Being safe around collaborative and versatile robots in shared spaces

Protocol

Test Safety Related Sensor System

MSD-3

The purpose of this protocol is to extend the validation of the skill "Maintain Safe Distance" when complex safety-related sensor systems (SRSS) are installed within the workcell, by characterizing the SRSS performance. The characterization is based on the measurement of the response time of the system and results accuracy. Results are expressed in human operator position, human operator perimeter violation, human operator movement speed and a true/false detection of the human operator falling to ground.

Readiness Level	Description
6	Protocol is published over the toolkit, under evaluation, and open for community feedback.

COVR is a community effort and values any honest feedback to our services. Please feel free to express your opinion about this protocol. The feedback form is only one click away. Thanks for making COVR even better!

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1 Introduction

In order to maintain a safe distance between human operator and robot in a collaborative workcell or in a shared working scenario, the use of external sensors is required, aimed at detecting the operator position and, in some cases, also the robot pose. When advanced localization or recognition functionalities are required by the specific application, the use of a single sensor can be insufficient; therefore, the design of the safety system can include more sensors, or a network of different sensors. In these conditions, the features of each implemented sensor have an impact on the final performance and it can be useful to characterize the sensor network as a whole before validating the robotic application.

This protocol therefore illustrates how to characterize the performance of a system of sensors featuring different sensing technologies used for the safety of persons in a collaborative robot production environment. A generic safety-related sensors system, called SRSS in the document, can be conceived indeed as an additional safety system that does not interfere with the automatic protection mechanism of the robot.

In order to concretely describe a test protocol for a generic safety-related sensor system, a network of radars and infrared array sensors is considered in this document, as an example. Such a system has no specific applications, but can be implemented in an industrial indoor workplace involving a collaborative robot and a human operator.

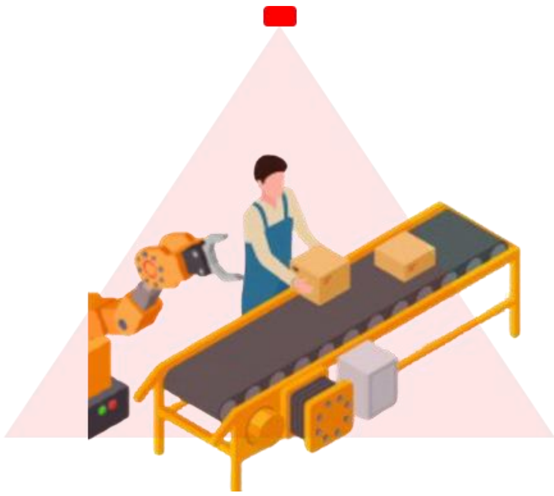


Figure 1 Safety-related Sensor System Human-Robot

1.1 Scope and limitation

This protocol is specifically limited to the following profile:

Skill	Maintain Safe Distance
System	Generic multi-sensor system
Sub-System	-
Domain	Manufacturing, public, consumer, logistics
Conditions	Indoor – factory, warehouse, indoor- public place
Measurement Device(s)	Laser distance sensor, USB camera, laser velocimeter

	Warning
⚠	This protocol supports users only to validate the effectiveness of the skill listed in the profile above. The skill should be a technical measure for the robot system to mitigate the risk of one potentially hazardous situation as identified in the mandatory risk assessment. Consequently, the risk assessment must be done before using this protocol.

1.2 Normative Reference

Before using this protocol, please make yourself familiar with the following regulations and standards referenced by this protocol:

ISO/TS 15066:2016

ISO 13850 (Safety of machinery, Emergency stop function)

ISO 13855 (Safety of machinery, Positioning of safeguards with respect to the approach speeds of part of the human body)

IEC 60204-1 (safety-rated monitored stop)

IEC/TS 62046:2008 (default speed of human)

ISO/IEC Guide 98-3:2008 (evaluating standard uncertainty)

Please consider also of the following regulations and standards, even if this protocol does not specifically refer to them:

EN ISO 10218-1:2011

EN ISO 10218-2:2011

Directive 2006/42/EC

It might be helpful to consider the following regulations and standards, even if they are out of scope:

EN ISO 12100

1.3 Definitions and Terms

Collaborative operation (source:EN ISO/TS 15066)

State in which a purposely designed robot system and an operator work within a collaborative workspace.

Collaborative robot (source:ENISO 10218-2)

A robot designed for direct interaction with a human within a defined collaborative workspace.

Collaborative workspace (source: ISO/TS 15066)

Space within the operating space where the robot system (including the workpiece) and a human can perform tasks concurrently during production operation.

Accuracy (ISO 5725-1)

The closeness of computations or estimates to the exact or true values.

Uncertainty (ISO Guide 98-3)

A parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand.

System integrator

Company or person who created the collaborative robot and brought it into productive operation. The system integrator is responsible for doing the risk assessment and must ship the collaborative robot with an instruction manual, which refers to the residual risks of the robot system.

Application (source: EN ISO 10218-2)

Intended use of the robot system, for instance, the process, the task and the intended purpose of the robot system (for instance, spot welding, painting, assembly, palletizing).

Distance measuring system

System to measure the one-dimensional distance over time between two objects

Response Time

The time from a change of a measured physical property until the corresponding change of the safety related information provided at the output unit

2 Concept and Objectives

The aim of the present protocol is to provide a further generalization to validate applications, which use the skill "Maintain safe distance". The protocol is indeed focused on the characterization of a generic SRSS implemented in a robotic workcell or in a shared working scenario designed for the co-presence, and even collaboration, of robots and human operators.

The system integrator in the design phase of a process involving a robot sharing the workplace with a human operator shall initially perform a risk assessment for the application. After that, sensor safety requirements are defined. The choice of sensors shall consider the safety related function, the choice of the collaborative method as described in the ISO/TS 15066, the robot application, the presence of human operator and their actions, functionalities needed to reduce the risk and the detection capability. Depending on risks identified, their seriousness, frequency of exposition, the probability, and the possibility of limitation, sensor level of safety performance (SIL level) is defined, as described in the standard IEC 62061.

The SRSS monitoring target is the human operator sharing the collaborative workplace with a robot. Practical examples are based on a multi-sensor platform, composed by a network of infrared arry passive sensors and FMCW Radars, transmitting data to a processing unit. In such a combined system, data acquired by sensors can be pre-processed by an appropriate processing unit in order to transmit only some information (such as the localization coordinate of a detected object in the sensor reference axes), or transmitted as full raw-data, for example radar complex samples or infrared thermal maps.

The system can be validated by testing different functionalities that are considered relevant for the specific robotic application. The testing strategy regarding the following "functions" in particular are described in this protocol:

1. Human operator localization;
2. Perimeter Safeguarding;
3. Human operator speed estimation;
4. Human Fall Detection.

The first function detects the presence of the human operator in the sensing zone and estimates the position coordinates. The second function detects the passing of the monitored perimeter by the human operator. The third function estimates the speed and the direction of a moving human operator in the sensing zone. The fourth function detects the fall of a detected human operator to the ground.

The last three functions can output a binary output, true/false, setting a threshold line for the perimeter safe-guarding, a threshold for the speed estimation, and a threshold for the fall detection. Thresholds can be tested during the calibration phase. The localization function can be used for the integration in a spatial monitoring system for the real-time computation of the separation distance of the human operator from the robot. In this case the output is a two-dimensional coordinate in the x-y plane.

The aim of installing a SRSS is to (ISO/TS 15066):

- Implement an automatic safety-rated monitored stop, in order to stop or decelerate (stop category 2 in accordance with IEC 60204 -1) the COBOT when the operator enters the collaborative workspace;
- Implement a speed and separation monitoring method with the robot and the operator moving concurrently inside the collaborative workspace.

The first method is used for example with perimeter protection in the case of sharp objects manipulated on the production lines, or in the case of fast and high payload robots. The second method can be used in workplace where human-robot collisions are possible but should be avoided and/or limited.

2.1 Hazardous Situations

The risk assessment specifies under which hazardous situations the robot could operate. The validation measurement determines whether the applied safety skill (and ultimately the chosen safety functions) mitigates the risk sufficiently.

2.2 Target Behavior and Metrics of the Safety Skill

The target behavior of the skill "Maintain safe distance" to be validated is the capability to stop or decelerate the robot if the safety distance between the AGV and the safety-related object is below the threshold specified in the risk assessment, or alternatively if the human operator violates a safety perimeter around the robot arm. To this aim, this protocol shows how to assess SRSS accuracy.

Depending on the working scenario, further target behaviors to be validated is to stop or decelerate the robot if the human operator speed in the collaborative workspace is above a threshold or in the case of human falling to the ground after an accident caused or not by the robot.

Relevant metrics are the following:

- Human operator localization: **accuracy** evaluated as the absolute positioning error in [mm], **response time** in [ms];
- Perimeter Safeguard: **accuracy** evaluated as the distance in [mm] of the human operator from the perimeter in the precise moment the perimeter violation is detected, **response time** in [ms] as the time of arrival of the detection since the human operator has passed the perimeter, **false positive probability**;
- Human Speed estimation: **accuracy** evaluated as the absolute speed error in [mm/s], **response time** in [ms];
- Fall Detection: **missing detection capability**.

The assessed features of the SRSS can be then used for the application of the following formula, described in the technical specification ISO/TS 15066, to be applied to the whole system to determine the minimum separation distance between the robot and the operator at a time t_0:

$$S_p(t_0) = S_h + S_r + S_s + C + Z_r + Z_d$$

The formula defines the protective separation distance between the human operator and the robot S_p as the sum of various terms. The SRSS affects the formula term Z_d with accuracy errors, and the terms S_h, S_r, and S_r with the reaction time T_r. S_h, S_r, and S_r are defined as “the contribution to the protective separation distance attributable to the operator’s change in location”, “the contribution to the protective separation distance attributable to the robot system’s reaction time” and “the contribution to the protective separation distance due to the robot system’s stopping distance”, respectively, and can be obtained by the formulas:

$$S_h = \int_{t_0}^{t_0+T_r+T_s} v_h(t)dt$$
$$S_r = \int_{t_0}^{t_0+T_r} v_r(t)dt$$
$$S_s = \int_{t_0+T_r}^{t_0+T_r+T_s} v_s(t)dt$$

In which T_r represents the stopping time of the robot (the “safeguard” stop), and v_h, v_r and v_s are the velocities of the operator, the robot and the robot while stopping, respectively. If the velocity of the operator is monitored, the term v_h shall take into account the SRSS accuracy, evaluated as hereafter described, otherwise the value of 1.6 m/s must be considered, as per the standards.

Once the SRSS performance are assessed by this protocol, a further, comprehensive validation using a protocol must be performed to finally validate the whole collaborative task.

Note: The fall detection is a function not directly involved with the separation distance concept, but it can be useful in order to hurry an assistance operation inside the collaborative workplace after an incident causing the human fall to the ground, by automatically stopping the robot and activating an alarm, but it also can be useful to prevent collisions with the robot or other items caused by the unusual position of the human operator and his impossibility to rapidly move away. The response time in this case is not a significant metric because it depends on the seriousness of the accident and not on the collaborative robot movement or collision risks.

3 Conditions

Since the SRSS can be different and used in different applications and conditions, the integrator shall evaluate the condition compatibility with sensors characteristics and performance.

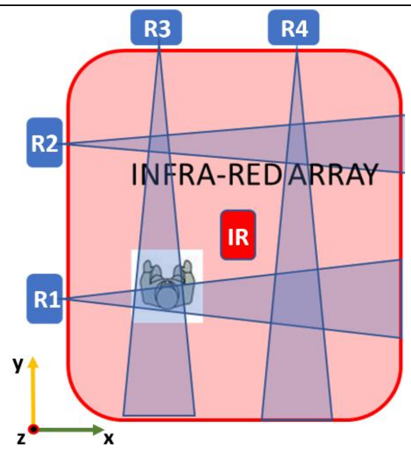
3.1 System

No robotic systems are required for protocol application. In the complete collaborative application, the system can be:

- A robotic arm, with different functionalities;
- A moving robot in a limited area.

Furthermore, the configuration of the SRSS must be described using the table in Annex A, as per the following example.

Example: SRSS Configuration

<table>
<tr><td colspan="2">SRSS Architecture</td></tr>
<tr><td>Main features</td><td>Layout</td></tr>
<tr><td>Total area: $20m^2$
Ceiling Height: $5m$
Contour: Rectangular, $4m * 5m$
List of sensors:
• 4x FMCW Radar sensors
• 1x Infra-red array</td><td>
</td></tr>
</table>

Sensor Details	
Sensor IR	
Manufacturer	The Safety Sensor Company 1
Model / type	Sensor IRab
Short description	Infra-red array sensor
Position in the workspace	$x = 2.5\text{ m}, y = 2.5\text{ m}, z = 4\text{ m}$
Mounting and orientation	Ceil mounted, orientation: $-\vec{z}$
Sensor R1	
Manufacturer	The Safety Sensor Company 2

Model / type	Sensor R1bc
Short description	FMCW radar
Position in the workspace	$x = 0\ \mathrm{m}, y = 1.5\ \mathrm{m}, z = 1.2\ \mathrm{m}$
Mounting and orientation	Wall mounted, orientation: $\vec{x}$
Sensor R2	
…	

3.2 Environment

Environmental conditions may influence the SRSS skills performance, depending on the implementation and the sensing technology. In general, the system should operate under the same conditions, as it will be in its real application. Expected/known environmental characteristics, such as the presence of smog, fog, gas, high level of electro-magnetic fields and/or metallic obstacles must be replicated for the validation measurement.

4 Setup

4.1 Test Arrangement

A laser distance sensor will be used for test execution. Use a carriage with a reflector mounted on a pole fixed to the center of the carriage in order to measure the distance between the human operator and anypoint in the sensing zone.

A USB camera will be used for test execution. Connect the camera to a PC and use a video recording software with the capability to label each frame with a timestamp.

A Laser Velocimeter with high accuracy and sampling rate will be used for tests execution. Since data of the instrument will be compared directly with data of the SRSS the velocimeter shall be a class of precision higher than the SRSS.

4.2 Sensing devices

The details of the used sensors has to be reported in the table in Annex A. Sensors must comply with the minimum requirements according Table 1.

Table 1: Requirements for the sensing devices

Sensor	Requirement	Minimum	Recommended
Laser distance sensor	Resolution [mm]	0.5	0.1
Laser distance sensor	Sampling rate [kHz]	1	
Laser velocimeter	Resolution [m/s]	0.05	0.03
Laser distance sensor	Sampling rate [kHz]	1	
USB camera	Sampling rate [Hz]	30[1]	240

[1] A higher value allows to assess the T_r with a higher resolution. The T_r will be indeed rounded up accordingly. **Example:** USB camera with 60 Hz; the T_r will be assessed with a resolution of 34 ms (1/30), rounded up.

Example: Sensing devices

Feature	Laser distance sensor	Laser velocimeter	USB camera
Manufacturer and type	Sensor Company, LDS	Sensor Company, LV	Sensor Company, USBC
Resolution	$0.1\ \mathrm{mm}$	$0.025\ \mathrm{m/s}$	$-$
Sampling rate	$1.5\ \mathrm{kHz}$	$1.5\ \mathrm{kHz}$	$-$
Frame per second	$-$	$-$	$120\ \mathrm{Hz}$
Recorded area	$-$	$-$	$\approx 4\ \mathrm{m}^2$

4.3 Data Acquisition

The setup for data acquisition must comply with the following steps:

- Connect the SRSS processing unit to the field bus connector to the PC and start a continuous acquisition;
- Connect the camera to the video recording PC;
- Check the time synchronization between all PCs.

5 Procedure

5.1 Test Plan

For each function, a validation test has to be planned. Tests are generic, they shall be adapted to the specific application, the user must test each possible hazard situations as recorded by the risk assessment. Tests are intended for the validation of a generic SRSS composed by sensors of different technologies.

Sensing zones in all tests are assumed to be square in shape, if a collaborative workplace has a more complex geometry divide it into squares and execute tests for each square.

As described in Section 3, environmental conditions affect the performance of sensors depending on their technology, if the application involves harsh environmental conditions the integrator shall repeat the test in that condition, in order to verify if the variation of the specific function performance still satisfy the separation distance formula and the risk assessment requirements.

TEST	DESCRIPTION	METRIC
Localization Accuracy	Evaluating the distance between expect position coordinates and estimated position coordinates	Localization error $[\mathrm{mm}]$
Localization Response Time	Evaluating the time difference between the human operator stop in a new position and the arrival of the position coordinates within the accuracy range	Response Time $[\mathrm{ms}]$
Localization Sensing area	Accuracy test repeated at the border of the expected area, computation of the resulting area	Area $[\mathrm{m}^2]$

Perimeter Safeguard Positive	Evaluating the distance between the perimeter and the human operator coordinates after passing the perimeter and the arrival of the alarm signal. Evaluating the time difference between the passing of the perimeter and the arrival of the alarm.	Distance [mm] Response Time [ms]
Perimeter Safeguard Negative	Checking the effect of the localization accuracy on the skill as false alarms generation	True/false
Movement Speed Accuracy	Evaluating the difference between speed measurement from a laser velocimeter and the estimation of the SRSS	Speed error [mm/s]
Movement Speed Respone Time	Evaluating the time difference between the human operator stop after moving along a path and the arrival of the speed estimates from the SRSS equal to 0 within the accuracy range	Response Time [ms]
Fall Detection		True/false
Fault Test	Checking the safety design as required by IEC 61508 is correct, the communication loss with a sensor shall force the SRSS to a safe-state	True/false
Unexpected Environment	Checking an unexpected local environment condition such as condensation, vapor, dust, smoke, obstructing the sensor. The SSR shall enter the safe-state in that case.	True/false

5.2 Preparation

5.2.1 Setup

The SRSS needs two main preliminary steps before executing tests:

- Calibration;
- Alignment.

Algorithms of each sensor must be calibrated acquiring data from the empty sensing zone before entering the normal operating state.

The alignment step is needed to define common spatial reference axes and a synchronized timeline in order to apply a correct data fusion. The spatial alignment establishes a conversion rule from sensor frame to the global frame. Global frame coordinates may be referred to a fixed point in the sensing zone, for example a corner, or the base of the robotic arm. The reference transformation may imply a translation and a rotation.

The perimeter safe-guard validation tests require the definition and transmission to the SRSS of the perimeter coordinates, as interlinked lines. In order to compensate the localization measurement error, the perimeter shall be enlarged in the perpendicular direction of an amount equal to the accuracy. A calibration dedicated only to this function can be limited to the sensing zone on the area just around the perimeter.

The fall detection skill calibration requires no alignment steps since localization and spatial referencing is not needed.

5.2.2 Environmental Conditions

Environmental conditions potentially affecting the validation results can be diffused in the whole space or local, surrounding only a single sensor.

For each test the ambient temperature, the humidity, the visibility and the compound decreasing the visibility shall be reported.

The report form in the Annex shall be used to document these conditions.

5.3 Test Execution and data analysis

5.3.1 Localization test

The localization test shall assess the accuracy and response time, and sensing zone of the SRSS. A series of localization tests are performed with a human operator in different position in the sensing zone:

- The laser distance sensor is placed at a certain position $P_D = [x_D, y_D]$ with an α orientation with respect to the global frame;
- The human operator moves to a position P_h^R and stop;
- The measured position coordinates in the global frame $P_h^S = [x_S, y_S]$ are read from the SRSS, with a high frequency polling time;
- The distance d_L is acquired by the laser distance sensor;
- Repeat the sequence for different positions (at least 3).

With reference to Figure 2, for each acquisition, the reference position coordinates $P_h^L = [x_L, y_L]$ are obtained by the vector sum of the position of the laser and the distance value read d_L:

$$\begin{bmatrix} x_L \\ y_L \end{bmatrix} = \begin{bmatrix} x_D \\ y_D \end{bmatrix} + d_L \begin{bmatrix} \cos\alpha \\ \sin\alpha \end{bmatrix}$$

The module of the difference between the two positioning vectors is the measurement error of the test E_{acc}, as per the following equation:

$$E_{acc} = \sqrt{(x_L - x_R)^2 + (y_L - y_R)^2}$$

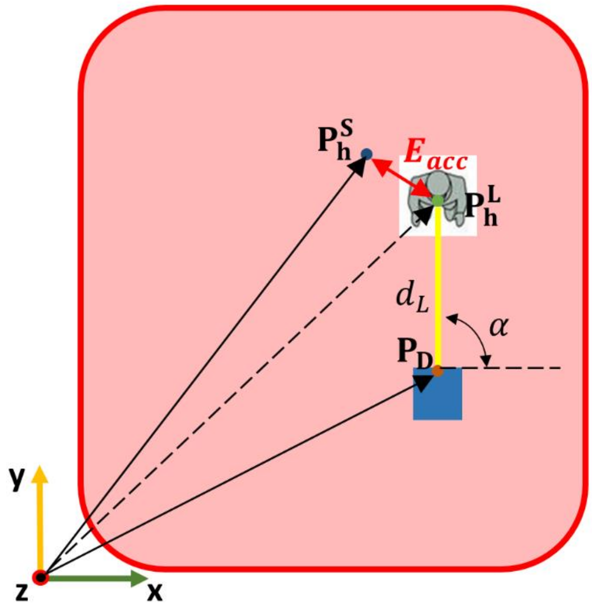


Figure 2 Calculation of the measurement error E_{acc} for the Localization function

If required for the selected uncertainty evaluation method, compute the average value $\overline{E_{acc}}$, the variance Var and maximum error E_{acc}^{max}. The measurement uncertainty has to be obtained derived from the accuracy error. For instance, according to the ISO guide 98-3, it can be obtained by the following equation:

$$U_{acc} = E_{acc}^{max}/\sqrt{3}$$

The obtained value can be assigned to the term Z_d. Report the procedure in the dedicated table in the Annex.

Example: Uncertainty calculated for a SRSS

Localization Test / Position uncertainty				
Trial	**1**	**2**	**3**	**…**
$\boldsymbol{P_h^L}$	$[500, 1100]$ mm	$[-2000, 200]$ mm	$[750, 800]$ mm	
$\boldsymbol{P_h^S}$	$[530,1050]$ mm	$[-2050, 180]$ mm	$[790, 840]$ mm	
$\boldsymbol{E_{acc}}$	58 mm	54 mm	57 mm	
$\boldsymbol{\overline{E_{acc}}}$	56 mm			
$\boldsymbol{Var}$	3 mm			
$\boldsymbol{E_{acc}^{max}}$	58 mm			
$\boldsymbol{U_{acc}}$	33 mm	**Methodology**	Type B, according to ISO guide 98-3	

The response time is tested by acquiring the position change of the human operator with the camera installed on a PC and a video capture software at the same time of the data coming from the SRSS:

- The video recording PC and the PC reading data from the SRSS are time synchronized (i.e. with a Network Time Protocol server);
- The acquiring software starts recording the video;
- The data coming from the SRSS is stored or plotted on a chart;
- The human operator moves to a new position and then stops;

- Register timestamp t_V of the frame corresponding to the human operator stop in a new position;
- Register time t_S in which the SRSS detects the human in the new position;
- Repeat the sequence for different positions (see below).

The difference $E_t = t_V - t_S$ is the result of each trial. Finally compute the average, variance and maximum error. The test can be repeated with the human operator moving to the limit of the sensing zone in the positions shown in the Figure 3 in order to verify also the sensing zone perimeter is as expected; as shown in the figure, for a rectangular area, 9 different acquisitions are expected. The E_t^{max} will correspond to the highest E_t found in the different acquisitions; T_r can be assumed equal to E_t^{max}.

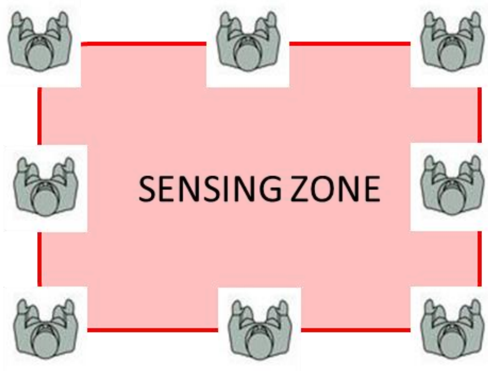


Figure 3: Validating the sensing zone area

Example: Response time observed for a SRSS with a rectangular supervised working area

Localization Test / Response time			
Position	t_S [hh:mm:ss]	t_V [hh:mm:ss]	E_t [ms]
1	00:24:52.349	00:24:52.475	126
2	00:27:35.892	00:27:36.080	188
3	00:30:47.952	00:30:48.123	171
4	00:34:12.365	00:34:12.521	156
5	00:37:36.985	00:37:37.098	113
6	00:39:14.237	00:39:14.424	187
7	00:43:91.542	00:43:91.687	145
8	00:45:37.284	00:45:37.459	175
9	00:48:64.862	00:48:65.048	196
E_t^{max} [ms]	196		

The accuracy and the response time can be combined in the formula (1) of the ISO/TS 15066 with

$$Z_d = U_{acc}$$

and

$$T_r = E_t^{max} \quad .$$

5.3.2 Perimeter Safeguard Test

The perimeter safe-guarding test shall verify that the accuracy, the response time and the perimeter coverage of the SRSS are within the expected values.

Two kind of tests shall be executed, a positive test activating the safeguard alarm, and a negative test avoiding the safeguard alarm at the perimeter border. The possibility of highlighting the safeguarded area, i.e. with ground decals, should be considered to support the personnel involved in the test

The positive test shown in the Figure 4 has the following steps:

- Place the laser distance sensor within the safeguarded area, sensing towards the perimeter at a known distance d_P;
- A human operator starts moving from outside the perimeter into it, towards the distance meter;
- As soon as the safeguard detection is received by the polling software the test ends;
- The test is successful if the safeguard alarm has been raised by the SRSS;
- The response time can be calculated with the same method of the chapter 5.3.1 using the camera;
- The accuracy E_{acc} is represented by the distance of the human operator from the perimeter when the alarm is received from the SRSS, measured with the laser distance sensor as difference between the distance of the laser from the perimeter d_P and the acquired distance d_L (see Figure 4);

$$E_{acc} = d_P - d_L$$

- The test is repeated for different positions (at least one per meter of perimeter length) along the perimeter starting from the extreme points and covering each corner.

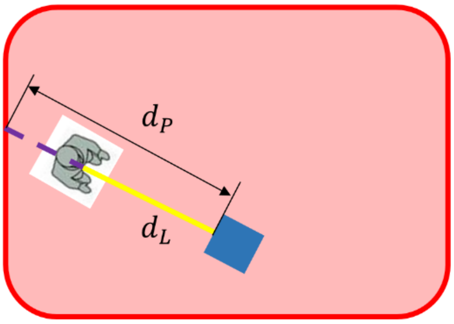


Figure 4: Calculation of the error related to the Perimeter safeguarding function

The maximum E_{acc} obtained in all the trials will affect the actual safeguarded area: depending on the specific implementation and requirements, either the sensors are to be adjusted in order to supervise a wider area (enlarged in all directions by a quantity equal to E_{acc}^{max}), or, keeping the same configuration, the actual safeguarded area must be considered smaller (shrank in all directions by a quantity equal to E_{acc}^{max}).

The response time can be calculated as described for the localization function and affects the formula (1) in ISO/TS 15066 likewise.

The negative test shown in the Figure 5 has the following steps:

- The human operator moves from outside the perimeter towards it stopping just before passing it and then goes back;
- The test is successful if the safe-guard alarm is not raised by the SRSS;
- Repeat the test in all the zones of the perimeter (at least one trial per two meters of perimeter length);
- The test can be considered passed if no false positives are detected during the test, , otherwise a new calibration of the system should be considered.

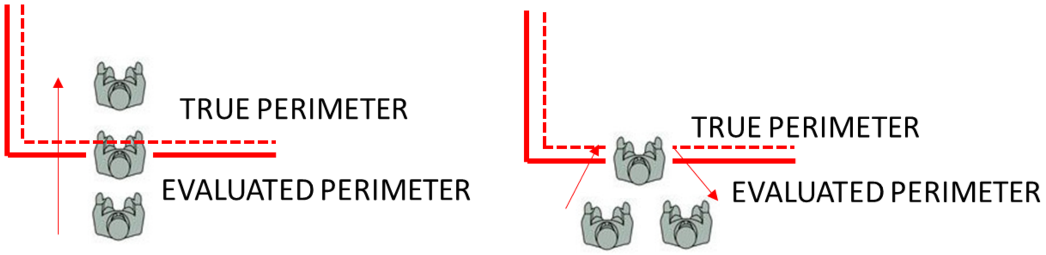


Figure 5: Perimeter safe-guard Positive Test (left) and Negative Test (right)

5.3.3 Speed Estimation Test

The speed estimation test shall verify the accuracy and the response time of the SRSS are within the expected values. The speed estimation accuracy is evaluated following these steps:

- Start the acquisition of the laser velocimeter;
- Start the acquisition of the SRSS;
- The human operator starts moving and then stops;
- The difference between the maximum speed acquired with the laser velocimeter v_h^V and the maximum speed acquired with the SRSS v_h^S is the test result $E_{acc,v}$;
- The test must be repeated at least three times;
- The measurement uncertainty $U_{acc,v}$ can be obtained with a process similar to the localization function.

When the velocity acquired by a SRSS v_h^S is used for the calculation of the equation (1) in ISO/TS 15066, the velocity value to be considered is affected by this uncertainty as follows:

$$v_h = v_h^S + U_{acc,v}$$

5.3.4 Fall Detection

The fall detection skill validation test can be executed with the human operator squatting down to the ground. The test can be executed with the camera as described in the chapter 5.3.1 in order to estimate the response time. The test can be repeated in the workplace adding some unexpected heat sources degrading the skill as described in the risk assessment. Heat sources outside the line of sight of the human operator shall not interfere with the detection capability.

5.3.5 Other tests

The standard IEC 62998-1 requires some other tests to qualify a SRSS:

- Routine tests;
- Endurance tests;
- Maintenance tests.

The test can per periodically executed repeating tests described above, in order to evaluate the performance degradation over the time.

In order to evaluate the safety function in the case of hardware faults or data transmission failure the SRSS can be tested by disconnecting a single sensor used in a redundant operating mode from the power source. The SRSS shall enter the safe-state. The test shall be repeated for each sensor of the SRSS. This test shall be planned in the maintenance test plan.

In order to evaluate a typical unexpected but very likely situation a single sensor of the SRSS can be obscured with a metal plate just in front of the sensor. The SRSS shall enter the safe-state. The test shall be repeated for each sensor of the SRSS. Even if radar sensors are declared to work without obstacles between them and the human operator in the sensing zone obscuration can be caused by grime, dust or condensation.

Repeat the corresponding skill test for each sensor and for each potential obstructing source, as described in the risk assessment, using for example a smoke-simulator spray and evaluating the effect on the detection capability. Degraded accuracy and response time shall be reported in the SRSS characteristics.

5.4 Report

Tests results must be reported tables described in the annexes 6.1. For each skill and for each environment/scenario considered, a table must be compiled. Different sensors combination, installation places and environment conditions can be compared to obtain the optimal SRSS layout.

Use the last section in the form to recall the overall result of the text.

Example: SRSS test final report

Functions	**Test result**
Localization	$U_{acc} = 33\ \mathrm{mm}$ $E_t^{max} = 126\ \mathrm{ms}$
Perimeter safe-guarding	$E_{acc}^{max} = 62\ \mathrm{mm}$ $E_{t,per}^{max} = 141\ \mathrm{ms}$
Speed estimation	$U_{acc,v} = 0.2\ \mathrm{m/s}$
Fall Detection	PASSED

6 Annex

6.1 Report Form

Use the form on the next pages to record the data for each test.

Setup

SRSS Configuration

SRSS Architecture	
Main features	**Layout**

Sensor Details	
Sensor 1	
Manufacturer	
Model / type	
Short description	
Position in the workspace	
Mounting and orientation	
Sensor 2	
…	

Sensors for the test

Feature	**Laser distance sensor**	**Laser velocimeter**	**USB camera**
Manufacturer and type	Sensor Company, LDS	Sensor Company, LV	Sensor Company, USBC
Resolution			
Sampling rate			
Frame per second			
Recorded area			

Miscellaneous

Environment	
Temperature	
Humidity	
Fog, Vapor, Gas, Condensation, Smoke	
Local Grime	
Potential Sensors Obstructions	

Localization Test

Localization Test / Position uncertainty				
Trial	**1**	**2**	**3**	**…**
d_P				
d_L				
E_{acc}				
$\overline{E}_{acc}$				
Var				
E_{acc}^{max}				
U_{acc}		**Methodology**		

Localization Test / Response time			
Position	t_S **[hh:mm:ss]**	t_V **[hh:mm:ss]**	E_t **[ms]**
1			
2			
3			
…			
E_{acc}^{max} **[ms]**			

Perimeter Safe-guard test

Perimeter Safe-guard Positive Test / Position uncertainty				
Trial	**1**	**2**	**3**	**…**
P_h^L				
P_h^S				
E_{acc}				
E_{acc}^{max}				

Perimeter Safe-guard Positive Test / Response time			
Position	t_S **[hh:mm:ss]**	t_V **[hh:mm:ss]**	E_t **[ms]**
1			
2			
3			
…			
E_{acc}^{max} **[ms]**			

Perimeter Safe-guard Negative Test	
Position	**Result**
1	
2	
3	
…	
PASS	

Speed Estimation test

Speed estimation Test				
Trial	**1**	**2**	**3**	**…**
v_h^S				
v_h^V				
$E_{acc,v}$				
$< E_{acc,v} >$				
Var				
$E_{acc,v}^{max}$				
$U_{acc,v}$		**Methodology**		

Fall Detection test

Fall detection Test	
Position	**Result**
1	
2	
3	
…	
PASS	

Test summary

Functions	**Test result**
Localization	
Perimeter safe-guarding	
Speed estimation	
Fall Detection	
…	