Teaching and understanding intelligent service robots: A Machine Learning Approach

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Abstract. One of the most important aspects in service robotics is the communication of service robots with their users. Since these users must in general be considered as not familiar with either robots or computers, this communication must take place in a human-oriented manner and employ human-understandable symbols. Here, two techniques relying heavily on learning mechanisms are presented that facilitate this kind of communication: **Programming by Demonstration** enables the user to easily communicate action and world knowledge to the robot. **Operational Concepts** support this task, but they can as well be used by the robot itself in order to communicate its own knowledge to the user in an understandable way.

1 Introduction

Enormous potential markets exist for mobile robots in the areas of materials transport, mobile surveillance systems, and floor cleaning. In addition, the idea of the "personal robot" or "personal robotic assistant" (e.g., for aiding the elderly or disabled) is lately receiving a lot of attention. Robot manufacturers all over the world are expecting to open a new, consumer-oriented market that will allow for sales figures far beyond those that can be obtained from today's industrial robots. In areas such as service and personal assistance, mobile robots are expected to create these rapidly growing markets[1, 8].
However, the use of robots in a personal environment is not straightforward. Today's mobile service robots rely on a very limited set of commands such as `move_forward` and `turn_left` and do not have to communicate extensively with their users. However, a personal service robot needs to provide an advanced user interface that allows for intuitive configuration, maintenance, and control by unskilled operators. Throughout this paper, two techniques rooted in Machine Learning are proposed as building blocks for this interface: On the one hand, **Programming by Demonstration** is a mean to ease robot configuration and programming. On the other hand, **Operational Concepts** that are grounded in both the robot's perceptions and actions are presented. Since they represent the robot's perceptions and actions on a human-oriented level of abstraction, these concepts can be used both for supporting the PbD-based task specification as well as for communicating robot knowledge to a human user.

2 Human-Robot Interaction

Two basic aspects of the interaction between the robot and the user can be distinguished (Fig. 1). Firstly, the user wants to configure and instruct the robot. This requires to translate the user's language into the robot's, i.e., to compile user intentions into actual robot programs. Secondly, to allow the user to efficiently control and maintain the robot, the low-level numerical representations used by the robot have to be translated into an understandable form. Both aspects are related to the problem of *symbol grounding* [3].

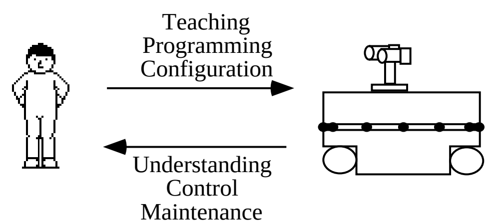

Fig. 1. *Human-Robot Interaction in the context of personal service robots.*

The proposed solution is to enable the robot to built up the necessary communication skills partly autonomously, i.e., to **learn** semantically meaningful descriptions of its own perceptions, actions, and states and to use these descriptions both to communicate robot knowledge to the user and to interpret user demonstrations, i.e., to acquire human action knowledge.

Operational Concepts are a mean to enable the user to *understand* easily what the robot is doing. In general, this task requires to build abstract descriptions of situations and actions the robot encounters. Classes of similar objects are usually called *concepts*, and these concepts are most often described on the basis of perceptions.

However, both psychology and computer science indicate that human concepts are not only characterized by perceptual features, but also by the actions that can be performed at instances of the concept. E.g., "moving along a doorway" and "moving through a doorway" are two different concepts. However, if objects are represented both in terms of robot actions and robot perceptions, both concepts and can be easily distinguished. To combine perceptions and actions in a concept description is the basic idea of operational concepts [7, 6]. These concepts, such as through_door or along_door, are built on top of a hierarchy of increasingly abstract features, as in

$$\mathsf{jump(right,\ T_1,\ T_2,\ parallel)\ \&\ jump(left,\ T_1,\ T_2,\ parallel)} \\ \rightarrow \mathsf{through\_door(T_1,\ T_2)},$$

where jump denotes a decrease in the distance measurements occuring during a particular time span $[T_1, T_2]$. Since all antecedents of the rules in these hierarchy are directly derived from either robot perceptions or robot actions, these rules can be applied continuously in order to verify what the robot is doing. They can, however, as well be used to specify tasks in terms of key objects, or to analyze already executed tasks, i.e., to aid the user in understanding the robot's performance.

While Operational Concepts provide a way to describe objects in the robot's environment in a flexible, easily usable and easily understandble way, the actual use of the concepts like the use of whatever world knowledge the robot might have is still dependend on the task the robot has to perform. To specify this task in the robot's language is in general as difficult a job as maintaining and monitoring the robot. **Robot Programming by Demonstration** is an intuitive method perform this job. The user, acting as a teacher, *shows* how a particular task should be carried out. The demonstration is monitored using an interface device that allows the measurement and recording of both the applied commands as well as the data simultaneously perceived by robot's sensors. On the task level, demonstrations result in reusable programs that are built on the base of a well-defined set of elementary robot skills [2], such as

approach_door → through_door → ... → dock

On the skill level, control functions performing perception-action transformations can be learned from user demonstrations in order to actually realize a skill [5]. On both levels, the human teacher cannot be expected to demonstrate an optimal solution of the task at hand, so adaptation must be considered [4].

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