Robotic Ontological Standard Development Life Cycle

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Abstract— The current growth of research and application development in robotics has triggered many efforts in robot standardization led by international, technical and professional associations such as the Institute of Electrical and Electronics Engineers (IEEE). As robotics is a fast-pace changing domain, the development of robotic standards needs to be adapted to that field's requirements. Hence, we propose in this paper a new standard development methodology which could be applied when producing new IEEE standards such as P7007, the IEEE Ontological Standard for Ethically Driven Robotics and Automation Systems.

I. INTRODUCTION

Nowadays, robots are present in the most varied types of environments where they have to perform tasks which have been exclusively performed by humans until recently, e.g. in the elderly care sector.

Hence, robotic standard development is a high-priority task [1]. Indeed, standards represent a consensual view of a particular subject, associated to technology solutions, human or environment safety, good practices, etc. These are elaborated by official Working Groups (WGs), commonly associated with international Standard Development Organisations (SDOs), such as IEEE[1], IEC[2], or ISO[3]. WGs are formed by stakeholders from different domains and from different horizons such as research, industry, or government. During the development of a standard, all the stakeholders have an equal opportunity to contribute to it; the process being governed by the leaders appointed by the SDO. In particular, the IEEE WGs operate under the procedures and policies defined by IEEE, which have as core five basic principles, namely, openness, due process, balance, right to appeal, and consensus. For IEEE, standards are essential to advance global prosperity through the promotion of technological innovation.

For example, developing standards to define how robots can interact properly with humans [2] will ensure end-users some guarantee that the robot can interact safely and ethically. Indeed, in domains such as elderly care technologies or elderly assistive living, it is important robots do not become a threat, e.g. to privacy, daily interpersonal contact and citizens' control over their own lives, and avoid any negative impact on people, like e.g. the elderly feeling of being treated like an object rather than a human.

At the moment, in Europe, matters related to Ethics and Robotics could be addressed through the General Data Protection Regulation (GDPR) [3], but outside Europe, they should be addressed through policies or other contractual solutions because of the current lack of international ethical standards in the robotic field. It is also evident that some ethical rules can be provided by the Law, but in certain cases, they might result in policies or agreements. On the other hand, standards that tackle the interaction with humans are few, and they are mainly concerned with the safety issues of robots, e.g. ISO 13482-2014 Robots and robotic devices (Safety requirements for personal care robots) and ISO/TS 15066-2016 Robots and robotic devices (Collaborative robots). Safety has been thus discussed in international standardization organizations, but no ethical standard has been yet published. Thence, there is an urgent need to fill this gap by developing new robotic standards such as the IEEE P7007[4] Ontological Standard for Ethically Driven Robotics and Automation Systems.

In particular, ontological standard [4] development is important because ontologies allow to capture and represent consensual knowledge in an explicit and formal way, independently of a particular programming language. In general, ontologies explicit the relevant knowledge about a domain in a computer-interpretable format, facilitating automatic reasoning over that knowledge to infer new information [5]. Furthermore, ontology standards enable shared commitments across multiple domains and between independently developed applications. In addition, ontologies are an efficient approach to disambiguate knowledge used among groups of humans, robots, and other artificial systems that share the same conceptualization. This point is one of the major advantages of ontological standards when compared to non-ontological ones as pointed out by Prestes et al [6].

The development process of a domain-specific ontology needs to be completed in a consistent and systematic way [7] to fulfill its goals, since only high-quality ontologies can hope to become cornerstones of the community effort. Therefore, several methodologies to rigorously build ontologies have been proposed in the literature. These methods mainly rely on certain modelling principles that must be followed in order to assure that the obtained product is mature and effectively commits to the shared knowledge.

[1] http://www.ieee.org
[2] http://www.iec.ch
[3] https://www.iso.org/

[4] https://standards.ieee.org/develop/project/7007.html

Such established methodologies include Cyc Methodology [8], Enterprise Ontology (EO) Methodology [9], Toronto Virtual Enterprise (TOVE) Modelling Methodology [10], KACTUS Methodology [11], Skeletal Methodology [12], METHONTOLOGY [13], SENSUS Methodology [14], the Enhanced Methodology [15], or the Integrated Ontology Development Methodology [16].

For example, the IEEE 1872-2015 Standard Ontologies for Robotics and Automation has been developed using the METHONTOLOGY approach as described in Section II. However, only concepts have been developed in the IEEE 1872-2015 standard.

Thence, another approach is required to develop a robotic ontological standard such as the IEEE P7007 standard which aims to end up with the relevant taxonomy and its properties, but also with its deployment for particular use cases. For this purpose, we have developed a methodological approach to develop such standard. Thus, the contributions of this paper are twofold. On one hand, we propose the Robot Standard Ontological Development Life Cycle (RoSaDev), and on the other hand, we introduce a normalized approach to prepare and present use cases to deploy the standard on.

The remainder of this paper is structured as follows. Background information about the development of ontological standards is presented in Section II, while the proposed ontological standard development life cycle is described in Section III. Its use for the P7007 ethically driven robotic ontological standard development is reported in Section IV and, in particular, its application in context of elderly care. Conclusions are given in Section V.

II. PRELIMINARIES: PREVIOUS ROBOTIC ONTOLOGICAL STANDARDS

The IEEE 1872-2015 Standard Ontologies for Robotics and Automation standard establishes a series of ontologies about the Robotics and Automation (R&A) domain [6], e.g. the *Core Ontology for Robotics and Automation (CORA)*. A core ontology specifies concepts that are general in a whole domain such as Robotics. In the case of CORA, it defines concepts such as Robot, Robot Group, and Robotic System. Its role is to serve as basis for other more specialized ontologies in R&A. Moreover, it determines a set of basic ontological commitments, which should help robot developers and other ontologists to create models about robots.

Further initiatives currently in development are the standards IEEE P1872.1 and P1872.2. The IEEE P1872.1, which is under development by the *Robot Task Representation Working Group*, intends to standardize an ontology and repository for robot task procedures [17]. The IEEE P1872.2, being developed by the *Autonomous Robotics (AuR) Ontology Working Group* aims to define standard ontologies for Autonomous Robotics systems [18]. Both are extensions of IEEE 1872-2015 standard and are using CORA as their core ontology.

At the inception of the CORA project, it was assumed that its modelling principles will be followed to assure that any later addition commits to the shared knowledge. CORA
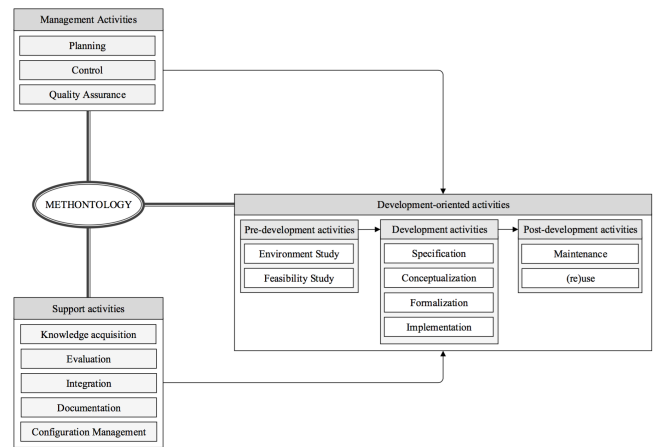

Fig. 1: Methontology Development Life Cycle.

needed to ensure the mutual agreement among stakeholders and the potential of the reuse of the knowledge, allowing smooth data integration upward as well as downward. As CORA intended to become an exemplary ontology, the following attributes were considered based on the Ontology Design Patterns (ODP) of the NeOn project[5]:

- the ontology must be well designed for its purpose;
- it shall explicitly include stated requirements;
- it must meet all and for the most part, only the intended requirements;
- it should not make unnecessary commitments or assumptions;
- it should be easy to extend to meet additional requirements;
- it reuses prior knowledge bases as much as possible;
- there is a core set of primitives that are used to build up more complex parts;
- it should be easy to understand and maintain;
- it must be well documented.

In particular, CORA was developed following the METHONTOLOGY approach (Fig. 1), since it is a sistematization of what has been since before it. This involves five sets of activities, namely, *pre-development*, *development*, *post-development*, *management*, and *support* [13].

More specifically, the development activities constitute the core of the methodology and include the four main phases of the ontology development, i.e. the specification, the conceptualization, the formalization, and the implementation. During the pre-development activities, the methodology specifies the environment study and the feasibility study. The post-development activities are performed after the development of a version of the ontology, and include the maintenance and the ontology reuse, while the management activities are performed during the whole process of ontology development and include scheduling, control, and quality assurance. The support activities can be performed during the development activities as well, and usually include the

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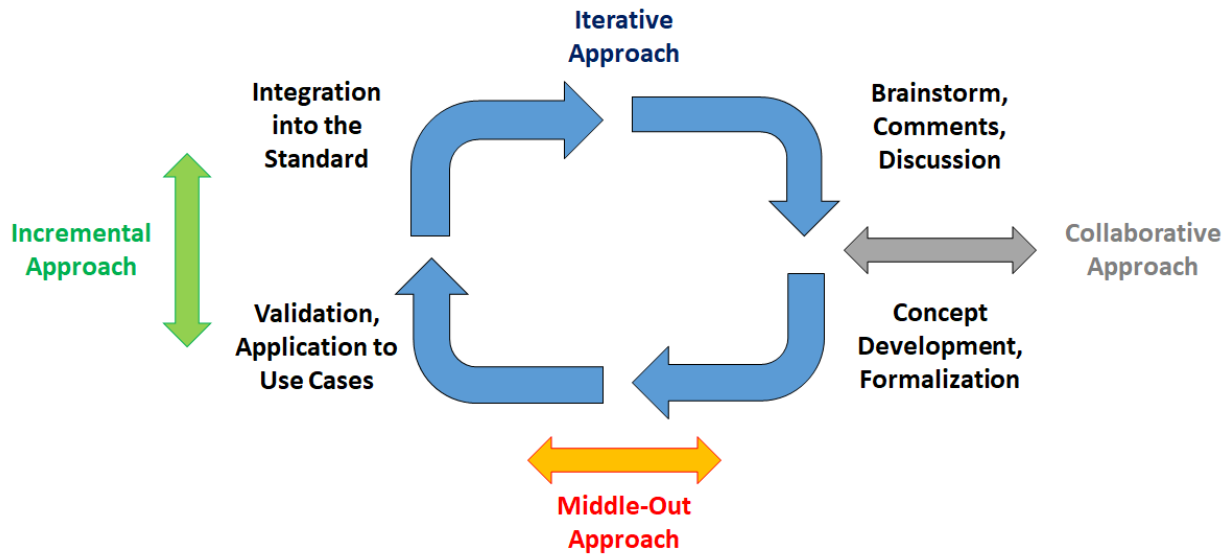
[5]http://ontologydesignpatterns.org

Fig. 2: Proposed Ontological Standard Development Life Cycle (RoSaDev).

knowledge acquisition, the evaluation, the integration, the documentation, and the configuration management [13].

Hence, while P7007 ontological standard will inherit some concepts from the IEEE 1872-2015 ontological standard and therefore from CORA, P7007 necessitates a full development of ontological concepts inherent to ethically driven robotics, including on one hand their formalization as well as axiomatization, and on the other hand, their domains' identification as well as application guidelines. Therefore, P7007 development aims to follow the Robotic Ontological Standard Development Life Cycle presented in Section III.

III. PROPOSED ROBOTIC ONTOLOGICAL STANDARD DEVELOPMENT LIFE CYCLE

Like for softwares and systems which follow IEEE 1075-1995 Standard for Software Development Process or IEEE 1074-1997 IEEE Standard for Developing Software Life Cycle Processes, the development of standards, and in particular robotic ontological standards, requires the adoption of a development life cycle as advised in ISO/IEC/IEEE 12207 and ISO/IEC/IEEE 15288 standards. In the past, many standards have been developed using waterfall-type approaches. However, such methodologies have long-duration cycles and do not address anymore the need of quickly expanding technological fields such as robotics.

1) Proposed Life Cycle: Hence, the proposed life cycle (RoSaDev) to develop a robotic ontological standard is an Agile-inspired, iterative method which involves four steps as illustrated in Fig. 2. The first step consists in identifying the ontological concepts for the standard, and is followed by their development and formalization. These steps are carried out in a collaborative way through brainstorms and discussions, reaching consensus between the multiple stakeholders such as experts from Public Bodies, Academia, and Industry. The concept development is following a middle-out approach to address potential use cases developed as explained in

Section III-.2. Indeed, there is a need of a standard approach, not only theorised but mainly practised, e.g. by the private sector. Therefore, besides being a means for the identification of necessary concepts and relations to be formalized in the standard, each use case constitutes the basis for the validation step, leading to an incremental integration of validated concepts within the standard being developed.

2) Proposed Use Case Development: In our middle-out approach adopted to produce a robotic ontological standard, the development of use cases along the development of the standard concepts mentioned in the Section III-.1 is necessary, since concepts and use cases are both crucial elements of this approach. Thence, we propose to normalize the use case development itself by introducing the Use Case Template adapted from [19] as follows:

Use Case Template

- *Name*: The use case name, which ideally should implicitly express aspects of the use case purpose.
- *Identifier (optional)*: A unique identifier that can be used by other project artifacts to reference the use case.
- *Author(s)*: Name of person or persons composing the use case.
- *References*: References in the literature relevant to the use case.
- *Context Description*: A descriptive summary of the use case actors, its goals and purposes, when it applies, and relevant associated pre-suppositions, and environmental context.
- *Intent/Purpose*: A brief description of the intent of the use case.
- *Preconditions*: An enumeration of conditions that should hold before the actions, tasks, and events specified in the use case are considered or enacted.
- *Scenario (aka Course of Action)*: A descriptive characterization of the sequence of events, tasks, and actions

taken by the actors and agents identified in the use case. This is the principal use case component and should focus on the elicitation and identification of concepts, properties, and relationships requiring formalization in the ontological standard.

- *Alternate Related Scenario (optional)*: Alternate event and task sequences that elaborate related exception conditions or failures associated with the principal scenario's descriptive logic.
- *Postconditions*: An enumeration of conditions that hold after the actions, tasks, and events specified in the use case are considered or enacted.
- *Relevant Knowledge*: Identify what are the concepts, relations and attributes that appear in the use case (and that are relevant to represent the knowledge necessary for the use case). It is a result of the analysis of both the scenario and the competency question previously described.

3) Proposed Information Flow Scheme Among Working Sub-Groups: Information required to create appropriate ontological concepts and relevant use cases should be shared and discussed collaboratively among standard Working Group (WG) members as mentioned in Section III.1. Moreover, the flow of information and developed knowledge in between the working sub-groups (WSGs) is set to be horizontal rather than hierarchical, as it matches well with the developed Agile, iterative approach. Indeed, the horizontal flow allows to refine the ontological concepts, use cases, etc. several time, and this under different angles resulting from the different potential specificities of each of the WSG.

IV. APPLICATION AND DISCUSSION

Our robotic ontological standard development life cycle proposed in Section III is used in the development of the *P7007 IEEE Ontological Standard for Ethically Driven Robotics and Automation Systems*, which is currently elaborated by P7007 active working subgroups (WSGs) focused on aspects such as Robot Ethics Knowledge Representation, Robot Ethical Behaviour Assessment, Ethical Robot Design, Ethical Violation Management, Transparency, Data Privacy & Protection, and Healthcare.

P7007 targets to create a standard constituted by a set of ontologies necessary to establish ethically driven methodologies for the design of Robots and Automation Systems. These ontologies aim to define a set of concepts and their relationship that will enable the development of Robotics and Automation Systems in accordance with worldwide Ethics and Moral theories, with a particular emphasis on aligning ethics and engineering communities to understand how to pragmatically design and implement these systems in unison. Indeed, P7007 intends to assist stakeholders such as industries and organisations which often seem to evaluate ethical rules only as a cost, whereas ethics are 'processes' and their systematic and possibly automatic assessment to comply with the Law is the right way to address them. Hence, P7007 robotic ontological standard can be used in multiple ways, i.e. as (i) a guide for teaching ethical design;

(ii) a reference by policy makers and governments to draft AI related policies; (iii) a common vocabulary to enable the communication among government agencies and other professional bodies around the world; (iv) a framework to create systems that can act ethically; and (v) a foundation for the elaboration of other ethical compliance standards.

For this purpose and as per robotic ontological standard development life cycle proposed in this paper, several use cases from *Ethical Design* to *Healthcare Robots* have been defined by the P7007 WSGs. In particular, a use case has been produced *Robot Companion for the Elderly* as follows:

- *Name*: Robot Companion to Recognize Elderly's Behaviour and to Suggest Actions
- *Identifier (optional)*: P7007 Use case 7
- *Author(s)*: P.J.S. Goncalves
- *References*: Project EuroAGE[6]
- *Context Description*: A robot companion moving in care homes that is able to monitor elderly persons' behaviour and interact with them to suggest some activities. For example:
  - if the elderly person is bored, the robot may suggest to play a board game;
  - if the elderly person needs to talk to his family, the robot may suggest a Skype call;
  - if the elderly person has fallen, the robot may call help to his/her caregiver.
- *Intent/Purpose*: The use case describes how the robot can analyse the elderly persons' behaviours and take the action to suggest activities.
- *Preconditions*: The elderly person is at the care home. The robot is at the care home. The robot can move in the care home. The robot is always looking after the elderly persons. The robot must have the required capabilities, in terms of software and hardware, to be able to perform the use case. A risk assessment of the care home, i.e. of the environment where the robot should operate, is done.
- *Scenario (aka Course of Action)*: The scenario is very complex because it needs several capabilities/services that have to exist in the robot, e.g. face recognition, voice recognition, emotion recognition, elderly person's pose recognition, voice synthesis, Skype call, call for caregiver's help, play a board game, etc. Using the above capabilities, the robot must, at a given sample time, check the status of the elderly person and infer its behaviour. With the voice, the face, the pose, and the emotion recognition capabilities, the robot can estimate the current emotional status of the elderly people. Based on that information, the robot can query its knowledge base and may suggest:
  - a Skype call to a family member if the elderly person is sad;
  - a card game if the elderly person is bored;
  - a call for help to the caregiver if the elderly person has fallen.

In this scenario, the robot must respect the user's will, i.e. must allow the user to activate/deactivate its help, and/or ignore the robot's suggestion. In this use case, and because the robot can move close to the elderly person, the robot must operate in line with the safety standards, both hardware and software.

- *Alternate Related Scenario (optional)*: The use case can also be applied or extended for care robots deployed at elders' homes.
- *Postconditions*: The elderly person emotional status. The capability that was instantiated as the result of the query to the robot knowledge base. The current result of the recognition process. The success or not of the *recognition→action* process, at each sample time.
- *Relevant Knowledge*: {capability, behaviour, services, actions, recognition, Skype call, call for help, user's will, safety, ignore, interaction, pose recognition, voice recognition, play board game, emotion recognition, activate, deactivate, knowledge base, task}.

In this specific use case, some relevant aspects of the Companion Robot domain that should be captured for a Robotic Ontological Standard are represented. This use case could be refined itself as the result of our adopted, iterative and collaborative development approach. The resulting use case 7.b is thus an example of a specific use case that highlights some more particular events and leads to the capture of further ontological concepts, as follows:

- *Name*: Robot Companion to Recognize Elderly's Behaviour and to Suggest Actions
- *Identifier (optional)*: P7007 Use case 7.b
- *Author(s)*: P.J.S. Goncalves and M. Houghtaling
- *References*: Project EuroAGE and [20]
- *Context Description*: A provider of an elder care and companion robot has designed and enabled it with the capability to monitor and evaluate elderly persons' behaviour and to interact with them when recognizing various emotional and physical states among the care home residents. The robot's behaviour is enabled and guided by:
  - duty rules intended to insure the safety and well-being of the assisted companions;
  - essential sensing and recognition capabilities including facial, voice, pose, and emotional states;
  - a knowledge base of its repertoire of tasks and services applicable to detect emotional and physical states of the home care residents;
  - a history of its interactions with its assisted companions.
- *Intent/Purpose*: The use case describes how a Care Robot can analyze the elderly persons' behaviours and take actions to suggest social and ethical enabled interactions.
- *Preconditions*: The Elder Care Robot is deployed in an elder care home to assist several elderly residents at the home. Each of the residents under the home's care has given its consent to receive the robot's assistance.

The Elder Care Robot can move around the care home to monitor specific physical and emotional states of its assigned residents and it possesses a repertoire of tasks and services it can pursue or apply for specific states and situations that it detects. The Elder Care Robot can maintain a history of the detected activities, states, and situations in which it has interacted with its assigned residents. The Elder Care Robot has the following duty rules that govern its behaviour when detecting potential interaction situations:

- The Care Robot is obligated to minimize harm to residents;
- The Care Robot is obligated to maximize respect for the residents' autonomy;
- The Care Robot is permitted to use its situation analysis and awareness capabilities to choose actions that promote the well fair of its assigned residents.

- *Scenario (aka Course of Action)*: The elder care companion robot is assigned to monitor several elderly residents in the community entertainment room of an elderly care facility. The robot observes that an elderly woman, Anna, appears to be sad. The robot queries its knowledge base and finds that it has been some time since Anna has communicated with her family. It applies one of its permitted duty rules and suggests that the robot initiates a Skype call to Anna's family. Anna agrees and the agent starts a Skype call session for Anna. The companion robot subsequently observes that an elderly man, Giacomo, appears to be bored. It applies another of its permitted duty rules and suggests that Giacomo plays a board game with the robot. Giacomo replies that he is deep in thought planning next week's party and does not wish to play a board game now. The robot apologizes for its interruption and moves away. Next, the companion robot observes that it is time for another elderly man, Sean, to take his medicine. He moves to Sean and suggests that Sean takes his medicine. Sean refuses to do it. The robot warns Sean that it will notify the care support staff if he does not take the medicine. Sean continues to refuse to take the medicine, so the care robot requests assistance from the care facility staff. Together they convince Sean to take his medicine.
- *Alternate Related Scenario (optional)*: N/A
- *Postconditions*: The elder care robot successfully applied both of its obligation duty rules and one of its permitted behaviour rules:
  - It correctly prioritized its minimize harm obligation over the maximize respect for individual autonomy by calling for assistance with Sean refusing to take his medicine;
  - It appropriately applied its maximize respect for the individual by acknowledging Giacomo's disinterest in playing a board game, and apologized for interrupting Giacomo unnecessarily;

– It applied one of its permitted rules to engage Anna with a Skype call to her family after recognizing her sad mental state and conferring with its history and knowledge bases.

- *Relevant Knowledge*: {emotional state recognition, physical pose and body language, situation awareness, harm vs respect situations, social interaction norms, user's will and autonomy}.

Hence, such developed *Robot Companion for the Elderly* use cases allow us, on one hand, to identify the competency questions and relevant knowledge which will be the basis for the development of the ontological standard concepts useful for Ethically Driven Companion Robots, and on the other hand, to set the basis of the validation framework of the potentially developed ontological concepts as per our middle-out-based life cycle as described in Section III.1. Moreover, the development of these use cases followed the template presented in Section III.2. That facilitates the sharing of the common understanding about real-world situations involving in this case Companion Robots. Thus, the information embedded in these use cases will be shared horizontally among the WSGs as explained in Section III.3 and scrutinized by the different WSGs to analyze the use cases' specific aspects the WSGs are dedicated to. As an example, the use case 7 developed by the P7007 Healthcare WSG has been refined by the P7007 Ethical Violation Management WSG leading to the use case 7.b which will be studied as well by the P7007 Transparency WSG in order to benchmark the transparency of such Companion Robots.

V. Conclusions

In this work, we introduce a robot ontological standard development life cycle which suits the fast-changing robotic field. The elaboration and adoption of the robotic ontological standard development life cycle at an early stage of the standard development strength the consistency of the overall development process and contribute to the quality of the end product, i.e. the robotic ontological standard. Furthermore, the proposed methodology for the development of standards provides coherent guidelines to all the standard WSGs, allowing them to consistently develop the ontological concepts within the WG and facilitating the sharing of the produced knowledge among the WSGs. Hence, the presented robot ontological standard development life cycle is aimed to be applied during the development of the P7007 standard. In particular, following the proposed robot ontological standard development life cycle for the case of Companion Robots led us to quickly and coherently apprehend the related domain and to identify the relevant ontological concepts useful for Ethically Driven Companion Robots.

VI. Acknowledgment

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