

IEEE Standard for Autonomous Robotics (AuR) Ontology

IEEE Robotics and Automation Society

Developed by the
Standing Committee for Standards

IEEE Std 1872.2™-2021

STANDARDS

IEEE Standard for Autonomous Robotics (AuR) Ontology

Developed by the

Standing Committee for Standards
of the
IEEE Robotics and Automation Society

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Abstract: This standard extends IEEE Std 1872™-2015, IEEE Standard for Ontologies for Robotics and Automation, to represent additional domain-specific concepts, definitions, and axioms commonly used in Autonomous Robotics (AuR). This standard is general and can be used in many ways—for example, to specify the domain knowledge needed to unambiguously describe the design patterns of AuR systems; to represent AuR system architectures in a unified way; or as a guideline to build autonomous systems consisting of robots operating in various environments.

Keywords: automation, autonomous robots, IEEE1872.2™, ontology, robotics

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Introduction

This introduction is not part of IEEE Std 1872.2-2021, IEEE Standard for Autonomous Robotics (AuR) Ontology.

There is an increasing demand from government and private agencies alike to use autonomous robots like unmanned aerial vehicles (UAVs), unmanned ground vehicles (UGVs), unmanned surface vehicles (USVs), and autonomous underwater vehicles (AUVs) for tasks such as homeland security, reconnaissance, search and rescue, surveillance, data collection, and urban planning. Ontologies in autonomous robotics (AuR) provide a unified way of representing the underlying semantics that defines the vocabulary, thereby allowing precise knowledge transfer for problem solving and unambiguous communications between heterogeneous autonomous systems. Creating ontologies in autonomous robotics may have a huge impact directly and indirectly on all robotics and automation (R&A) domains. The main benefit of a domain ontology is to set standard definitions of shared concepts identified in the requirement phase, as well as to define relations between the concepts and their properties. Well-founded ontologies capture the domain terminology in both semantic and logical frameworks, which allows building a formal theory of the domain. This theory provides a much harder limit to the possible interpretations of the terms in the domain, constituting a more preferable tool for standardization work than a simple list of terms/definitions written in natural language. Furthermore, an ontology may serve further purposes as systems synthesis and operation. In the tradition of symbolic artificial intelligence, a domain ontology provides a clear set of symbols to be used in reasoning mechanisms for autonomous systems, such as classification, inference, and planning. The domain structure encoded in ontologies can be expected to provide the blueprint for application programming interfaces (APIs) in domain-specific software packages and model for databases. Another potential area to use AuR ontologies is in agent communications, where an ontology provides vocabulary and precise semantics. For instance, future unmanned systems may need to work in teams and communicate with other unmanned vehicles to share information and coordinate activities.

This standard is a follow-on to IEEE Std 1872™-2015 (IEEE Standard Ontologies for Robotics and Automation). IEEE Std 1872 CORA was created to support follow-on standards such as this one (refer to S.R. Fiorini et al [B1]).¹ CORA was developed to be a high-level standard from which domain-specific efforts could build from. The approach was to define concepts in CORA that were generic to all robot domains, and then these domains could specialize these concepts to address their specific information requirements. When the working group that developed CORA was created, based on the interests of the working group members, it was expected that sub-groups would emerge that would specialize the concepts represented in CORA. The groups are organized in two layers. The middle-layer groups develop ontologies regarding transversal notions in robotics. Lower-layer groups concern specific domains in robotics and use concepts from CORA and middle-layer groups.

The Robot Task Representation Sub-Group (P1872.1) develops a broad standard that provides a comprehensive ontology for robot task structure and reasoning. In this context, task refers to the concrete decomposition from goal to sub-goals that enables the human/robot to accomplish the outcome at a specific instance in time. In order to accomplish this, there is a need for a standard providing an explicit knowledge representation for robot tasks.

The AuR Sub-Group aims to create ontologies that specify the domain knowledge needed to build autonomous robots, operating in the air, ground, and underwater environments. Benefits include having a common knowledge base for the development and integration of systems from different manufacturers, which may enable interoperability and catapult design to a new level. The AuR Working Group intends to extend CORA and define domain-specific concepts and axioms. This document describes the AuR Working Group's analysis of various autonomous robots (flying, ground, underwater, etc.) to identify the components necessary to endow robots with autonomy—including the hardware and software.

¹ The numbers in brackets correspond to those of the bibliography in Annex D.

Ancillary Open Source

Participants in the IEEE 1872.2 Working Group have created ancillary files developed separately from this standard, including OWL files, and will contribute the files to the IEEE SA Open Source Platform in the project located at: <https://opensource.ieee.org/aur/owl>. These files will be available for public input, but will not be considered part of IEEE's standards development activities.

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IEEE Standard for Autonomous Robotics (AuR) Ontology

1. Overview

1.1 Scope

This standard is a logical extension to IEEE Std 1872™-2015, IEEE Standard for Ontologies for Robotics and Automation.¹ The standard extends the core ontology for robotics and automation (CORA) ontology by defining additional ontologies appropriate for Autonomous Robotics (AuR) relating to the following:

- a) The core design patterns specific to AuR in common robotics and automations (R&A) sub-domains
- b) General ontological concepts and domain-specific axioms for AuR
- c) General use cases and/or case studies for AuR

1.2 Purpose

The purpose of the standard is to extend the CORA ontology to represent more specific concepts and axioms that are commonly used in autonomous robotics. The extended ontology specifies the domain knowledge needed to build autonomous systems comprised of robots that can operate in all classes of environments. The standard provides a unified way of representing autonomous robotics system architectures across different R&A domains, including, but not limited to, aerial, ground, surface, underwater, and space robots. This allows unambiguous identification of the basic hardware and software components necessary to provide a robot, or a group of robots, with autonomy, i.e., endow robots with the ability to perform desired tasks in all classes of environments without continuous explicit external guidance.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{2,3}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

¹ Information on references can be found in Clause 2.

² The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

³ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 1872™-2015, IEEE Standard Ontologies for Robotics and Automation.^{4,5}

3. Definitions, acronyms, and abbreviations

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁶

3.1 Background of autonomous robotics

“Autonomy is the extent to which a robot can sense its environment, plan based on that environment, and act upon that environment with the intent of reaching some task-specific goal (either given to or created by the robot) without external control” (Beer, Fisk, and Rogers [B2]). AuR has identified the components of autonomous robotics, such as sensors, estimation, plans, actuators, control, processing elements, and communication elements.

actuator: An entity that makes some change.

communication element: An entity that passes information between the sender and the recipient.

control: Respond to the input in order to reach some desired output.

estimation: A process to infer the state, based on sensor information, previous knowledge, and some algorithm.

plan: A proposed arrangement in advance that considers a list of intended steps/actions associated with timing and resources for doing or achieving a goal in the future.

processing element: A computational element with processing capability upon which software artifacts may be deployed for execution.

sensor: An entity that measures some property of a phenomenon that may be altered/changed by some stimulus to produce, in general, a quantity.

3.2 Autonomous robotics (AuR) ontology definitions

The following definitions are part of the base concepts of the Autonomous Robotics Ontology. Those are formally defined in 4.4, where the AuR Ontology axioms are presented.

⁴ IEEE publications are available from the Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

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⁶ *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

architectural behavior: The architectural behavior of an object is the internal organization of the flow of information that determines the object's actions. Reactive behavior, deliberative behavior, and cognitive behavior are subtypes of architectural behavior.

behavior: The behavior of an object is an element of one of the following classes: manifested behavior, engineering behavior, emergent behavior, architectural behavior, or rule behavior.

emergent behavior: The emergent behavior of an object is the set of relationships chosen to describe the object relevant interactions.

engineering behavior: The engineering behavior of an object is the description of the manifested behavior given by a set of state variables.

function: The function of an object is the role that the manifested behavior of the object plays in the event.

function execution: A function execution is an event in which the manifested behavior of an object plays a role with respect to a goal.

information interaction: An information interaction is an interaction in which there are no direct exchanges of physical forces.

interaction: Given an event, the interaction among (some or all) the objects participating in it, is the change of the objects' qualities and their relationships during the event.

manifested behavior: The manifested behavior of an object in an event is the evolution of the object's qualities and of the relationships holding among that object and any other object participating in the event.

object-centered environment: Given an event, the object-centered environment of an object in the event is a physical object comprising all the entities (with their relationships) that participate in the event and that could potentially interact with the object during the time of the event.

object-centered environment description: The object-centered environment description of an object in an event is a description of the object-centered environment in that event.

object-centered external environment description: The object-centered external environment description (EED) of an object in an event is the description of the object-centered environment without the information about the object itself.

physical interaction: An interaction in which there are direct exchanges of physical forces.

rule behavior: The rule behavior of an object is the set of rules and decision methods that an agent has and can possibly use to decide its actions.

3.3 Acronyms and abbreviations

AuR	autonomous robotics
BFO	basic formal ontology
CORA	core ontology for robotics and automation
DOLCE	descriptive ontology for linguistic and cognitive engineering
DUL	DOLCE ultralite
FOL	first-order logic
OWL	web ontology language
R&A	robotics and automation

SLAM	simultaneous localization and mapping
SUMO	suggested upper merged ontology

4. Concepts and axioms

4.1 Overview

This clause formally defines the main concepts and the axioms for the Autonomous Robotics Ontology of the terms and definitions of Clause 3.

In detail, an ontology is defined to be a logical theory consisting of a set of formulas whose models approximates as well as (formally) possible the intended models, i.e., those models that satisfy the conceptualization and the ontological commitments (Guarino, Oberle, and Staab [B3]).⁷

Being a logical theory, an ontology consists of individuals, classes, relations, and axioms. The exact list changes depending on the specific logic language one adopts. Usually, an ontology is given in first-order logic (FOL) (Smullyan [B4]), or in web ontology language (OWL) (Antoniou and van Harmelen [B5]). Individuals are the objects in the ontology, the things the ontology is about. Classes are properties and are used to identify the individuals that satisfy that property. Functions provide ways to identify and relate individuals. Relations are connections across individuals or classes. Axioms are expressions in the language that use the previous elements to state what is true in the ontology.

Ontology classifications usually divide ontological systems in upper-level, reference, domain, and application (see Figure 1). An upper-level ontology focuses on broadly applicable concepts such as object, event, state, quality, and high-level relations like part hood, constitution, participation, and dependence. Examples are the suggested upper merged ontology (SUMO) (Niles and Pease [B6]), Cyc ontology (Lenat and Guha [B7]), the basic formal ontology (BFO) (Arp, Smith, and Spear [B8]), and the DOLCE foundational ontology with its extension DOLCE+DnS Ultralite (DUL) (Masolo et al. [B9]). A reference ontology is an ontology that focuses on a discipline being highly reusable within the discipline [medical, engineering, enterprise, etc. (Guarino, Oberle, and Staab [B3])]. When the ontology focuses in a more limited area, e.g., autonomous or collaborative robotics, it is called a domain ontology. This type of ontology contains vocabulary about concepts within a domain and their relationships; about the activities taking place in that domain; and about the theories and elementary principles governing that domain. The concepts in domain ontologies are usually specializations of concepts already defined in upper-level and in reference ontologies, and the same could occur with the relations. Some examples are the core ontology for robotics and automation (CORA) (IEEE Std 1872-2015) and the ontology presented in this standard.⁸ An application ontology contains all the definitions needed to model the knowledge required for a particular application, e.g., robot grasping system or simultaneous localization and mapping (SLAM).

This clause starts with an overview of the existing relations between AuR ontology and CORA (in 4.2). Then, once identified a representative set of definitions of Clause 3, the clause presents usage examples of each term and its rationale. Moreover, an ontological implementation is included, which contains examples of integration of the AuR ontology with the upper ontologies, DUL, and SUMO. First, those upper-level concepts useful for the integration are introduced (in 4.3). Then, the resulting axioms (in 4.4) are proposed and described using OWL, including examples and rationale. Note that even though the proposed ontology is based on some general terms (primitives), it does not commit to any specific upper-level ontology.

⁷ The numbers in brackets correspond to those of the bibliography in Annex D.

⁸ Information on references can be found in Clause 2.