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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

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Foreword

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

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 method 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, as well as the ability to detect and avoid obstacles. 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*

ISO 8373:2012, *Robots and robotic devices — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8373 and the following apply.

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

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

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

3.1
robot
programmed actuated mechanism with a degree of autonomy, moving within its environment, to perform intended tasks

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

Note 2 to entry: The classification of robot into industrial robot or *service robot* (3.4) is done according to its intended application.

[SOURCE: ISO 8373:2012, 2.6, modified — The words "actuated mechanism programmable in two or more axes" have been replaced with "programmed actuated mechanism".]

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

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

[SOURCE: ISO 8373:2012, 2.13]

3.3
mobile platform
assembly of all components of the *mobile robot* (3.2) 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: Because of possible confusion with the term "base", it is advisable not to use the term "mobile base" to describe a mobile platform.

[SOURCE: ISO 8373:2012, 3.18]

3.4
service robot
robot (3.1) that performs useful tasks for humans or equipment excluding industrial automation applications

Note 1 to entry: Industrial automation applications include, but are not limited to, manufacturing, inspection, packaging, and assembly.

Note 2 to entry: While articulated robots used in production lines are industrial robots, similar articulated robots used for serving food are service robots.

[SOURCE: ISO 8373:2012, 2.10]

3.5
navigation
deciding on and controlling the direction of travel, derived from localization and the environment map

Note 1 to entry: Navigation can include *path* (3.14) planning for pose-to-pose travel and complete area coverage.

[SOURCE: ISO 8373:2012, 7.6]

3.6
load
force and/or torque 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 8373:2012, 6.2.1]

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 8373:2012, 6.2.2]

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 which can influence robot performance (such as electrical supply instability, electromagnetic fields) within which the performance of the *robot* ([3.1](#)) specified by the manufacturer is valid

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

[SOURCE: ISO 8373:2012, 6.1]

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 usually generated after the installation of the robot and can be modified by a trained person under defined conditions.

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

[SOURCE: ISO 8373:2012, 5.1.1]

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 world 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 8373:2012, 4.5, 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 8373:2012, 4.5.1]

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

[SOURCE: ISO 8373:2012, 4.5.2]

3.14
path
ordered set of *poses* ([3.11](#))

[SOURCE: ISO 8373:2012, 4.5.4]

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

[SOURCE: ISO 9283:1998, 3.1, modified]

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:

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

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

4 Test conditions

4.1 General

The robot shall be completely assembled, fully charged and operational, based on the manufacturer specification. All self-diagnostic tests shall be satisfactorily completed. 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.

Each test described in each clause of this document can have different 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 LU is defined as the maximum of the width w and the length l of the mobile platform, as shown in Figure 1. The LU value used for the test shall be declared in the test report.
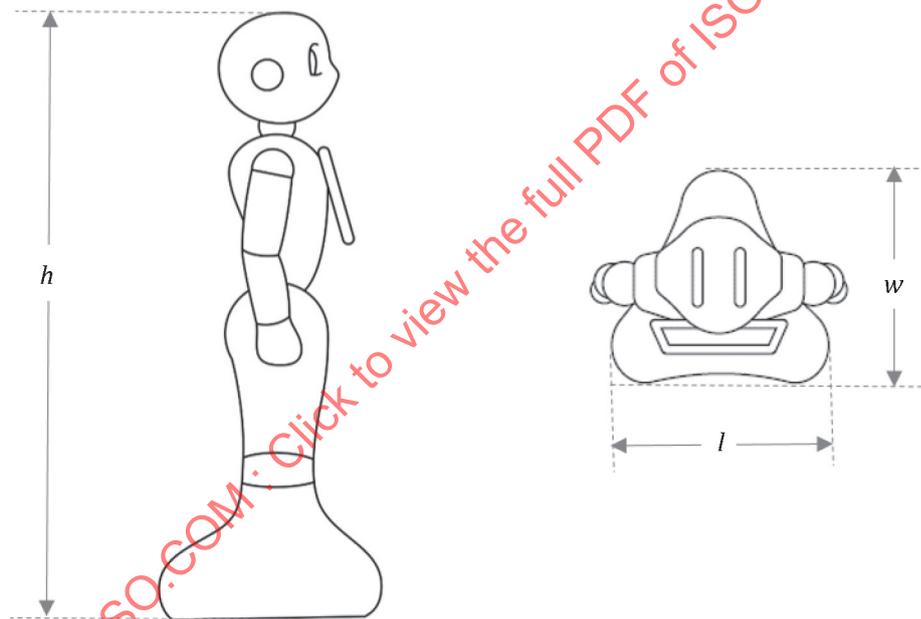

Figure 1 — Dimensions of mobile platform

Straight path, rectangular path and composite path are used in this document (see Figures 2, 3 and 4). The value of 5 LU 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.
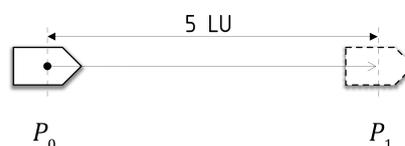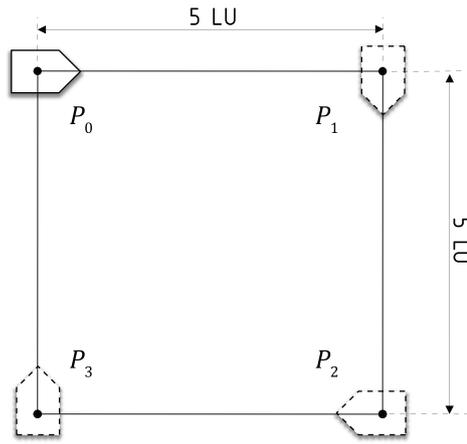

Figure 2 — Straight path
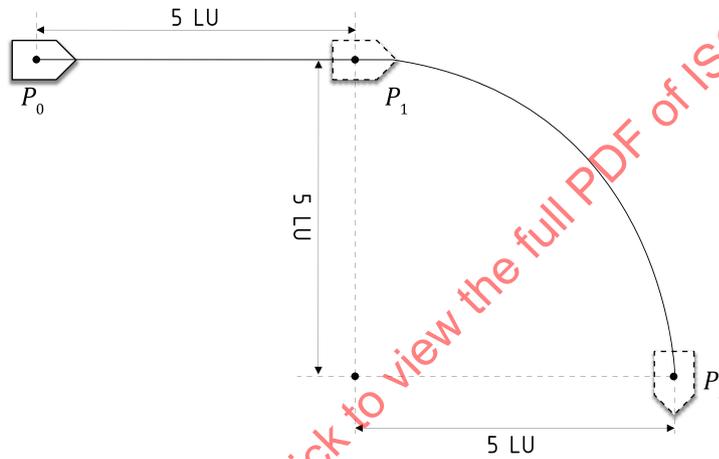
Figure 3 — Rectangular path

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 following formula.

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

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

where

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

x_C, y_C are the command values

x_j, y_j are x and y values of the jth trial

n is the number of trials

Orientation accuracy A_o is calculated by following formula:

$$A_\mathrm{o} = \left|\bar{o} - o_c\right|$$

$$\bar{o} = \frac{1}{n}\sum_{j=1}^{n} o_j$$

where

o_c is the angle of the command pose

o_j is the angle of the jth attained pose

n is the number of trials

and where the absolute value is then recast into the range (−180, +180).
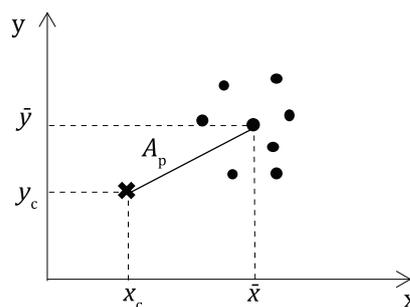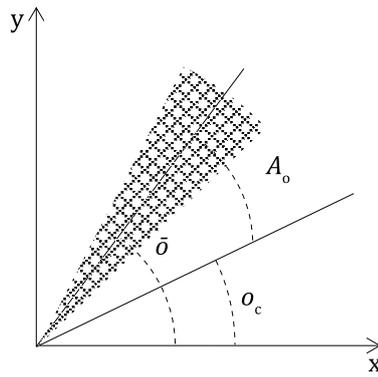

Figure 5 — Position accuracy

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 following formula:

$$R_\mathrm{p} = \bar{l} + 3S_l$$

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

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

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

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

where

S_l is the standard deviation

l_j is the distance between the jth position and barycentre

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

x_j, y_j are x and y values of the jth trial

n is the number of trials

Orientation repeatability R_o is calculated by following formula:

$$R_o = 3S_o$$

$$S_o = \sqrt{\frac{\sum_{j=1}^{n}\left(\bar{o} - o_j\right)^2}{n-1}}$$

$$\bar{o} = \frac{1}{n}\sum_{j=1}^{n} o_j$$

where

S_o is the standard deviation

o_j is the angle of the jth attained pose

n is the number of trials

5.3 Test facility

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 position P_0 of the respective path.

b) The mobile platform is commanded to follow the path autonomously with the rated speed.

c) When it reaches the goal position, 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						

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. The robot does not necessarily recognize the kind of obstacle.
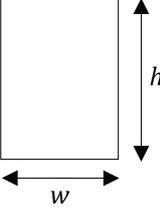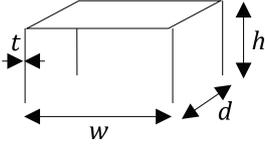
6.2 Test facility

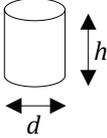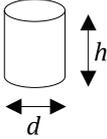The test area should be large enough to accommodate the robot and obstacles with the maximum specified range declared by manufacturers, as shown in Figure 7. There should not be any obstructions between the robot and obstacles. The wall of the test space should not contain any markings to guide the robot.
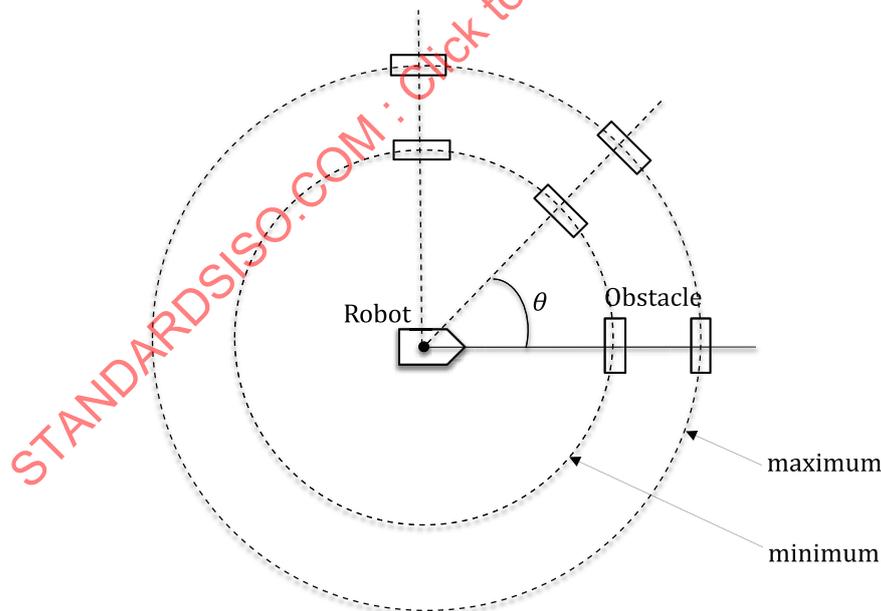
Figure 7 — Test layout for obstacle detection

The specifications for the obstacles used in the test are given in Table 2.

Table 2 — Obstacle types

Name	Geometry	Description
Wall		Plate, resembling a wall segment (both pine wood plates and un-coloured soda-lime glass 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 pine wood and steel 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: < 0,05 m
Large cylinder		Large closed cylinder, resembling a human torso (grey surface with diffuse reflectance value of 27 % to 33 %, as described in IEC/TS 61496-4-3) 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 (grey surface with diffuse reflectance value of 27 % to 33 %, as described in IEC/TS 61496-4-3) 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, steel 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 position 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			
		225			
		270			
		315			
	Maximum	0			
		45			
		90			
		135			
		180			
		225			
		270			
		315			

# 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 evasion movement. 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 position, 9 LU away from the goal position 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 position and goal position 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 position P_0 to the goal position P_G.
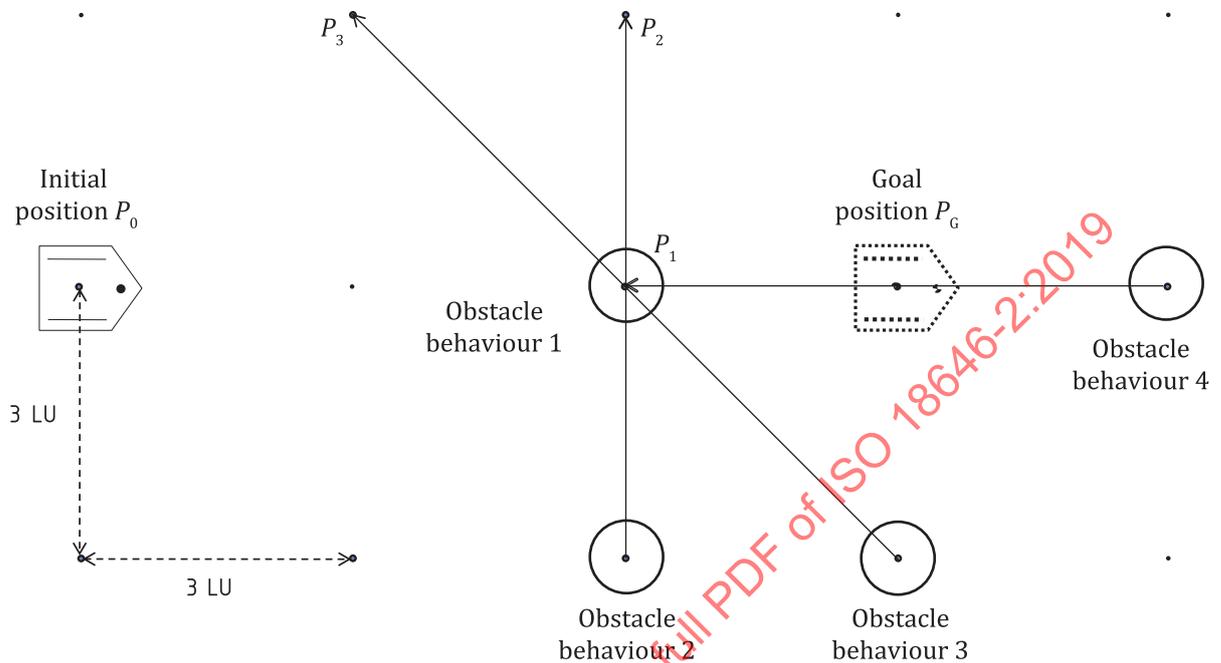
Figure 8 — Test layout and obstacle behaviour (top view)

The speed of obstacle shall be set to 1,6 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)   pine 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 position P_0 and an obstacle is placed at its initial positions for each obstacle behaviour 1, 2, 3 or 4, respectively.