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IEEE Standard for Robot Map Data Representation for Navigation

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IEEE Std 1873™-2015

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IEEE Standard for Robot Map Data Representation for Navigation

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of the
IEEE Robotics and Automation Society

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Abstract: A map data representation of environments of a mobile robot performing a navigation task is specified in this standard. It provides data models and data formats for two-dimensional (2D) metric and topological maps.

Keywords: IEEE 1873™, map data representation, metric map, robot navigation, topological map

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Introduction

This introduction is not part of IEEE Std 1873™-2015, IEEE Standard for Robot Map Data Representation for Navigation.

This standard specifies map data models and formats for robot navigation tasks. The standard provides specifications for representing two-dimensional (2D) metric and topological maps. A recommendation for exchanging map data among robots, computers, and other devices is provided.

To this end, the standard:

a) Defines a hierarchy of terminologies related to two-dimensional robot maps for navigation in indoor and outdoor environments;

b) Specifies a data model for each element of the hierarchy; and

c) Specifies an XML format for map data exchange between different robots, computer systems, and devices.

Three-dimensional, dynamic, and semantic maps are not considered in this standard, which is one possible extension thereof within the next few years to accommodate current technology development.

The rest of this section provides introduction to robot maps, including a few typical use cases of robot maps. The *map data representation* (MDR) is explained in conjunction with robot navigation in 2D indoor and outdoor environments. Technical issues are also introduced to highlight the needs for this standardization.

More specifically, the Background clause provides the background of MDR specifications. The Industry practices of MDR clause provides practical examples of robot navigation relevant to MDR specifications in the form of use cases. The Use case and benefit examples clause describes a typical use case in which a mobile robot utilizes a map for navigation tasks and indicates benefits that are obtained by standardization of MDR for robot navigation.

Background

One of the basic elements of robot navigation is a map with which a mobile robot can perform localization and motion planning. In order for the mobile robot to operate properly, a map may need to be available a priori or constructed during operation. Figure a illustrates a generic structure of robot navigation technology, comprising localization, mapping, and motion control.

Metric maps are perhaps the most popular type of maps used in everyday activities; for example, city maps or maps used for hiking or orienteering. A metric map explicitly encodes the physical layout of a target space and positions of physical objects therein.

Metric maps can be subdivided into continuous or discrete metric maps. An orienteering map is an example of a continuous metric map, where lines, points, and other geometric symbols mark the positions and shapes of paths, rocks, and so on. An example of a pure point map is reported in Holz and Behnke [B4].[a] Points may also have associated uncertainty information, represented as a 2x2 covariance matrix, as in the Normal Distributions Transform (NDT) representation (Saarinen et al. [B8]) (see Figure b).

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[a] The numbers in brackets correspond to those of the bibliography in Annex B.

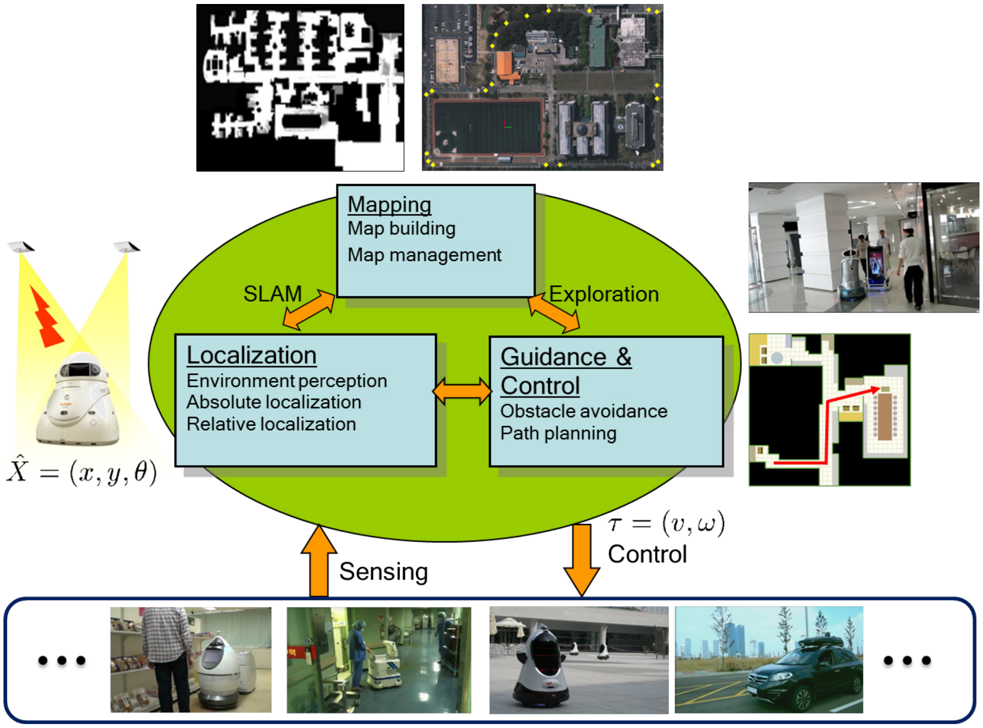

Figure a—Structure of robot navigation technology

Discrete metric maps are not so common for everyday human use, but are ubiquitous in robotics applications. They can be thought of as bitmap representations of, for example, the floor plan of a building, where the space is discretized by pixels to form a digital image thereof, where each pixel describes whether the corresponding part of the map belongs to the floor or wall of the space (Elfes [B2]; Moravec [B5]) (see Figure c).

A topological map represents an environment in the form of a graph consisting of a set of nodes (or vertices) and edges connecting the nodes (Choi et al. [B1]).

An everyday example of a topological map is the one commonly used for subway or bus networks, where primary information consists of nodes in the map (stations) and the connectivity between them (which subway or bus line goes between which stations). In this form of topological maps, relative positions and distances between map elements are less important. An example from robotics is a map of a building interior, where nodes in the map denote landmarks or distinctive features of the corresponding places, and edges represent possible routes for a mobile robot to navigate from one room to another (for example, see Figure d).

Once a physical environment is mapped to a topological map, path planning becomes a simple graph search. Also, topological representation is much more compact than metric maps. However, the drastic reduction in data comes at the cost of increased perceptual aliasing. Vertices of a topological map are augmented with various types of landmarks, requiring a proper interpretation of sensor readings to infer locations of a mobile robot. Reducing perceptual aliasing is critical for the success of robot navigation. Therefore, the data format should be defined so that various kinds of information can be included in the nodes and edges of a topological map to reduce the perceptual aliasing.

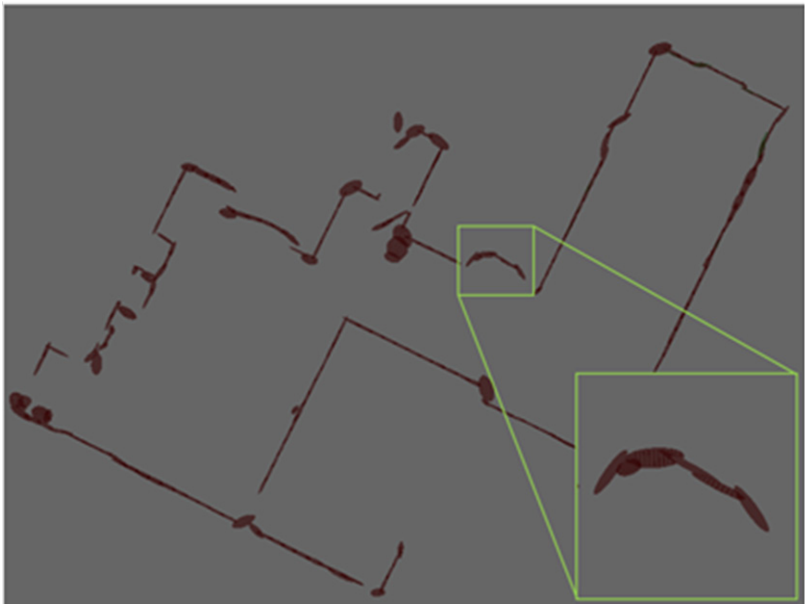

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Figure b—Continuous metric map with confidence ellipsoids (i.e., a point with an associated covariance matrix), scaled and oriented according to the Gaussian probability of occupancy in the local neighborhood. The excerpt shows a magnified portion of the map.

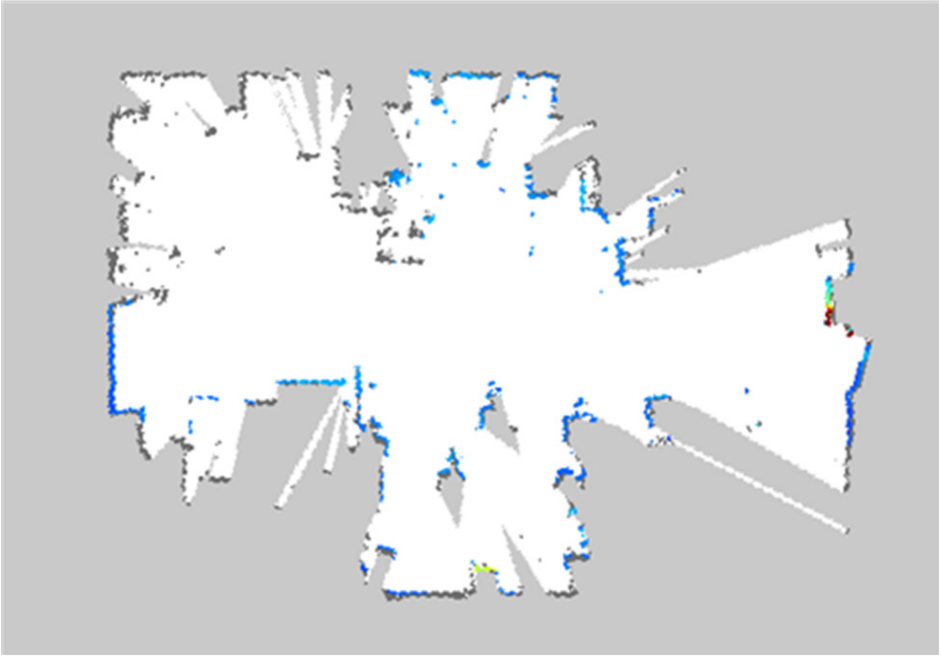

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Figure c—Discrete metric map, showing the interior of a furnished room. The grey level of each cell represents how likely it is to be free space. White means *certainly free*, black means *certainly occupied*, and mid-grey means *unknown*. In this example, colorized cells (blue-yellow-red) also represent *occupied space*, and additionally store the temperature of the surface, as measured by a thermal camera.

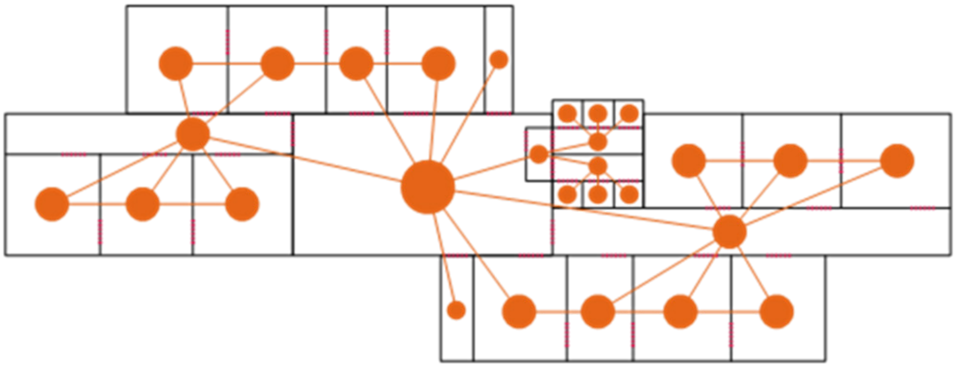

Figure d—Example of a topological map

There are various kinds of resources that can be used to develop a robot system providing a navigation capability. Examples include OpenSLAM (http://openslam.org/), Robot Operating System (ROS) (http://wiki.ros.org/), Mobile Robot Programming Toolkit (MRPT) (http://www.mrpt.org/), ORCA (http://orca-robotics.sourceforge.net/), Player and Stage (http://playerstage.sourceforge.net/), and many more from commercial software products. However, incompatibility among map data formats of the respective software tools makes reuse of existing software or integration of system components coming from different stakeholders a laborious task. This causes additional costs for developing robotics systems based on navigation and prevents service providers, possibly from other technical fields, from entering robotics industry.

A few *standard developing organizations* (SDOs) have already published a series of standards specifying application schemas for facilitating spatial data exchange, including Open Geospatial Consortium (OGC) City Geography Markup Language (CityGML) [B6] and Web Map Service (WMS) from OGC, and Geography Markup Language (GML) from ISO TC 211. The existing standards for encoding and exchanging spatial data, however, do not satisfy requirements specific to robotics: accuracy requirements and probabilistic nature of robot navigation. Moreover, previous Geographic Information System (GIS) standards concentrate on either metric or topological maps, not to mention the inadequacy of geographic scale in terms of robot navigation. For example, CityGML deals only with simple topological relationships (“contained in”) among spatial entities that carry their geometrical information, while WMS provides spatial maps only in the form of conventional graphic files: BMP, TIFF, JPEG, PNG, SVG, and the like.

Based on these findings, the MDR standard attempts to aggregate the existing spatial data encoding and exchanging practices, tailoring them to suit the requirements raised by robot navigation tasks in 2D indoor and outdoor environments: map quality in terms of metric accuracy, probabilistic behavior of robot navigation, and capability of handling metric and topological maps.

From the standpoint of (autonomous) mobile robotics, a map available to a mobile robot can come from several sources, including Simultaneous Localization and Mapping (SLAM), executive drawings or floor plans, and human mapping. The mobile robot can use the obtained map for many tasks, including motion planning, map update, localization, and obstacle avoidance. However, this document is only concerned with a common representation of environments, independently of its origin or purpose.

Industry practices of MDR

This clause provides a few examples of industry practices of robot navigation, emphasizing the usage of map data. In fact, these examples illustrate realistic use cases of robotic services utilizing navigation functionality. It should be noted that the following examples are selected to highlight some present and future industry practices; therefore, they are not intended to limit the technical scope of this standard to the application areas illustrated therein.

Table a specifies a use case in which a mobile robot provides a transportation service at a shopping mall. The types of maps employed are a metric map, a topological map, and a floor plan crafted manually for a user interface.

Table a—Robotic transportation service

Brief description	A mobile robot transports purchased items to a place designated by a shopper in a large shopping mall. The robot also provides a guidance service to shoppers.
Types of maps	—Metric map: the whole space is divided into a group of smaller-sized occupancy grid maps (10 m × 10 m). The grid maps are generated from a scanning laser sensor mounted on the robot, each cell of which is 1 cm × 1 cm. —Topological map storing visual features: consists of Speeded Up Robust Features (SURF) feature vectors (64 dimensions) and their positions (3 *dimensions*). —Floor plan crafted manually.
Usage of maps	—Metric map and topological map: self-localization of a mobile robot; specifically, metric map for accurate localization in a local area and topological map for global localization. —Floor plan map: user interface for people.

Table b specifies a use case in which a mobile robot performs a surveillance task along the perimeter of an airport.

Table b—Robotic surveillance system

Brief description	A mobile robot, equipped with a 2D laser scanner and a stereo camera, performs surveillance and patrol tasks in a facility complex.
Types of maps	—Metric map #1: 2D occupancy grid map is used for representing an outdoor environment. The map is generated by a 2D laser scanner sensor. —Metric map #2: 3D voxel map is used.[a] The map is generated by a stereo camera system. About 200 MB memory is required to cover a 100 m × 40 m area with 0.1 m resolution.
Usage of maps	—Metric map #1: ground vehicle navigation (including obstacle avoidance and path planning). —Metric map #2: ground vehicle localization and tele-operation (remote sensing).

[a] A voxel is an atomic element (e.g., a cubic cell) of a regular grid in the three-dimensional space.

Table c specifies a use case in which a group of mobile robots share a 2D metric, semantic,[b] and topological map to provide a delivery service in a large-scale hospital environment.

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[b] A semantic map for a mobile robot is a map that integrates spatial information encoding the surroundings of the mobile robot and semantic knowledge (human-level knowledge, like the names and functions of the rooms) about the surrounding environment (Galindo et al. [B3]).

Table c—Hospital delivery robot

Brief description	A mobile robot equipped with two 2D laser scanners (at middle and lower part of the robot platform) and six ultrasonic sensors is used for medical equipment or items delivery in a large-scale hospital environment.
Types of maps	—Metric map: 2D occupancy grid map generated by two 2D laser scanner sensors. —Semantic map: a dedicated grid map describing classified area information in a hospital is generated from the 2D occupancy grid map. —Topological map: node registration by using infrared retro-reflective markers attached on the ceiling. SLAM is used to estimate a robot pose, which is eventually utilized to derive node poses.
Usage of maps	—2D occupancy grid map: indoor robot localization. —Semantic map: task, path, and motion planning. —Topological map: a user interface between the robot and the user.

Use case and benefit examples

This clause presents an example of a use case for MDR. Figure e is a block diagram illustrating the relationship among various components of a map system specific to robot navigation functionality. In fact, the block diagram shows conceptual scenarios of a map creation use case [with associated steps from 1) to 4)] and a map retrieval use case [with associated steps from 6) to 8)] at the same time.

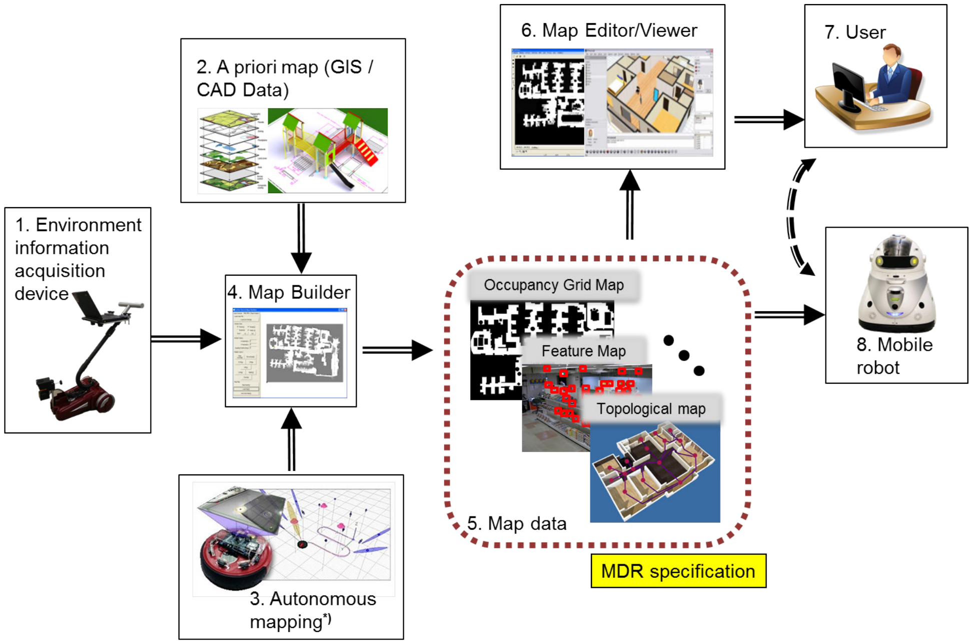

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Figure e—Block diagram illustrating generation and use of a map for robot navigation

1) Environment information acquisition device: a robot, a specially designed mapping device, a surveying tool, or any kind of equipment used by a human for gathering structural information of the environment in question manually or semi-autonomously.

2) A priori map: a map possibly provided a priori in the form of CAD drawings or other relevant format describing the environmental structures.

3) Autonomous mapping: a robot or any kind of device capable of gathering environmental information autonomously by employing, for example, a Simultaneous Localization and Mapping (SLAM) algorithm.

4) Map builder: a software system that is used by a human or by an algorithm to construct a map after spatial data acquisition, refining the initial maps built from manual, semi-autonomous, or autonomous mapping. The map builder can be located in any place as long as an external request for the constructed map can be handled, for example, in the internal memory of a robot or an external computer.

5) Map data: metric or topological maps conforming to the MDR specification.

6) Map editor/viewer: a software system used by a human to edit, revise, or display maps for a particular robot application.

7) User: a developer or an end-user who actually uses the map for task monitoring or robot control purpose.

8) Mobile robot: a hardware platform that performs a navigation task by using the map constructed. The mobile robot can perform map merging or sharing depending on task requirements. This mobile robot can be the same robot used in the step 3 or a different one.

The benefits that can be obtained from the MDR standard can be described as follows.

a) **To provide a common spatial representation for various types of robot systems employing navigation functionality**: The primary benefit of this standard is that robot maps are represented in a common data model so that development and deployment of various robotic applications based on robot navigation can be facilitated. Such applications include, but are not limited to, autonomous road navigation, robotic logistic systems, robots for defense and rescue, and service robots for personal/domestic applications such as robotic vacuum cleaners and entertainment robots.

b) **To facilitate robotics technology development**: The MDR standard will contribute to promote development of good experimental methodologies for mobile robotics as a valuable tool for facilitating comparison and evaluation of maps obtained with different systems.

c) **To reduce development and deployment costs**: Complying with a standard for MDR makes vendor's components more compatible with others and therefore makes their products more desirable and more likely to win contracts. Standards compliance is particularly important in environments where devices from diverse vendors inter-operate, such as factories and military environments, where data interchange is a common occurrence.

Contents

IEEE Standard for Robot Map Data Representation for Navigation

1. Overview

This standard specifies a common representation of two-dimensional (2D) maps intended for mobile robot navigation in indoor and outdoor environments.

1.1 Scope

This standard provides specifications for representing 2D metric and topological maps. This standard defines a recommended format for exchanging map data among robots, computers, and other devices. The map representation format specified by this standard only considers static maps; in other words, moving objects are not explicitly represented in the maps. Additionally, no limit is placed on geographic scale or sensor modalities in applying this standard.

To this end, the standard:

a) Defines a hierarchy of terminologies related to 2D robot maps for navigation in indoor and outdoor environments;

b) Specifies a data model for each element of the hierarchy; and

c) Specifies an XML format for map data exchange between different robots, computer systems, and devices.

There are several standards related to map specifications already published or under development from other *standard developing organizations* (SDOs), including the International Organization for