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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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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- withdrawn,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 = θ0 + θ1x) 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.