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Human-Machine Interaction for Intuitive Programming of Assembly Tasks in Construction

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Abstract

A variety of robot programming techniques exists ranging from constraint based over skill based programming to learning by demonstration. In order to extend their applicability propose to join some of these approaches. We therefore combine visual CAD based programming with skill based programming through demonstration. This constitutes the basis of the outlines strategy. We then employ human feedback through hand gestures for incremental parameter modification. We propose this approach in order to potentially lower times to production for new products and allow efficient use of robotics in low lot-sizes especially in the context of assembly for construction.

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Keywords: Robot programming, Skill based programming, Visual programming, CAD based programming, Gesture recognition, Construction

1. Introduction

Classic industrial robot programming is a static process: In order to achieve a certain motion, a set of predefined positions in Cartesian coordinates or axis angles are used for motion planning. This process creates a predictability within robot positioning but does not offer the flexibility that is required to deal with high tolerances. To compensate for measurement differences and product variations sensors can be used for dynamic adaptation of positions. This approach is especially feasible in conjunction with high product quantities. However, in order to achieve lower changeover times and to utilize the flexibility of robotics for mass customization and the production of individualized products new methods need to be integrated. A number of approaches were created within mobile and service robotics which have to be able to work within unknown, dynamically changing and seldom predictably environments. Though a wide variety of approaches exist, the common denominator is a process of autonomous decision making. The results of this process can either be unpredictable, as is the case with autonomous behavior, or hard to define and program, as is the case with state machine based approaches.

The complexity of working with uncertainty and tolerances requires a deeper knowledge in multiple areas of robotics. In order to make robotics accessible to a wider range of workers this complexity needs to be mediated. While constraint based robot programming [1] made accessible implementation for a variety of tasks possible it still requires detailed knowledge of control theories and controller strategies. Constraints need to be defined and the resulting motion is not intuitive for people with a less technical background.

The application of robotics in construction constitutes an ideal and difficult testing environment. Construction environments are inherently unstructured. Due to fluctuations within the work force a number of untrained personal needs to be able to control and manipulate robotic tasks. In most cases robots also need to perform their tasks without separating safety measures in direct collaboration with human workers. The Association for Robots in Architecture works on making robotics accessible to the creative community. An approach that had significant success was the combination of graphical programming of parametric geometries with robotics, allowing for parametric robot control and mass customization.

While being easy to use, this user-friendly approach focuses on CAD based robot programming and currently does not include sensor feedback. New industrial controller systems allow a more direct access to robot actuators and a more extensive use of sensors. At the same time industrial robot manufactures want to extend the use of robotics through mobile platform development.

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Both developments need to be considered for easy-to-program interfaces for new industrial robots. We present our first concepts and results for a new combined approach towards transportable robot programming. The approach combines interactive, skill based [2], constraint based [1] and parametric robot programming [3]. Within this paper we present the considered methodology as illustrated in figure 1 that extends the parametric robot programming. The central building block will be described in more detail in section 6.

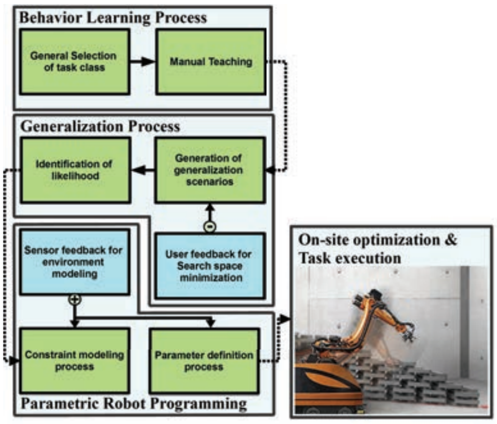

Fig. 1. The programming methodology.

2. Robots in the Construction Industry

The construction industry has always aspired to reach a similar degree of automation as the automotive industry. However, where the production lines of the automotive industry are fabricating a single product with only slight variances over the entire product's lifetime, especially the high-end construction industry deals with small lot sizes where in an extreme case a façade structure may consist only of unique panel geometries. Currently, many building components are therefore manually fitted on-site by workers, especially in low-wage countries where construction tolerances are generally accepted to be higher.
Strategies such as BIM (Building Information Modeling) [4] attempt to control construction processes in a more effective fashion by working with intelligent objects that can be assigned properties and parameters. Rather than drawing lines and applying hatchings to declare materials, objects such as walls are directly placed in a 3D-environment and given parameters that set their construction phase, material, and even costs. This results in a model theoretically capable of organizing the assembly of highly complex building structures. However, in order to communicate with the workers on-site, this complex model has again to be broken down into printed, physical plan drawings, which are then followed by workers with a certain amount of autonomy. In practice, even the most well-planned construction site is therefore an unstructured environment where the current state of the site only loosely correlates with the building information model's construction phase.
Thus, the main challenges of automation in the construction industry are the small lot sizes and the unstructured environments, coupled with the generally high complexity of modern buildings. In order to establish robots in construction thy need to be able to mediate the complexity and should therefore be easily programmable for a wide variety of tasks.

3. Parametric Robot Control

Commercial software for the programming and simulation of robotic arms such as KUKA SimPro are modeled after the teaching by demonstration process of robotic arms. Rather than guiding the physical robot, a digital model is placed in 3D-space and the robot's positions are recorded. These movement component can then be coupled with logic components to handle subprograms, loops, conditionals, etc. For many industrial processes, such a work flow is ideal as it allows an intuitive and safe interaction with the robot. While it requires a relatively large time-investment into the programming of more complex cycles, the generated revenue by the mass-production of the resulting element easily offsets the programming costs.
Challenges only arise with smaller lot sizes, where the programming makes up an increasingly large part of the costs of the final product. This is exacerbated in the construction industry, where complex, free-formed buildings can consist of countless individual parts. In order to cope with this complexity, we can utilize the fact that these individual parts are often based on a single, global topology that is then adjusted to fit the local conditions, e. g. a façade that uses a standardized aluminum profile system to create simple n-gons, which can vary in size, angle, and filling material (transparent/opaque). Rather than manually drawing hundreds of individual panels, parametric design software today allows architects and designers to create a single, parametric model that can be dynamically fitted to the local conditions.
In previous research we have developed software tools that allow us to directly integrate the fabrication logic into the same parametric model that controls the geometric shape of the model [5]. Thus, whenever a parametric object is adapted to new local conditions, not only its geometry but also its construction logic is updated, enabling the immediate robotic fabrication of the part as is illustrated in Figure 2.

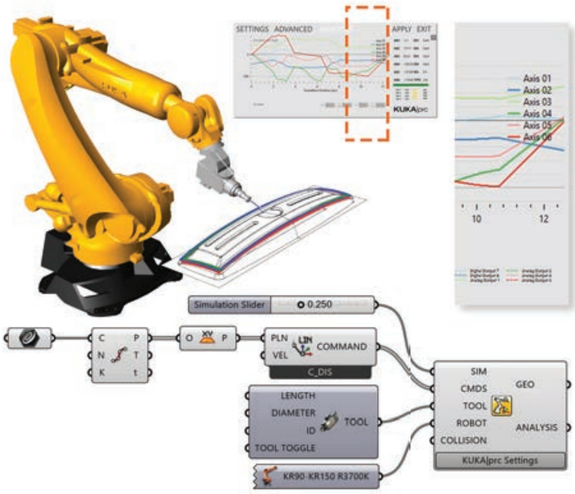

Fig. 2. Parametric robot control through KUKA|prc: Visual programming components (below), robot simulation with axis graph (above).