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EDITORIAL

Special issue on ontologies and standards for intelligent systems: editorial

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Abstract

Day by day, new intelligent systems and autonomous machines are being developed to help and assist humans in a myriad of activities ranging from smart manufacturing to smart cities. Such new-generation intelligent systems need to work in teams and communicate with humans and other agents/robots to share information and coordinate activities. Furthermore, there is an increasing demand from government agencies and the private sector alike to use Unmanned Aerial Vehicles (UAVs), Unmanned Ground Vehicles (UGVs), Unmanned Surface Vehicles (USVs), and Autonomous Underwater Vehicles (AUVs) for tasks including search and rescue, surveillance, and monitoring. As these intelligent systems have to interact with humans in several scenarios involving multi-agent collaboration, data collection, and decision-making, it is urgent to discuss the technical as well as the ethical aspects in their design and function. Hence, ontology-based models for this Robotics and Automation (R&A) domain have the potential to enable a clear communication among the different intelligent systems and stakeholders, the formulations of standards, and the building of AI-based and robotics systems with full alignment with what stakeholders expect from these intelligent systems, in terms of economical benefits and enhanced human well-being.

1. Introduction

Intelligent systems, such as intelligent agents and intelligent robots, are becoming a mainstream domain with a wide range of applications with middle- and long-term impact on everyone lives all over the world. With the current intelligent robotic systems relying more and more on robot–robot communication and human–robot interaction, a vocabulary with clear and concise definitions is a *sine qua non* component in terms of communication, to enable information exchange among any group of intelligent agents, which can be human or non-human actors. This need for a well-defined knowledge representation is becoming evident if one considers the growing complexity of behaviors that intelligent systems are expected to perform as well as the rise of multi-agent and human—robot collaboration. Hence, the existence of a standard knowledge representation would

(i) define precisely concepts and relations in the robotics and automation knowledge representation that could include, but is not limited to, intelligent systems' software and hardware, environment, cause and effects of performing actions, relationship among intelligent robots, agents, and people;
(ii) ensure common understanding among members of the scientific community;
(iii) facilitate efficient data integration and transfer of information among intelligent systems.

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Therefore, this special issue has the purpose to increase interest in the standardization work for the Robotics and Automation (R&A) domain as well as in the related technical and ethical challenges involved in such intelligent systems. Our previous work in this context resulted in the very first IEEE RAS standard, named *IEEE 1872-2015 – IEEE Standard on Ontologies for Robotics and Automation*. This 2015 IEEE SA Emerging Technology Award-wining standard defined a core ontology to specify the main concepts, relations, and axioms of robotics and automation and has become a reference for knowledge representation and reasoning in robots, as well as a formal reference vocabulary for communicating knowledge about R&A between robots and humans. As extensions to the IEEE 1872-2015 standard, new standard development has been approved by the IEEE Robotics and Automation Society (RAS), the IEEE Standard Association (IEEE-SA), and the IEEE Robotics and Automation Standards Committee (RAS-SC). Hence, the *IEEE P1872.1 RAS Standard on Robot Task Representation (RTR)* Working Group is currently working to provide a robot task ontology for knowledge representation and reasoning in robotics and automation. Likewise, the *IEEE P1872.2 RAS Standard on Autonomous Robotics (AuR) Ontology* Working Group works toward a unified way of representing autonomous robotics architectures across different R&A domains, to provide a robot with autonomy. Aligned with these efforts, the *IEEE 7007-2021 RAS Ontological Standard for Ethically Driven Robotics and Automation Systems* Working Group's activities addressed the main issues concerning the development of Ethical AI and Robotics systems using an ontology-based approach to define the foundation of ethics concepts and terminology for robotic and intelligent systems in accordance with Ethics and Moral theories, leading to the 2021 IEEE SA Emerging Technology Award 'for developing an innovative ontological standard on the ethics of artificial intelligence'.

This special issue aims thus to discuss this emergent domain through review articles and research papers from different areas with two main objectives:

1. highlight the recent developments in ontology-based approaches to describe the robotics and automation domain in terms of general knowledge and applications;
2. share and compare different viewpoints from AI and robotics practitioners, looking for a common ground to combine distinct approaches toward the development of standards as part of the IEEE Standard Projects.

This special issue is structured to provide information to Academia and Industry, interested in advancing the interaction between humans and intelligent systems using a standardized and formal terminology, and to serve the public sector using autonomous systems to deliver automated services, such as police and emergency responders.

Topics of interest include, but not limited to:

- Autonomous systems and autonomous robotics,
- Ontology-based development for Robotics and Automation,
- Ontology-based standards for Robotics and Automation,
- Knowledge representation and reasoning for Robotics and Automation using ontologies,
- Robot–robot interaction and/or human–robot interaction using ontologies,
- Building ethical AI and intelligent systems,
- Trust in AI, intelligent agents, and robots,
- Industry 4.0, factory 4.0, smart manufacturing,
- Smart cities, smart technologies and applications.

It is worth noting that this special issue was organized following the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2018) Workshop on *'collaboratively working towards ontology-based standards for robotics and automation' (WOSRA)* (Bermejo-Alonso *et al*. 2018), which speakers were invited to submit extended versions of their works for this special issue of *The Knowledge Engineering Review (KER)* journal.

The submitted papers have undergone peer review with one or two revised versions being checked by the KER reviewers. This has resulted in six papers being accepted and published in this special issue.

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These articles provide an overview of current research directions which are being explored within the scientific community across the globe.

2. Contents of the special issue

In this 155-page-long special issue[1], we have presented six articles which report on world-leading research about *ontologies and standards for intelligent systems*.

The first paper is a review article focused on standard ontologies for autonomous robotic systems and is followed by two papers which are dealing with ontologies and communication policies for agent systems. The fourth paper is a review article describing ontologies and ontological standards for Industry 4.0 robotic agents and is heading the top-10 list of the most read articles for this journal up to now. The final two papers are research articles about advanced aspects and applications of ontologies for intelligent systems in context of Industry 4.0 and further smart applications.

More specifically, in the first contribution to this special issue (*'A review and comparison of ontology-based approaches to robot autonomy'*), Olivares-Alarcos *et al*. (2019) examines ontologies that are used to conceptualize parts of the autonomous robotics domain. Such a formal conceptualization of the autonomous robotics domain in a machine-understandable form, which is understood by robots generating and using this knowledge, is an important factor to support the robot's autonomy and its different cognitive capabilities, while relaxing the programming effort required to match the expectations of research and industry, in order to deliver robotic systems that can autonomously perform a large variety of tasks in a large variety of environments.

In the second article of this special issue (*'Agent mining approaches: An ontological view'*), Grislin-Le Strugeon *et al*. (2021) analyses ontologies for agent systems and formalizes both agent's knowledge and data mining domain to provide the ontological representation of the agent mining domain according to the addressed problems, the application domains, the agent-related and mining-related elements, the models, processes, and algorithms. Since ontologies offer the capability to express semantics and constraints from the concepts, the shared knowledge obtained about the agent mining approaches could be specified and represented explicitly, resulting in the design of communication and coordination elements for the agents to share their common environment made of common resources. This ontological view leading to a 'shared virtual world' being the basis for the agent interactions and helping the intelligent agents in their communication and cooperation by improving among other, aspects such as agents' decision-making, negotiation, and collaboration.

The third article of this special issue (*'Toward an interdisciplinary integration between multi-agents systems and multi-robots systems: A case study'*) also focuses on communication policies of agent systems. In particular, Botelho *et al*. (2020) describes further challenges of the distributed artificial intelligence domain in terms of communication, coordination, interaction, and integration of agent systems, such as multi-robot systems, that are composed of a group of robots working cooperatively, and multi-agent systems, that are computational systems consisting of a group of agents which interact with each other to solve a problem.

In the fourth paper of this special issue (*'Ontologies for Industry 4.0'*), Sampath Kumar *et al*. (2019) studies ontologies for the Industry 4.0 domain, formalizing the smart manufacturing knowledge to develop an interoperable communication model which efficiently interconnect various intelligent systems interacting reliably and securely with each other. Indeed, as Industry 4.0 is driven by digital data, connectivity, and cyberphysical systems, and as it relies heavily on robotic agents which have to evolve and perform the main operations in smart manufacturing environment and which are solicited to communicate with human operators, customers, or with diverse distributed partners, the standardization together with the formalization of knowledge representation are crucial for the Industry 4.0. For this purpose, ontologies have been identified as a solution for the standardized, formal representation of the vocabulary describing the key concepts related to this fourth industrial revolution.

[1] https://www.cambridge.org/core/journals/knowledge-engineering-review/collections/ontologies-and-standards-for-intelligent-systems

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In the next paper of this special issue (*'Enhancing RFID system configuration through semantic modelling'*), Tsalapati *et al*. (2021) proposes a domain ontology for the configuration of radio-frequency identification (RFID) systems, which are a key element of the Industry 4.0 for data exchange within the realm of the internet of things (IoT). The ontology is thus an extensive formal representation of RFID technologies, and its formal semantics is defined by using a knowledge representation language to ensure a precise specification of the meaning of the described elements that is both machine- and human-readable. The machine readability allows automated logical deduction techniques (i.e., automated reasoning) on the conceptual schema deriving implicit information from the explicit representation, while the human readability allows a shared understanding of the RFID technology domain; the dynamic nature of the semantic technologies enable an easy path for expanding the incorporated knowledge.

In the final contribution to this special issue (*'Ontologies for cloud robotics'*), Pignaton de Freitas *et al*. (2020) explores standard ontologies for cloud robotic systems (CRS), which are systems using cloud computing to share data and resources of distributed robotic systems that constitute useful technologies for Industry 4.0 and smart applications. Hence, in order to get coherent agent-to-cloud communications and efficient agent-to-agent collaboration within these cloud robotic systems, there is a need to use a standardized approach and to formalize the knowledge representation in the cloud robotics domain. Therefore, the use of standard ontologies provides a mean to define formal concepts and their relations in both a standard and interoperable way, aiding multi-agent coordination as well as human–robot interaction.

3. Conclusions and acknowledgment

The Guest Editors would like to thank all the authors who submitted their valuable contributions to this special issue. The published articles address key challenges of the development and application of ontologies and standards for the intelligent systems.

Thanks are extended to all the reviewers of the journal papers submitted to this special issue for their time and constructive comments.

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