Ontology based robot reasoning in the elderly care domain - the EUROAGE projects

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***Abstract*—This paper describes the actions developed and currently in development within the EUROAGE projects related to the ontology-based robot reasoning in the elderly care domain. Recent ontology-based standards were developed (IEEE 1872-2015; IEEE 1872.2-2021; IEEE 7007-2021), and others are currently in development (IEEE P1872.1; IEEE P1872.3) to improve robot performance while executing tasks. This is a very hot topic in current standardization efforts worldwide. The elderly care domain has special characteristics related to interactions with humans and robots living in the same workspace. As such, robots must also commit to social and ethical norms (IEEE 7007-2021). The robot and the actions it can perform in such interactions are defined according to the IEEE 1872-2015. Moreover, a semantic map of the environment was developed (using some concepts from the IEEE 1872.2-2021) where the robot can interact with the elder and the sensors in the smart home. In this environment, an ontology-based platform was developed that allows the robot to interact with the objects, e.g., to pick a cell phone or bottle of water, using semantic information from that environment to solve demanded tasks. Ongoing efforts are underway to thoroughly add to the reasoning framework of the previously stated standards and the concepts from the IEEE 7007-2021 to ensure that the robot's actions are ethically and socially correct.**

Keywords—knowledge representation, autonomous robotics, ontologies, semantic maps.

I. Introduction

The EUROAGE [1] projects (EuroAGE and EuroAGE2) are developed with the main goal: to develop technology to help elders to have an active and healthy living. Several tasks were developed in this broad scope, e.g., serious games development, cognitive games with robots, and robots for elderly care.

Serious games were developed for elders to engage in cognitive and physical activities. In [2] was proposed an exercise which consists of the projection on the floor of a virtual board with which the elders interact directly. An RGB-D sensor was used to identify the elder's position within the board.

Games, where elders interact with robots, were also developed where robots are tele-operated by elders to pick and place specific-colored objects in the game area [3]. Following the developed technology, a validation pilot study [4] was completed in a nursing home.

The project also involved the development of social robots to interact with elders in their homes and/or nursing houses. The robots have been developed by the partners with several hardware options, where most of them were mobile robots with human-robot interaction (HRI) to engage, e.g., conversation, social navigation or monitoring of elder activities [5,6]. Moreover, those robots interact with the sensors deployed in the smart home environment explicitly developed for the project in the partner's laboratories. The robotic solution that will be further presented in this paper is the one developed at Instituto Politécnico de Castelo Branco (IPCB) robotics laboratory. Other approaches exist in the literature, presented in the literature review of the above cited papers. However, the project's scope was to develop (EuroAGE project) robotic applications for the specific regions of the center of Portugal and Extremadura in Spain and to pilot them (EuroAGE2) in the region's nursing homes. Moreover, another important aim was to deploy prototypes close to the market using existing robotic standards.

The following section presents the robot and ontology-based control architecture of the robot developed to interact with elders in their homes and/or nursing houses. The following section presents the ontologies developed based on existing ontology standards for the domain-specific scenario of Social Robots for the Elderly. The paper ends with the conclusions and future work section.

II. Robot and ontology-based control architecture

A. Robot description

For the robots developed in the IPCB robotics laboratory, all the components follow the IEEE 1872-2015 as presented in work published in [7]. All the robot components and actions follow the concepts presented in the standards, i.e., are instances of the concepts in the ontology.

Figure 1 is depicted the Autonomous Mobile Manipulator Robot (AMMR) where are implemented the developed frameworks during the EuroAGE projects. There is present an omnidirectional mobile base (named IDMIND) with mecannum wheels, allowing the robot the capability to move in any direction. A Universal Robot UR3 robotic manipulator is mounted on the mobile platform. Such systems are powered using batteries placed in the robot base that are charged in the docking station. The robot manipulator is equipped with a Robotiq 2f-140 gripper. This gripper allows proper object manipulation for everyday objects present in the homes. A set of sensors (e.g., rear, and front lasers, video and RGB-D cameras for autonomous navigation and obstacle recognition) are also present on the mobile base, allowing the robot manipulator to perceive its workspace. All the software developed to control the robot is developed using Robot Operating System (ROS), which allows a proper information flow amongst all the software and hardware agents present in the smart home ecosystem where the robot performs its given tasks. The framework has been implemented and tested within ROS Noetic and Ubuntu 20.04.4 LTS operating system.

Fig. 1. Autonomous mobile manipulator robot.

In the current work, a small set of concepts was used to simplify the reasoning engine, not fully following the IEEE 1872-2015 standard. It is depicted in Figure 2, the instances used in this work: *ur3_arm* and *idmind*. Moreover, the relationships between classes are presented, which allows inferences from the knowledge base of the global ontological framework.

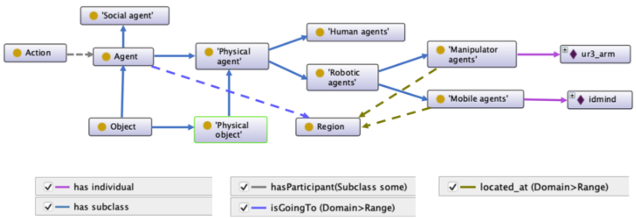

Fig. 2. Autonomous mobile manipulator robot instances in the ontology.

B. Smart home description

Figure 3 presents the environment where the robot performs its tasks. The case of the EUROAGE projects is a smart home with several objects, as presented in the figure. This paper does not discuss the sensors and controllers (for monitoring purposes) that are part of the environment and communicate with the framework using specifically designed ROS messages.

C. Global knowledge engine conceptual framework

Figure 4 depicts the global knowledge engine framework [8] that allows the robot to plan its actions using relevant semantic information from the environment. It comprises three main layers: reasoning, planning and low-level robot control. The reasoning layer relies on the ontologies developed in the work, to be introduced in the next section. The Home environment ontology is the domain-specific ontology for these projects, i.e., the main ontology, and covers all the concepts from the robot, the environment and the agents that interact with them. The box named "*PDDL ontology*" is the sub-set of the main ontology that is related to the concepts needed to define a PDDL (The Planning Domain Definition Language) problem and domain. The PDDL problem file is then defined using the instances of the ontology for the specific task needed to be performed by the robot. The information for each one of the instances is stored using a MongoDB database.

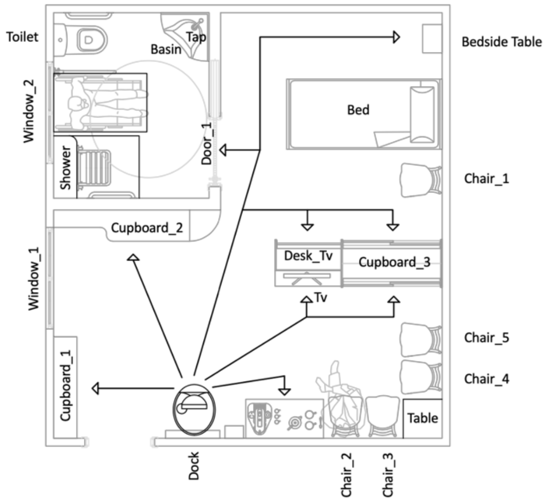

Fig. 3. Smart home environment.

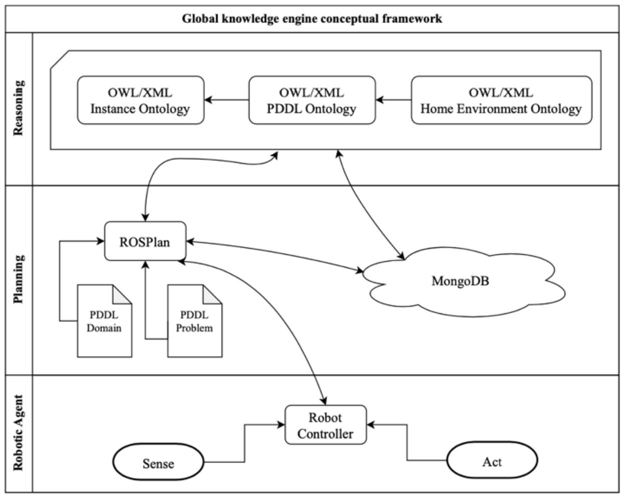

Fig. 4. Global knowledge engine conceptual framework [8] containing a Reasoning layer that is based on an ontology, a Planning layer that is based on the Planning Domain Definition Language (PDDL), a relational database (MongoDB), which is queried using the ontology and ROSPlan, and a Robot layer that is based on the robot controller, and its sensing and acting devices.

The ROSPlan [9] framework was used to perform the planning tasks in this framework. It is a high-level tool proven well for planning in the ROS environment. In the framework's scope developed in [8] and continuously evolving, it generates the PDDL problem, the plan, the action dispatch, the replanning, etc. Different action interfaces have been written in C++ to control the Autonomous Manipulator Mobile Robot (Fig. 9), i.e., its "*Mobile agent actions*", "*Manipulator agent actions*" and "*Gripper actions*", for proper interaction with the robot presented previously. These interfaces are constantly listening to the action ROSPlan messages. Moreover, the MongoDB database was used for semantic memory storage, e.g., fixed locations, robots, smart-home objects and their properties, goal parameters, etc.

III. STANDARD ONTOLOGIES APPLIED TO THE DOMAIN-SPECIFIC SCENARIO OF SOCIAL ROBOTS FOR THE ELDERLY

Recent ontology-based standards were developed (IEEE 1872-2015; IEEE 1872.2-2021; IEEE 7007-2021), and others are currently in development (IEEE P1872.1; IEEE P1872.3) to improve robot performance while executing tasks. This is a very hot topic in current standardization efforts worldwide.

EUROAGE projects aim to apply these standards and the domain ontology SSN [10] (Semantic Sensor Network), an ontology for IoT devices and sensor networks in the elderly care domain, where robots interact with humans, the environment, and other machines. This section presents the first efforts to integrate the concepts defined in the standards as mentioned above and the SSN ontology, which has as a fundamental layer the upper ontology DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineer) to accompany the interpretation of some relevant concepts and thus builds a prototype ontology with a high level of flexibility for the specific domain.

Following the above-stated assumptions, figure 5 shows a snapshot of the main ontology developed, which depicts some concepts of the domain-specific home environment. It was designed for an agent to interpret and interact with its surrounding environment. In this case, the environment of a smart home, with a special focus on the internal (*Indoor Environment*).

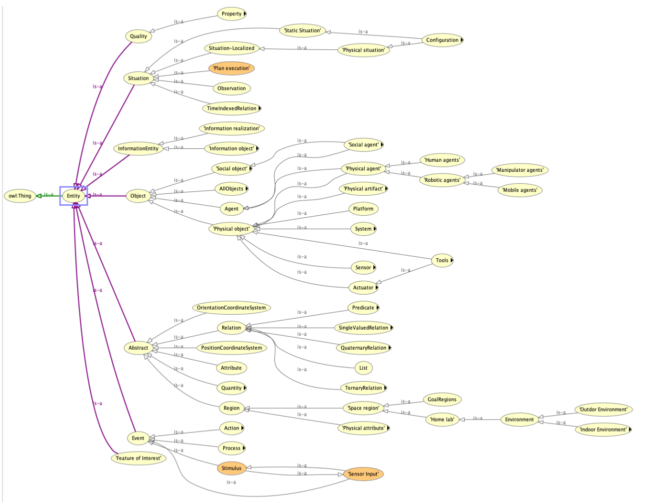

Fig. 5. Snapshot of the ontology.

Several Object properties were created to relate the different concepts of *Object*, *Region* or *Agent*, so that an agent can characterize its surrounding environment. As such, the properties are for:

- *ObjectProperty*: *belowOf*; *isMember*; *isObjectOf*; *isPartOf*; *LeftOf*; *onTopOf*; *RightOf*.
- *LocationProperty*: *isConnectedTo*;
- *AgentProperty*: *isGoingTo*; *isIn*.

The object properties were defined to clearly state the relationships between concepts, e.g., the properties *belowOf*, *LeftOf*, *onTopOf* and *RightOf*, define the relationships between the different concepts of "*Indoor objects*" and "*Outdoor objects*". The properties *isGoingTo* and isIn are defined to correlate the *Agent* concept with the *Environment*. (e.g., The robot *isIn* the living room, but *isGoingTo* the bedroom).

The objects that can be found in a specific region of the environment are defined through concepts and relationships. (i.e., in a room, there can be an object of the type of bed, chair, television, carpet, etc.). Thus, an agent can search for an object by its place with the highest probability of it being found (i.e., if the agent must find a toothbrush, it knows that this object is usually in a bathroom).

As an example of instantiation of concepts and their relationships, figure 6 presents the ontology used to instantiate some of the smart home objects belonging to the instance: "BathRoom_1" in the environment.

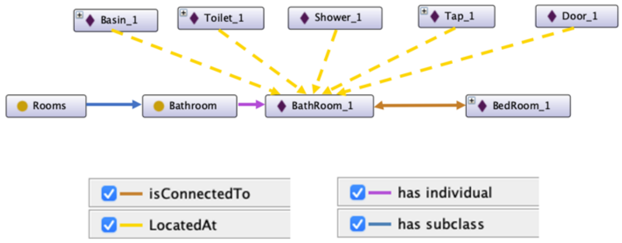

Fig. 6. Example of the ontology being used to instantiate the house objects belonging to the instance: "*BathRoom_1*", present in the home environment.

Based on the knowledge of the dimensions of the rooms of the environment, the following SWRL (Semantic Web Rule Language) rule can be written to automatically identify the space of the environment in which the agent is.

$$\text{Agent(?Ag)} \wedge \text{position\_x(?Ag,?px)} \wedge \text{position\_y(?Ag,?py)} \wedge$$
$$\text{swrlb:greaterThanOrEqual(?px,0)} \wedge \text{swrlb:lessThanOrEqual(?px,3)} \wedge$$
$$\text{swrlb:greaterThanOrEqual(?py,−3)} \wedge \text{swrlb:lessThanOrEqual(?py,2)} \wedge$$
$$\rightarrow \text{located\_at(?Ag, LivingRoom 1)}$$

Having the environment ontologically modelled, the next step of the work is to model the robotic motion planning concepts and regions where the robot can perform its tasks. Figure 7 are presented the possible paths that a robot can assume (*FreePath*; *CollidingPath*) and the possible trajectories.

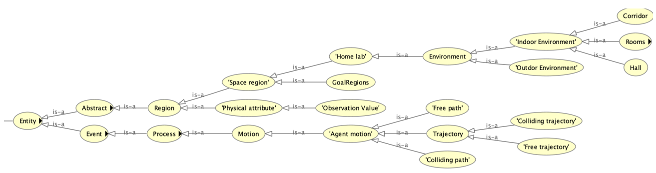

Fig. 7. Snapshot of the ontology related to motion planning and regions to perform tasks.

Figure 8 shows the "*Task State*". For example, the concept *ObjectState*: *FixedObject* and *ManipulableObject* in the environment to correctly identify if an object is manipulable (i.e., is within the manipulator's workspace). Using the ontology concepts, the following SWRL rule can be written to automatically identify which objects are in the robot arm workspace (*ManipulableObject*).

$$\text{AllObjects(?obj) ^ robotic\_arm(?r) ^ Reach(?r,?re)}$$
$$\text{^ EuclideanDistance(?obj, ?dist) ^ swrlb:lessThan(?dist,?re)}$$
$$\rightarrow \text{ManipulableObject(?obj)}$$

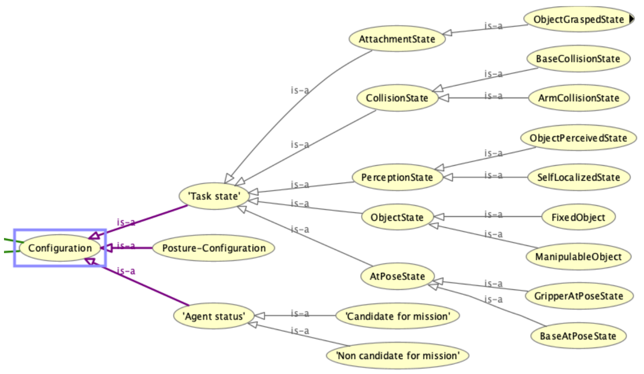

Fig. 8. Snapshot of the ontology related to motion configurations while performing tasks.

The following phase represents the knowledge of the robotic action that will be used in ROSPlan to obtain the plan for the tasks that the robot can be asked to perform. Figure 9 presents a snapshot of the AMMR actions within the smart home environment. The actions are clearly separated for the "*Manipulator agent actions*", the "*Mobile agent actions*", and the "*Gripper actions*", showing the modularity of the ontology definitions.

Fig. 9. Snapshot of the ontology related to robot actions to perform tasks.

During the execution of the plan, the properties of the mobile robot instance (*idmind*) are represented. The data properties are constantly updated and stored in the framework database, allowing the global system to know the current state of the mobile robot. Figure 10 can also depict the robot's several components that allow it to perform the several types of actions previously presented. Moreover, it can also be asserted that the robot is in *LivingRoom_1*.

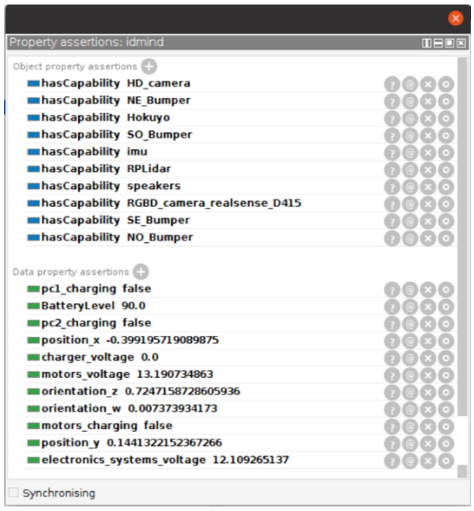

Fig. 10. Properties of the mobile robot instance (*idmind*).

The final step is to define the PDDL problem (task definition) to be used by ROSPlan. A sample task is presented in Figure 11, where the goal is to place an object (obj_1) in the LivingRoom and then move the robot to the docking station. Given the goal, the framework automatically obtains the PDDL problem file by using the information (e.g., data properties) of the objects in the database, their locations, and all the agents in the environment. In fact, the sections *init* and *objects*, are obtained directly from the information stored in the ontology-based knowledge base. The planning result, obtained from ROSPlan, is presented in Figure 12, which presents the sequence of actions and their duration, that the robot must perform to achieve the task.

IV. Conclusions and Future Work

This work presented the current efforts to achieve Ontology-based robot reasoning in the elderly care domain within the EUROAGE projects framework. In this scope, some project outcomes were presented, with a special focus on a smart home environment where an autonomous mobile manipulator robot performs tasks.

A semantic map of the environment was developed (using some concepts from the IEEE 1872.2-2021) where the robot can interact with the elder and the sensors in the smart home. In this environment, an ontology-based platform was developed that allows the robot to interact with the objects, using semantic information from that environment to solve demanded tasks. Ongoing efforts are underway to fully add to the reasoning framework of the previously stated standards and the concepts from the IEEE 7007-2021 to ensure that the robot's actions are ethically and socially correct.

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```
(define (problem problem_1)
(:domain idmind_global)
(:objects

    ; robots
    idmind - robot

    ; robot available platforms, to store objects inside the robot
    platform_middle platform_left platform_right - robot_platform

    ; robotic_arms
    ur3_arm - arm

    ; locations
    LivingRoom BedRoom - location
    dock - location

    ; objects
    NULL - object
    obj_1 - object
)
(:init

    (= (total-cost) 0)

    ; robot initial conditions : location
    (at idmind dock) ; idmind is at start position
    (docked idmind)

    (aligned_with idmind NULL)

    ; status of the arm at the beginning
    (arm_is_free ur3_arm)

    ; where are the objects located?
    (on obj_1 BedRoom)

)
(:goal (and
            ; transportation tasks
            (on obj_1 LivingRoom)
            (docked idmind)
        )
)
(:metric minimize (total-cost))
)
```

Fig. 11. Sample task definition in PDDL.

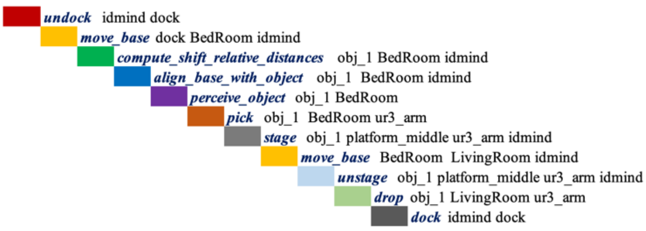

Fig. 12. Plan generated from the PDDL problem using ROSPlan

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