OBEliSK: Novel Knowledgebase of Object Features and Exchange Strategies

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Abstract. This paper presents the design and development of a system intended for storing, querying and managing all required data related to a fluent human-robot object handover process. Our system acts as a bridge between visual perception and control systems in a robotic setup intended to collaborate with human partners, while the perception module provides information about the exchange environment. In order to achieve these goals, a semantic-ontological approach has been selected favouring system's interoperability and extensibility, complemented with a set of utilities developed ad-hoc for easing the knowledge inference, query and management. As a result, the proposed knowledgebase provides a completeness level not previously reached in related state of the art approaches.

Keywords: Ontologies, Knowledge Representation, Handling Affordances, Semantic Modelling, Assistive Robotics

1 Introduction

The work described in this paper comprises the design and development of a knowledgebase about the domain elements involved in the action of exchanging common objects between humans and robotic agents. Our approach requires an in-depth study of the state of the art, inputs from the perception system and a clear definition of the outputs required by the robotic control architecture. The main purpose of this knowledgebase is to model and transfer the acquired knowledge from human-human object exchange experiments to a robotic system, in order to achieve a fluent interaction between human and robotic agents.

The remainder of this paper is organized as follows. The next section (Section 2) introduces the theoretical concepts involved in our work. In Section 3, a current state of the art analysis is performed. Section 4 describes the design and development process of OBEliSK (Object Exchange applied Semantic Knowledgebase). Finally, we present our conclusions in Section 5.

2 Theoretical frame

Specific-domain knowledge is usually represented by means of ontological systems described by a computational model, composed by a set of entities corresponding to real world items, such as agents, objects or events connected by domain-specific rules [1]. This kind of representation requires an approach far from the "classical" relational database [2], so in this case we have considered using graph databases [3], [4]. The main advantage of such representation is the flexibility that provides when linking related entities, attributes and properties. For representing knowledge through this approach, while extending its usefulness, the Semantic Web [5], provides a common framework for sharing and reusing data and defines a standardized set of technologies, arranged in a hierarchical architecture. Additionally, the RDF (Resource Description Framework) [6] was designed as a method for splitting knowledge into small pieces of data, complemented with a set of rules defining the semantics of these individual fragments of isolated information, relying on RDF/XML syntax for expressing (i.e. serialize) a linked data graph as an XML document. Notation3 [7], Turtle [8] and N-Triples [9] formats were defined in order to ease the reading of RDF documents for humans. The Web Ontology Language (OWL) [10] was also selected in order to represent the envisioned model. A key benefit of the semantic-ontological approach is its reusability empowering, leading to knowledge representations that might be re-used in the development of different systems addressing similar purposes, while bringing interoperatibility between heterogeneous systems according to a consensuated knowledge representation.

As an approach for improving the expressiveness of traditional propositional logic, Description Logic (DL) languages were introduced as knowledge representation methods providing a logical formalism for ontology design, useful for concept representation and reasoning on the of domain-centred terminological knowledge. An axiom, as fundamental modeling element of a DL, is defined by a logical statement composed by a set of concepts, individuals and their relationships. A terminological axiom is defined as

$$C \doteq D \mid C \sqsubseteq D$$

where C and D are concepts. A finite set of terminological axioms is known as T-Box T and is defined using the following descriptions. Note that $I \models C$ stands for *"I models C"*, where I is an interpretation function and C is a concept

$$I \models C \sqsubseteq D \iff C^I \subseteq D^I \qquad I \models T \iff I \models \Phi \; \forall \, \Phi \in T$$

An assertional axiom, representing concepts positively stated, is composed by a set of statements representing basic knowledge about individuals classified within the T-Box hierarchy. An A-Box A is stated according to these definitions:

$$I \models a : C \iff a^I \in C^I \qquad I \models (a,b) : R \iff \left(a^I, b^I\right) \in R^I$$

$$I \models A \iff I \models \Phi \; \forall \; \Phi \in A$$

where a and b are individuals and R is a particular role. Given these formal definitions, a knowledgebase K is an ordered pair of T-Box and A-Box, defined as follows:

$$K = (T, A) \qquad\qquad I \models K \iff I = T \wedge I = A$$

3 State of the art

Before starting with the design of a new ontology for the described problem, we carried out a study and evaluation of several related approaches that could help in the design of OBEliSK, including the following ones:

- **DEXMART**. This project's [11] key objectives were, among others, *i)* the development of original approaches for interpretation, learning and modelling of human object manipulation actions, and *ii)* the design of novel techniques for task planning for conferring the robotic system with self-adapting capabilities.
- **GRASP**. This project [12] had the objective of designing a cognitive system capable of grasping and handling objects in open environments where unexpected events may occur.
- **HANDLE**. Its [13] aim was to understand and replicate human object grasping and skilled hand movements using an anthropomorphic artificial hand by means of object affordances characterization for learning and replicating human handling tasks.
- **RoboEarth**. Designed as a cloud computing service, this robotic-oriented database [14] is focused on making robots capable of learning new abilities from other robots by easing their communication.

As summarized in Table 1, our approach tries to improve some of the shortages found in the previous state of the art study. The main advantage of our knowledgebase design is that provides the required set of mechanisms that makes it suitable for working together with both artificial vision and cognitive control modules, providing the robot with the required skills for achieving a fluent object exchange process.

4 Knowledgebase design

Within the scope of the CogLaboration project, there is a need for modelling the entities to be handled by the robotic system. Instead of using a traditional relational database system, the decision of modelling the object taxonomy using semantic web based technologies provides the ability of modifying and expanding the knowledgebase in an easy and comprehensive way.

Table 1. Comparative analysis of different capabilities of our approach versus other representative projects introduced in Section 3.

Functionality	OBEliSK	DEXMART	GRASP	HANDLE	RoboEarth
Integrated perception	✓	✗	✓	✗	✓
Human-like handling	✓	✓	✗	✓	✗
Obstacle avoidance	✓	✗	✓	✗	✓
Multi-mode grasping	✓	✓	✓	✓	✓
Object handover	✓	✗	✗	✗	✗
Standarized data store	✓	✗	✓	✗	✓
Motion constraints mgt.	✓	✓	✗	✗	✗
Learning capabilities	✓	✓	✗	✗	✗
Data management tool	✓	✗	✗	✗	✗

4.1 Object perception

The perception system captures a 3-D model of the object using a Kinect sensor. Object models are processed and a set of partial views is extracted from the whole model. These views are then employed for computing feature descriptors to be used in the classification process. Taking into account that is impractical to store these views (161 per object; 30 MB each) in a serialized form in the knowledgebase, views' file paths are stored instead. This is because transmission and deserialization tasks are highly time-consuming and is unacceptable to be used in *i)* the perception subsystem, intended for real-time operation, and *ii)* the robotic cognitive control subsystem, conceived for executing a fluent interaction.

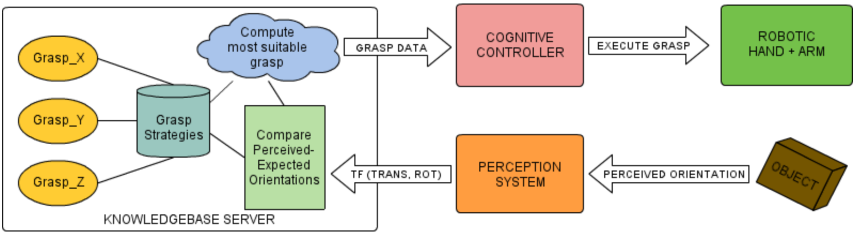

Fig. 1. Grasp strategy selection task flow, from the object's perception to the robotic physical motion execution.

4.2 Object handling

Exchange properties. Besides the object visual properties representation, it is also crucial to store and manage the set of features describing the way in which each object can be handled during the handover phase of the exchange process. Each object is associated to a set of grasp postures and delivery strategies, defining different ways the robot can handle it. Moreover, in order to ensure a proper manipulation process for certain objects, we have introduced the concepts of *Motion Constraint*, standing for the restrictions to be applied to some objects during their handling, and *Symmetry Axis*, representing the object's axial symmetry, if there are any.

Object affordances. We have also explored the concept of object affordances [15] within the task of modelling the ontology [16]. The taken approach is related to the concept of affordances and based on the idea of categorizing objects based on how they are used. According to Gibson's Theory of Affordances [17], affordances can be seen as the sum of the properties of a situation, including agents, environment and objects, especially those that describe how they can be used to do something [18].

Grasping phase. The set of grasps to be considered relies on the automatic grasping capabilities provided by the IH2 Azzurra [19] robotic hand. These grasps are based on the taxonomy developed by Cutkosky [20] and modelled under the class *GraspType*. As far as the work developed by Cutkosky is the design of the grasp taxonomy, the modelling process using OWL is made straight from that one to our model, thanks to the hierarchical shape and the classification-oriented vocabulary respectively. Each grasp instance, called *named individual* inside this context, represents an object-specific grasping configuration.

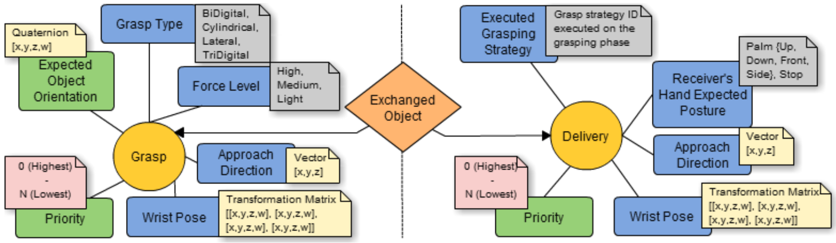

Fig. 2. *Grasp* and *Delivery* model conceptualizations.

Delivery phase. We also considered the idea of improving the knowledgebase value for the project by extending the initial conception of a grasping database to a fully-featured handling knowledgebase, covering in this way the second half of the object exchange process. The control system has to be provided with relevant data about the object handover, being capable to deliver the previously grabbed object to the recipient in a fluent and natural way.

Table 2. Summary of grasp and delivery actions model concepts

Concept	Grasping ph.	Delivery ph.
Object involved in the action	✓	✓
Grasp type, from taxonomy primitives	✓	✗
Expected object orientation/receiver's hand posture	✓	✓
Grasp strategy previously executed	✗	✓
Grasp force level to be reached by the fingers	✓	✗
Object's grab/release approach direction	✓	✓
Robotic hand wrist pose	✓	✓
Strategy selection preference (priority)	✓	✓

4.3 Knowledgebase data management

Data processing and storage in this kind of databases is not trivial. Having a large amount of information and a defined ontology, it is mandatory to fully respect the relational integrity restrictions between entities and their properties. Semantic-ontological data management is usually done through semantic-oriented tools, such as Protégé [21]. With the aim of ease this task, a utility has been developed focused on offering the simplest way to manage the knowledgebase contents. It consists of a web-application acting as interface between the user and the triple store where the ontology data is saved.

5 Conclusions

This paper introduced the design of a robotic handling knowledgebase by means of semantic-ontological technologies, providing an interesting and innovative approach. The developed system meets the expectations and overcomes them, as we extended the initially proposed grasping model to a complete exchange one due to the inclusion of object delivery concepts, improving the object handling fluency of the robotic system, including its adaptability to each particular situation in non-deterministic scenarios.

We are concerned with the interoperability needs of this task among the rest of project's developments, so we have dedicated a considerable amount of our efforts to provide simple, understandable and comprehensive interfaces for both inputs and outputs of this system.

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