IEC TS 62998-1:2019 type tests can be performed as simulation tests. The use of simulation is described in more detail in Annex D of IEC TS 62998-1:2019.

5.3.4 Provide confidence information at the output unit

Algorithms used to provide confidence information related to a decision information or measurement information at the output unit of an SRSS shall not result in coverage or decision probability beyond the limits stated in Table 5 of IEC TS 62998-1:2019 or identified in accordance with Formula (1) of IEC TS 62998-1:2019.

NOTE It can be valuable if algorithms are used to provide real time confidence information either as analogue or digital signal at the output unit.

The results of the verification in accordance with 5.3.2 and 5.3.3 may be used to identify:

– accuracy of measurement information as part of the confidence information;

– uncertainty of measurement information as part of the confidence information;

– probability of decision information as part of the confidence information;

5.4 Maintenance phase

Algorithm maintenance is the work that keeps the SRS/SRSS running with the expected detection capability and dependability of the detection capability. It has to be performed for changes of the physical properties, the environmental conditions and modification of the intended use, which can impact the detection capability.

NOTE Small changes of objects and the environment can be hidden and can have a serious impact on the detection capability.

The manufacturer of an SRS/SRSS shall define appropriate measures to analyse:

– the impact of changes on the detection capability and the dependability of the detection capability;

– if changes are already covered within the training data if applicable.

Annex A
(informative)

Physical property reflectivity for visible light or near infrared radiation

A.1 Process in accordance with IEC TS 62998-1

For an SRS using visible light or near infrared radiation, the physical property reflectivity can be relevant to perform the safety-related functions (see Table 2 of IEC TS 62998-1:2019). As stated in IEC TS 62998-1:2019, 5.8.2.1 a property shall be representative for the safety related objects and relevant for the sensing technology. If reflectivity is identified as property, then it is used for the analysis as stated in Figure G.2 of IEC TS 62998-1:2019. If different properties of an object or objects are identified as relevant then the combinations of properties may be used for the analysis.

The reflectivity of an object may be quantified by:

– the reflection coefficient in case of specular reflection;
– the diffuse reflectance value in case of diffuse reflection;
– the bidirectional reflectance distribution function in case of a mixed reflection.

The manufacturer of an SRS should derive the properties related to person or parts of person (e.g. reflectivity) and their limits from:

a) application standards applicable for the intended use;
b) product standards applicable for the sensing technology and the intended use;
c) acknowledged state of research and technology documents under consideration for the applicability to the intended use;
d) data derived from the intended use (e.g. during field tests);
e) risk assessment in the application.

NOTE 1 Typically derived properties and their limits are not rated as known in functional safety, e.g. in the evaluation of random failures in electronics or the evaluation of the reliability of detection within these limits. For example, for the property maximum size of persons, a 95-percentile value is widely used in a) and b).

The manufacturer of an SRS should derive the properties related to hazardous objects, objects present in the surroundings or automation related objects (e.g. reflectivity) and their limits from:

a) acknowledged state of research and technology documents under consideration for the applicability to the intended use;
b) data derived from the intended use (e.g. during field tests);
c) risk assessment in the application.

NOTE 2 Neither application standards nor product standards are known that can be recommended for the identification of properties of hazardous objects, objects present in the surroundings or automation related objects.

NOTE 3 An example for a relevant hazardous object can be a bicycle if the intended use of an SRS is in a public area. The property reflection for tire and frame of the bicycle are more specifically described in “Bicyclist target ACEA specifications Version 1.0” [21].

The SRS manufacturer should consider that the derived properties and their limits are applicable for the intended use taking into account the following aspects:

– different environmental influences can be present which interfere to different degrees with the physical characteristics and thus influence the dependability of the detection capability by the SRS;
– inappropriate limits can increase the risk in the application that an object will not be reliably detected by an SRS;

– inappropriate limits can increase the risk of a SRS being bypassed in the application and thus being ineffective;
– Inappropriate limits can prevent an economically appropriate or technically feasible realization of an SRS for the application.

A.2 Persons or parts of a person

For SRS intended to be used in industrial manufacturing, following deterministic ranges of diffuse reflectance values can apply for analysis, test, or both, of the detection capability and the dependability of the detection capability if the material representing persons or parts of persons has a diffuse reflection characteristic.

If the safety related function of the SRS is based on the detection of human skin as parts of persons, then Table A.1 applies.

Table A.1 – Range of diffuse reflectance values of human skin if detection of skin can be derived from the intended use

	SRS/SRSS performance class A	**SRS/SRSS performance class** B	**SRS/SRSS performance class** C	**SRS/SRSS performance class** D	**SRS/SRSS performance class** E	**SRS/SRSS performance class** F
Range for 380 nm to 550 nm	5 % to 45 %	5 % to 45 %	5 % to 45 %	5 % to 45 %	5 % to 45 %	5 % to 45 %
Range for 550 nm to 780 nm	7 % to 65 %	7 % to 65 %	7 % to 65 %	7 % to 65 %	7 % to 65 %	7 % to 65 %
Range for 780 nm to 1100 nm	20 % to 45 %	20 % to 45 %	20 % to 45 %	20 % to 45 %	20 % to 45 %	20 % to 45 %
Range for 1 100 nm to 1 600 nm	5 % to 35 %	5 % to 35 %	5 % to 35 %	5 % to 35 %	5 % to 35 %	5 % to 35 %
Range for 1 600 nm to 3 000 nm	3 % to 15 %	3 % to 15 %	3 % to 15 %	3 % to 15 %	3 % to 15 %	3 % to 15 %

For human skin, the same range of diffuse reflectance values is stated for all SRS/SRSS performance classes at a defined wavelength range. The distribution of the diffuse reflectance value between different populations is considered as low and the range of the diffuse reflectance value is assumed as being appropriately detectable by the SRS using infrared light [22], [23], [24] or visible light [22], [23], [24], [25].

If the safety related function of the SRS is based on the detection of parts of persons covered with clothes, then Table A.2 applies.

Table A.2 – Range of diffuse reflectance values of clothes if detection of parts of persons can be derived from the intended use

	SRS/SRSS performance class A	**SRS/SRSS performance class** B	**SRS/SRSS performance class** C	**SRS/SRSS performance class** D	**SRS/SRSS performance class** E	**SRS/SRSS performance class** F
Range for 380 nm to 780 nm	5 % to 90 %	4 % to 90 %	3 % to 90 %	2 % to 90 %	2 % to 90 %	2 % to 90 %
Range for 780 nm to 1 100 nm	10 % to 90 %	7 % to 90 %	4 % to 90 %	2 % to 90 %	2 % to 90 %	2% to 90 %

NOTE 1 Detection of parts of persons is related to investigations of clothes that can be worn on lower limbs or upper limbs or the torso.

At wavelength range from 380 nm to 780 nm and for clothes following the acknowledged state of the art, as identified in [26], [27], resulting in a minimum value of 2 % used for performance class D. The data shown as colour distribution in [27] was transferred into a distributed correlated range of diffuse reflectance values. The data shows a mean value at 16,7 % and a narrow distribution. The qualitative analysis of the correlated range results in a lower limit of 5 % for performance class A. For performance classes B and C the corresponding mean values between performance class D and A were estimated as representative.

At wavelength range above 780 nm up to 1 100 nm and for clothes, the minimum value of 2 % diffuse reflectance of performance class D of an AOPDDR in accordance with IEC 61496-3 [9] is used. AOPDDR are often used in high-risk applications detecting the lower limbs of persons. The value of 2 % is limiting for the design of an AOPDDR. To scale the design limitations with the performance classes another document was identified. For lower performance classes A, B and C, an IEEE document [26] is used. The document shows diffuse reflectance values from 4 % up to 75 % for 800 nm up to 1 100 nm in Table 1 [26]. The standard deviation in Table 2 [26] is about 16 % and the median 58 %. The distribution of diffuse reflectance values for clothes is broad. Based on an approximation of the mean equal to the median, minimum diffuse reflectance value of about 10 % is identified by applying a 3 Sigma criterion to the data. For very low risk applications of performance class A in an industrial environment the 10 % value is appropriate for the diffuse reflectance. For medium risk applications using performance class C the stated 4 % values is used. For low-risk applications of performance class B, the average of performance class C and A is used. For performance classes E and F, the values of performance class D is used that is already very design limiting and at the limit of achievable state of the art for an SRS. For the maximum value 90 % as stated for AOPDDR performance class D is used for all performance classes because it is not seen as limiting for the design as the minimum value.

NOTE 2 As per definition, the median does not necessarily consider all data as it is robust to outliers.

If the safety related function of the SRS is based on the detection of the whole body of persons mainly covered with clothes, then Table A.3 applies.

Table A.3 – Diffuse reflectance values if detection of the whole body of persons can be derived from the intended use

	SRS/SRSS performance class A	SRS/SRSS performance class B	SRS/SRSS performance class C	SRS/SRSS performance class D	SRS/SRSS performance class E	SRS/SRSS performance class F
Range for 380 nm to 780 nm	5 % to 90 %	4 % to 90 %	4 % to 90 %	3 % to 90 %	3 % to 90 %	3 % to 90 %
Range for 780 nm to 1100 nm	10 % to 90 %	9 % to 90 %	7 % to 90 %	6 % to 90 %	6 % to 90 %	6 % to 90 %

At wavelength range above 780 nm up to 1 100 nm, the minimum value of 6 % or less for performance class D is considered for person detection as stated in ANSI/ITSDF B 56.5:2019-00. ANSI/ITSDF B 56.5:2019-00 is a safety standard for driverless, automated guided industrial vehicles and automated functions of manned industrial vehicles. For sensors used for person detection, tests are required that detect objects with at least 6 % diffuse reflectance value. The 6 % value can be qualitatively comprehended with the combination of parts of body with skin and typically two different types of clothing. The area of skin surface is estimated at 5 % of a whole-body surface and the clothes with approximately 47,5 % using 2 % as diffuse reflectance value and 47,5 % using 10 % as diffuse reflectance value. For performance class C the one portion of the clothes is considered with 4 % as diffuse reflectance values and the other is left with 10 % as diffuse reflectance value resulting in 7 %. For performance class B, then 7 % is used for one portion of clothes and the other is left with 10 % resulting in 9 %. For performance class A, 10 % for both portions of clothes are used resulting in 10 %.

NOTE 3 The data distribution of clothing is derived from investigations [26], [27] of clothes typically worn in public areas.

At wavelength range from 380 nm to 780 nm and for clothes the acknowledged state of the art, as identified in [26] and [27], results in a minimum value of 2 % used for performance class D. The data shown as colour distribution in [27] was transferred into a distributed correlated range of diffuse reflectance values. The data indicate a mean value at 16,7% and a relatively small distribution. Following the same procedure as described for infrared light, the combination of Table A.1 and Table A.2 values results in the values stated in Table A.3.

The detection of body of persons using Table A.3 can be achieved e.g. by identification of parts of a person or the integrated signal over the body. An analysis should identify if whole body detection can be claimed. The analysis should take into consideration, for example, the sensing unit arrangement and used algorithms.

If safety related objects with different properties than those stated in Table A.1 to Table A.3 are identified as relevant during a risk analysis in the intended use, then their reflectivity should be used instead or in addition (e.g. retroreflective material on clothes or specific working clothes with low reflectivity).

Annex B
(informative)

Physical property reflectivity for millimetre wave radiation

For an SRS using millimetre wave radiation, the physical property reflectivity can be relevant to perform the safety-related functions (see Table 2 of IEC TS 62998-1:2019). As stated in IEC TS 62998-1:2019, 5.8.2.1, a property shall be representative for the safety related objects and relevant for the sensing technology. If reflectivity is identified as a property, then it is used for the analysis as stated in Figure G.2 of IEC TS 62998-1:2019. If different properties of an object or objects are identified as relevant, then the combinations of properties may be used for the analysis.

The reflectivity of an object may be quantified by its RCS.

The RCS of a safety related object describes the following object's physical properties:

– geometry (shape, size, orientation, etc.);
– surface material reflectivity.

NOTE 1 The RCS of objects can vary with respect to the wavelength of the radar radiation.

The manufacturer of an SRS should derive the properties related to person or parts of person (e.g. reflectivity) and their limits from:

a) application standards applicable for the intended use;
b) product standards applicable for the sensing technology and the intended use;
c) acknowledged state of research and technology documents under consideration for the applicability to the intended use;
d) data derived from the intended use (e.g. during field tests);
e) risk assessment in the application.

NOTE 2 Typically derived properties and their limits are not rated as known in functional safety, e.g. in the evaluation of random failures in electronics or the evaluation of the reliability of detection within these limits. For example, for the property maximum size of persons, a 95-percentile value is widely used in a) and b)

The manufacturer of an SRS should derive the property related to hazardous objects, objects present in the surroundings or automation related object (e.g. reflectivity) and their limits from:

a) application standards applicable for the intended use;
b) acknowledged state of research and technology documents under consideration for the applicability to the intended use;
c) data derived from the intended use (e.g. during field tests);
d) risk assessment in the application.

The SRS manufacturer should consider that the derived properties and their limits are applicable for the intended use taking into account the following aspects:

– different environmental influences can be present which interfere to different degrees with the physical characteristics and thus influence the dependability of the detection capability by the SRS;
– inappropriate limits can increase the risk in the application that an object will not be reliably detected by an SRS;
– inappropriate limits can increase the risk of an SRS being bypassed in the application and thus being ineffective;
– Inappropriate limits can prevent an economically appropriate or technically feasible realization of an SRS for the application.

Appropriate coverage of the RCS of the safety related object on the detection capability of an SRS may be validated by field tests instead of using deterministic values for analysis or e.g. type test. If the detection capability is validated by field test, then the dependability of detection shall be recorded and analysed at the end of the field test. The manufacturer considering the SRS/SRSS performance class may specify the duration of the field test. At the end of the field test appropriate risk reduction may be verified using the field test records.

For further information on RCS, see [28], [29] and [30].

Annex C
(informative)

Physical property temperature for middle infrared radiation

C.1 Process in accordance with IEC TS 62998-1

For an SRS using middle infrared radiation of a safety-related object, the temperature is relevant to perform the safety-related functions (see Table 2 of IEC TS 62998-1:2019). As stated in IEC TS 62998-1:2019, 5.8.2.1 a property shall be representative for the safety related objects and relevant for the sensing technology. If the temperature is identified as property, then it is used for the analysis as stated in Figure G.2 of IEC TS 62998-1:2019. If different properties of an object or objects are identified as relevant, then the combinations of properties may be used for the analysis.

The manufacturer of an SRS should derive the properties (e.g. temperature) related to person or parts of person and their limits from:

a) application standards applicable for the intended use;
b) product standards applicable for the sensing technology and the intended use [10];
c) acknowledged state of research and technology documents under consideration for the applicability to the intended use;
d) data derived from the intended use (e.g. during field tests);
e) risk assessment in the application.

NOTE 1 Typically derived properties and their limits are not rated as known in functional safety, e.g. in the evaluation of random failures in electronics or the evaluation of the reliability of detection within these limits. For example, for the property maximum size of persons, a 95-percentile value is widely used in a) and b).

The manufacturer of an SRS should derive the properties related to hazardous objects, objects present in the surroundings or automation related object (e.g. temperature) and their limits from:

a) acknowledged state of research and technology documents under consideration for the applicability to the intended use;
b) data derived from the intended use (e.g. during field tests);
c) risk assessment in the application.

NOTE 2 Neither application standards nor product standards are known that can be recommended for the identification of properties of hazardous objects, objects present in the surroundings or automation related objects.

The SRS manufacturer should consider that the derived properties and their limits are applicable for the intended use taking into account the following aspects:

– different environmental influences can be present which interfere to different degrees with the physical characteristics and thus influence the dependability of the detection capability by the SRS;
– inappropriate limits can increase the risk in the application that an object will not be reliably detected by an SRS;
– inappropriate limits can increase the risk of an SRS being bypassed in the application and thus being ineffective;
– inappropriate limits can prevent an economically appropriate or technically feasible realization of an SRS for the application.

C.2 Exemplary determination of the temperature

The temperature of a safety-related object may be determined in accordance with Clause C.1, d). The temperature should be quantified as:

– temperature range starting from the minimum up to the maximum of the observed surface; and

– temperature distribution over the observed surface.

The following effects should be considered during the measurement of the temperature:

– the wavelength range used by the measurement equipment (see Figure C.1);

NOTE 1 The absorbance of the propagation medium depends on the used wavelength range. Errors in the measurement can be reduced by appropriate selection of the wavelength range.

– the temperature range of the measurement environment that should be representative for the intended use;

NOTE 2 The surface temperature of a person varies with the environmental temperature.

– the variance of surface conditions;

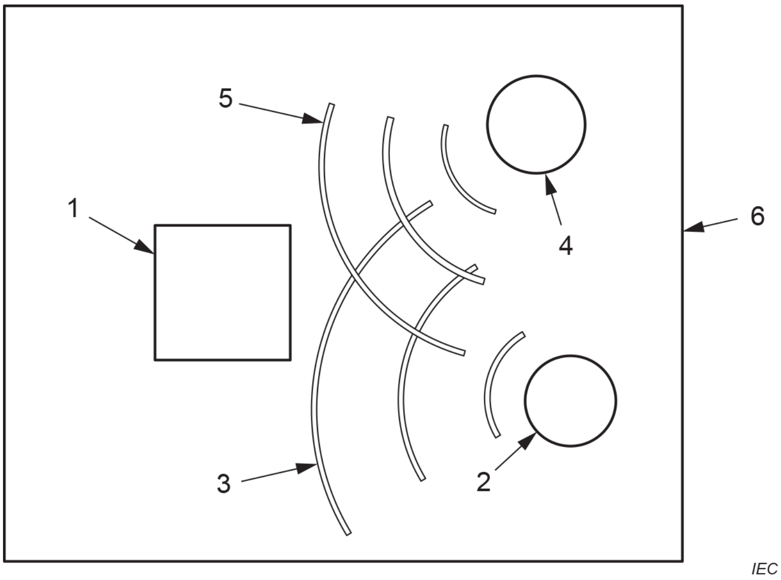
NOTE 3 The surface temperature varies in example with the clothes of a person or which part of the person is measured [31], [32].

– the propagation medium that should be representative for the intended use;

NOTE 4 The absorbance varies with the used medium. If the medium is air, then the influence of the altitude is relevant. At different altitudes the absorbance is different.

– thermal reflections from other objects present in the surrounding.

NOTE 5 Objects with regular reflection characteristic are of special relevance (e.g. glass, metals, or wet surfaces).



Key

1 measurement equipment

2 surface of the safety-related object

3 thermal radiation emitted by the safety-related object and passing through the propagation medium

4 surface of another object present in the surrounding

5 thermal radiation emitted by another object present in the surrounding and passing through the propagation medium

6 measurement environment

Figure C.1 – Illustration of temperature measurement

Annex D
(informative)

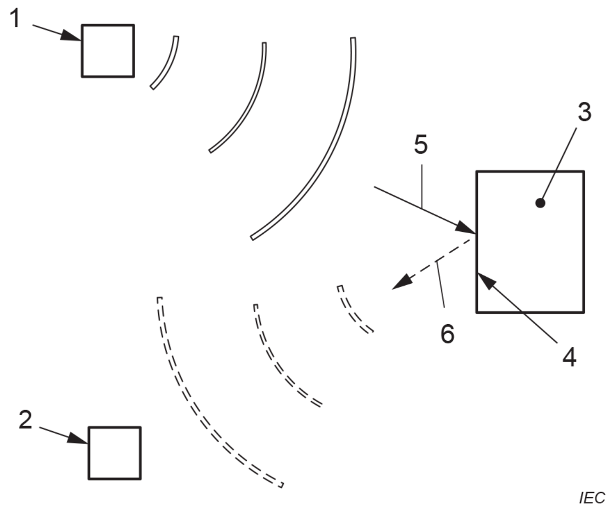
Physical property reflectivity for ultrasound wave radiation

For an SRS using ultrasound wave radiation, the physical property reflectivity can be relevant to perform the safety-related functions (see Table 2 of IEC TS 62998-1:2019). As stated in IEC TS 62998-1:2019, 5.8.2.1, a property shall be representative for the safety related objects and relevant for the sensing technology. If reflectivity is identified as property, then it is used for the analysis as stated in Figure G.2 of IEC TS 62998-1:2019. If different properties of an object or objects are identified as relevant, then the combinations of properties may be used for the analysis.

The reflectivity of an object may be quantified by its:

– acoustic impedance or reflection coefficient in case of a specular reflection (see Figure D.1); or

– radar cross section in case of a diffuse or mixed reflection (see Figure D.2).



Key

1 emitter

2 receiver

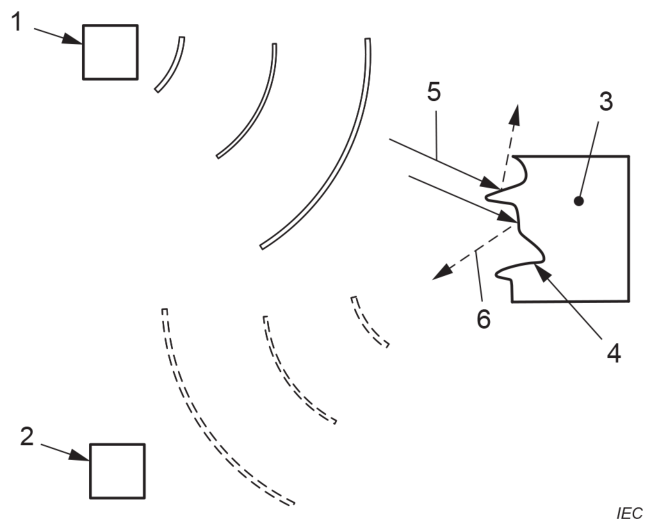
3 mechanical properties of the object

4 geometry of the object surface

5 incident radiation

6 reflected radiation

Figure D.1 – Object ultrasonic reflectivity quantified by acoustic impedance or reflection coefficient



Key

1 emitter

2 receiver

3 mechanical properties of the object

4 geometry of the object surface

5 incident radiation

6 reflected radiation

Figure D.2 – Object ultrasonic reflectivity quantified by radar cross section

In case a part of the ultrasound wave radiation is transmitted into the object and absorbed by the object, the associated increase in temperature of the safety related object should be analyzed [5], [6], [7]. Furthermore, the propagation medium should be analysed since its mechanics determine the velocity of sound and hence can cause systematic over/under estimation of the detection capability.

The manufacturer of an SRS should derive the property related to person or parts of person (e.g. reflectivity) and their limits from:

a) application standards applicable for the intended use [8];
b) product standards applicable for the sensing technology and the intended use;
c) acknowledged state of research and technology documents under consideration for the applicability to the intended use;
d) data derived from the intended use (e.g. during field tests);
e) risk assessment in the application.

NOTE 1 Typically derived properties and their limits are not rated as known in functional safety, e.g. in the evaluation of random failures in electronics or the evaluation of the reliability of detection within these limits. For example, for the property maximum size of persons, a 95-percentile value is widely used in a) and b).

The manufacturer of an SRS should derive the property related to hazardous objects, objects present in the surroundings or automation related objects (e.g. reflectivity) and their limits from:

a) acknowledged state of research and technology documents under consideration for the applicability to the intended use;
b) data derived from the intended use (e.g. during field tests);
c) risk assessment in the application.

NOTE 2 Neither application standards nor product standards are known that can be recommended for identification of properties for hazardous object, object present in the surroundings or automation related object.

The SRS manufacturer should consider that the derived properties and their limits are applicable for the intended use taking into account the following aspects:

– different environmental influences can be present which interfere to different degrees with the physical characteristics and thus influence the dependability of the detection capability by the SRS;
– inappropriate limits can increase the risk in the application that an object will not be reliably detected by an SRS;
– inappropriate limits can increase the risk of an SRS being bypassed in the application and thus being ineffective;
– Inappropriate limits can prevent an economically appropriate or technically feasible realization of an SRS for the application.

Bibliography

[1] IEC 60050-300, *International Electrotechnical Vocabulary (IEV) - Part 300: Electrical and electronic measurements and measuring instruments - Part 311: General terms relating to measurements - Part 312: General terms relating to electrical measurements - Part 313: Types of electrical measuring instruments - Part 314: Specific terms according to the type of instrument*

[2] IEC 60050-171, *International Electrotechnical Vocabulary (IEV) - Part 171: Digital technology - Fundamental concepts*

[3] IEC 60050-801, *International Electrotechnical Vocabulary (IEV) - Part 801: Acoustics and electroacoustics*

[4] IEC 60050-845, *International Electrotechnical Vocabulary (IEV) - Part 845: Lighting*

[5] IEC 60601-2-5, *Medical electrical equipment - Part 2-5: Particular requirements for the basic safety and essential performance of ultrasonic physiotherapy equipment*

[6] IEC 60601-2-37, *Medical electrical equipment - Part 2-37: Particular requirements for the basic safety and essential performance of ultrasonic medical diagnostic and monitoring equipment*

[7] IEC 60601-2-62, *Medical electrical equipment - Part 2-62: Particular requirements for the basic safety and essential performance of high intensity therapeutic ultrasound (HITU) equipment*

[8] IEC TS 61206, *Ultrasonics - Continuous-wave Doppler systems - Test procedures*

[9] IEC 61496-3, *Safety of machinery - Electro-sensitive protective equipment - Part 3: Particular requirements for active opto-electronic protective devices responsive to diffuse Reflection (AOPDDR)*

[10] IEC 62642-2-2, *Alarm systems - Intrusion and hold-up systems - Part 2-2: Intrusion detectors - Passive infrared detectors*

[11] ISO/IEC 18000 (all parts), *Information technology - Radio frequency identification for item management*

[12] ISO/IEC 20924:2021, *Information technology - Internet of Things (IoT) - Vocabulary*

[13] ISO/IEC 22989:2022, *Information technology - Artificial intelligence - Artificial intelligence concepts and terminology*

[14] ISO/IEC 25000, *Systems and software engineering - Systems and software Quality Requirements and Evaluation (SQuaRE) - Guide to SQuaRE*

[15] ISO/IEC 25012, *Software engineering - Software product Quality Requirements and Evaluation (SQuaRE) - Data quality model*

[16] ISO/IEC 26907, *Information technology - Telecommunications and information exchange between systems - High-rate ultra-wideband PHY and MAC standard*

[17] ISO/IEC 26908, *Information technology - Telecommunications and information exchange between systems - MAC-PHY interface for ISO/IEC 26907*

[18] ISO/IEC Guide 99:2007, *International vocabulary of metrology - Basic and general concepts and associated terms (VIM)*

[19] ISO 8729-2:2009, *Ships and marine technology - Marine radar reflectors - Part 2: Active type*

[20] ISO/IEC/IEEE 15026 (all parts), *Systems and software engineering - Systems and software assurance*

[21] Bicyclist target ACEA specifications Version 1.0, November 2018, https://www.acea.be/uploads/publications/Bicyclist_target-ACEA_specifications.pdf

[22] Spectral reflectance variability of skin and attributing factors, Catherine C. Cooksey, Benjamin K. Tsai, and David W. Allen Sensor Science Division, National Institute of Standards and Technology Gaithersburg, MD, USA 20899

[23] Advances in active Near-Infrared Sensor Systems for material classification and skin detection for safety applications. Safety Science Monitor ,Issue 2013, VOL 17, Article 1

[24] Human skin detection in the visible and near infrared. Applied optics. Vol. 54 No. 35, December 2015

[25] Visible Reflectance Spectroscopy of Human Skin: the use of CIE L*a*b* Colour Analysis for In Vivo Ethnic Skin Characterization, Copyright ©2012, PerkinElmer, Inc. April 2012

[26] Infrared Reflectivity of Pedestrian Mannequin for Autonomous Emergency Braking Testing, In 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC) (pp. 2230–2235). https://doi.org/10.1109/ITSC.2016.7795916

[27] Determination of Pedestrian Mannequin Clothing Colour for the Evaluation of Image Recognition Performance of Pedestrian Pre-Collision Systems. Paper Number 15-0227.

[28] Articulated pedestrian target ACEA specifications Version 1.0, October 2015, https://www.acea.be/uploads/publications/Articulated_Pedestrian_Target_Specifications_-_Version_1.0.pdf

[29] F.-G. J. C. Jean-Marc, Radar Cross Section Measurements of Pedestrian Dummies and Humans in the 24/77 GHz Frequency Bands. Publications office of the European Union, 2013. [Online]. Available: http://publications.jrc.ec.europa.eu/repository/handle/JRC78619

[30] RCS measurements of a human hand for radar-based gesture recognition at E-band, in: 2016 German Microwave Conference (GeMiC), https://ieeexplore.ieee.org/document/7461605

[31] Radostina A. Angelova1,Elena Georgieva, Detelin Markov,Tsvetan Bozhkov,Iskra Simova,Nushka Kehaiova,Peter Stankov, Estimating the Effect of Torso Clothing Insulation on Body Skin and Clothing Temperatures in a Cold Environment Using Infrared Thermography, FIBRES & TEXTILES in Eastern Europe 2018, Vol. 26, 4(130), 129

[32] Lee J H, Kim Y K, Kim K S, Kim S. Estimating Clothing Thermal Insulation Using an Infrared Camera. Sensors. 2016; 16(3), 341-358

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