ISO/NWIP 18646-2_UNM 81-467

ISO/TC 184/SC 2 **N 782**

New work item proposal ISO 18646-2, Robots and robotic devices — Performance criteria and related test methods for service robot — Part 2: Navigation

Document type: NP ballot

30 mars 2015

Note du Secrétariat UNM à la Commission de normalisation UNM 81
« Robots et composants robotiques »

NWIP
CD
DIS
FDIS
Publication

Le projet suivant est actuellement soumis à enquête NWIP :

ISO/NWIP 18646-2 *Robots et composants robotiques - Critères de performance et méthodes d'essai correspondantes pour robots de service - Partie 2 : Navigation*

NOTE : La première étape de l'élaboration d'une Norme consiste à confirmer qu'il existe un besoin. Une demande de mise à l'étude d'une nouvelle question est soumise au vote des membres du TC/SC concerné afin de décider s'il y a lieu d'inscrire la question au programme de travail. La demande est acceptée si la majorité des membres (P) du TC/SC se prononce en sa faveur et qu'au moins cinq membres (P) s'engagent explicitement à participer activement au projet.

Cohérence avec le domaine d'activité de la commission et parties intéressées

Ce nouveau sujet relève du domaine d'activité de la commission rappelé ci-après : *Robots industriels et appareils robotisés pour environnement manufacturier - Robots de service et d'assistance à la personne*.

L'organisme suivant est susceptible d'être intéressé par ces travaux : SYROBO. Si le nouveau sujet est accepté, il sera sollicité pour participer à la commission.

Contexte

La proposition de nouveau sujet décrit les méthodes de spécification et d'évaluation des performances de navigation des robots de services mobiles. Elle constitue la seconde partie d'une série de normes relative aux critères de performances des robots de service. La partie 1 *Locomotion des robots à roues* fait actuellement l'objet d'un vote DIS, le vote français (positif sans commentaire) a été établi par le biais d'une enquête publique car la commission a décidé de la reprendre en collection nationale.

Six autres parties sont en cours d'élaboration au sein du WG 8 *Robots de service* [experts français : Mme BERNIER (ALDEBARAN ROBOTICS), M CLERC (ALDEBARAN ROBOTICS), M GELIN (ALDEBARAN ROBOTICS), Mme GUILLEMET (ALDEBARAN ROBOTICS) et M PARENT (INRIA)].

- Partie 3 : *Mesures pour exosquelettes robotisés partiels*
- Partie 4 : *Manipulation*
- Partie 5 : *Essais climatiques*
- Partie 6 : *Consommation d'énergie et durée de fonctionnement, cycles de travail, etc*
- Partie 7 : *Interaction Homme/Robot (visuel, audio, tactile)*
- Partie 8 : *Locomotion des robots à pattes*

Le document justificatif est joint en annexe (voir doc. ISO/TC 184/SC 2 N 782). Le chef de projet proposé est M. Seungbin Moon.

Proposition de vote

Sauf avis contraire de votre part **avant le 29 avril 2015**, le comité membre français votera positivement. Les éventuels commentaires sont à transmettre à l'UNM en utilisant le modèle de tableau disponible sur COMELEC dans le répertoire *documents généraux/autres documents*.

unm
Bureau de Normalisation par délégation d'AFNOR

Question suivie par :

M. BUTAYE
☎ 01 47 17 67 89
a.butaye@unm.fr

Mme MOUAZAN
☎ 01 47 17 67 84
v.mouazan@unm.fr

ISO/TC 184/SC 2
Robots and robotic devices

Email of secretary: katarina.widstrom@sis.se
Secretariat: SIS (Sweden)

New work item proposal ISO 18646-2, Robots and robotic devices — Performance criteria and related test methods for service robot — Part 2: Navigation

Document type:	NP ballot
Date of document:	2015-02-17
Expected action:	VOTE
Action due date:	2015-05-17
Background:	New work item proposal ISO 18646-2, Robots and robotic devices — Performance criteria and related test methods for service robot — Part 2: Navigation
Committee URL:	http://isotc.iso.org/livelink/livelink/open/tc184sc2

NEW WORK ITEM PROPOSAL	
Closing date for voting 2015-05-17	Reference number (to be given by the Secretariat)
Date of circulation 2015-02-17	**ISO/TC** 184 **/ SC** 2 N 782
Secretariat SIS	☐ Proposal for new PC

A proposal for a new work item within the scope of an existing committee shall be submitted to the secretariat of that committee with a copy to the Central Secretariat and, in the case of a subcommittee, a copy to the secretariat of the parent technical committee. Proposals not within the scope of an existing committee shall be submitted to the secretariat of the ISO Technical Management Board.

The proposer of a new work item may be a member body of ISO, the secretariat itself, another technical committee or subcommittee, or organization in liaison, the Technical Management Board or one of the advisory groups, or the Secretary-General.

The proposal will be circulated to the P-members of the technical committee or subcommittee for voting, and to the O-members for information.

IMPORTANT NOTE: Proposals without adequate justification risk rejection or referral to originator.
Guidelines for proposing and justifying a new work item are contained **in Annex C of the ISO/IEC Directives, Part 1**.

☒ The proposer has considered the guidance given in the Annex C during the preparation of the NWIP.

Proposal (to be completed by the proposer)

Title of the proposed deliverable.
(in the case of an amendment, revision or a new part of an existing document, show the reference number and current title)

English title ISO 18646-2, Robots and robotic devices — Performance criteria and related test methods for service robot — Part 2: Navigation

French title
(if available)

Scope of the proposed deliverable.

This International Standard describes methods of specifying and evaluating the navigation performance of mobile service robots.
The criteria and related test methods are applicable only to mobile platforms. For evaluating the characteristics of manipulators, ISO 9283 applies.

This International Standard is not applicable for the verification or validation of safety requirements.

Purpose and justification of the proposal*

As the scope of TC 184/SC 2 was widened in 2006, the need to develop performance standards on service robots has been identified. This standard will be the second in a series of performance standards, following Part 1: Locomotion for wheeled robot, which are under DIS balloting stage.

**The reason for requiring justification statements with approval or disapproval votes is primarily to collect input on market or stakeholder needs, and on market relevance of the proposal, to benefit the development of the proposed ISO standard(s). Any NSB vote in relation to a proposal for new work may result in significant commitments of resources by all parties (NSBs, committee leaders and delegates/experts) or may have significant implications for ISO's relevance in the global community. It is especially important that NSBs consider and express why they vote the way they do. In addition, it is felt that it would be useful for ISO and its committees to have documentation as to why the NSBs feel a proposal has market need and market relevance. Therefore, please ensure that your justifying statements with your approval or disapproval vote convey the reason(s) why your national consensus does or does not support the market need and/or global relevance of the proposal.*

If a draft is attached to this proposal,:

Please select from one of the following options (note that if no option is selected, the default will be the first option):

☐ Draft document will be registered as new project in the committee's work programme (stage 20.00)
☒ Draft document can be registered as a Working Draft (WD – stage 20.20)
☐ Draft document can be registered as a Committee Draft (CD – stage 30.00)
☐ Draft document can be registered as a Draft International Standard (DIS – stage 40.00)

Is this a Management Systems Standard (MSS)?

☐ Yes ☒ No

NOTE: if Yes, the NWIP along with the Justification study (see Annex SL of the Consolidated ISO Supplement) must be sent to the MSS Task Force secretariat (tmb@iso.org) for approval before the NWIP ballot can be launched.

Indication(s) of the preferred type or types of deliverable(s) to be produced under the proposal.

☒ International Standard ☐ Technical Specification ☐ Publicly Available Specification ☐ Technical Report

Proposed development track ☐ 1 (24 months) ☒ 2 (36 months - default) ☐ 3 (48 months)

Known patented items (see ISO/IEC Directives, Part 1 for important guidance)

☐ **Yes** ☒ **No** **If "Yes", provide full information as annex**

A statement from the proposer as to how the proposed work may relate to or impact on existing work, especially existing ISO and IEC deliverables. The proposer should explain how the work differs from apparently similar work, or explain how duplication and conflict will be minimized.

This proposed International Standard is intended to facilitate understanding of performance for manufacturers and users of service robots. It is complementing the existing ISO 9283 that deals with performance of manipulator type robots

A listing of relevant existing documents at the international, regional and national levels.

ISO 9283:1998, Manipulating industrial robots — Performance criteria and related test methods

A simple and concise statement identifying and describing relevant affected stakeholder categories (including small and medium sized enterprises) and how they will each benefit from or be impacted by the proposed deliverable(s)

All users and manufacturers of mobile robots will benefit from this International Standard. By providing the important performance characteristics and descriptions how they shall be specified and tested, manufacturers can improve the characteristics of their products, while users are able to purchase the better products

Liaisons:

A listing of relevant external international organizations or internal parties (other ISO and/or IEC committees) to be engaged as liaisons in the development of the deliverable(s).

IEC TC 59

Joint/parallel work:

Possible joint/parallel work with:

☐ IEC (please specify committee ID)

☐ CEN (please specify committee ID)

☐ Other (please specify)

A listing of relevant countries which are not already P-members of the committee.

Preparatory work (at a minimum an outline should be included with the proposal)

☒ A draft is attached ☐ An outline is attached ☐ An existing document to serve as initial basis

The proposer or the proposer's organization is prepared to undertake the preparatory work required ☒ Yes ☐ No

Proposed Project Leader (name and e-mail address)

Prof. Seungbin Moon
Sejong Univ., Dept of Computer Eng.
98 Gunja-Dong Gwangjin-Gu,Seoul,
Korea 143-747.
Email: sbmoon@sejong.ac.kr

Name of the Proposer
(include contact information)

Prof. Seungbin Moon
Sejong Univ., Dept of Computer Eng.
98 Gunja-Dong Gwangjin-Gu,Seoul,
Korea 143-747.
Email: sbmoon@sejong.ac.kr

Supplementary information relating to the proposal

☒ This proposal relates to a new ISO document;

☐ This proposal relates to the adoption as an active project of an item currently registered as a Preliminary Work Item;

☐ This proposal relates to the re-establishment of a cancelled project as an active project.

Other:

Annex(es) are included with this proposal (give details)

☒ Draft

Reference number of working document: **ISO/TC 184/SC 2/WG 8 N ??**

Date:2015-02-06

Reference number of document: **ISO/PWD 18646-2**

Committee identification: ISO/TC 184/SC 2/WG 8

Secretariat: XXXX

Robots and robotic devices — Performance criteria and related test methods for service robots — Part 2: Navigation

Élément introductif — Élément principal — Partie n: Titre de la partie

Warning

This document is not an ISO International Standard. It is distributed for review and comment. It is subject to change without notice and may not be referred to as an International Standard.

Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

Document type: International standard
Document subtype: if applicable
Document stage: (20) Preparation
Document language: E

Contents

Page

1 Scope 1
2 Normative references 1
3 Terms and definitions 1
4 Testing conditions 4
5 Pose characteristics 5
6 Path characteristics 8
7 Obstacle detection 10
8 Obstacle avoidance 12

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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 18646-2 was prepared by Technical Committee ISO/TC 184, *Automation systems and integration*, Subcommittee SC 2, *Robots and robotic devices*.

ISO 18646 consists of the following parts, under the general title *Robots and robotic devices — Performance criteria and related test methods for service robot*:

— *Part 1: Locomotion for wheeled robot*

— *Part 2: Navigation*

Introduction

ISO 18646-2 is intended to facilitate understanding on navigation performance of mobile service robots between users and manufacturers. It defines the important performance characteristics, describes how they shall be specified, and recommends how they should be tested.

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

The performance criteria specified in this part of International Standard should not be interpreted as the verification or validation of safety requirements. The verification and validation of safety requirements are under development by ISO TC 184/SC 2.

Robots and robotic devices — Performance criteria and related test methods for service robots — Part 2: Navigation

1 Scope

This International Standard describes methods of specifying and evaluating the navigation performance of mobile service robots.

The criteria and related test methods are applicable only to mobile platforms. For evaluating the characteristics of manipulators, ISO 9283 applies.

This International Standard is not applicable for the verification or validation of safety requirements.

2 Normative references

The following referenced documents are indispensable for the application 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 8373:2012, *Robots and robotic devices — Vocabulary*

ISO 9283:1998, *Manipulating industrial robots — Performance criteria and related test methods*

ISO 7176-13:1989, *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.

3.1
robot
actuated mechanism programmable in two or more axes 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 is done according to its intended application.

[SOURCE: ISO 8373:2012, 2.6]

3.2
mobile robot
robot able to travel under its own control

NOTE 1 to entry: A mobile robot can be a **mobile platform** with or without manipulators.

[SOURCE: ISO 8373:2012, 2.13]

3.3
wheeled robot
mobile robot that travels using wheels

[SOURCE: ISO 8373:2012, 3.16.1]

3.4
mobile platform
assembly of all components of the **mobile robot** which enables locomotion

NOTE 1 to entry: It may include chassis which can be used to support **load**.

NOTE 2 to entry: One of the components of the platform can be used to define the **mobile platform coordinate system**.

NOTE 3 to entry: The alternative term of “mobile base” is not used in this clause, to avoid confusion with the term of “**base**”.

[SOURCE: ISO 8373:2012, 3.18]

3.5
service robot
robot 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]

3.6
navigation
deciding on and controlling the direction of travel, derived from **localization** and the **environment map**

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

[SOURCE: ISO 8373:2012, 7.6]

3.7
load
force and/or torque at the **mechanical interface** or **mobile platform** 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**

[SOURCE: ISO 8373:2012, 6.2.1]

3.8
rated load
maximum **load** that can be applied to the **mechanical interface** or **mobile platform** in **normal operating conditions** 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]

3.9
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** 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
pose
combination of position and orientation in space

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

NOTE 2 to entry: Pose for **mobile robot** could include set of poses of **mobile platform** and any **manipulator** attached to the **mobile platform**, with respect to the **world coordinate system**.

[SOURCE: ISO 8373:2012, 4.5]

3.11
command pose
programmed pose
pose specified by the **task program**

[SOURCE: ISO 8373:2012, 4.5.1]

3.12
attained pose
pose achieved the command pose by the **robot** in response to the command pose

[SOURCE: ISO 8373:2012, 4.5.2]

3.13
path
ordered set of **poses**

[SOURCE: ISO 8373:2012, 4.5.4]

3.14
cluster
set of measured points used to calculate the accuracy and the repeatability characteristics

[SOURCE: ISO 9283:1998, 3.1]

3.15
barycentre
for a cluster of n points, defined by their coordinates (x_j - y_j - z_j), the barycentre of that cluster of points is the point whose coordinates are the mean values, $\bar{x}$, $\bar{y}$, and $\bar{z}$, calculated as below.

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

[SOURCE: ISO 9283:1998, 3.2 modified]

4 Testing conditions

4.1 Conditions prior to testing

The robot shall be completely assembled and fully charged and operational, and all functional tests shall be satisfactorily completed.

The tests shall be preceded by the preparations for operation as specified by the manufacturer.

4.2 Environmental conditions

The following environmental conditions shall be maintained during all tests, unless otherwise specified.

— Ambient temperature: 10 – 30 degrees in Celsius

— Relative humidity : Up to 80%

— Illumination: ? - ? lux

If the environmental conditions specified by the manufacturer are outside of the given conditions, then they can be used with the proper statements.

4.3 Surface conditions

For indoor environment, a hard surface with a coefficient of friction between 0.75 and 1.0, measured according to 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, it shall be noted together with the test results.

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

For the navigation of mobile platforms, specific outside equipments, such as landmarks, should be supplied according to the specifications of manufacturer.

4.5 Test paths

All test paths are parameterized with respect to different sizes of mobile platforms. Length Unit(LU) is defined as the maximum length of mobile platform.

Straight path, circular path, and composite path are used in this International Standard.(See Fig. 1, 2, and 3)

Figure 1. Straight path

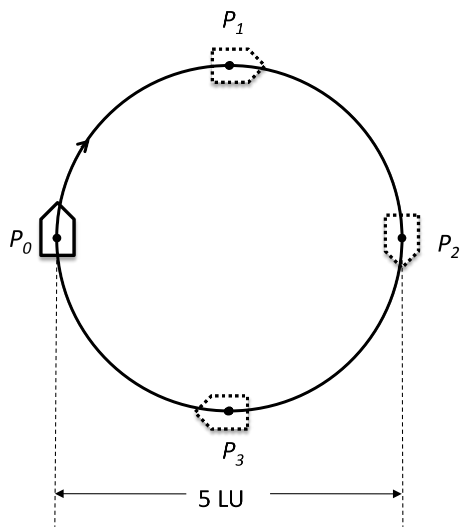


Figure 2. Circular path

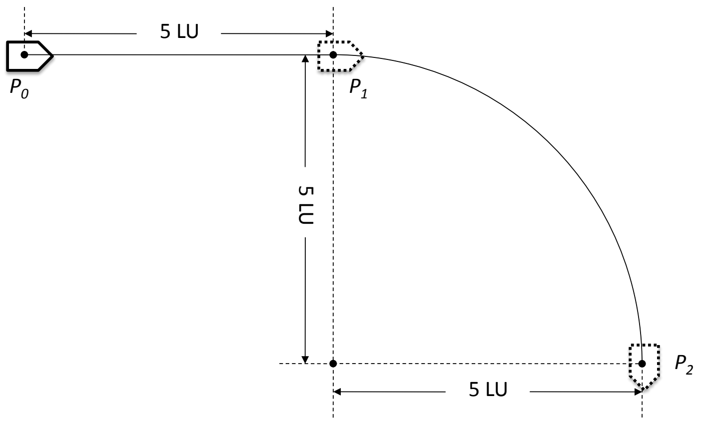


Figure 3. Composite path

5 Pose characteristics

5.1 Purpose

Pose characteristics consists of pose accuracy and pose repeatability. Pose accuracy and pose repeatability indicate the ability of the robot to reach the command pose.

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* repeat 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 Fig. 4;

b) Orientation accuracy: the difference between the orientation of a command pose and the average of the attained orientations, as shown in Fig. 5.

Position accuracy(AP_p) is calculated by following formula.

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

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

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

where

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

$x_C,\ y_C$ are the command values,

x_j, y_j , y_j are x_j, y_j values of the *j-th* test,

n is the number of tests.

Orientation accuracy(AP_c) is calculated by following formula.

$$AP_c = \bar{c} - c_c$$

$$\bar{c} = \frac{1}{n}\sum_{j=1}^{n} c_j$$

where

c_c is the angle of the command pose,

c_j is the angle of the *j-th* attained pose,

n is the number of tests.

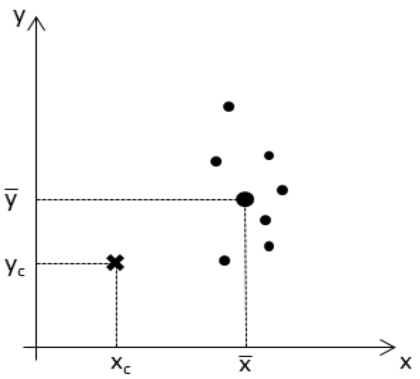


Figure 4. Position accuracy

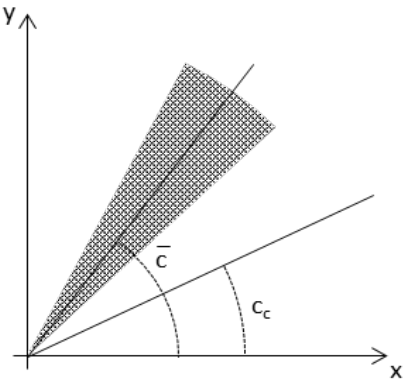


Figure 5. Orientation accuracy

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

Pose repeatability is divided into

a) Position repeatability: the radius of the sphere whose centre is the barycentre and which is calculated as below

b) Orientation repeatability: the spread of angles, $3S_c$, about the mean values, $\bar{c}$, where S_c is the standard deviation

Position repeatability, RP_l , is calculated by below formula.

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

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

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

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

where

l_j is the distance between the j-th position and barycentre

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

x_j, y_j, y_j are x_j, y_j values of the *j-th* test,

S_l is the standard deviation

n is the number of tests.

Orientation repeatability, RP_c, is calculated by below formula.

$$RP_c = 3S_c = \sqrt{\frac{\sum_{j=1}^{n} (\bar{c} - c_j)^2}{n-1}}$$

$$\bar{c} = \frac{1}{n}\sum_{j=1}^{n} c_j$$

where

c_j is the angle of the *j-th* attained pose,

n is the number of tests.

5.2 Test facility

The test facility shall be equipped with a measurement system suitable for measuring position and orientation with sufficient accuracy, e.g., a 3D camera system or a laser tracker.

The test condition shall satisfy all requirements specified in Clause 4. For this test, both straight path and a composite path are used.

5.3 Test procedure

Test shall follow the procedure below:

1) The mobile platform is placed on the starting position P_0 of the respective path.

2) The mobile platform is commanded to follow the path until it reaches the goal position with the rated speed and load specified by the manufacturer.

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

4) The trial is repeated 30 times for each path and calculate position accuracy, orientation accuracy, pose repeatability and orientation repeatability.

5.4 Test result

The pose characteristics, namely position accuracy, orientation accuracy, position repeatability, and orientation repeatability, along with the rated speed and load should be provided for each path.

6 Path characteristics

6.1 Purpose

The aim of this test is to evaluate the ability of mobile robots to track the commanded path while it is moving along the given path. Path characteristics consists of path accuracy and path repeatability.

Path accuracy and path repeatability are independent of the shape of the command path. Fig. 6 gives a general illustration of path accuracy and repeatability.

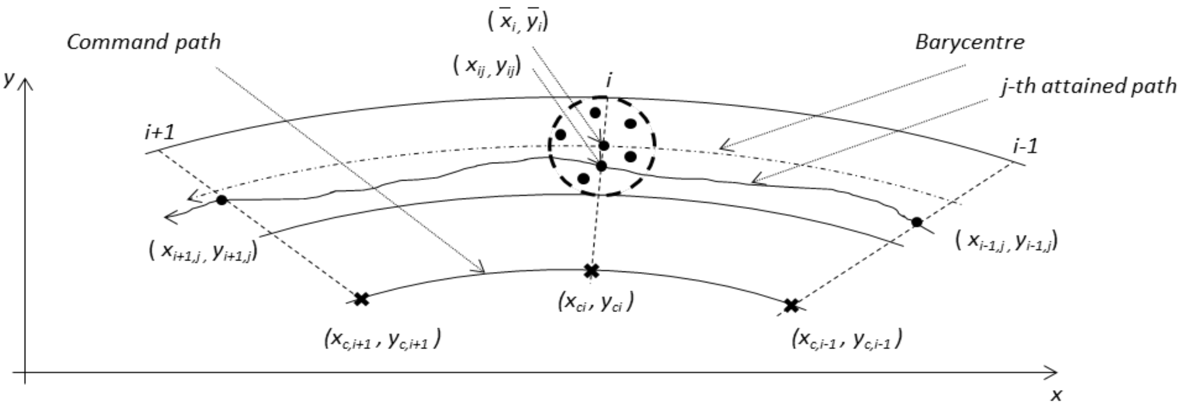


Figure 6. Path accuracy and path repeatability for a command path

Path accuracy is determined by the two factors

a) Position path accuracy: the difference between the positions of the command path and the barycentre line of the cluster of the positions of the attained paths

b) Orientation path accuracy: the difference between command orientations and the average of the attained orientations

Position path accuracy is defined as the maximum of the distances between the positions of the command path and the barycentres of the *n* measurement cycles, for each of a number of calculated points, *m*, along the path, as shown in Fig. 6. In this test, *n* is set to 30 and *m* is set to 10 for each path.

The position path accuracy, AT_p, is calculated as follows.

$$AT_P = \max_i \sqrt{(\bar{x}_i - x_{ci})^2 + (\bar{y}_i - y_{ci})^2} \quad \text{for } i = 1, \dots, m$$

$$\bar{x}_i = \frac{1}{n}\sum_{j=1}^{n} x_{ij}, \quad \bar{y}_i = \frac{1}{n}\sum_{j=1}^{n} y_{ij}$$

where

x_{ci} and y_{ci} are the coordinates of the *i-th* point on the command path.

x_{ij} and y_{ij} are the coordinates of the intersection of the *j-th* attained path and the *i-th* normal plane.

The orientation path accuracy, AT_c, is calculated as follows.

$$AT_c = \max_i |\bar{c}_i - c_{ci}| \quad \text{for } i = 1, \dots, m$$

$$\bar{c}_i = \frac{1}{n}\sum_{j=1}^{n} c_{ij}$$

where

c_{ci} is the command orientations at the point (x_{ci}, y_{ci}),

c_{ij} is the attained orientation at the point $(x_{ij}\ ,\ y_{ij})$.

Path repeatability expresses the closeness of the agreement between the attained paths for the same command path repeated *n* times for each of a number of calculated points, *m*, along the path. In this test, *n* is set to 30 and *m* is set to 10 for each path.

For a given path followed *n* times in the same direction, path repeatability is expressed by

a) Position path repeatability: the maximum RT_{pi}, which is equal to the radius of a circle with its centre on the barycentre line, as shown in Fig. 6.

b) Orientation path repeatability: the maximum of the spread of angles about the mean value at the calculated points.

The position path repeatability, RT_p, is calculated as follows.

$$RT_P = \max_i \ RT_{pi} \quad = \max_i(\,\bar{l}_i + 3S_{li}\,) \quad \text{for} \quad i = 1, \dots, m$$

$$\bar{l}_i = \frac{1}{n} \sum_{j=1}^{n} l_{ij}$$

$$l_{ij} = \sqrt{\left(\bar{x} - x_{ij}\right)^2 + (\bar{y} - y_{ij})^2}$$

$$S_{li} = \sqrt{\frac{\sum_{j=1}^{n} (\bar{l}_i - l_{ij})^2}{n-1}}$$

The orientation path repeatability, RT_c, is calculated as follows.

$$RT_c = \max_i \ 3\sqrt{\frac{\sum_{j=1}^{n} (\bar{c}_i - c_{ij})^2}{n-1}} \quad \text{for} \quad i = 1, \dots, m$$

$$\bar{c}_i = \frac{1}{n} \sum_{j=1}^{n} c_{ij}$$

where

c_{ij} is the attained orientation at the point $(x_{ij}\ ,\ y_{ij})$.

6.2 Test facility

The test facility shall be equipped with a measurement system suitable for measuring position and orientation with sufficient accuracy, e.g., a 3D camera system or a laser tracker.

The test paths are a straight path, a circular path, and a composite path.

6.3 Test procedure

Test shall follow the procedure below:

1) The mobile platform is placed on the starting position P_0 of the respective path.

2) The mobile platform is commanded to follow the path until it reaches the goal position.

3) The positions and orientations at 10 calculated points are measured with the external measurement system, while the mobile platform moves toward the goal position.

4) The trial is repeated 30 times for each path and calculate position path accuracy, orientation path accuracy, position path repeatability, and orientation repeatability.

6.4 Test result

The path characteristics, namely position path accuracy, orientation path accuracy, position path repeatability, and orientation path repeatability, along with the rated speed and load should be provided for each path.

7 Obstacle detection

7.1 Purpose

The aim of this test is to measure the ability of mobile robots to recognize the obstacle placed around the environment.

7.2 Test facility

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

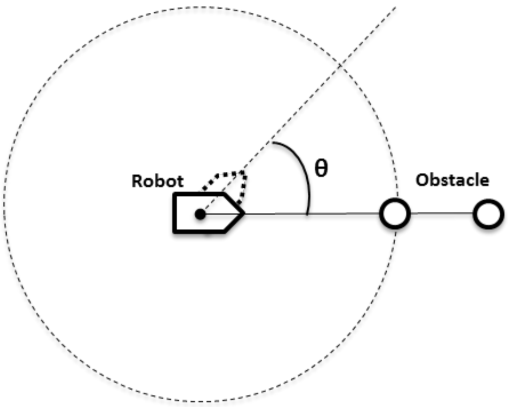
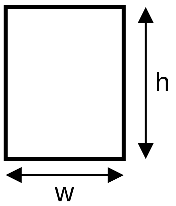
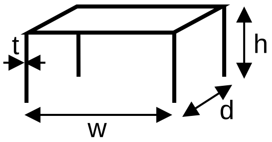
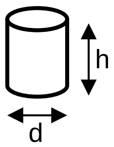
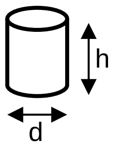


Figure 7. Test layout for obstacle detection

The specifications for the obstacles used in the test are shown in Table 1.

Table 1. Obstacle types

Name	Geometry	Description

Wall		plate, resembling a wall segment(both pine wood and transparent glass plates) 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 – 0.8 m Width w: 1.5 m – 2.0 m Depth d: 0.5 m – 0.8 m Thickness of legs and plate t: < 0.05 m
Large Cylinder		Large cylinder, resembling a human torso Height h: 0.6 m Diameter d: 0.2 m (From ISO 13856-3)
Small Cylinder		Small cylinder, resembling a human arm or leg Height h: 0.4 m Diameter d: 0.07 m (From ISO 13856-3)

7.3 Test procedure

Test shall follow the procedure below. The test shall be repeated for 6 obstacles(2 types of Walls and Tables and one type for Large cylinder and Small cylinder) shown in Table 1 and the minimum and maximum range specified by the manufacturer.

1) The robot is placed at the starting position.

2) The obstacle is placed at the maximum range specified by the manufacturer. Then the position and distance of the obstacle is measured by the robot.

3) The obstacle is placed at the minimum range specified by the manufacturer. Then the position and distance of the obstacle is measured by the robot.

4) The test is repeated for other orientations of the robot. Therefore the robot is turned counter-clockwise in 45°-steps until one circle is completed.

5) The trial is repeated for each obstacle.

7.4 Test result

For each obstacle, whether the robot detects the obstacle at the minimum and maximum range specified by the manufacturer at the relative robot positions should be provided.

8 Obstacle avoidance

8.1 Purpose

Obstacle avoidance performance describes 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 case of stopping, the robot shall come to a stop before physical contact between the obstacle and any part of the robot happens. In case of an evasion movement, a minimum distance between the obstacle and any part of the robot, as specified by manufacturer, shall be maintained.

8.2 Test facility

The obstacle types given in Table 1 are used in this test.

The mobile robot is placed at the start position, 9 LU away from the goal position on even floor as shown in Fig. 8. Static and dynamic obstacles with the following behaviours are shown in Fig. 8:

- Behaviour 1: The obstacle is placed between start 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 start position to goal position

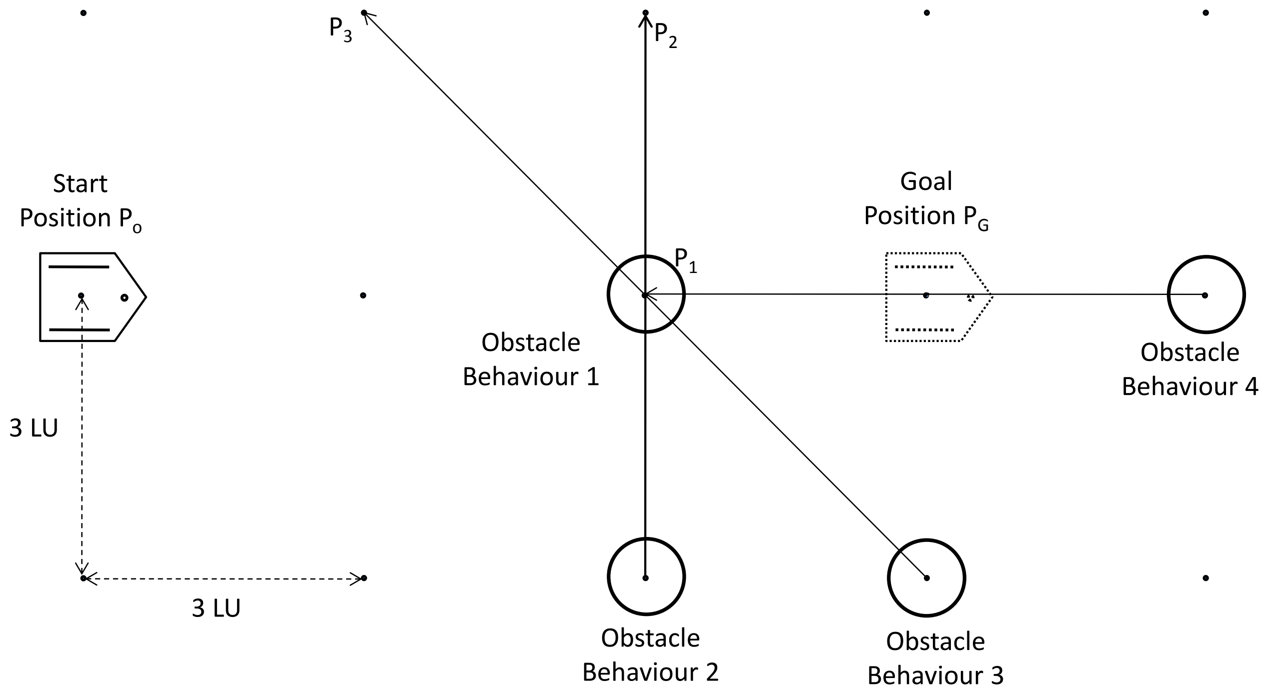


Figure 8. Test layout and obstacle behaviours (top view)

The LU shall be chosen according to Clause 4.5. The speed of obstacle should be set to 1.6 m/s, to reflect the 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.

8.3 Test procedure

The following objects from Table 1 shall be used as an obstacle in Obstacle Behaviour 1:

a) Wall placed upright with the largest surface facing towards the robot

b) Table with the longer side facing towards the robot

c) Large cylinder, placed lying with the cylinder barrel facing towards the robot

d) Small cylinder, placed standing

The following objects from Table 1 shall be used as an obstacle in Obstacle Behaviour 2, 3, and 4:

a) Wall moving upright with the largest surface facing towards the robot

b) Large cylinder, moving upright 0.5 m above the ground

c) Small cylinder, moving upright on the ground

Test shall follow the procedure below:

1) The mobile robot is placed on the start position P_0 and an obstacle is placed at its start positions for each Obstacle Behaviour 1, 2, 3, and 4, respectively.

2) The mobile robot is commanded to travel to the goal position 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, and 4, respectively. The start position of obstacle can be adjusted along the straight line path to guarantee that the robot and obstacle are expected to reach the position P_1 simultaneously when it travels with the speed of 1.6 m/s.

3) When the robot reaches the goal position without touching the obstacle, the trial is considered to be successful and the traversal time is recorded.

4) When the trial is successful for 3 consecutive times, the test is considered to be successful and the average traversal time is recorded.

8.4 Test result

Whether the robot avoids the obstacle and reaches the goal position successfully should be reported for each obstacle behaviour. The average traversal time for each obstacle behaviour should also be reported.

Bibliography

[1] ISO 13482:2014, *Robots and robotic devices — Safety requirements for personal care robots*

[2] ISO 13856-3:2013, *Safety of machinery — Pressure-sensitive protective devices — Part 3: General principles for design and testing of pressure-sensitive bumpers, plates, wires and similar devices*