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Contexts for Symbiotic Autonomy: Semantic Mapping, Task Teaching and Social Robotics

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Abstract

Home environments constitute a main target location where to deploy robots, which are expected to help humans in completing their tasks. However, modern robots do not meet yet user's expectations in terms of both knowledge and skills. In this scenario, users can provide robots with knowledge and help them in performing tasks, through a continuous human-robot interaction. This human-robot cooperation setting in shared environments is known as *Symbiotic Autonomy* or *Symbiotic Robotics*. In this paper, we address the problem of an effective coexistence of robots and humans, by analyzing the proposed approaches in literature and by presenting our perspective on the topic. In particular, our focus is on specific contexts that can be embraced within Symbiotic Autonomy: *Human Augmented Semantic Mapping*, *Task Teaching* and *Social Robotics*. Finally, we sketch our view on the problem of knowledge acquisition in robotic platforms by introducing three essential aspects that are to be dealt with: environmental, procedural and social knowledge.

Introduction

Robots are expected to support human activities in everyday scenarios, by interacting with different kinds of users. In particular, domestic robots (i.e. robots operating in our homes) have already entered the market. Examples are cleaning robots or telepresence robots for elderly care. In these contexts, the interaction with the user plays a key role and the importance of enabling untrained users to interact with personal robots has increases. The goal of the research in *Human-Robot Interaction* (HRI) is to realize robotic systems that exhibit a natural and effective interaction with users. Therefore, robots should be provided with sensory systems able to understand and replicate human communication, such as speech, gestures, voice intonation, pragmatic interpretation, and any other non-verbal interaction.

An increasing number of researchers propose to exploit human-robot interaction to enable robots to

- understand the environment they are moving in;
- accomplish tasks that would be otherwise unachievable.

This field of research has been called *Symbiotic Autonomy*. Symbiotic Autonomy (Rosenthal, Biswas, and Veloso 2010) or Symbiotic Robotics (Coradeschi and Saffiotti 2006) is a general philosophy adopted for robot design. Under this principle, robots are not seen any more as fully autonomous, holistic machines working in a static and known environment. Instead, they are seen as pervasive systems working in symbiosis with people and their environments. Researchers have started to explicitly represent in robots their own limitations, in order to decide when to exploit human help to overcome their inabilities. Due to its nature, Symbiotic Autonomy heavily relies on Human-Robot Interaction for task execution.

This paper provides our perspective on Symbiotic Autonomy and how interacting with humans can be helpful for robots to achieve their tasks. In particular, our research focuses on specific applications of this paradigm.

Contexts for Symbiotic Autonomy

This section addresses three research contexts, which appear to be significantly related to the notion of Symbiotic Autonomy. In particular, we focus on *Human Augmented Semantic Mapping*, *Task Teaching* and *Social Robotics*. In fact, these tasks may substantially rely on the interaction with the user, in order to overtake the limitations of the robot knowledge and to understand the proper behavior to be adopted.

Human Augmented Semantic Mapping

In order to enable the robot to execute complex tasks and understand humans, environmental information needs to be semantically labeled. Semantic Mapping is the process of constructing an environment representation that associates symbols to objects and locations of the world. This way the robot is able to execute commands like *"move to the dining room"*, without being tele-operated by the user and without the user's help in specifying the target position in terms of coordinates.

The problem of formalizing the *semantic knowledge* and generate semantic maps has been the focus of several works (Kuipers and Byun 1991; Hertzberg and Saffiotti 2008). In literature, two approaches are mainly employed in dealing with this problem: *fully automatic* and *user supported* map generation. The former relies on the robot sensors information available and interactions with humans are not expected. The latter, often known as *Human Augmented Semantic Mapping*, the user actively supports the robot in acquiring the required knowledge about the environment. Moreover, even though the robot is able to autonomously recognize objects, the user help is exploited in grounding the corresponding symbols.

In this work, we focus on the solutions which have been proposed according to this approach. In this framework humans are seen as sources of information that the robot can interrogate to acquire knowledge. For example, the work by (Zender et al. 2008) proposes a system which is able to create conceptual representations of indoor environments. They consider a robotic platform which owns a built-in knowledge. In this case, the user role is to support the robot in place labeling. In (Pronobis and Jensfelt 2012), a multi-layered semantic mapping algorithm is presented. The algorithm combines information about the presence of objects and semantic properties related to the space, such as room size, shape and appearance. Whenever an user input is provided, it is combined as additional property about existing objects into the system. In the work by (Nieto-Granda et al. 2010), spatial regions are associated to a semantic labels. The user is considered as an instructor which helps the robot in selecting the correct labels.

More complex and advanced forms of human-robot collaboration are considered in few works. The semantic map is built through a complete collaboration between human and robot. In fact, this interaction aims at objects recognition and positioning, rather than a simple place categorization and labeling. Such interactions are to some extent more complex and require advanced methods for natural language understanding. In fact, these systems are supposed to work even when non-expert and untrained users are considered. In this respect, multi-modal interaction represents an ideal communication means, as it able to deal with information of different nature. In example, in (Kruijff et al. 2006) a system that aims at improving the mapping process by clarification dialogues between human and robot using natural language is introduced.

Following the view that considers the human operator as a fundamental source that the robot can query to acquire knowledge, (Randelli et al. 2013) introduce a system to generate semantic maps through multi-modal interactions. In this scenario, they use spoken languages to command the robot, and a vision system to enable the robot to perceive the objects that the user wants to identify and label. (Bastianelli et al. 2013) generalize the approach to enable robots to incrementally build a semantic map of different environments, while interacting with different users. They formalize the acquired environmental knowledge for enabling robots to ground high-level motion and navigation commands to a structured representation of a metric map enriched with user specifications (see also (Capobianco et al. 2014)). Given a rich semantic map built with the help of the user, the system can perform qualitative spatial reasoning (Gemignani, Capobianco, and Nardi 2015).

Task Teaching

Once the surrounding world has been suitably acquired and represented, robots can act in it and perform requested tasks. To execute regular tasks, robots need to solve environmental constraints and satisfy specific high-level requirements imposed by a user. In this scenario, robots actions and, more in general, robots tasks have to be represented in a way that allows the agents to continuously change its configuration in order to adapt itself to the current situation. A new research topic that has emerged in the last decade, which seems to be related to the paradigm of Symbiotic Autonomy, is teaching a robot new tasks by interacting with the user. Usually, these tasks can be regarded as compositions of primitive behaviors that can be combined by the user as background knowledge. Such actions are often represented in graph-like structures, coded in a specifically designed language. An example is (Matuszek et al. 2013), where a language called *Robot Control Language* (RCL) is employed and action specifications are compounded, respectively, for representing and executing route instructions, given natural language commands. In (Nicolescu and Mataric 2003), the authors address this problem through a simple method for learning from demonstration of high level tasks. These are built from a pre-existing behavior knowledge. In particular, this work presents a learning approach which is composed of two main phases. The user gives first a demonstration of the action to be learnt. Then the robot is allowed to refine the acquired novel capabilities, by practicing for a small amount of trials under the supervision of the teacher. Similarly, (Rybski et al. 2008) introduce a method for teaching tasks through natural language. Tasks are represented as directed acyclic graphs, composed of action primitives and verbally described and transcribed through a statistical *Automatic Speech Recognition* tool (ASR).

The above-cited works do not take into account the problem of teaching a robot parametric tasks. However, when a robot is instructed with a new task, the learning process can be made more intuitive by referring to general action structures, rather than teaching instances of more general concepts. An example is the work in (Connell et al. 2012), that introduces a simple approach to parametric actions learning. The *Microsoft ASR Engine* is employed to teach a robot how to poke objects. Another example tackling the problem of learning parametric tasks is presented in (She et al. 2014). In this work, the authors describe a three-tier representation that supports both the conversion of natural language into robot actions and the application of existing planning algorithms.

(Gemignani, Bastianelli, and Nardi 2015) contributed in learning parameterized representation of robot tasks that are form of complex task specifications in a *Task Description Language* and can be executed on the robot via a mapping to *Petri Net Plans* (PNP). (Gemignani, Veloso, and Nardi 2015) face the problem of teaching new tasks to a robot that has a restricted or specific representation of the environment, which is not known by a generic user interacting with the robot. The authors introduce the concept of *sensing descriptors* to represent robots sensing capabilities and interpret spoken commands given by the user. Eventually, the authors are able to demonstrate how the descriptors of the robots are enriched through continuous interactions with multiple users. Lately, in (Klee et al. 2015) the authors formalize a sparse robot cooperation to complete tasks. The proposed solution is capable of acquire new tasks in a distributed way and to allow robots, with different world representations, to cooperate simultaneously executing multi-robot joint plans.

Social Robotics

Socially acceptable behaviors are a fundamental requirement in order to enable robots to enter our environments and initiate a cooperation with humans in a symbiotic fashion. Robots have to behave in human environments respecting common social rules, inherently imposed by the human partner. These rules depend on different factors such as dialogues, robot appearance, and most importantly, the distance that humans and robots have during the social interaction. Social distances are a central component in the field of social interaction known as *Human-Robot Proxemics*. The contributions presented in this research area try to establish social baselines for the behavior of a robot by highlighting the factors that influence the interaction in different settings of *users studies*. For instance, (Takayama and Pantofaru 2009) categorize the comfort level of the users according to their gender, pet ownership and personality characteristics. In (Walters et al. 2008), Walters *et al.* enable a short spoken interaction between humans and robot. In this setting, the authors measure the human comfort level while changing the robot voice type (e.g. male, female, mechavoice). In (Mitsunaga et al. 2008), an autonomous adaptation of the behavior of a robot which interprets the comfort level of the human users is proposed. Then the robot is able to dynamically change its position and gaze parameters.

To what extent social distances influence to humans' collaboration in the context of the Symbiotic Autonomy has not been specifically addressed. In this respect, we recently started investigating social rules that a robot has to respect in order to act and coexist in human centric environments. We evaluated the *Collaboration Attitude* in the human robot interaction framework, as proposed by Symbiotic Autonomy, where the robot is asking for human help in performing tasks otherwise not achievable (e.g. a robot asking to be plugged in for charge, or to open a closed door). Therefore, we analyzed the factors that might influence the user behavior in a social context, and studied the fluctuations of the Collaboration Attitude variable, that are related to them. Specifically, we evaluated the response of the users with respect to the behavior of the robot by varying:

- the relative distance that the robot has with respect to the user, and
- the environment where the experiment has been ran.

Hence, the working hypothesis of our user study is the following:

> *"The Collaborative Attitude between robots and humans in the context of Symbiotic Autonomy has not a constant value in all the environments, and there are different factors influencing it. We consider the environment, where the interaction takes place, and different distances as two of the main components influencing the Collaboration Attitude of humans towards requests for help issued by robots."*

To fulfill our aim, we set up a modified version of a Turtlebot[1] robot in an indoor office environment in order to estimate the degree of Collaboration Attitude and the significance of the distance and environment factors for it. All the experiments have been conducted in our department with a medium sized robot interacting with a set of heterogeneous randomly selected users. We executed different runs of the experiment varying the relative distance and the environment. At the end of each experiment, we validated and collected data, by asking the user to fill out a questionnaire that is directly displayed on the robot. The questionnaire aims at understanding the Collaboration Attitude of the subject and to what extent he or she is inclined to further help the robot. In particular, during the questionnaire, the robot keeps asking for help for three additional different tasks, which are organized to be more and more demanding. Finally, we evaluated the collected data through a statistical analysis.

On the one hand, the outcomes showed a strong significance of the distance factor with respect to humans' Collaboration Attitude. The most collaborative distance seems to be the personal one, where the robot approaches humans with a distance between $0.45m$ and $1.2m$. On the other hand, the environment factor seems to not affect the collaboration of the users shown to the robot. In particular, our user study involved relax and activity areas, as a good dichotomy in an indoor office environment. This contrasts our initial hypothesis, where we expected a more collaborative behavior when the users are not involved in duties. In addition, we observed that interesting humans' features could influence the Collaboration Attitude, such as gender and height. In fact, an analysis of the gender information confirmed that females are usually more inclined to collaboration. The height feature suggests that the perception of distances varies depending on the height of the subject. This recommends that proxemics settings take into account subjects height.

Conclusion & Future Work

In conclusion, Symbiotic Autonomy involves manifold aspects of robot design and implementation and it raises several questions to be investigated. Specifically, we identified the following interesting issues, which will be the focus of our oncoming research:

- understanding the contextual features (e.g. environmental or task-driven) that a can be exploited by a Human-Robot Interaction framework in order to enable an effective robotic interface;
- developing an approach that learns the specific language of a given user and the social approaching rules to it, to support the deployment of robots as personal and adaptive talking devices;

The former is based on the idea that the interaction is influenced by several aspects, that are often not taken into

[1] http://www.turtlebot.com/

account. These factors can be heterogeneous and allow to capture different dimensions of the interaction problem. For example, contextual information such as environment representation and robot features play a crucial role in the interaction, as they allow to contextualize the interaction flow.

The latter is motivated by the idea that adapting the robot to the current user is essential when we want to design home service robots. In fact, such robots are expected to operate in home environments, where a complete knowledge of the user vocabulary and habits can support a substantial personalization of the robot.

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