A Library of Skills and Behaviors for Smart Mobile Assistant Robots in Automotive Assembly Lines

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ABSTRACT

In the automotive industry, market demands tend to require more variants of products while life cycles become shorter. This means an increasing complexity in automotive assembly lines. Therefore, flexible assistant systems will be needed in the future to optimally support human workers. In this work, a library of skills for human-robot collaboration is developed and behaviors are introduced as additional module in a skill framework that allows intuitive programming of smart robots.

Keywords
Human-robot Collaboration, Skills, Programming, Automotive

1. INTRODUCTION

Humans and mobile robots working together in teams are considered to be the basic work principle in the smart factory as stated by Bochmann et al. [2]. Dynamic environments like shared workplaces require intelligent reactions and fast adaption to new situations. Therefore, collaborative robots are not programmed deterministically anymore, but need to become more flexible. Thus assistant robots will not follow fixed, repetitive sequences anymore, but logical behaviors based on the interpretation of different sensors. Skill-based programming is an approach to manage the complexity of such robotic systems.

Figure 1: Skill framework organized in three layers of abstraction, adapted from Pedersen et al. [3]

The general architecture is organized in three layers in order to reduce the complexity in the design of such systems (Figure 1). In the lowest layer, primitives (e.g. “move linear”, “open gripper”) are used to describe the basic robotic movements and actions. The primitives are directly connected to the hardware and developed by programming experts. Using the existing primitives, automation and robotic experts then build skills (e.g. “pick”, “place”) for particular industries and application areas. Finally, robot tasks (e.g. “assemble a part”) can easily be combined by assembly planners and only need to be configured by the workers in the line.

In this work, a library of skills for human-robot collaboration is developed based on the analysis of standardized work descriptions of existing workplaces in automotive assembly lines. In order to enable the integration of intelligent behaviors, a new class “behavior” is introduced on the first layer to extend the skill framework.

2. STATE OF THE ART

A popular approach in programming smart robots is the use of frameworks that allow a distributed development of software components by standardized interfaces, like the ROS framework (www.ros.org). Further developments like the ROCK framework (www.rock-robotics.org) focus on the modularity of software components to achieve a higher degree of hardware independence. Skill-based programming of industrial and assistance robots is a promising approach to reduce the software complexity and therefore the development effort for various applications, as stated by Bjorkelund et al. [1]. A skill is defined as one or a combination of multiple primitives that are executed in a series. Another constraint is that only one skill at a time can be executed. Different frameworks have been introduced, e.g. by Wahrburg et al. [5] or Pedersen et al. [3], to enable the implementation of skills in robotics. New developments like the assistant robots of F&P-Robotics (www.fp-robotics.ch) or Franka Emika (www.franka.de) allow programming by using an intuitive graphical interface that is based on the combination of different skills to a task. These interfaces are suitable for the easy programming of simple robot tasks. But in order to enable flexible human-robot collaboration, the frameworks have to be adapted specifically for physical interaction.

Compact and intuitive libraries of modules have to be developed with focus on human-robot collaboration. Therefore, robots need to be capable of executing intelligent behaviors (e.g. adaptive stiffness or active collision avoidance). Behaviors are implicit commands that are continually executed and supervised, parallel to the execution of primitives.

3. METHODOLOGY

Existing workplaces, where people are working in teams, are identified and analyzed in order to find skills needed for robot collaboration. Manual work steps can be described in a standardized format, where each movement of the worker is
categorized and assigned a standardized time unit. The categories in MTM-UAS (Measured Time Methods – Universal Analysis System) are taken as base for the skill library, as proposed by Teiwes et al. [4]. The categories have to be adapted since some are very detailed and specific, whereas other categories are too general to be used as skills in a robot framework. Furthermore, MTM is not optimized to describe collaboration between workers, i.e. processes where physical interaction is needed in order to perform a task. Therefore, additional skills are defined in order to enable physical human-robot collaboration.

An extension of common skill frameworks by a set of behaviors for direct human-robot interaction is proposed. This extension is required, since only one skill is performed at a time by definition. While executing a skill, the robot still needs to monitor its environment and react instantaneous to movements of the worker. Possible behaviors for robots working in teams with humans are identified and combined with different primitives.

4. RESULTS & DISCUSSION

A skill library for robotic assistant systems in automotive assembly lines is developed using primitives known from the literature, describing basic operations a universal mobile robot is capable of. In total 13 skills are needed to perform the majority of the tasks in automotive assembly lines. From the categories of MTM, 7 skills are adapted and extended by 6 skills from the analysis of workplaces with human teams. The skills Pick, Place, Move along Path, Navigate, Wait, Handle/Apply Tool, and Trigger are known from standardized work descriptions and have also been used in other skill-based programming frameworks for conventional robotics. These skills enable the robot to perform simple tasks without interacting with human workers. The most important skills in automotive assembly probably are Pick and Place, where the Pick skill can be highly complex and is subject of current research in robotics.

![Figure 2: Definition of a pick-skill using primitives and behaviors (left), and the easy configuration during application (right).](image)

A simple Pick skill is presented for the library that is completely configured by the worker (Figure 2). It does not include any image recognition or knowledge based picking of parts out of a storage box. Functions like these need to be integrated into the existing skills in the future to allow for more complex processes. A specialty is the skill Handle/Apply Tool, where additional inputs and outputs (e.g. activating and deactivating a screwdriver) have to be considered. The second group of skills is adapted from the interaction in teams in automotive assembly that mainly refers to the sensitivity of the robot. The skills Position, Hold, Align, Apply Force, and Apply Force along Path are integrated in the library in order to allow the physical interaction between humans and robots. These skills enable the use of sensitive functions and forces, which are often needed in assembly tasks (e.g. mounting parts with tight tolerances).

Using the provided library, almost all tasks in automotive assembly lines can be performed by a robot. The disadvantage is that by only using its skills, the robot has no intelligence and cannot react on actions or movements of the worker. In order to enable smart human-robot interaction and to guarantee the safety of the worker, the skills have to be extended by a set of behaviors. The integration of behaviors in the defined skills and their combination with the execution of primitives enables the robot to perform skills in human-robot collaboration. Simple behaviors are for example different Speed Modes. If the robot provides force control, additional behaviors are the Compliant Mode or the Collision Detection. Because these behaviors are mainly dependent of the robot’s sensors and the capability to interpret its environment, only a small set of standard behaviors is proposed. The set of behaviors is extended the more sensors and functionalities are provided by the robot. An example is shown in Figure 2, where additional cameras for the recognition of external objects enable a Collision Avoidance behavior that is used during the first movement of a pick skill.

5. CONCLUSION & OUTLOOK

A library of 13 skills has been introduced for the easy configuration of robotic assistant systems in automotive assembly lines. New frameworks have to be developed that allow the integration of behaviors and a more detailed development of skills, e.g. the combination of multiple skills to more sophisticated skills. Also, intuitive interfaces are needed for the easy generation of tasks and skills. The skill library needs to be further developed in other to be also implemented in other industries, where different tasks might have to be performed.

6. REFERENCES


