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Robotics — Performance criteria and related test methods for service robots —

Part 2:
Navigation

Robotique — Critères de performance et méthodes d'essai correspondantes pour robots de service —

Partie 2: Navigation

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 299, *Robotics*.

This second edition cancels and replaces the first edition (ISO 18646-2:2019), which has been technically revised.

The main changes are as follows:

— Clauses 8 to 10 have been added for path deviation, narrow passage and mapping accuracy.

A list of all parts in the ISO 18646 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is intended to specify performance criteria and test methods for navigation of mobile service robots. It defines performance characteristics, describes how they are specified and recommends how to test them.

The characteristics for which test methods are given in this document are those considered to affect robot performance significantly. It is intended that the reader of this document selects which performance characteristics are to be tested, in accordance with the specific requirements.

The performance criteria specified in this document are not intended to be interpreted as the verification or validation of safety requirements.

Robotics — Performance criteria and related test methods for service robots —

Part 2:
Navigation

1 Scope

This document describes methods of specifying and evaluating the navigation performance of mobile service robots. Navigation performance in this document is measured by pose accuracy and repeatability, ability to detect and avoid obstacles, path deviation, narrow passage, and mapping accuracy. Other measures of navigation performance are available but are not covered in this document.

The criteria and related test methods are applicable only to mobile platforms that are in contact with the travel surface. For evaluating the characteristics of manipulators, ISO 9283 applies.

This document deals with indoor environments only. However, the depicted tests can also be applicable for robots operating in outdoor environments, as described in Annex A.

This document is not applicable for the verification or validation of safety requirements. It does not deal with safety requirements for test personnel during testing.

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.

ISO 7176-13, *Wheelchairs — Part 13: Determination of coefficient of friction of test surfaces*

3 Terms and definitions

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

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
robot
programmed actuated mechanism with a degree of autonomy to perform locomotion, manipulation or positioning

Note 1 to entry: A robot includes the control system.

Note 2 to entry: Examples of mechanical structure of robots are manipulator, *mobile platform* (3.3) and wearable robot.

[SOURCE: ISO 8373:2021, 3.1]

3.2
mobile robot
robot (3.1) able to travel under its own control

Note 1 to entry: A mobile robot can be a *mobile platform* (3.3) with or without manipulators.

Note 2 to entry: In addition to autonomous operation, a mobile robot can have means to be remotely controlled.

[SOURCE: ISO 8373:2021, 4.15]

3.3
mobile platform
assembly of the components which enables locomotion

Note 1 to entry: A mobile platform can include a chassis which can be used to support a *load* (3.6).

Note 2 to entry: A mobile platform can provide the structure by which to affix a manipulator.

Note 3 to entry: Mobile platform following a predetermined *path* (3.14) indicated by markers or external guidance commands, typically used for logistic tasks in industrial automation is also referred to as Automated Guided Vehicle (AGV) or Driverless Industrial Truck. Standards for such vehicles are developed by ISO/TC 110.

[SOURCE: ISO 8373:2021, 4.16]

3.4
service robot
robot (3.1) in personal use or professional use that performs useful tasks for humans or equipment

Note 1 to entry: Tasks in personal use include handling or serving of items, transportation, physical support, providing guidance or information, grooming, cooking and food handling, and cleaning.

Note 2 to entry: Tasks in professional use include inspection, surveillance, handling of items, person transportation, providing guidance or information, cooking and food handling, and cleaning.

[SOURCE: ISO 8373:2021, 3.7]

3.5
navigation
process which includes path planning, *localization* (3.17), *mapping* (3.18), and providing the direction of travel

Note 1 to entry: Navigation can include path planning for pose-to-pose travel and complete area coverage.

[SOURCE: ISO 8373:2021, 8.6]

3.6
load
force, torque or both at the mechanical interface or *mobile platform* (3.3) which can be exerted along the various directions of motion under specified conditions of velocity and acceleration

Note 1 to entry: The load is a function of mass, moment of inertia, and static and dynamic forces supported by the *robot* (3.1).

[SOURCE: ISO 8373:2021, 7.2]

3.7
rated load
maximum *load* (3.6) that can be applied to the mechanical interface or *mobile platform* (3.3) in *normal operating conditions* (3.9) without degradation of any performance specification

Note 1 to entry: The rated load includes the inertial effects of the end effector, accessories and workpiece, where applicable.

[SOURCE: ISO 8373:2021, 7.2.1]

3.8
rated speed
maximum speed of *mobile platform* (3.3) equipped with *rated load* (3.7) in *normal operating conditions* (3.9)

[SOURCE: ISO 18646-1:2016, 3.11]

3.9
normal operating conditions
range of environmental conditions and other parameters within which the *robot* (3.1) is expected to perform as specified by the manufacturer

Note 1 to entry: Environmental conditions include temperature and humidity.

Note 2 to entry: Other parameters include electrical supply instability and electromagnetic fields.

[SOURCE: ISO 8373:2021, 7.1]

3.10
task program
set of instructions for motion and auxiliary functions that define the specific intended task of the *robot* (3.1) or robot system

Note 1 to entry: This type of program is generated by the task programmer.

Note 2 to entry: An application is a general area of work; a task is specific within the application.

[SOURCE: ISO 8373:2021, 6.1]

3.11
pose
combination of position and orientation in space

Note 1 to entry: Pose for the manipulator normally refers to the position and orientation of the end effector or the mechanical interface.

Note 2 to entry: Pose for a *mobile robot* (3.2) can include the set of poses of the *mobile platform* (3.3) and of any manipulator attached to the mobile platform, with respect to the mobile platform coordinate system.

Note 3 to entry: For mobile robots in contact with a flat surface, orientation is typically a scalar angle about the normal to the flat surface, with respect to a reference direction.

[SOURCE: ISO 8373:2021, 5.5, modified —Note 3 to entry has been added.]

3.12
command pose
programmed pose
pose (3.11) specified by the *task program* (3.10)

[SOURCE: ISO 8373:2021, 5.5.1]

3.13
attained pose
pose (3.11) achieved by the *robot* (3.1) in response to the *command pose* (3.12)

[SOURCE: ISO 8373:2021, 5.5.2]

3.14
path
route that connects an ordered set of *poses* (3.11)

[SOURCE: ISO 8373:2021, 5.5.4]

3.15
cluster
set of measured points used to calculate the accuracy and the repeatability characteristics

[SOURCE: ISO 9283:1998, 3.1]

3.16
barycentre
point whose coordinates are the mean values of a *cluster* (3.15) of points

Note 1 to entry: For a cluster of n points defined by their coordinates (x_j — y_j — z_j), the barycentre of that cluster of points is calculated as follows:

$$\overline{x} = \frac{1}{n}\sum_{j=1}^{n} x_j, \overline{y} = \frac{1}{n}\sum_{j=1}^{n} y_j, \overline{z} = \frac{1}{n}\sum_{j=1}^{n} z_j$$

[SOURCE: ISO 9283:1998, 3.2, modified]

3.17
localization
recognizing *pose* (3.11) of *mobile robot* (3.2), or identifying it on the environment map

[SOURCE: ISO 8373:2021, 8.2]

3.18
mapping
map building
map generation
constructing the environment map to describe the environment with its geometrical and detectable features, landmarks and obstacles

[SOURCE: ISO 8373:2021, 8.5]

3.19
test configuration
particular arrangement of test objects

3.20
trial
single instance of test procedure performed under identical *test configuration* (3.19)

Note 1 to entry: A trial can be repeated multiple times.

4 Test conditions

4.1 General

The robot shall be completely assembled, fully charged and operational, based on the manufacturer specification. Appropriate precautions should be taken to protect the personnel during the test.

The tests shall be preceded by the preparations for operation as specified by the manufacturer. These preparations shall be reported in the test report.

All conditions specified in Clause 4 should be satisfied for the tests described in this document, unless it is stated otherwise in the specific clauses.

The tests described in this document may have multiple test configurations which require separate test procedures. For each test configuration, multiple trials should be conducted if specified in the test procedure.

4.2 Environmental conditions

The following typical indoor environmental conditions should be maintained during all tests:

— ambient temperature: 10 °C to 30 °C;

— relative humidity: 0 % to 80 %;

— illumination: 100 lux to 1 000 lux.

The environmental conditions shall be declared in the test report. The manufacturer may specify environmental conditions outside these ranges (see Annex A).

NOTE Even though reflectivity can affect performance, it is not included in these environmental conditions.

4.3 Travel surface conditions

A hard, even and horizontal travel surface with a coefficient of friction between 0,6 and 1,0, measured in accordance with ISO 7176-13, shall be used.

4.4 Operating conditions

All performance shall be measured under normal operating conditions. When the performance is measured in other conditions, those conditions shall be declared in the test report.

For all tests, the robot shall be tested at the rated speed and equipped with the rated load, unless otherwise specified.

For the navigation of mobile platforms, external equipment, such as landmarks, shall be supplied according to the specifications of the manufacturer. Information on the external equipment, such as locations and types of landmarks, shall be provided in the test report.

4.5 Test paths

All test paths are parameterized with respect to the sizes of mobile platforms. Length unit, L_U, is defined as the multiples of 500 mm according to the width, w, the distance across the forward direction, of the mobile platform, as shown in Figure 1. The width, w, shall take into account not only the mobile platform but also any protruding part of the mobile robot, for example, arm or shelf. The L_U value used for the test shall be declared in the test report.

$$L_U = \left\lceil \frac{w}{500} \right\rceil \times 500\ mm$$

$\lceil x \rceil$ is the ceiling function that maps real number x to the least integer greater than or equal to x.

Length unit, L_U, may be increased from the above value for each test specified in this document if it is determined necessary to accommodate the test. For instance, when the length of mobile robot does not allow the proper motion in Clause 10, the larger value of L_U can be used for the test.

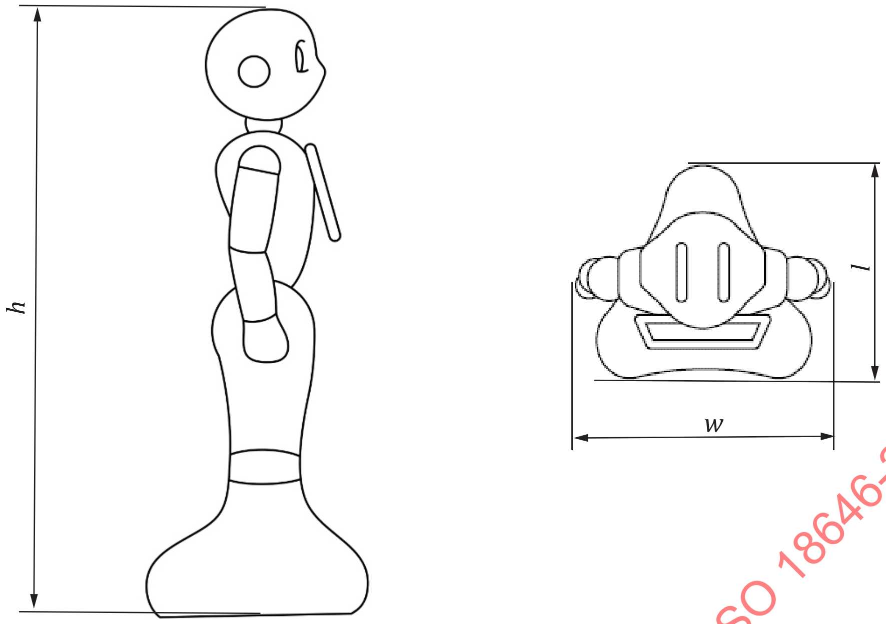


Figure 1 — Dimensions of mobile platform

Straight path, rectangular path and composite path are used in this document (see Figures 2, 3 and 4). The value of 5 L_U is selected to normalize the travel distance of various sizes of robots when we measure the pose characteristics in Clause 5. Alternatively, the travel distance can be specified by the manufacturer considering specific applications. Straight path moves from the initial pose of P_0 until it reaches the goal pose of P_1. Rectangular path moves from the initial pose of P_0 to P_1, P_2, P_3, and finally to the goal pose of P_0. Composite path moves from the initial pose of P_0 until it reaches the goal pose of P_2 via P_1.

Rectangular and composite paths tests may be made either in the clockwise or counter-clockwise directions.

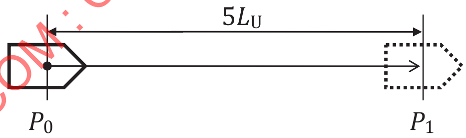


Figure 2 — Straight path

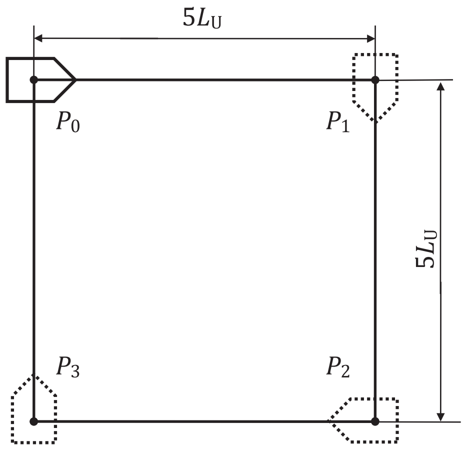


Figure 3 — Rectangular path

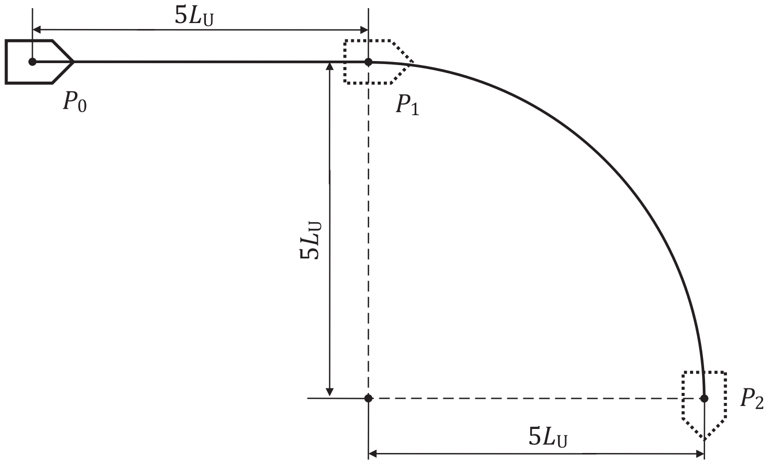


Figure 4 — Composite path

5 Pose characteristics

5.1 Purpose

The purpose of this test is to determine the pose characteristics, which include pose accuracy and pose repeatability. Pose accuracy and pose repeatability indicate the ability of the robot to reach the command pose.

5.2 Relevant characteristics

5.2.1 Pose accuracy

Pose accuracy is defined as the deviation between a command pose and the mean of the attained poses when the robot approaches the command pose from the same initial pose after *n* repeated visits.

Pose accuracy is divided into:

a) position accuracy: the difference between the position of a command pose and the barycentre of the attained positions, as shown in Figure 5;

b) orientation accuracy: the difference between the orientation of a command pose and the average of the attained orientations, as shown in Figure 6.

Position accuracy A_p is calculated by the following formula.

$$A_{\mathrm{p}} = \sqrt{(\bar{x} - x_C)^2 + (\bar{y} - y_C)^2}$$

$$\bar{x} = \frac{1}{n}\sum_{j=1}^{n} x_j, \bar{y} = \frac{1}{n}\sum_{j=1}^{n} y_j$$

where

$\overline{x}, \overline{y}$	are the averages
x_c, y_c	are the command values
x_j, y_j	are x and y values of the j^{th} trial
n	is the number of trials

Orientation accuracy A_o is calculated by the following formula:

$$A_o = \left|\overline{z}\right|$$

$$\overline{z} = \frac{1}{n}\sum_{j=1}^{n} z_j$$

$$z_j = \text{recast}\left(o_j - o_c\right)$$

where

o_c	is the angle of the command pose
o_j	is the angle of the j^{th} attained pose,
n	is the number of trials

and where the function recast( ) gives the value recast into the range (−180, +180).

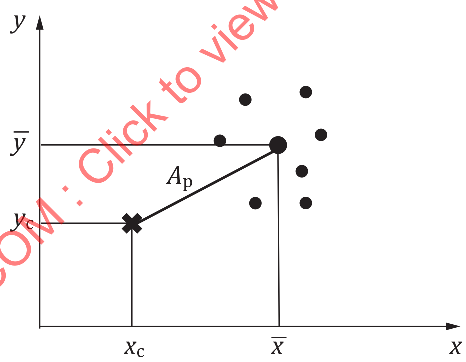


Figure 5 — Position accuracy

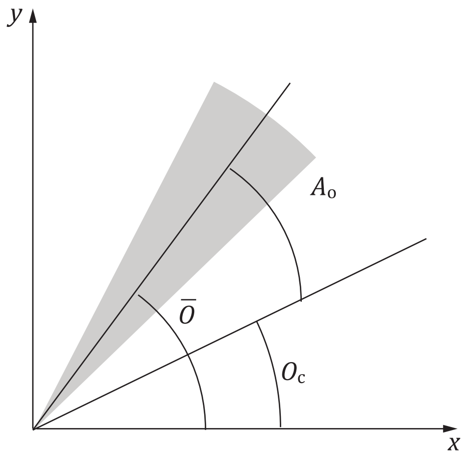


Figure 6 — Orientation accuracy

5.2.2 Pose repeatability

Pose repeatability is defined as the closeness of agreement among the attained poses after n repeated visits to the same command pose from the same initial pose.

Pose repeatability is divided into the following.

a) Position repeatability: It is the radius of the circle which encompasses $\bar{l} + 3S_l$ of the attained poses. Its centre is the barycentre of the attained poses. The position repeatability is calculated as below.

b) Orientation repeatability: It is the spread of angles, $3S_o$, about the mean values, $\bar{o}$, where S_o is the standard deviation.

Position repeatability, R_p, is calculated by the following formula:

$$R_p = \bar{l} + 3S_l$$

$$S_l = \sqrt{\frac{\sum_{j=1}^{n} \left(\bar{l} - l_j\right)^2}{n-1}}$$

$$\bar{l} = \frac{1}{n}\sum_{j=1}^{n} l_j$$

$$l_j = \sqrt{\left(\bar{x} - x_j\right)^2 + \left(\bar{y} - y_j\right)^2}$$

$$\bar{x} = \frac{1}{n}\sum_{j=1}^{n} x_j, \bar{y} = \frac{1}{n}\sum_{j=1}^{n} y_j$$

where

S_l is the standard deviation

l_j is the distance between the j^{th} position and barycentre

$\overline{x}$, $\overline{y}$ are the averages

x_j, y_j are x and y values of the j^{th} trial

n is the number of trials

Orientation repeatability R_o is calculated by following formula:

$$R_o = 3S_o$$

$$S_o = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}\left(z_j - \overline{z}\right)^2}$$

$$\overline{z} = \frac{1}{n}\sum_{j=1}^{n} z_j$$

$$z_j = \text{recast}(o_j - o_C)$$

where

S_o is the standard deviation

o_C is the angle of the command pose

o_j is the angle of the j^{th} attained pose

n is the number of trials

and where the function recast( ) gives the value recast into the range (−180, +180).

5.3 Test facility

The test area may contain artificial landmarks as well as natural landmarks as specified by the manufacturer. The information on the environment shall be provided in the test report, as the features of test environment can influence the pose characteristics.

The test facility shall be equipped with a measurement system suitable for measuring position and orientation with sufficient accuracy with respect to the intended use of the robot, e.g. a 3D camera system or a laser tracker. The type and accuracy of the measurement system shall be included in the test report.

For this test, a straight path, a rectangular path and a composite path are used.

5.4 Test procedure

This test consists of six test configurations of a straight path, a rectangular path and a composite path, with no load and with the rated load. Each trial shall follow the procedure below.

a) The mobile platform with a specified load is placed on the initial pose P_0 of the respective path.

b) The mobile platform is commanded to follow the path autonomously with the rated speed. The mobile platform may have to stop completely at the intermediate points.

c) When it reaches the goal pose, position and orientation are measured with the external measurement system.

The trial is repeated 30 times for each path and load condition. Position accuracy, orientation accuracy, position repeatability and orientation repeatability are calculated from the collected data.

5.5 Test result

The pose characteristics (i.e. position accuracy, orientation accuracy, position repeatability and orientation repeatability) shall be declared in the test report. The test report shall also include the specific test conditions, including friction conditions, rated speed and rated load. An example format is given in Table 1.

Table 1 — Test report

Characteristics	Straight path		Rectangular path		Composite path	
	no load	rated load	no load	rated load	no load	rated load
Position accuracy						
Orientation accuracy						
Position repeatability						
Orientation repeatability						
The information on the test environment shall be provided.						

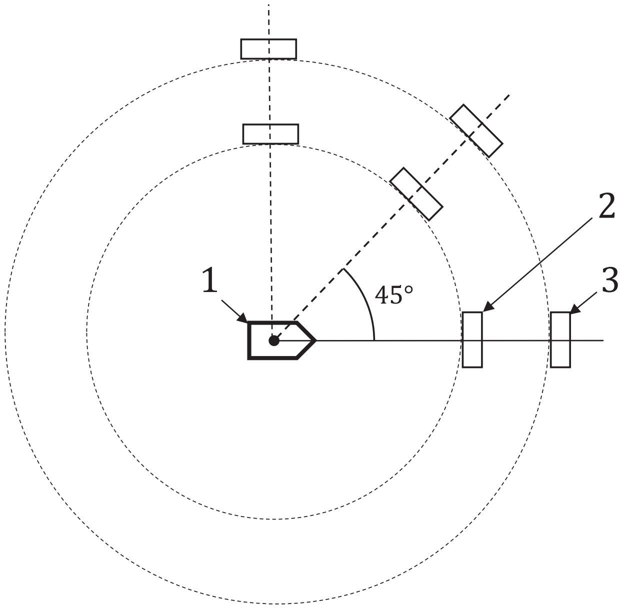
6 Obstacle detection

6.1 Purpose

The purpose of this test is to determine the ability of mobile robots to detect the obstacle and measure the distance to obstacles of different geometry and material. Test parameters are based on the manufacturer specified minimum and maximum sensing ranges. For the purpose of this test, the robot is not required to recognize the kind of obstacle.

6.2 Test facility

The test area should be large enough to accommodate the robot and obstacles with the maximum specified range declared by manufacturers, as shown in Figure 7. There should not be any obstructions between the robot and obstacles. The wall of the test space should not contain any markings to guide the robot.



Key

1 robot

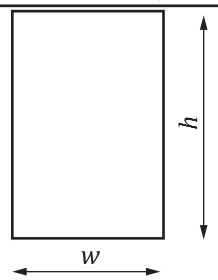
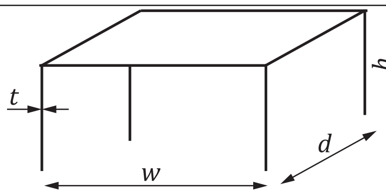
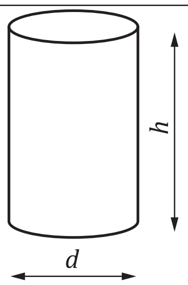
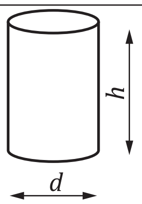
2 obstacles at the minimum range

3 obstacles at the maximum range

Figure 7 — Test layout for obstacle detection

The specifications for the obstacles used in the test are given in Table 2. The manufacturer may specify more obstacles in addition to the obstacles in Table 2, considering the intended use of the robot. A support or fixture may be used to ensure the stable vertical position of the obstacles during the test.

Table 2 — Obstacle types

Name	Geometry	Description
Wall		Plate, resembling a wall segment (both wood plates and uncoloured acrylic or polycarbonate plate with a transmissivity of more than 80 %) Height *h*: 1,5 m Width *w*: 1 m
Table		Plate with four legs, resembling a table (both wood and metal legs) Height *h*: 0,7 m to 0,8 m Width *w*: 1,5 m to 2,0 m Depth *d*: 0,5 m to 0,8 m Thickness of legs and plate *t*: 0,03 m to 0,05 m
Large cylinder		Large closed cylinder, resembling a human torso (Styrene foam painted in a dark shade of grey) Height *h*: 0,6 m Diameter *d*: 0,2 m (see ISO 13856-3)
Small cylinder		Small closed cylinder, resembling a human arm or leg (Styrene foam painted in a dark shade of grey) Height *h*: 0,4 m Diameter *d*: 0,07 m (see ISO 13856-3)

6.3 Test procedure

This test consists of six test configurations, including plate wall, glass wall, wood table, metal table, large cylinder and small cylinder, as shown in Table 2. Each trial shall follow the procedure below.

a) The robot is placed at the initial pose.

b) After the obstacle is placed at the maximum specified range declared by manufacturer, the position of the obstacle is measured by the robot.

c) After the obstacle is placed at the minimum specified range, the position of the obstacle is measured by the robot.

d) Steps b) and c) are repeated with the obstacles placed on a line in a 45° angle relative to the line of sight of the robot in the counter-clockwise direction. The angle is further increased in 45° increments each time Step d) is reached. When the initial pose is reached, the procedure is stopped. The orientation of the obstacle is always adapted so that its biggest side faces the robot. The relative positioning of obstacles can be achieved by moving the robot instead of the obstacle.

6.4 Test result

For each obstacle, whether the robot detects the obstacle at the minimum and maximum range at the relative robot positions should be declared in the test results. For each trial, the accuracy of the distance where the robot detects the obstacle from the position of the object is determined. The accuracy is expressed as a percentage value of the distance of the obstacle from the robot. The average accuracy is calculated as the mean value of the accuracy of each trial. The specific test conditions, including dimensions and colours of obstacles, shall be declared in the test report using Table 3, for the obstacle types specified in 6.3.

Table 3 — Test report

Obstacle	Range	Counter clockwise angles (in degrees)	Distance	Accuracy	Average accuracy
Obstacle types (with dimensions and colours)	Minimum	0			
		45			
		90			
		135			
		180/-180			
		-135			
		-90			
		-45			
	Maximum	0			
		45			
		90			
		135			
		180/-180			
		-135			
		-90			
		-45			

7 Obstacle avoidance

7.1 Purpose

The purpose of this test is to determine the ability of a robot to prevent a collision with a static or dynamic obstacle, either by stopping or by conducting an appropriate evasive manoeuvre. In the case of stopping, the robot is expected to stop before physical contact between the obstacle and any part of the robot occurs. In the case of an evasion movement, a minimum distance between the obstacle and any part of the robot, as specified by manufacturer, shall be maintained.

7.2 Test facility

The obstacle types given in Table 2 are used in this test.

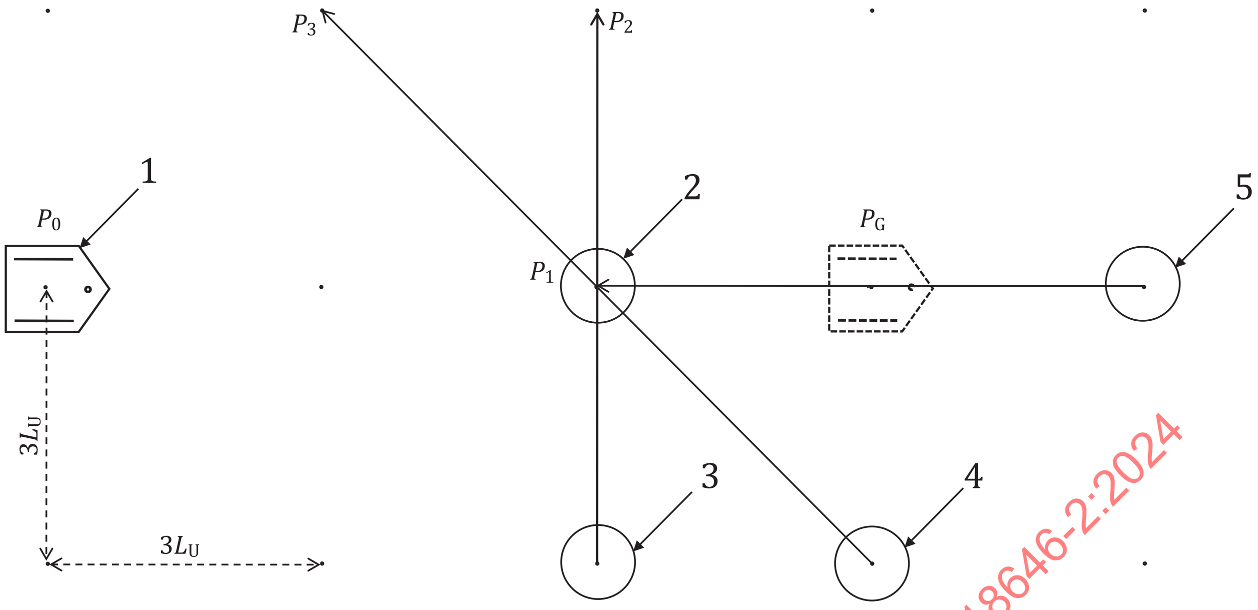
The mobile robot is placed at the initial pose, 9 L_U away from the goal pose on an even floor as shown in Figure 8. Static and dynamic obstacles with the following behaviour are shown in Figure 8:

— behaviour 1: the obstacle is placed between initial pose and goal pose at P_1 and remains static;

— behaviour 2: the obstacle moves to position P_2, crossing the path of the mobile robot in a 90° angle;

— behaviour 3: the obstacle moves to position P_3, crossing the path of the mobile robot in a 45° angle;

— behaviour 4: the obstacle moves to position P_1, blocking the direct path from the initial pose P_0 to the goal pose P_G.



Key

1 robot
2 behaviour 1
3 behaviour 2
4 behaviour 3
5 behaviour 4

Figure 8 — Test layout and obstacle behaviour (top view)

The speed of obstacle shall be set to 1,6 ± 0,2 m/s, to reflect typical human walking speed. The movement of the obstacle shall be synchronized with the movement of the mobile robot so that they are expected to reach the position P_1 at the same time.

The following objects from Table 2 shall be used as an obstacle in obstacle behaviour 1:

a) wood wall placed upright with the largest surface facing towards the robot;

b) table with the longer side facing towards the robot;

c) large cylinder, lying on the lateral side with lateral side facing towards the robot;

d) small cylinder, standing upright.

The following objects from Table 2 shall be used as an obstacle in obstacle behaviour 2, 3 and 4:

a) large cylinder, moving upright 0,5 m above the ground;

b) small cylinder, moving upright on the ground.

7.3 Test procedure

This test consists of ten test configurations as described above. Each trial shall follow the procedure below.

a) The mobile robot is placed on the initial pose P_0 and an obstacle is placed at its initial poses for each obstacle behaviour 1, 2, 3 or 4, respectively.

b) The mobile robot is commanded to travel autonomously to the goal pose P_G with the rated speed and load applicable for the given scenario specified by the manufacturer, while the obstacle is commanded to move toward its final position for obstacle behaviour 2, 3 or 4, respectively. The initial position of the obstacle can be adjusted along the straight line path so that the robot and obstacle are expected to reach the position P_1 simultaneously when the obstacle travels with the speed of 1,6 m/s.

c) When the robot reaches the goal pose, the traversal time is recorded. When the pose of robot is within the position repeatability and orientation repeatability defined in Clause 5, we assume that it has reached the goal pose.

A trial shall be considered to be a failure if the robot does not reach the goal pose or if it touches the obstacle during the travel. Obstacle avoidance is declared successful for the specific test configuration after three consecutive successful trials from the beginning. If there is at least one failure out of the first three trials, this test should be declared to be a failure. The average traversal time without an obstacle from the first three successful trials shall be selected as the traversal time without an obstacle, T_0. The maximum traversal time with an obstacle from the first three successful trials shall be selected as the traversal time with an obstacle, T_1. The delay factor, defined as T_1 / T_0, is calculated.

7.4 Test result

For each test configuration, whether the obstacle avoidance is successful or not shall be declared in the test report. The specific test conditions, including the dimensions and the colours of obstacles and the traversal time along with the delay factor, shall be declared in the test report using Table 4.

Table 4 — Test report

Obstacle behaviour	Obstacle	Success/Failure	Traversal time (s)	Delay factor
behaviour 1	Wood wall			
	Table			
	Large cylinder			
	Small cylinder			
behaviour 2	Large cylinder			
	Small cylinder			
behaviour 3	Large cylinder			
	Small cylinder			
behaviour 4	Large cylinder			
	Small cylinder			

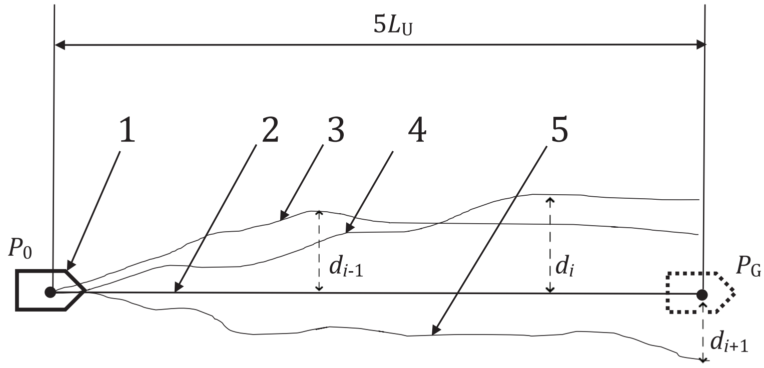
8 Path deviation

8.1 Purpose

The purpose of this test is to determine the maximum deviation of the attained path from the command path. Path deviation indicates the ability of a mobile robot to track the command path.

8.2 Test facility

The setup for this test is shown in Figure 9. The robot is commanded to move from the initial pose to the goal pose in a straight path, specified in Clause 4.



Key

1 robot

2 command path

3 $(i - 1)^{th}$ attained path

4 i^{th} attained path

5 $(i + 1)^{th}$ attained path

Figure 9 — Path deviation for a command path

Deviation d_i is defined as a maximum deviation between the command path and the *i*-th attained path along the normal direction. The maximum deviation, *d*, is determined as below.

$$d = \max |d_i| \quad \text{for } i = 1, \ldots, n$$

The test facility shall be equipped with a measurement system suitable for measuring pose with sufficient accuracy with respect to the intended use of the robot, for example, a 3D camera system or a laser tracker. The type and accuracy of the measurement system shall be included in the test report.

8.3 Test procedure

This test consists of two test configurations of a straight path with no load and the rated load. Each trial shall follow the procedure below.

a) The mobile platform with a specified load is placed on the initial pose P_0.

b) The mobile platform is commanded to follow the path until it reaches the goal pose. When the pose of robot is within the position repeatability and orientation repeatability defined in Clause 5, we assume that it has reached the goal pose. The deviation of position is measured with the external measurement system during the motion.

c) The maximum value of deviation for the given attained path is recorded.

The trial is repeated for 30 times and maximum value for all trials is recorded as the maximum deviation.

8.4 Test result

The maximum path deviation along with the average and standard deviation from the 30 deviations of d_i shall be declared in the test report. The test report shall also include the specific test conditions, including friction conditions and the rated speed. See Table 5 for an example format.

Table 5 — Test report

Characteristics	Straight path	
	no load	rated load
Maximum path deviation		
Average path deviation		
Standard deviation		
The information of the coefficient of friction and the rated speed shall be provided.		

9 Narrow passage

9.1 Purpose

The purpose of this test is to determine the ability of the robot to travel through a narrow passage.

9.2 Test facility

The setup for this test is shown in Figure 10, where the length of the narrow passage is 4 L_U. The robot is placed at initial pose, P_0, where the most protruding part of the robot is 2 L_U away from the center of the opening of the narrow passage whose width is declared by the manufacturer. The robot should travel from the initial pose to the goal pose without contacting the walls. The goal pose is where any part of the robot is 2 L_U away from the center of the closing of the narrow passage.

The test facility shall be equipped with a measurement system suitable for measuring position and orientation with sufficient accuracy with respect to the intended use of the robot, for example, a 3D camera system or a laser tracker. The type and accuracy of the measurement system shall be included in the test report.

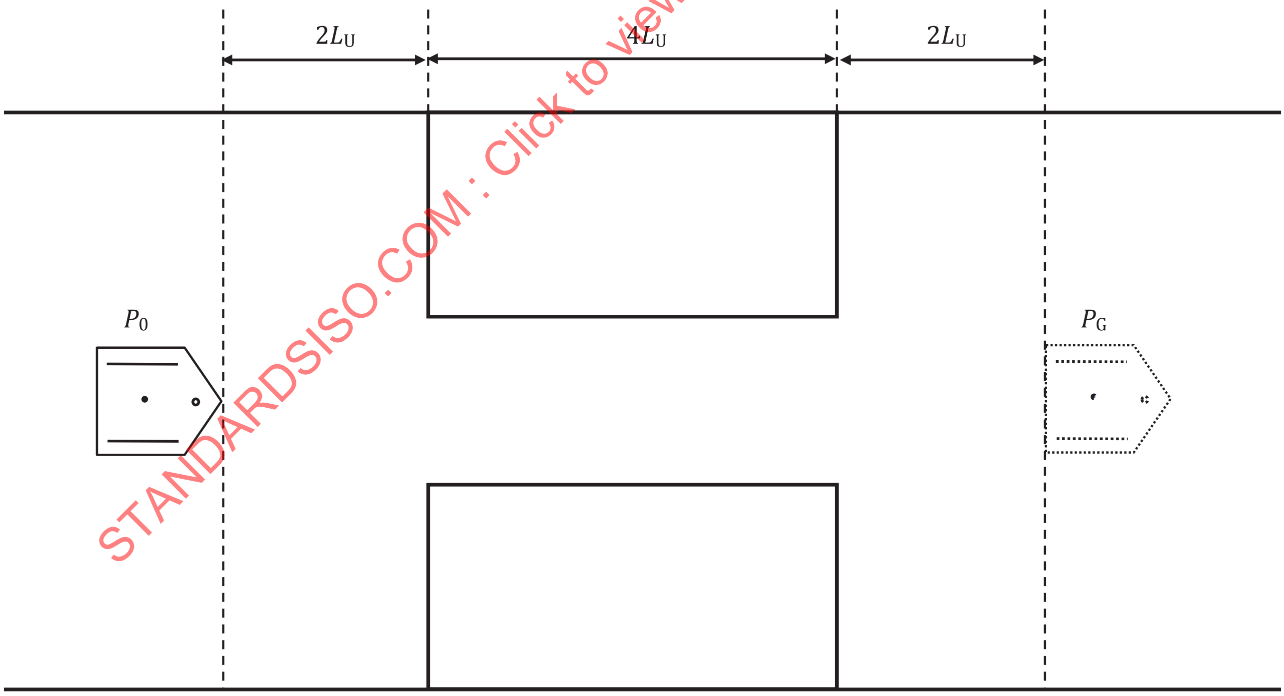


Figure 10 — Test area for narrow passage

9.3 Test procedure

This test consists of two test configurations of the no load and the rated load.

Each trial shall follow the procedure below.

a) The mobile platform with the specified load is placed on the initial pose P_0.

b) The mobile platform is commanded to reach the goal pose P_G.

c) When it reaches the goal pose, the traversal time is recorded. When the pose of robot is within the position repeatability and orientation repeatability defined in Clause 5, we assume that it has reached the goal pose.

A trial shall be considered to be a failure if the robot hits the wall during the travel or does not reach the goal pose. The trial is repeated 5 times and the average traversal time from 5 consecutive successful trials is recorded.

9.4 Test result

The traversal time to pass the narrow passage shall be declared in the test report. The test report shall also include the specific test conditions, including friction conditions. An example format is given in Table 6.

Table 6 — Test report

Characteristics	no load	rated load
Traversal time 1st trial		
Traversal time 2nd trial		
Traversal time 3rd trial		
Traversal time 4th trial		
Traversal time 5th trial		
Average traversal time		
The information of the coefficient of friction shall be provided.		

10 Mapping accuracy

10.1 Purpose

The purpose of this test is to evaluate the accuracy of the map acquired through map building. This value is important for quantifying the ability of a robot to generate a map of an unknown environment.

10.2 Test facility

The test area for mapping accuracy is shown in Figure 11, where the test area is a square space with 7 L_U × 7 L_U. The test area contains features of a circular column with the diameter 1 L_U at the center and four T-shaped walls installed at the designated location as shown in Figure 11. The height of a circular column and T-shaped walls should be higher than the height of the robot under testing. The thickness of the T-shaped walls should be between 100 mm and 300 mm. The material of a circular column and T-shaped walls are not designated as they can be decided by the tester.