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TECHNICAL REPORT

colour inside

Safety of machinery –
Part 2: Examples of application

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Safety of machinery –
Part 2: Examples of application

INTERNATIONAL
ELECTROTECHNICAL
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SAFETY OF MACHINERY –

Part 2: Examples of application

FOREWORD

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IEC TR 62998-2, which is a Technical Report, has been prepared by IEC technical committee TC 44: Safety of machinery – Electrotechnical aspects.

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

Enquiry draft	Report on voting
44/849/DTR	44/865A/RVDTR

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

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

This document is to be used in conjunction with IEC TS 62998-1:2019.

A list of all parts in the IEC 62998 series, published under the general title *Safety of machinery*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://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withdrawn,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

Safety-related sensors are applied to machinery presenting a risk of personal injury. They provide protection by causing the machine to revert to a safe condition before a person can be placed in a hazardous situation.

IEC TS 62998-1:2019 is intended for use by safety-related sensor manufacturers and integrators of safety-related sensors for the design of safety-related sensor systems used for the protection of persons.

This document gives guidance for manufacturers and integrators on the application of IEC TS 62998-1:2019.

SAFETY OF MACHINERY –

Part 2: Examples of application

1 Scope

This document establishes guidance for the application of IEC TS 62998-1:2019.

It provides examples of:

– application for which SRS/SRSS are relevant,
– use of SRS/SRSS information from an application point of view,
– fusion of SRS into SRSS for given applications, and
– appropriate information for use for given applications.

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

3 Terms, definitions and abbreviated terms

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 Terms and definitions

3.1.1
mobile robot
robot able to travel under its own control

[SOURCE: ISO 8373:2012, 2.13, modified – The note has been omitted.]

3.1.2
robot
actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks

[SOURCE: ISO 8373:2012, 2.6, modified – Notes 1 and 2 have been omitted.]

3.2 Abbreviated terms

CHE container-handling equipment

ALARP as low as reasonably practical

LiDAR light detection and ranging

MOR meteorological optical range

TOF time of flight

SLAM Simultaneous Localization and Mapping

SRS safety-related sensor

SRSS safety-related sensor system

SCS safety-related control system

4 Applications for mobile robots

4.1 General

This example covers the integration and installation phase using fusion of three SRSs into an SRSS in accordance with Clause 6 of IEC TS 62998-1:2019 to improve sensing zones and safety-related zones in accordance with requirements for the intended use. The intended uses are 2 different mobile robot types, in accordance with ISO 13482:2014, that operate autonomously in a public area with limited access. The reader should be aware that the following descriptions are not based on comprehensive analysis and are only examples for mobile robotics.

NOTE ISO 13482:2014 covers mobile robots operating in an autonomous manner. For simplification, the term "mobile robot" will be used from now on.

Two different mobile robots operate on a certain university campus with buildings to achieve:

transport of in-house mail items among office buildings of the university, and

cleaning of pavements of the university.

Figure 1 shows the typical outdoor pavement of a university campus. Person(s) being present or approaching the safety related zone(s) of an SRSS should be detected and the safety-related control system should initiate appropriate reaction of the mobile robot.

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Figure 1 – Outdoor scene

4.2 SRSS on mail transport mobile robot

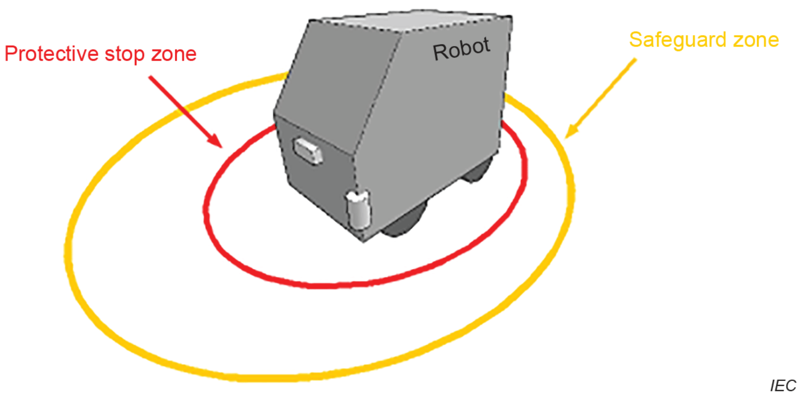
4.2.1 Intended use

The intended use should be determined (see 6.2.1 of IEC TS 62998-1:2019) by the integrator. It is defined by the following selected example items:

1) The mobile robot is a Type 1.1 robot specified in ISO 13482:2014 with a weight of 30 kg and size of length: 500mm × width: 500mm × height: 600mm.
2) The mobile robot automatically navigates the pavement connecting the university office buildings. The path of the robot is predetermined according to the map created by SLAM technology [1][1] and physical constraints. The map includes position information for objects that are fixed along the pavement, such as guardrails, building walls, trees, etc. By referring to the map, the robot determines its own restricted space (ISO 13482:2014, 3.18.2) while moving.
3) The mobile robot moves during daytime on non-carriageways where:
   a) light vehicles such as bicycles are not allowed to enter;
   b) wheelchairs can enter;
   c) pavements are smooth paved with slopes of up to 5 degrees in some areas, as shown in Figure 1;
   d) standing or walking people on the pavements are adults and/or children. Children under and including 3 years are assumed to be controlled and children from 4 years up to including 10 years are assumed to be accompanied by adults. An adult might not accompany children over 10 years up to 14. For the purpose of this example, the speed of a person towards the mobile robot is assumed to be between 0 mm/s and 800 mm/s if the person enters into the safeguarded zone.

   NOTE The speed in this example deviates from ISO 13855:2010 under the assumption of different human behaviour in this application. For other applications, faster or slower speeds might be more appropriate. On the campus, people are informed by organizational measures and warning signals that running is not allowed in the areas where mobile robots are present. Other examples of properties are given in 4.2.4.
4) The mobile robot:
   a) is intended to make a protective stop when a standing or walking person comes into the protective stop zone (see Figure 2);
   b) is intended to reduce the speed when a standing or walking person moves into the safeguarded zone (see Figure 2);
   c) is driven with a speed up to 700 mm/s reduced by the safety related speed control function down to 300 mm/s;
   d) can reduce speed within 0,5 s from 700 mm/s to 300 mm/s, and another 0,2 s to reduce to zero speed;
   e) is intended to be used in the daytime.
5) The outdoor environmental conditions during operation:
   a) can be up to 10 mm/h precipitation;
   b) can have light interference representing daytime.

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



The mobile robot has two distinctive zones, in accordance with ISO 13482:2014. The protective stop zone, where the mobile robot performs a protective stop, and the safeguarded zone, where a safety-related speed control function is performed when a safety-related object is detected. In accordance with IEC TS 62998-1:2019, the protective stop zone and safeguarded zone would be safety-related zone(s).

Figure 2 – Mobile robot with 2 distinctive safety-related zones

4.2.2 SRSS performance class determination

In the chosen approach, using ISO 13482:2014 the required performance level of the safety functions of a Type 1.1 mobile robot is PL b, in accordance with ISO 13849-1:2015. The safety functions include the protective stop function, the safety-related speed control function, the hazardous collision avoidance function, and the travel surface detection function in accordance with ISO 13482:2014, which will be initiated by the SRSS.

The required performance class of the SRSS corresponding to PL b is the sensor performance class B specified in IEC TS 62998-1:2019.

4.2.3 SRS limits of use and SRSS function

The SRSS consists of three SRSs defined by the manufacturer as follows (see Figure 3).

1. SRS1: a 2D LiDAR suitable to be used up to PL b, in accordance with ISO 13849-1:2015, which allows the detection of persons and other safety-related objects and the measurement of their positions and velocities with high accuracy. The systematic capabilities are assessed in accordance with IEC TS 62998-1:2019. The sensing zone is up to a radius of 7 000 mm, and a viewing angle of 270°. The detection capability is given for safety-related objects with the properties: minimum size 40 mm × 40mm; minimum object reflectivity 5 %; maximum object speed 1 600 mm/s. The response time is 0,05 s. Use in indoor and outdoor environmental conditions is possible within defined limits.
2. SRS2: a TOF camera suitable to be used up to PL b, in accordance with ISO 13849-1:2015, which allows detecting parts of 3D volumes of persons, road surface, and other safety-related objects using 3D imaging technology. The systematic capabilities are assessed in accordance with IEC TS 62998-1:2019. SRS2 is capable of measuring the position and velocity of objects within the 3D sensor coordinate system. The sensing zone is up to 4 000 mm and vertical and horizontal field of views angle of 60° and 70°, respectively. The detection capability is given for safety-related objects with properties: minimum size 40 mm × 40 mm × 40 mm; minimum object reflectivity 5 %; maximum object speed 1 600 mm/s. The response time is 0,05 s. It is possible to distinguish a paved road surface and other objects three-dimensionally. Use in indoor and outdoor environmental conditions is possible within defined limits.
3. SRS3: the same specification as SRS1.

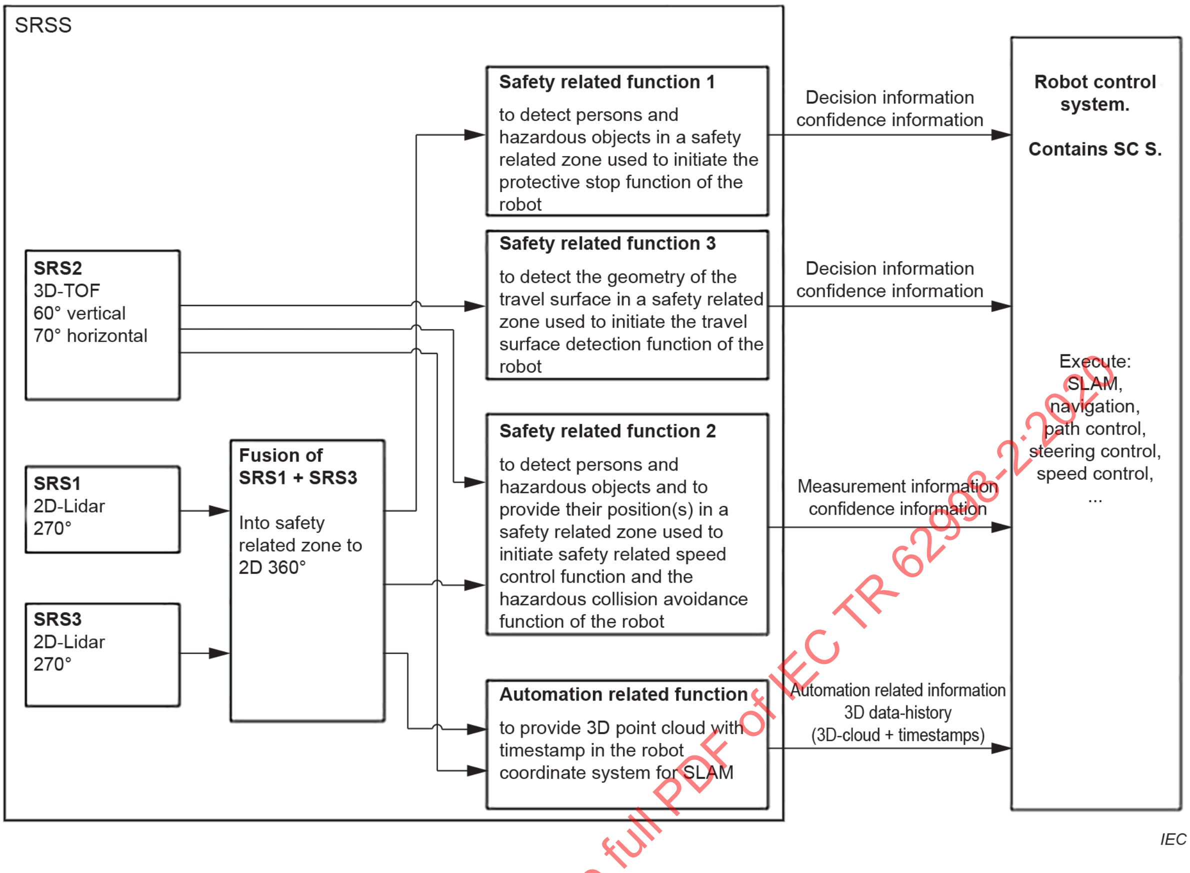


Figure 3 – Combination of three SRSs into an SRSS and SRSS functions

The target applications require four SRSS functions (see Figure 3):

- Safety-related function 1: to detect persons and hazardous objects in the protective stop zone for initiating the protective stop function specified in ISO 13482:2014, 6.2.2.3.
- Safety-related function 2: to detect persons and hazardous objects and to provide their positions and velocities as safety-related information for the safety-related speed control function and/or the hazardous collision avoidance function specified in ISO 13482:2014, 6.4 and 6.5.2.1.
- Safety-related function 3: to detect the geometry of the travel surface of the robot as specified in ISO 13482:2014, 6.5.3. When a travelable surface is observed in the travelling direction of the robot, the robot can move forwards. If the robot moves backwards, the road surface that it has already travelled is definitely present, so this function is not required.
- Automation related function: to provide 3D point cloud with timestamp in the robot coordinate system for SLAM.

4.2.4 Safety-related requirements

The SRSS safety-related requirements should be specified by the integrator (see 6.2.1 of IEC TS 62998-1:2019) based on the intended use. For example, see the requirements defined in Table 1.

Table 1 – Safety-related requirements

Term	Requirement	Details
SRSS performance class	B	See 4.2.2 Intended to be integrated from SRS of the same performance class B
Demand rate of SRSS safety related function(s)	10/h	
SRSS response time	0,1 s	
SRSS detection capability	e.g. Person related properties: Sizes representing a 4-year-old person in an upright position. Minimum reflection value 5 % Speed 800 mm/s e.g. Hazardous object properties: Sizes representing wheelchair Minimum reflection value 5 % Speed 800mm/s	See 4.2.5
SRSS sensing zones	e.g. Safety related zones 2-dimensional; 360° with S_0 = 656 mm and S_1= 1 255 mm; 3-dimensional; vertical and horizontal field of view 60°; with S_0 = 656 mm and S_1= 1 255 mm;	See 4.2.6

4.2.5 Object classes and physical properties

The SRSS detection capability should be specified by the integrator in accordance with 6.2.3 of IEC TS 62998-1:2019. The following specific examples are considered.

Object classes to be analysed are:

1) objects used to perform the person detection function;
   a) supervised children up to and including 3 years;
   b) accompanied children between 4 years and including 10 years;
   c) unaccompanied children between 11 years and including 13 years;
   d) adult persons from 14 years.
2) objects used to perform the hazardous object function;
   a) wheelchairs.
3) objects used to perform the automation related function
   a) landmarks used for navigation.

Furthermore, only the properties of an accompanied standing or walking child will be analysed for the safety-related function 1 and safety related function 2.

For safety related function 2, the limit that SRS2 detects is the forearm of a 4-year-old child. The simplified shape is estimated as cylinder with a diameter of 40 mm or more and a length of 200 mm.

NOTE 1 The 5th percentile value of the hand width and the hand length of a Japanese 4-year-old child is 49 mm and 107 mm respectively. There is no arm length data for the child [2].

For safety-related function 1, the lower limbs of a 4 year-old-child are used to identify the minimum size. The simplified shape is estimated as cylinder with a diameter of 50 mm in mounting height of SRS1 and SRS3.

NOTE 2 The 5th percentile value of circumference is estimated based on Data for Japanese Children measured for calf and ankle [3].

For the safety-related function 3, performed by SRS2 of the SRSS, the travelling surface to be detected is a continuous flat surface or smooth curved surface with a slope of 5° or less in front of the robot.

NOTE 3 SRS1 may detect the road surface as a hazardous object at the entrance to the slope. Other measures might be put in place to prevent a permanent stop of the mobile robot.

The minimum diffuse reflectivity used as representation for a person, a hazardous object, and a travel surface is assumed to be 5 % or more at the wavelength used by each SRS.

NOTE 4 The 5 % minimum reflectivity value is taken for a safety function of PL b following the ALARP principle. Many standard LiDAR sensors state 10 % as minimum reflectivity value in security and automation applications, or 6% minimum reflection value is required for person detection with sensors used on automated guided vehicles in accordance with B56.5:2012. In general, additional validation in the application can be required for mobile robots within information for use as a possibility to test appropriateness of used object properties or stated performance (e.g. speed of objects or minimum reflection value). The minimum reflectivity value is discussed specifically taking care of the situation that many people using sensors for person protection in machinery are focused on it. The reader of this document is asked to consider that detection capability of SRS is often based on a combination of different properties and not a single one taken for deterministic analysis. For example, a combination of low reflection value with small object size and maximum assumed speed can be estimated as of very low probability. The practical use and the combination of properties, under consideration of their probability distribution, is an increasing challenge in applications of SRSs and SRSS.

The speed of persons moving during daytime towards the mobile robot is assumed to be 800 mm/s.

NOTE 5 Persons moving over the university are informed that mobile robots are in progress and that they are required to stay at a distance from them.

For the automation-related function of the SRSS, all objects within the SRSS sensing zone representing reliable, fixed landmarks on the mobile-robot travelling path will be identified within a procedure during the starting of operation.

4.2.6 Sensing zones

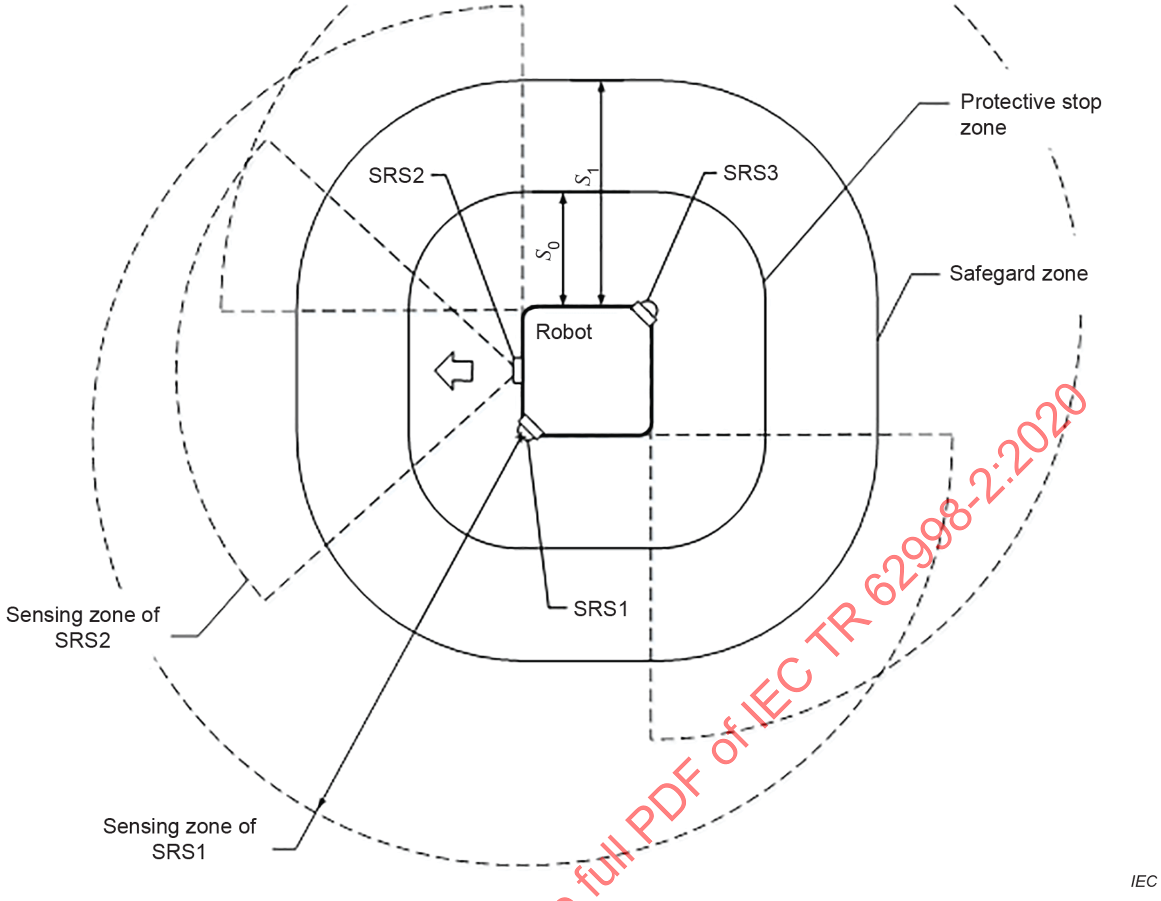
The integrator should specify the SRSS sensing zones in accordance with 6.2.4 of IEC TS 62998-1:2019.

The mounting position and the sensing zone of each SRS, and the improved safety-related zones of the SRSS after fusion, are shown in Figure 4 and Figure 5.

SRS1 and SRS3 are mounted horizontally on the left front and the right rear of the robot, respectively, at a height of 200 mm from the ground level. By mounting SRS1 and SRS3 to the opposite corners of the robot, it is possible to observe the entire circumference of the robot without blind spots.

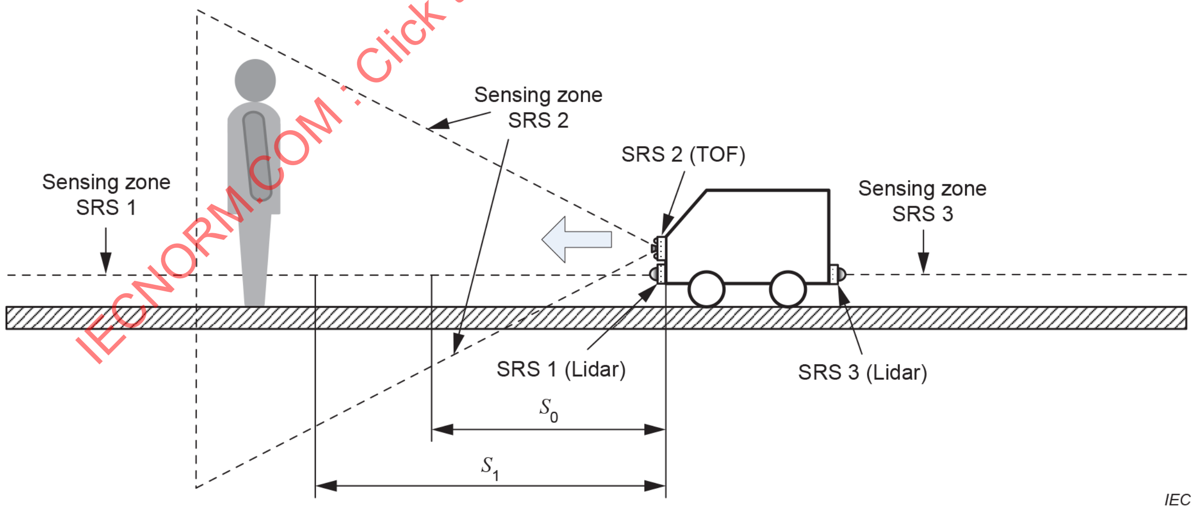
SRS2 is mounted at the centre of the front of the robot at a height of 400 mm to measure in the direction of robot’s movement. It enables detection of safety-related objects above the detection plane of SRS1 and carries out the travel surface detection function.

The mounting positions of the SRS are calibrated with a dedicated calibration tool before use.



Exemplary top view.

Figure 4 – Mounting positions and sensing zones of the SRS and safety-related zones of SRSS



Exemplary side view not corresponding to top view.

Figure 5 – Mounting positions and sensing zones of the SRS and safety-related zones of SRSS

The safety-related zones of the SRSS correspond to the protective stop zone and safeguarded zone of the robot. They are defined by distances S_0 and S_1 respectively from the robot's outer surface, as shown in Figure 4.

NOTE This is not in accordance with informative Annex C of ISO 13482:2014, which references the centre point of the robot and not the outer surface. To prevent confusion for the typical, assumed reader of this document, the calculations are based on concepts of ISO 13855:2010 as referenced in normative Subclause 5.10.8.3 of ISO 13482:2014. Concepts of ISO 13855:2010 are adapted in accordance with the results of an assumed, exhaustive, application specific risk assessment. Existing calculations in accordance with ISO 13855:2010 seem to be developed often under consideration of "high" performance classes like PL d respective SIL 2 and parameters considered out of context (e.g. speed without consideration of direction of movement, stopped hazardous movement when hazardous point is reached or bending over of a human body during movement).

S_0 is a minimum distance between the mobile robot and a safety-related object. It is assumed to be calculated based on concepts of ISO 13855:2010 and application of the specific risk assessment in accordance with ISO 12100 as follows:

$$S_0 = K \times T + C + M = \left(V_{\text{r-stop}} + V_{\text{obj}}\right) \times \left(T_{\text{SRSS}} + T_{\text{r}}\right) + 300\ \text{mm} + M \quad (1)$$

Where $V_{\text{r-stop}}$ is a maximum speed of the robot when initiating a protective stop, V_{obj} is the approaching speed of the object, T_{SRSS} and T_{r} are the response times of the SRSS and the robot respectively, and M is the measurement uncertainty determined in accordance with 4.2.8, which can be half value of the coverage intervals around the measurement distance (for values see Table 2 of this document).

The distance C is an additional distance in millimetres, based on intrusion towards the danger zone prior to actuation of the protective equipment in accordance with concepts of ISO 13855:2010. The value of C is the result of an analysis of potential hazards for the lower limbs. For upper limbs, there is no significant hazard due to the characteristic of the mobile robot.

NOTE 2 If it is significant, an additional stopping distance can be considered when S_0 is calculated.

S_1 specifies the safeguarded zone where the robot is moving with maximum speed $V_{\text{r-reduce}}$ when initiating the safety-related speed control function for speed reduction down to $V_{\text{r-stop}}$. The formula for the calculation is as follows:

$$S_1 = \left(V_{\text{r-reduce}} + V_{\text{obj}}\right) \times \left(T_{\text{SRSS}} + T_{\text{r}}\right) + C + M \quad (2)$$

The safety related zones of the SRSS sensing zone are determined as follows:

S_0 = (300 mm/s + 800 mm/s) × (0,1 s + 0,2 s) + 300 mm + 26 mm = 656 mm

S_1 = (700 mm/s + 800 mm/s) × (0,1 s + 0,5 s) + 300 mm + 55 mm = 1 255 mm

The automation related zone of the SRSS is the union of the sensing zones of the SRS.

4.2.7 Dependability under environmental influences

The SRSS integrator should specify the limits of all relevant environmental influences (see 6.2.5 of IEC TS 62998-1:2019).

In the following, the integrator verified that no failure to danger occurs and normal operation is achieved within the specified limits for the environmental influences of precipitation and direct sunlight in 4.2.1.

NOTE Further information is given in Annex F of IEC TS 62998-1:2019 for environmental influences and the use of environmental classes in accordance with IEC 60721 series.

4.2.8 Safety-related information

The SRSS integrator should specify logic functions performed in a processing unit of the SRSS and should specify the safety-related information provided by the SRSS (see 6.2.6 of IEC TS 62998-1:2019). Examples of safety-related information are given in the following paragraphs.

The SRSS provides safety-related information as output signals. The safety-related information (see Figure 3) of the SRSS consists of:

decision information relating to safety-related function 1, binary;

decision information related to safety-related function 3, binary;

measurement information related to safety-related function 2, n-ary;

confidence information for all safety-related function, n-ary.

The automation-related information of the SRSS output functions consists of:

point cloud for SLAM, n-ary;

The confidence information provided within the information for use as stated by the manufacturer is as follows:

For each SRS the stated performance class is B. The required one for the SRSS is also B.

The stated coverage probability or decision probability is $1 - 10^{-6}$. The required one is determined in accordance with Formula (1) in IEC TS 62998-1:2019 as follows:

> coverage probability or decision probability > 1 – (upper limit PFH corresponding to SRS/SRSS performance class B)/(the application-specific demand rate) = $1 - 10^{-5} / 10 = 1 - 10^{-6}$.

The manufacturers provide results of confidence information of each SRS depending on the detection distance. The value of the coverage interval is determined statistically from the uncertainty of the SRS.

In addition to the information for use provided by the manufacturer, the integrator is performing their own measurements in accordance with Figure 6. The tests are carried out using a test piece with about 5 % reflection value. The experimental results obtained by measuring the uncertainty of SRS1 and 3 and SRS 2 result in a standard deviation of 76,29 mm (SRS1 and 3) at 7 m distance and 48,24 mm (SRS2) at 4 m distance.

Because the coverage interval corresponding to the coverage probability $1 - 10^{-6}$ is calculated as $2 \times 4{,}89\sigma$, assuming that SRS1 and SRS2 use this LiDAR and TOF camera as sensor units respectively, the coverage interval of SRS1 at a distance of 7 m is 2 × 4,89 × 76,29 = 746,10 mm (±373,05 mm) and the coverage interval of SRS2 at distance 4 m is 2 × 4,89 × 48,24 = 471,75 mm (±235,88 mm). These values are below the ones provided by the SRS manufacturer within the information for use. For calculations in 5.2.6, the integrators decide to use the ones stated in Table 2.

Table 2 – Example of confidence information for SRS

Distance [m]	Coverage probability	Coverage intervals of SRS1/3 [mm]	Coverage intervals of SRS2 [mm]
1 m	$1 - 10^{-6}$	51,67	62,89
2 m	$1 - 10^{-6}$	53,43	110,60
3 m	$1 - 10^{-6}$	57,37	232,46
4 m	$1 - 10^{-6}$	72,08	471,75
5 m	$1 - 10^{-6}$	77,06	-
6 m	$1 - 10^{-6}$	106,17	-
7 m	$1 - 10^{-6}$	746,10	-

NOTE For calculation of M in Formulas (1) and (2), the half value in accordance with Table 2 is used under the assumption that a normal distribution can be claimed.

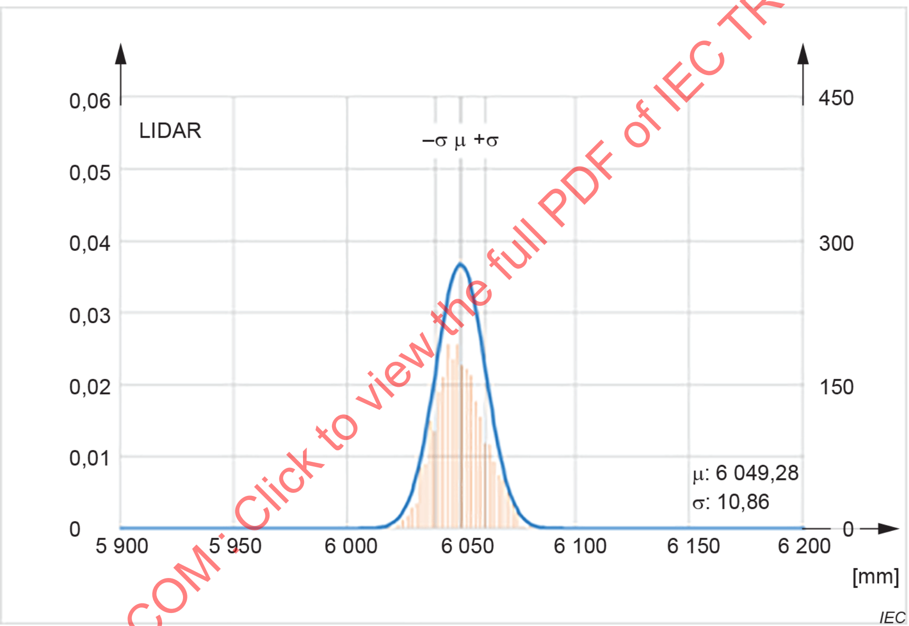


Figure 6 – Examples of measurement data for evaluation of coverage interval

4.2.9 Verification and validation

The SRSS integrator should verify and/or validate the SRSS in accordance with 6.2.3, 6.2.4 and 6.2.7 of IEC TS 62998-1:2019.

A normal operation laboratory test of the safety-related function 1 and 2 as example for verification of an SRSS is given in the following.

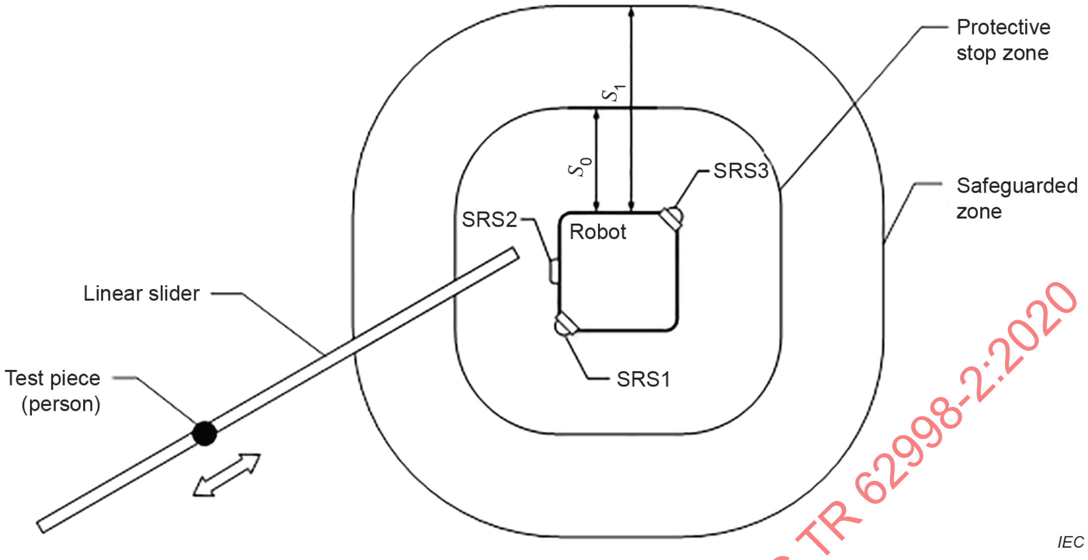
Test setup for normal operation test is as follows:

SRS1, SRS2, and SRS3 are mounted at predefined positions of the robot with the brackets, as defined by the manufacturer;

the safety-related zones described in 4.2.6 are determined as S_0 = 656 mm and S_1 = 1 255 mm;

as described in 4.2.5, a black cylinder with diameter 40 mm, height 200 mm and surface reflectivity 5 % is chosen as the test piece representing safety-related object properties for children.

Figure 7 illustrates the example of the test setup. The linear slider is placed at a location that intersects the protective stop zone and/or the safeguarded zone of the SRSS.



Exemplary top view

Figure 7 – Test setup

Test procedures are as follows:

1) Power on the SRSS.
2) Construct the map to register test equipment such as the linear slider.
3) Place the test piece on the linear slider.
4) Start to move the slider and let the test piece enter the safety-related zones at the maximum relative speed.
5) Record the safety-related information of the SRSS and the motion of the linear slider with timestamps.
6) Power off the SRSS.
7) Change the relative locations of the linear slider and repeat from at least the test piece approaches from the front, left, right, rear of the robot covering all field of views of the different SRS and relevant speeds of the test piece.
8) Analyse the recorded safety related information and the slider motion.

During further verification by the integrator, it was determined that the SRSS can be used within the limits of use as defined by the manufacturer of each SRS.

4.2.10 Information for use of the SRSS

This subclause describes the documentation of the limits of use in accordance with 6.2.2 of IEC/TS 62998-1:2019. Table 3 shows examples for the limit of use of an SRSS documented in the information for use of the SRSS.

Table 3 – Information for use of the SRSS

Clause(s) of IEC TS 62998-1:2019	Overview of information for use to be provided	Information for use of the SRSS
4.3	The supplier should state the SRS/SRSS performance class and the level of safety performance (PL, SIL or SIL CL) and the referenced standard.	The SRSS performance class is B in accordance with IEC TS 62998-1 to achieve the level of safety performance PL b in accordance with ISO 13849-1:2015.
5.2	The SRSS function should be defined by the manufacturer in accordance with general description of Table 2 of IEC TS 62998-1:2019.	Safety-related function 1: to detect persons and hazardous objects in the protective stop zone for initiating the protective stop function specified in ISO 13482:2014, 6.2.2.3. Safety-related function 2: to detect persons and hazardous objects and to provide their positions as safety related information for the safety-related speed control function and/or the hazardous collision avoidance function specified in ISO 13482:2014, 6.4 and 6.5.2.1. Safety-related function 3: to detect the geometry of the travel surface of the robot, which is specified in ISO 13482:2014, 6.5.3. When a travelable surface is observed in the travelling direction of the robot, the robot can move forwards. If the robot moves backwards, the road surface that has already travelled is definitely present, so this function is not required. Automation-related function: to provide a 3D point cloud with timestamp in the robot coordinate system for SLAM.
5.5	The supplier should provide information on the sensing zone(s) if applicable.	Achieved by SRS1 and SRS3 as part of the SRSS. Maximum size is of a radius of 7 000 mm and a viewing angle of 360° horizontally and 0.5° vertically. Achieved by SRS2 as part of the SRSS. Maximum size is of a radius of 4 000 mm and vertical viewing angle of 60° and horizontal viewing angle of 70°. For details, see Figure 4.
5.6	Specification of safety related zones.	The safety-related zone "S_0": corresponds to the protective stop zone of the mobile robot; and is used to perform safety-related function 1 of the SRSS; and is 2-dimensional; 360° with S_0 = 656 mm; 200 mm above ground. The safety-related zone "S_1": corresponds to the safeguarded zone of the mobile robot; and is used to perform safety-related functions 2 of the SRSS; and is 3-dimensional; vertical and horizontal field of view 60°; with S_1= 1 255 mm; 400 mm above ground, and is 2-dimensional; 360° with S_1 = 1 255 mm; 200 mm above ground For details, see Figure 4.
5.7	Specification of automation zones if applicable.	The automation related zone of the SRSS is the union of the sensing zones of the SRS
NOTE As example only the rows 1 to 5 of Table 7 of IEC TS 62998-1:2019 are used.		

4.3 SRSS on cleaning mobile robot

4.3.1 Intended use

The intended use should be determined (see 6.2.1 of IEC TS 62998-1:2019) by the integrator. It is defined by the following selected example items:

1) The mobile robot is a Type 1.2 robot specified in ISO 13482:2014 with a weight of 100 kg and a size of length: 800 mm × width: 800 mm × height: 1 000 mm.

   NOTE 1 In accordance with ISO 13482:2014, a type 1.2 robot is defined as large or not lightweight or fast or with a manipulator.

2) The mobile robot automatically navigates the pavement connecting the university office buildings. The path of the robot is predetermined according to the map created by SLAM technology [1] and physical constraints. The map includes position information for objects that are fixed along the pavement, such as guardrails, building walls, trees, etc. By referring to the map, the robot determines its own restricted space (ISO 13482:2014, 3.18.2) while moving.

3) The mobile robot moves during night-time on non-carriageways where:

   a) campus is closed for public from 2 a.m. to 5. a.m. and cleaning will be done during the night from 2 a.m. to 4 a.m. and only service people should be present;

   b) pavements are smoothly paved with slopes of up to 5° in some areas as shown in Figure 1;

      NOTE 2 There are also stairs where moving of robot is assumed as being suppressed by reliable SLAM technology. The robot is not intended to be used on general pavements which have intersections with carriageways. It is also not intended to run along such a carriageway with an intersection with a downward step towards different floors.

   c) Standing or walking people on the pavements are instructed adults over 18 years with a moving speed between 0 mm/s and 1 600 mm/s if the person enters into the safeguarded zone of a mobile robot.

      NOTE 3 Further information is given in 4.3.4.

4) The mobile robot:

   a) is intended to make a protective stop when a standing or walking person comes into the protective stop zone (see Figure 2);

   b) is intended to reduce the speed when a standing or walking person moves into the safeguarded zone (see Figure 2);

   c) is driven with a speed up to 700 mm/s reduced by the safety-related speed control function down to 300 mm/s;

   d) can reduce within 0,6 s from 700 mm/s to 300 mm/s, and another 0,3 s to reduce to zero speed.

5) Outdoor environmental conditions during operation with:

   a) precipitation up to 10 mm/h;

   b) light interference on the campus during night-time.

4.3.2 SRSS performance class determination

In the chosen approach, using ISO 13482:2014 the required performance level of the safety functions of a Type 1.2 mobile robot is PL d in accordance with ISO 13849-1:2015. The safety functions include the protective stop function, the safety-related speed control function, the hazardous collision avoidance function, and the travel surface detection function, which will be initiated by the SRSS.

The required performance class of the SRSS corresponding to PL d is the sensor performance class D specified in IEC TS 62998-1:2019.

4.3.3 SRS limits of use and SRSS function

The SRSS consists of three SRSs defined by the manufacturer as follows (see Figure 3):

1) SRS1: a 2D LiDAR suitable to be used up to PL d in accordance with ISO 13849-1:2015; SIL 2 in accordance with IEC 62061 and assessed to Type 3 in accordance with IEC 61496-1, which allows the detection of persons. Additional systematic capabilities for the detection of hazardous objects, positions of persons and hazardous objects and persons and the use

under outdoor environmental are assessed in accordance with IEC TS 62998-1:2019. The sensing zone is up to a radius of 7 000 mm and a viewing angle of 270°. The detection capability is given for safety-related objects with the properties: minimum size 40 mm × 40 mm; minimum object reflectivity 2 %; maximum object speed 1 600 mm/s. The response time is 0,05 s. Use in indoor and outdoor environmental conditions is possible within defined limits.

2) SRS2: a TOF camera suitable to be used up to PL d in accordance with ISO 13849-1:2015; SIL 2 in accordance with IEC 62061, which allows the detection of parts of 3D volumes of persons, road surface, and other safety-related objects using 3D imaging technology. The systematic capabilities are assessed in accordance with IEC TS 62998-1:2019. Capable of measuring the position of objects within the 3D sensor coordinate system. The sensing zone is up to 4 000 mm and vertical and horizontal fields of view angles of 60° and 70°. The detection capability is given for safety-related objects with properties: minimum size 40 mm × 40 mm × 40 mm; minimum object reflectivity 5 %; maximum object speed 1 600 mm/s. The response time is 0,05 s. It is possible to distinguish a paved road surface and other objects three-dimensionally. Use in indoor and outdoor environmental conditions is possible within defined limits.
3) SRS3: the same specification as SRS1.

The target applications require four SRSS functions (see Figure 3):

1) Safety-related function 1: to detect persons and hazardous objects in the protective stop zone for initiating the protective stop function specified in ISO 13482:2014, 6.2.2.3.
2) Safety-related function 2: to detect persons and hazardous objects and to provide their positions as safety related information for the safety-related speed control function and/or the hazardous collision avoidance function specified in ISO 13482:2014, 6.4 and 6.5.2.1.
3) Safety-related function 3: to detect the geometry of the travel surface of the robot, which is specified in ISO 13482:2014, 6.5.3. When a travelable surface is observed in the travelling direction of the robot, the robot can move forwards. If the robot moves backwards, the road surface that has already travelled is definitely present, so this function is not required.
4) Automation related function: to provide 3D point cloud with timestamp in the robot coordinate system for SLAM.

4.3.4 Safety-related requirements

The SRSS safety-related requirements should be specified by the integrator (see 6.2.1 of IEC TS 62998-1:2019) based on the intended use. For example, see the requirements defined in Table 4.

Table 4 – Safety-related requirements

Term	Requirement	Details
SRSS performance class	D	See 4.3.2. Intended to be integrated from SRS of the same performance class D
Demand rate of SRSS safety related function(s)	1/h	
SRSS response time	0,1 s	
SRSS detection capability	e.g. Person detection properties: e.g. Person related properties: Sizes representing 18-year-old person in upright position. Minimum reflection value 5 % Speed 1 600 mm/s	See 4.3.5.
SRSS sensing zones	e.g. Safety-related zones 2-dimensional; 360° with S_0 = 766 mm and S_1 = 1 965 mm; 3-dimensional; vertical and horizontal field of view 60°; with S_0 = 766 mm and S_1 = 1 965 mm.	See 4.3.6.

4.3.5 Object classes and physical properties

The integrator should specify the SRSS detection capability in accordance with 6.2.3 of IEC TS 62998-1:2019. The following specific examples are considered.

Object classes to be analysed are:

1) objects used to perform the person detection function:
   a) adult persons from 18 years.
2) objects used to perform the hazardous object function:
   a) not applicable.
3) objects used to perform the automation related function:
   a) landmarks used for navigation.

The properties of a standing or walking employed person moving during night-time will be analysed for the safety-related function 1 performed by SRS1 and SRS3 and safety-related function 2 performed by SRS2.

For safety-related function 2, the limit that SRS2 detects is the forearm of an 18-year-old person. The simplified shape is estimated as a cylinder with a diameter of 40 mm and a length of 200 mm.

NOTE 1 The sizes are based on ISO TR 7250-2:2010. 5th percentile value of the forearm fingertip length is 390 mm, and 147 mm wrist circumference. For simplification, a smaller cylinder is taken in this example as representation.

For safety-related function 1, the lower limbs of an 18-year-old person are used to identify the minimum size. The simplified shape is estimated as cylinder with a diameter of 50 mm in mounting height of SRS1 and SRS3.

NOTE 2 The sizes shown in ISO TR 7250-2:2010 are not representative for the mounting position of SRS1 and SRS3. For simplification, the minimum size of 50mm was taken from IEC TS 61496-4-3 as representative for the lower limbs.

For the safety-related function 3 performed by SRS2 of the SRSS, the travelling surface to be detected is a continuous flat surface or smooth curved surface with a slope of 5° or less in front of the robot.

NOTE 3 SRS1 may detect the road surface as a hazardous object at the entrance to the slope. Other measures might be set in place to prevent a permanent stop of the mobile robot.

The minimum diffuse reflectivity used as representation for an employed person, a hazardous object, and a travel surface is assumed to be 5 % or more at the wavelength used by each SRS.

NOTE 4 The 5 % minimum reflectivity value for persons is taken based on an organizational directive in the university for employed people working during night-time between 2 a.m. and 4.a.m. when the mobile robots are in operation. Clothes are provided by the university and people are instructed.

The speed of employed persons during night-time is considered to be 800 mm/s for safety related-function 1 and 1 600 mm/s for safety-related function 2.

NOTE 5 In this example, it is assumed that, during night-time, employees might recognize mobile robots later and move faster from an unrecognized mobile robot. When a person enters the safety-related zone S1, then additional warning information will be provided by the mobile robot and reduced speed of a person is considered in this example.

For the automation-related function of the SRSS, all objects within the SRSS sensing zone representing reliable, fixed landmarks on the mobile robot's travelling path will be identified within a procedure during bringing into operation.

4.3.6 Sensing zones

The SRSS sensing zones should be specified by the integrator in accordance with 6.2.4 of IEC TS 62998-1:2019.

The mounting position and the sensing zone of each SRS, and the improved safety-related zones of the SRSS after fusion are shown in Figure 4 and Figure 5.

SRS1 and SRS3 are mounted horizontally on the left front and the right rear of the robot respectively at a height of 200 mm from the ground level. By mounting SRS1 and SRS3 to the opposite corners of the robot, it is possible to observe the entire circumference of the robot without blind spots.

SRS2 is mounted at the centre of the front of the robot at a height of 400 mm to measure in the direction of the robot's movement. It enables the detection of safety-related objects above the detection plane of SRS1 and carries out the travel surface detection function.

The mounting positions of the SRS are calibrated with a dedicated calibration tool before use.

The safety-related zones of the SRSS correspond to the protective stop zone and safeguarded zone of the robot. They are defined by distances S_0 and S_1 respectively from the robot's outer surface as shown in Figure 4.

NOTE This is not in accordance with informative Annex C of ISO 13482:2014, which references the centre point of the robot and not the outer surface. To prevent confusion for the typical, assumed reader of this document, the calculations are based on concepts of ISO 13855:2010 as referenced in normative Subclause 5.10.8.3 of ISO 13482:2014. Concepts of ISO 13855:2010 are adapted in accordance with the results of an assumed, exhaustive, application specific risk assessment. Existing calculations in accordance with ISO 13855:2010 seem to be developed often under consideration of "high" performance classes like PL d respective SIL 2 and parameters considered out of context (e.g. speed without consideration of direction of movement, stopped hazardous movement when hazardous point is reached or bending over of a human body during movement).

S_0 is a minimum distance between the mobile robot and a safety-related object. It is assumed to be calculated based on concepts of ISO 13855:2010 and application-specific risk assessment in accordance with ISO 12100 as follows:

$$S_0 = K \times T + C + M = \left(V_{\text{r-stop}} + V_{\text{obj}}\right) \times \left(T_{\text{SRSS}} + T_{\text{r}}\right) + 300\ \text{mm} + M \tag{3}$$

Where $V_{\text{r-stop}}$ is a maximum speed of the robot when initiating a protective stop, V_{obj} is a detected approaching speed of the object, T_{SRSS} and T_{r} are the response times of the SRSS and the robot respectively and M is the measurement uncertainty determined in accordance with 4.3.8. The value of C is the result of an analysis of potential hazards for the lower limbs. For upper limbs, there is no significant hazard due to the characteristic of the mobile robot.

NOTE 3 If it is significant, an additional stopping distance might be considered when S_0 is calculated.

S_1 specifies the safeguarded zone where the robot is moving with maximum speed $V_{\text{r-reduce}}$ when initiating the safety-related speed control function for speed reduction down to $V_{\text{r-stop}}$. The formula for the calculation is as follows:

$$S_1 = \left(V_{\text{r-reduce}} + V_{\text{obj}}\right) \times \left(T_{\text{SRSS}} + T_{\text{r}}\right) + C + M \tag{4}$$

The safety related zones of the SRSS sensing zone are determined as follows:

S_0 = (300 mm/s + 800 mm/s) × (0,1 s + 0,3 s) + 300 mm + 26 mm = 766 mm

S_1 = (700 mm/s + 1 600 mm/s) × (0,1 s + 0,6 s) + 300 mm + 55 mm = 1 965 mm

The automation-related zone of the SRSS is the union of the sensing zones of the SRS.

4.3.7 Dependability under environmental influences

The SRSS integrator should specify the limits of all relevant environmental influences (see 6.2.5 of IEC TS 62998-1:2019). Examples of safety-related information are given in 4.3.8.

In the following, the integrator verified that no failure to danger occurs and normal operation is achieved within the specified limits for the environmental influences of precipitation and light interference on the campus in 4.3.1.

NOTE Further information is given in Annex F of IEC TS 62998-1:2019 for environmental conditions and the use of environmental classes in accordance with the IEC 60721 series.

4.3.8 Safety-related information

The SRSS integrator should specify logic functions performed in a processing unit of the SRSS and should specify the safety-related information provided by the SRSS (see 6.2.6 of IEC TS 62998-1:2019). Examples of safety-related information are given in the following paragraphs.

The SRSS provides safety-related information as output signals. The safety-related information (see Figure 3) of the SRSS consists of:

decision information relating to safety-related function 1, binary;

decision information related to safety-related function 3, binary;

measurement information related to safety-related function 2, n-ary;

confidence information for all safety-related functions, n-ary.

The automation related information of the SRSS output functions consists of:

point cloud for SLAM, n-ary.

The confidence information provided within the information for use as stated by the manufacturer as follows.

For each SRS, the stated SRS performance class is D. The required one for the SRSS is also D.

The stated coverage probability (decision probability) is $1 - 10^{-6}$. The required one is determined in accordance with Formula (1) in IEC TS 62998-1:2019 as follows:

> coverage probability or decision probability > 1 – (upper limit PFH corresponding to SRS/SRSS performance class D) / (the application specific demand rate) = $1 - 10^{-6}$ / $1 = 1 - 10^{-6}$.

The manufacturers provide results of confidence information of each SRS depending on the detection distance. The value of the coverage interval is determined statistically from the uncertainty of the SRS.

In addition to the information for use provided by the manufacturer, the integrator is performing their own measurements in accordance with Figure 6. The tests are done at 3 m using a test piece of about 5% reflection value. The experimental results obtained by measuring the uncertainty of SRS1/3 and SRS2 result in a standard deviation of 5,87 mm (SRS1/3) and 23,77 mm (SRS2).

Because the coverage interval corresponding to the coverage probability $1 - 10^{-6}$ is calculated as $2 \times 4{,}89\sigma$, assuming that SRS1 and SRS2 use this LiDAR and TOF camera as sensor units respectively, the coverage interval of SRS1 at a distance of 3 m is 2 × 4,89 × 5,87 = 57,37 mm (±28,69 mm) and the coverage interval of SRS2 is 2 × 4,89 × 23,77 = 232,46 mm (±116,23 mm). These values are below the ones stated by the SRS manufacturer. For calculations in 4.3.6, the integrators decided to use the ones stated in Table 2.

4.3.9 Verification and validation

As a subset of the required verification and validation activities in accordance with Clause 6 of IEC TS 62998-1:2019, a test of resulting SRSS detection capability is shown as an example.

A normal operation laboratory test of the safety-related function 1 and 2 as example for verification of an SRSS is given in the following.

NOTE For simplification, only the test set up using the 40 mm cylindrical test piece is described. This is only representative for test of safety-related function 2. For test of safety-related function 1, a diameter of 40 mm would be sufficient.

Test setup for normal operation test is as follows:

SRS1, SRS2, and SRS3 are mounted at predefined positions of the robot with the brackets, as defined by the manufacturer;

the safety-related zones described in 4.3.6 are determined as S_0 = 766 mm and S_1 = 1 965 mm;

as described in 4.3.5, a black cylinder with diameter 40 mm, height 200 mm and surface reflectivity 5 % is chosen as the test piece representing safety-relate object properties for children;

Figure 7 illustrates the example of the test setup. The linear slider is placed at a location that intersects the protective stop zone and/or the safeguarded zone of the SRSS.

Test procedures are as follows:

1) Power on the SRSS.
2) Construct the map to register test equipment, such as the linear slider.
3) Place the test piece on the linear slider.
4) Start to move the slider and let the test piece enter the safety-related zones at the maximum relative speed.
5) Record the safety-related information of the SRSS and the motion of the linear slider with timestamps.

6) Power off the SRSS.
7) Change the relative locations of the linear slider and repeat from at least the test piece approaches from the front, left, right, rear of the robot covering all field of views of the different SRS and relevant speeds of the test piece.
8) Analyse the recorded safety-related information and the slider motion.

During further verification by the integrator, it was determined that the SRSS can be used within the limits of use as defined by the manufacturer of each SRS.

4.3.10 Information for use of the SRSS

This subclause describes the documentation of the limits of use in accordance with 6.2.2 of IEC TS 62998-1:2019. Table 5 shows examples for the limit of use of an SRSS documented in the information for use of the SRSS.

Table 5 – Information for use of the SRSS

Clause(s) of IEC TS 62998-1:2019	Overview of information for use to be provided	Information for use of the SRSS
4.3	The supplier should state the SRS/SRSS performance class and the level of safety performance (PL, SIL or SIL CL) and the referenced standard.	The SRSS performance class is D in accordance with IEC TS 62998-1:2019 to achieve the level of safety performance PL d in accordance with ISO 13849-1:2015.
5.2	The SRSS function should be defined by the manufacturer in accordance with the general description of Table 2 of IEC TS 62998-1:2019.	Safety-related function 1: to detect persons and hazardous objects in the protective stop zone for initiating the protective stop function specified in ISO 13482:2014, 6.2.2.3. Safety-related function 2: to detect persons and hazardous objects and to provide their positions and velocities as safety related information for the safety-related speed control function and/or the hazardous collision avoidance function specified in ISO 13482:2014, 6.4 and 6.5.2.1. Safety-related function 3: to detect the geometry of the travel surface of the robot, which is specified in ISO 13482:2014, 6.5.3. When a travelable surface is observed in the travelling direction of the robot, the robot can move forward. If the robot moves backward, the road surface that it has already travelled is definitely present, so this function is not required. Automation related function: to provide 3D point cloud with time stamp in the robot coordinate system for SLAM.
5.5	The supplier should provide information on the sensing zone(s) if applicable.	Achieved by SRS1and SRS3 as part of the SRSS. Maximum size is of a radius of 7 000 mm and a viewing angle of 360° horizontal and 0,5 °vertical. Achieved by SRS2 as part of the SRSS. Maximum size is of a radius of 4 000 mm and vertical viewing angle of 60° and horizontal viewing angle of 70°. For details, see Figure 3.4.
5.6	Specification of safety related zones.	The safety-related zone "S0": corresponds to the protective stop zone of the mobile robot; and is used to perform safety related function 1 of the SRSS, and is 2-dimensional; 360° with S_0 = 766mm; 200mm above ground. The safety-related zone "S1": corresponds to the safeguarded zone of the mobile robot; and is used to perform safety related functions 2 and 3 of the SRSS, and is 3 Dimensional; vertical and horizontal field of view 60°; with S1 = 1 965 mm; 400 mm above ground, and is 2 Dimensional; 360° with S_1 = 1 965 mm; 200 mm above ground. For details, see Figure 4.
5.7	Specification of automation zones if applicable.	The automation related zone of the SRSS is the union of the sensing zones of the SRS

NOTE As an example, only the rows 1 to 5 of Table 7 of IEC TS 62998-1:2019 are used.

5 Application for container handling equipment for harbour logistics

5.1 General

This example covers the integration and installation phase using fusion of three SRS into an SRSS in accordance with Clause 6 of IEC TS 62998-1:2019. The goal is to improve the resulting dependability and the resulting performance class of the SRSS with respect to each SRS. The intended use is safeguarding of an autonomous container-handling equipment (CHE) in a harbour site where oversea containers are handled in a terminal area. The reader should be aware that the following descriptions are not based on comprehensive analysis and are only exemplary for a harbour application with strict management and control.

Figure 8 shows an example of an application of the SRSS mounted on a CHE used to control the motion in the presence of persons.

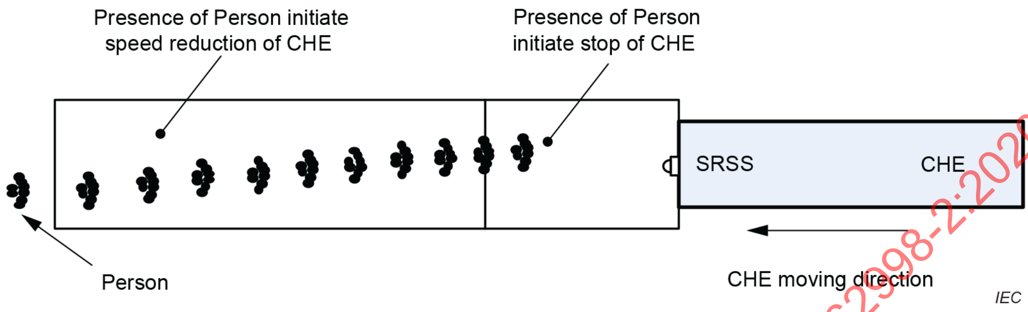


Figure 8 – CHE application

5.2 SRSS for CHE

5.2.1 Intended use

The intended use is determined (see 6.2.1 of IEC TS 62998-1:2019) by the integrator. It is defined by following selected example items:

1) The CHE is used to transport freight containers between a cargo ship and a storage site. It has a weight of 50 tons maximum when loaded and the following size: length: 12,2 m × width: 2,4 m × height: 4,2 m (with container).
2) The CHE autonomously operates in a restricted logistics area and uses odometry and inductive markers to navigate. Pedestrian traffic is restricted to situations when specifically instructed persons enter the site to do maintenance work.
3) Operation is 24 hours, 7 days per week:
   a) maintenance work is done only at specific times (e.g. 3 times per week) or on rare occasions when troubleshooting is required. The application specific demand rate is assumed as 1/day in operating area 1 of the CHE;
   b) the logistic site is separated into two distinct operation areas. Operation area 1 is a loading and storage area. It is a large and flat outdoor area with pathways and adjacent container storage areas;
   c) operation area 2 (see Figure 9) is a transfer area to convey the containers between loading and storage areas. It is a wide and flat outdoor area where pathways, but no storage or handling areas, are present. A CHE can move at higher speed in operation area 2 and person access is further restricted. This results in a lower demand rate compared to operating area 1;
   d) trained persons can be present on the pathways within the operation areas, especially in operating area 1. They are adult persons wearing clothing with reflective markers.

   NOTE 1 Obstacles that could block the direct line of sight between a person and the CHE are not allowed. The CHE monitors only the planned pathway and not the area left and right of its path.

   NOTE 2 For simplification, movement of persons is not considered in the example of the CHE application.
4) The CHE:
   a) is intended to stop completely when a person is at a distance of 4 m or less from the vehicle (in the pathway) in operating areas 1 and 2;
   b) is intended to reduce its speed upon detection of a person in its path in operating area 2. Slowing down starts at a relative distance of 13,32 m (see details below);

c) is driven with a maximum speed up to 20 km/h (5,56 m/s) in operating area 2;
d) is driven at a reduced speed of 9 km/h (2,5 m/s) in operating area 1;
e) route is planned in advance and thus the path taken is precisely known.

NOTE 3 For autonomous CHE, no C type standards are existing. All given requirements are assumed to be based on investigation by the integrator.

NOTE 4 For simplification, only straight movement of the CHE is considered.

5) Specified outdoor conditions for this particular application:
   a) temperature range −20 °C up to +40 °C;
   b) up to 10 mm/h precipitation;
   c) fog up to a density of MOR = 30 m;
   d) ambient light up to 40 000 lx (sunlight).

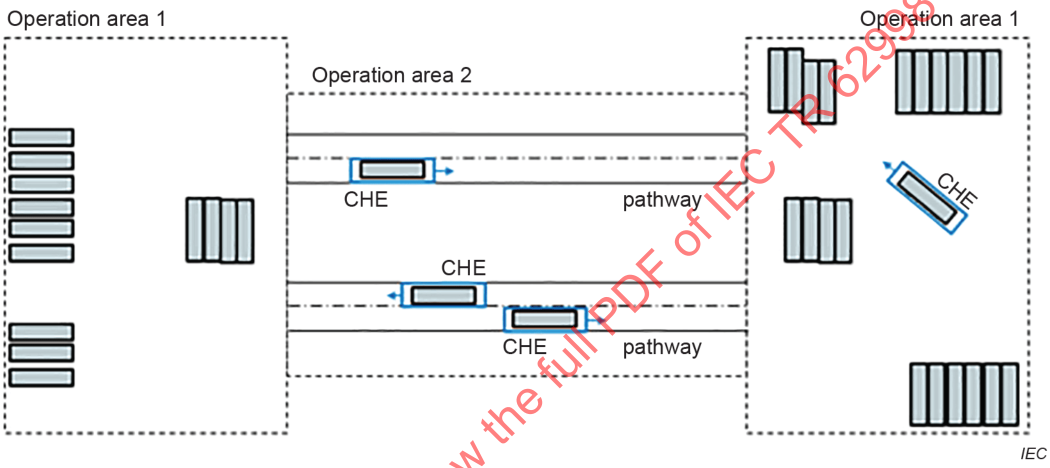


Figure 9 – Operation areas of CHE

5.2.2 SRS limits of use and SRSS function

The SRSS consists of three SRSs defined by the manufacturer as follows:

1) SRS1: A multi-layer laser scanner suitable to be used for risk mitigation up to PL b in accordance with ISO 13849-1:2015, which allows the detection of persons. The systematic capabilities are assessed in accordance with IEC TS 62998-1:2019 for SRS performance class B. It monitors the volume in front of the vehicle and detects objects within a range of 20 m. The horizontal field of view is 180°, the vertical field of view is 15° and the response time is 50 ms. The minimum object reflectivity assumed in this application is 6 %. The minimum size of objects representing a person is given by a cylindrical test piece with a diameter of 200 mm and a length of 600 mm. It provides safety-related information with the following attributes: position (the radial distance and direction), coverage intervals and coverage probability.

   NOTE 1 The minimum object reflectivity of 6 % is justified by the organizational measure that any person present in the operation area does wear reflective clothing and by the fact that the multi-layer detection will cover more than one plane of a person. Considering this specific application, it is very likely a) that a person will not be completely covered with 2 % black garment and b) that availability of the SRS would be inadequate under the specified environmental conditions if the SRS was required to detect 2 % reflectivity objects.

   NOTE 2 The minimum object size of 200 mm (diameter) × 600 mm (length) is justified by the SRS's multi-layer detection, because the detection is not limited by the worst-case assumption that only a single leg is covered by the scanning beam.

2) SRS2: A stereo camera suitable to be used up to PL b in accordance with ISO 13849-1:2015. The systematic capabilities are assessed in accordance with IEC TS 62998-1:2019 for SRS performance class B. It monitors the volume in front of the vehicle and detects objects within a range of 15 m. The horizontal field of view is 90°, the vertical field of view is 50° and the

response time is 40 ms. The minimum object reflectivity of this SRS is 6 %. The minimum size of objects representing a person is given by a cylindrical test piece with a diameter of 200 mm and a length of 600 mm. It provides safety-related information with the following attributes: position (the radial distance and direction), coverage intervals and coverage probability.

3) SRS3: A safety laser scanner suitable to be used up to PL d in accordance with ISO 13849-1:2015 or SIL 2 in accordance with IEC 62061, which detects persons and other safety-related objects at close range. The systematic capabilities are assessed in accordance with IEC TS 62998-1:2019 for SRS performance class D and IEC 61496-3 for Type 3. It monitors the area in front of the vehicle up to a distance of 4 m and has a response time of 0,1 s. The horizontal field of view is 190° and vertically it is a single plane. The specified minimum object reflectivity is 2 %. The minimum size of objects representing parts of a person (lower limbs) is given by a cylinder of a diameter of 70 mm and a length of 400 mm. Objects that are present in a safety-related zone causes SRS3 to send a safety-related stop signal to the CHE control.

The target applications require following safety related functions provided by the SRSS:

Safety-related function A to detect persons in the safety-related zone A to initiate the protective stop safety related function A in operating area 1.

Safety-related function B1 to detect persons in the safety-related zone B1 to initiate the protective stop safety related function B1 in operating area 2.

Safety-related function B2 to detect and localize persons in the safety-related zone B2 to initiate the slow down safety related function B2 in operating area 2.

Safety-related function B2 is used to reduce the CHE speed in operating area 2. If the speed is reduced and the person is still present, then the safety-related function B1 will initiate a protective stop of the CHE.

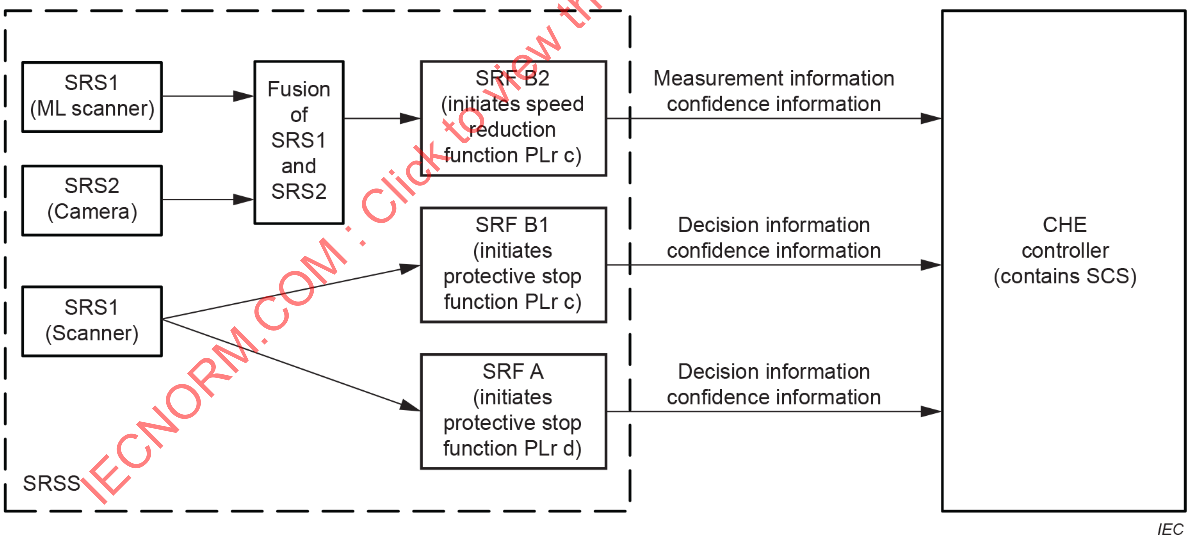


Figure 10 – SRSS structure and safety-related functions

5.2.3 SRSS performance class determination

A risk assessment in accordance with ISO 12100 yields two different PL respective SIL for the SRSS functions related to the two different areas where the CHE is operating.

Operating area 1:

In this area, the possibility of avoidance of the harm is low and the exposure rate is high. This results in a PLr d respective SIL2 for the safety-related function A ("Stop function").

Operating area 2:

In this area, the possibility of avoidance of the harm is high and the exposure rate is low. This results in a PLr C respective SIL1 for the safety-related function B1 ("Stop function") and the safety-related function B2 ("slow-down function").

The required sensor performance class of the SRSS for the safety related function A is D as specified in IEC TS 62998-1:2019, Table 1.

The required sensor performance class of the SRSS for safety related function B1 and B2 is C as specified in IEC TS 62998-1:2019, Table 1.

5.2.4 Safety-related requirements

The SRSS safety-related requirements should be specified by the integrator (see 6.2.1 of IEC TS 62998-1:2019) based on the intended use. For example, see the requirements defined in Table 6.

Table 6 – Safety-related requirements

Term	Requirement	Details
SRSS performance classes	D respective C related to the specific safety-related functions	See 6.2.3 and Figure 10. Performance class C achieved by integration of two SRS of performance class B. Performance class D provided by one SRS of performance class D
SRSS response time (s)	0,2 s (safety related function B2, SRS1 and SRS2 combined) 0,1 s (safety related function A and B1, SRS3)	
SRSS detection capability	e.g. Person-related properties: Adult persons (70 mm × 400 mm for detection of lower limbs and 200 mm × 600 mm for person detection represented by a torso) Minimum reflection value 2 % for lower limbs and 6 % for the torso (see Note 3)	See 6.2.5
SRSS sensing zones	e.g. Safety-related zones Safety-related zone A: 2-dimensional; 190° with S_1 = 4 m; width W_1 = 3 m Safety-related zone B2: 3-dimensional; vertical size: 0,3 m … 2 m; horizontal size: S_2 = 4 m … S_1 = 15 m; width: W_1 = 3 m. Safety-related zone B1: 2-dimensional; 190° with S_1 = 4 m; width W_1 = 3 m	See 6.2.6 and Figure 11 Safety-related zone B2 (safety-related speed reduction zone) does not overlap with safety-related zone B1.

People walking towards CHE or entering from the side into the pathway of the CHE are not considered in this application. If the entering of persons need to be considered, then the sizes of the safety-related zones are different.

5.2.5 Object classes and physical properties

The integrator specifies the SRSS detection capability in accordance with 6.2.3 of IEC TS 62998-1:2019. The following specific examples are considered.

The only relevant object class is "adult person".