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Mass Robotics Interoperability Standard - Version 1.0

For Industrial Mobile Robots

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Caution: This Mass Robotics Interoperability Standard may be revised or withdrawn at any time.

Mission Statement

The MassRobotics AMR Interoperability Standard aims to help enable organizations to deploy autonomous mobile robots AMRs from multiple vendors and have them coexist effectively, better realizing the promise of warehouse and factory automation. This standard will allow autonomous vehicles of different types to share information about their robot(s) location, speed, direction, health, tasking / availability and other performance characteristics with other similar vehicles to help them be better teammates on a warehouse or factory floor. Furthermore, it allows human agents to provide a similar set of information (through the use of external mobile devices) so that their work can be orchestrated alongside robots.

The MassRobotics AMR Interoperability Working Group helps improve the use and adoption of autonomous mobile robots.

The group's mission is to develop standards that will allow organizations to deploy autonomous mobile robots (AMRs) and other automation and collaborative equipment so that they may work together in the same environment, better realizing the promise of warehouse and factory automation. These standards will allow information sharing so they can better coexist on a warehouse or factory floor and increase the value that AMR based solutions provide overall. **This standard is not to be relied upon for any purposes related to safety.**

The AMR Interoperability Working Group will not address safety standards of AMRs and will not duplicate the efforts of ISO under the TC 299 WG (TS 15066, 18646, etc.), the IEEE RAS (such as 1872-2015 or 1873-2015 or active work 1872.2 and P2751) or the RIA (TR 15.606 or ANSI/RIA 15.06 or R15.08-1-2020)

Consensus for approval of this document was achieved by balloting the following members. Consensus approval of this document does not necessarily imply that all committee members voted for its approval. At the time it approved this document, the Committee had the following members:

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Introduction

As mobile robots become increasingly available and effective for use in industrial settings, there is a growing need for mobile robots from multiple vendors to be able to co-exist. While each robotic system will maintain responsibility for its own safety and navigation, standard communication protocols can allow robotic systems from different vendors to work more effectively, increasing the value to end users. The standard communication protocols are intended to facilitate communication, but not dictate whether the communication is robot to robot, fleet manager to fleet manager, or fleet manager to the customer enterprise resource management tool, or some combination of the above.

Terms which may be unique to this standard are defined in Section 2. The word “shall” is prescriptive, and describes mandatory requirements to comply with this document. The word “should” is a recommendation or good practice and can be a very strong recommendation or advisory. The word “may” is permissive, and the word “can” indicates that something is possible or a capability. Notes used in the document are used to provide explanations or examples and are not intended to be exhaustive.

Section 1 - Scope

This interoperability standard specifically applies to industrial mobile robots, the fleet manager of those robots (to the extent one exists), and systems that wish to communicate to those industrial mobile robots. For the purposes of this document industrial pertains to the production or of goods and related services and environments, including but not limited to manufacturing, laboratory, pharmaceutical, warehousing, distribution, logistics, and other workplaces not traditionally considered strictly “industrial.” Industrial mobile robots typically operated in a structured or semi-structured environment. Industrial mobile robots specifically excludes mobile robots used in education, entertainment, consumer, military, medical, surgical, and robots engaged in transport on the public highways.

The requirements and specifications herein are for the manufacturers of IMRs while the IMRs are operating in Autonomous, Semi-Automatic, or Assisted Mode. IMRs operated in Manual Mode are not subject to these requirements and specifications.

Section 2 - Terms and Definitions

2.1 Base Footprint - two-dimensional projection of the IMR working space (see Clause XX) onto the travel surface

2.2 Collision avoidance - safety function that takes a predetermined action (e.g, stopping, braking, decelerating) to prevent a collision or reduce the severity of a collision when an obstacle cannot be avoided

2.3 Docking - process of reaching and/or connecting to another object in order to perform an intended task

2.4 Failure - termination of the ability of an item to perform a required function

2.5 Fault - state of an item characterized by the inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources

2.6 Fleet Manager - component of an industrial mobile robot fleet (IMRF), the function of which is to monitor the industrial mobile robots (IMRs) and their position and movements within a defined area, and to coordinate the activities of the IMRF to carry out its programmed task(s)
2.7 Guidance - provision of external information to enable the mobile platform to navigate

2.8 Guided - using a guidepath (ANSI/ITSDF B56.5-2019) for automatic guidance

2.9 Industrial environment - workplace where the public is restricted from access or not reasonably expected to be present for the intended tasks and robot applications

2.10 Industrial Mobile Robot (IMR) - mobile platform capable of navigating through an industrial environment to reach a specified location

2.11 Industrial Mobile Robot Fleet (IMRF) - one or more IMRs that are collectively managed by a centralized system

2.12 Industrial Mobile Robot Fleet Manager (IMRFM) software program that manages an IMRF

2.13 Universally Unique Identifier(UUID) is considered a RFC 4122 compliant unique identifier

2.14 Mode of Travel

2.14.1 - Automatic Mode - case when all the functions of the IMR are directed by and under the control of programmed logic

2.14.2 - Semi Automatic Mode / Assisted Manual Mode - case when some functions of the IMR are activated and controlled by an operator, with all other functions of the IMR under automatic control

2.14.3 - Manual Mode - case when all functions of the IMR are under the control of a local operator by way of a wired or wireless means

2.14.4 - Maintenance Mode - diagnostic or service mode

2.15 Path planning - process of computing an obstacle-free path, through free space, between two poses

2.16 - Reference Location - One or more locations on each floor used as a reference for all IMR providers to include in their individual maps. All locational data shared will be a longitude and latitude relative to the Reference Location (0,0). Reference Locations can also be an elevator that goes in between floors.

2.17 - Space - three-dimensional volume

2.17.1 Free space - entire space through which an IMR can path plan

2.17.2 Maximum Space - Space that can be reached by the moving parts of the IMR

2.17.3 Monitored Space - space defined by the active field(s) of view of sensor(s) supporting perception systems for the purpose of dynamic responses to observed objects in the IMR's path

2.17.4 Operational Space - portion of the restricted space (Clause 2.14.5) that is actually used while performing all motions commanded by the task program

2.17.5 - Restricted Space - portion of the maximum space (see Clause 2.14.2) restricted by limiting devices that establish limits, where if another IMR enters will cause the robot to stop

2.17.6 - Working Space - Volume used by IMR to avoid obstacles during path planning

Section 3 - Common Reference Frame

To establish a common reference frame for IMRs from different vendors operating within the same facility, first we must identify one or more "planar datum" coordinate frame(s). These are assumed to be "flat" and have only x and y coordinates. Ramps or other third dimensional data should be projected down into a flat plane. Two provide the ability to transform, two or more Datum Reference Points that have physical representation in the facility (support columns, fiducials, etc) need to be specified in the facilities coordinate system.

If there are two or more maps, they should be in the same coordinate space. It is recommended, but not required, that we use latitude and longitude for the coordinate space.

The AMR vendor will need to map the same Datum Reference Points in their own coordinate system. By knowing these reference points in both coordinate systems, they can compute back and forth between the two systems.

Note: With exactly 2 DRP, user can compute a rotation, translation, and scaling (equal in x and y) between two maps. With exactly 3 DRP (not co-linear), users can compute an affine transformation. With 3 or more DRP (not co-linear), users can use the ADJUST method described here: https://pro.arcgis.com/en/pro-app/latest/tool-reference/data-management/warp.htm to get global and local matching.

3.1 Datum Reference Point:

A Datum Reference Point is defined by:

- id: String
- name: String
- x: double
- y: double

3.1.1 - The id is a UUID that defines this reference point. This is the identifier when internally referencing this point in software.

3.1.2 - The name is a user friendly name for display purposes. The name should not be used internally for referencing purposes - only for user display.

3.1.3 - The x is the x coordinate of the reference point in the common coordinate system. It is recommended that this be latitude.

3.1.4 - The y is the y coordinate of the reference point in the common coordinate system. It is recommended that this be longitude.

3.2 Planar Datum

A Planar Datum is defined by:

- id: String

- name: String
- level: int
- datumReferencePoints: List<(Datum Reference Point ids)>

3.2.1 The id is a UUID that defines this planar datum. This is the identifier when internally referencing this point in software. This identifier should be provided whenever a location is transmitted so that it is clear what the reference is.

3.2.2 - The name is a user friendly name for display purposes. The name should not be used internally for referencing purposes - only for user display.

3.2.3 - The level is an integer listing the floor that map is referencing. The ground floor is the zero reference. The first floor would be one, the basement would be considered negative one.

3.2.4 - The datumReferencePoints are a list of two or more Datum Reference Points. This needs to be at least two, but it is recommended that three or more are provided.   Note that reference points should be spaced out over the areaing being used by the AMRs to reduce the effects of measurement errors.

3.3 Location Points

A location point is defined by:

3.3.1 - Planar Datum Id. This needs to be specified if referencing the location of the AMR. In all other cases, this can be omitted, in which case, it is assumed that it is the same Planar Datum as the AMR.

3.3.2 - x as referenced by the Planar Datum

3.3.3 - y as referenced by the Planar Datum

3.3.4 - z in reference to the planar datum.   This is not an absolute height, but reference to the ground of the referenced planar datum. If this is omitted, it is assumed that the vehicle is on the ground.

3.3.5 - Pose quaternions (qx, qy, qz, w) utilizing the Planar Datum Id.

Section 4 - Industrial Mobile Robot Identity and Capability

4.1 - The IMR or IMRFM **shall** be capable of sending the following information about itself or the IMRs that it is managing:

- 4.1.1 - UUID (unique identifier used to identify this agv)
- 4.1.2 - Time stamp in Coordinated Universal Time (UTC)
- 4.1.3 - Manufacturer Name
- 4.1.4 - Robot Model
- 4.1.5 - Robot Serial Number or other unique identifier
- 4.1.6 - Base Robot Envelope (x, y, and z measurements in meters)

4.2 - The IMR or IMRFM **should** be capable of sending the following information about itself or the IMRs that it is managing:

- 4.2.1 - Max Speed (specified in m/s)
- 4.2.2 - Max Run Time (specified in hours)
- 4.2.3 - Emergency Contact Information
- 4.2.4 - Charger Type
- 4.2.5 - Support Vendor Name
- 4.2.6 - Support Vendor Contact Information

4.3 - The IMR or IMRFM **may** be capable of sending the following information about itself or the IMRs that it is managing:

- 4.3.1 - Link to product documentation
- 4.3.2 - Visual Thumbnail Image
- 4.3.3 - Cargo Type
- 4.3.4 - Cargo Capacity Volume limit
- 4.3.5 - Cargo Capacity Weight limit

4.4 - Message Frequency - The message containing this data shall be sent at least upon IMR power start up or upon request, and should be sent every time any data in Section 4 changes.

Section 5 - Industrial Mobile Robot Status

5.1 - The IMR or IMRFM **shall** be capable of sending the IMR's current operational state. The following status messages are acceptable operational states:

5.1.1 - The IMR's UUID as reported in the **Industrial Mobile Robot Identity and Capability** message

5.1.2 - Timestamp in Coordinated Universal Time (UTC)

5.1.3 - Operational state. This is defined as one of the following:

5.1.3.1 - Navigating - attempting to make progress to a new destination

5.1.3.2 - Idle - not actively navigating

5.1.3.3 - Disabled - not available to perform a mission

5.1.3.4 - Offline - no current messages

5.1.3.5 - Charging

5.1.3.6 - Waiting for human event

5.1.3.7 - Waiting on external event

5.1.3.8 - Waiting on internal event

5.1.3.8 - Manual Mode

5.1.3 - Location - This is a location point as specified in 3.3 Location Points

5.1.4 - Error Codes - If needed, one or more error codes will be sent as an array of strings. If the error codes are omitted it is assumed that the robot is functioning normally and fully operational. Example codes are included below, but may include other error codes:

5.1.4.1 - Robot safety stop based on sensors

5.1.4.2 - Robot stopped - manual estop selected

5.1.4.3 - Battery Low

5.1.4.4 - Robot Lost

5.1.4.5 - Robot Stuck

5.1.4.6 - etc (see appendix)

5.2 - The IMR or IMRFM **should** be capable of sending the following status message about itself or the IMRs that it is managing:

5.2.1 - Current linear in meters/sec

5.2.2 - Current angular velocity in quaternions/sec

5.2.3 - List of next working location(s). This will be a list of time (in UTC) and location (in 3.3 Location Points) where the robot will be doing work or reserving resources. This list should project no further than 15 minutes into the future and contain at most ten (10) items. It is recommended that at least the dest destination is provided.

5.3 - The IMR or IMRFM **may** be capable of sending the following status message about itself or the IMRs that it is managing:

5.3.1 - Battery Percentage

5.3.2 - Estimated remaining run time

5.3.3 - Path of intermediate forecast location and pose sampling for the future travel for the next 10 seconds. This will be a list of time (in UTC) and location (in 3.3 Location Points). This should include at most 10 locations and no more than one update a second.

5.3.4 - Load Percentage Used. This is a vendor specific metric from 0%-100% that represents how much of the carrying capacity of their robot is used. This can be any combination of volume, area, weight, or whatever the vendor thinks is appropriate to show usage.

5.4 - Message Frequency - The message containing this information shall be sent when the IMR in Section 5 changes, with a minimum frequency of sixty (30) seconds and maximum frequency of one (1) second.

Section 6 - Transport and Message Formats

It is important that we have a consistent transport and message format to allow for easy and reliable integration.

6.1 - All transport will be done over Websockets as standardized by IETF as RFC 6455 in 2011.

6.2 - Messaging will be done in JSON as standardized by ISO/IEC 21778:2017. The JSON schema document for this standard is available on GitHub at https://github.com/MassRobotics-AMR/AMR_Interop_Standard