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Autonomous production systems using open architectures and mobile robotic structures

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Abstract

This paper investigates the flexibility aspects of production systems that use highly interactive and autonomous mobile robotic units. Open communication architectures and ontology technologies enable the accurate representation of robot capabilities. Mobile robots can relocate themselves and support the production process, thus providing a higher reconfiguration potential. Services are used for real time transactions between stationary and mobile robots towards the implementation of a process plan. The units can cooperate and determine their course of actions. This approach was applied to an experimental cell, where the system managed to implement production plans for the packaging of small sized products without human intervention.

Keywords: System architecture; Reconfiguration; Robot; Planning;Assembly

1. Introduction

Typical manufacturing systems comprise rigid flow line structures by employing model-dedicated handling and transportation equipment of raw materials and components [1]. They have fixed control logic and the signals-based tasks sequencing requires significant effort for the implementation of changes in the production plan. In Figure 1, the hierarchical representation of an assembly line with multiple stations and resources (R1, R2 etc.) is shown along with the tasks' breakdown into operations for each resource. The current practices involve the use of Programmable Logical Controller (PLC) signals to denote the start/stop of the operations, requiring a hard-coded approach that signifies high complexity and downtime in case of changes.

These systems cannot follow the market needs, for fast introduction of new products or frequent improvement of the existing ones. New production systems need to exhibit attributes such as flexibility, reusability, scalability and reconfigurability [1-3].

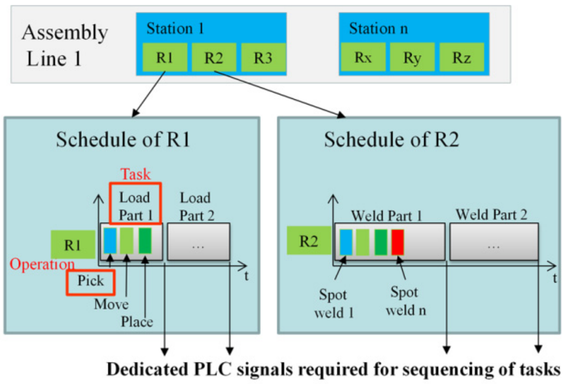

Fig. 1. Hierarchical model of production line and operations

In order for these goals to be achieved, alterations of the production and logistics processes are required to enable the system's fast reconfiguration with minimal human intervention [4]. The current problems addressed by this approach may be summarized into the following:

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- Reduction of hard wired control logic that allows limited or no reconfiguration capabilities and requires great effort in terms of human intervention. Activities such as those of scheduling, planning and programming of resources are now partially or individually automated. As a result, a significant reduction in the overall system reconfiguration time is expected.
- Reinforcement of random production flows through the use of mobile robots, eliminating the existing fixture based - static production paradigms that do not allow for changes in the production system structure.
- Autonomous behavior – planning of activities at multiple levels. Currently, autonomy is constrained by rules that are imposed by the strictly specified task execution routines for each resource. Robots however, can execute the same task, in a multitude of ways, but are now limited by the human dictated programming and planning. A significant reduction in programming efforts will be achieved.

This study considers the case of automated production systems, where mobile robotic units are used for the provision of the desired reconfiguration capabilities. In this paradigm, the mobile robots are capable of navigating into assembly stations and undertaking/supporting new assembly tasks automatically. The evolution of the production systems is conceptualized in Figure 2.

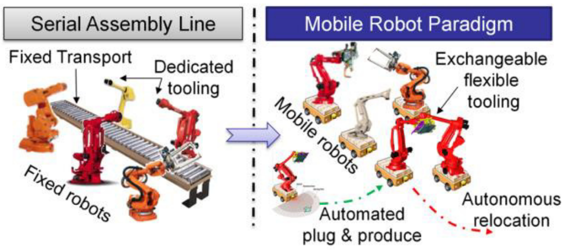

Fig. 2. Evolution of the production system

Different attempts have been made so far to introduce mobile manipulators to industrial environments and exploit their flexibility potential [5][5]. The latest examples involve the introduction of a mobile manipulator for assembly applications [6], the creation of an autonomous multi-purpose industrial robot [7] as well as the development of a high payload mobile manipulator for automotive Body in White (BiW) applications [8][8]. One of the most important problems of deploying mobile robots is that the environment around them is not static. Therefore, the mobile units should be capable of changing their path in case of any alterations in their surroundings [9-11].

The exploitation of the flexibility potential in systems that utilize mobile robots, signifies the definition and solution of a complex planning and scheduling problem. The first part of the problem deals with the production planning level (identification of tasks) and secondly, the scheduling part that deals with the assignment of these tasks to the resources [12]. Agent based systems have been the main research direction that has been followed towards addressing these problems [13,14].

In most of the aforementioned cases, the mobile robots act as individual units that execute the tasks foreseen in the production schedule. The main difference of this approach with past attempts lies in the flexible nature of robots:

- Robots are capable of undertaking a variety of tasks (processing and handling) and therefore, infinite alternatives can be realized when multiple aspects in the decision making: robot type selection, sequencing, motion planning etc, are being considered. This for example, contradicts the application of agents in Computer Numerical Controller (CNC) machines that are usually part of Flexible Manufacturing Systems (FMS). In this case, machines have several programs stored and the agents decide which one to execute on the basis of the pending operations.
- The dynamic nature of the tasks (pick and place from unknown positions, navigation in the shop floor etc.) discussed in this paradigm, requires a much more complex coordination between the resources (horizontal integration) themselves as well as the higher level coordination mechanisms/services (vertical integration) which has not been investigated into for such types of resources.
- Agent based approaches, although are flexible in pursuing a smooth operation, they are not generic enough to support a dynamic operation by multiple, however dissimilar resources. The wealth of the robotic equipment available and the respective capabilities offered, calls for technologies such as: Standardized interfaces for integration and configuration of different hardware and software components, through hardware and software abstraction capabilities and decoupling of parameters, request/storage/ acquisition with the use of open frameworks such as ROS [15].

The following sections present an approach, where the tasks are automatically allocated to the stationary and mobile robots, enabling a more dynamic approach to the system's reconfiguration. In this context, the underlying models and required technologies are presented in Section 2. Section 3, provides the details of such a system's implementation, while section 4, discusses its application in a case study. Finally, section 5, draws the conclusions of the approach and provides the outlook and challenges that future research should focus on.