A Knowledge-based Control Loop for a Reconfigurable Manufacturing Plant

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In Factories of the Future (FoF), the design and deployment of effective robotic systems in smart (structured) industrial environments is crucial for further automating tasks and processes. In this regard, one of the key enabling factors for highly automated production systems to efficiently compete in evolving production environments is strictly related to their capability to quickly adapt to (or even anticipate) changes in the production requirements [1]. Traditional plant control systems based on centralized/hierarchical control structures exhibit good performance in terms of productivity over a restricted and specific product range. However, these systems often require major overhauls of the control code in case any sort of system adaptation and reconfiguration needs to be implemented. Thus, these systems are not very efficient to face the current requirements of dynamic manufacturing systems (i.e., flexibility, expansibility, agility and re-configurability). For this reason, an increasing attention is being dedicated to Reconfigurable Manufacturing Systems (RMSs) [2], that are equipped with a set of reconfigurability enablers that can be related either to the single component of the system (e.g., the mechatronic device) or to the entire production cell and system layout. The role of each enabler is to implement the correct system reconfiguration in response to changes of the production demand. Among local enablers, AI based approaches have been considered (see e.g., [3]) nevertheless offline control models design remains a crucial step. So, structural modifications in the shop floor configuration usually entail a re-design of the control strategies that can be hardly manageable on line. We are addressing this problem within the GECKO project (Progetto Bandiera "Fabbrica del Futuro") that specifically deals with reconfigurable manufacturing systems.

The above fast adaptation capabilities strongly require the equipment to be knowledge-based and modular, so as to allow for high reconfigurability both from the reasoning and the mechanical standpoint. As for properly design suitable control reasoning features, a generic control architecture has been envisaged [4, 5] in order to (i) represent knowledge about its own internal status and exter-

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nal active connections and (ii) take advantage of off-the-shelf AI based temporal planning and execution techniques. Thus, a single node is to adapt intelligent control behaviors while facing mutating scenarios. And the production environment is composed by a community of generic control modules encapsulated in the physical mechatronic equipment that persistently communicate, cooperate and negotiate to guarantee the production goals. Each node operating in the shop-floor is equipped with a suitable I/O communication system capable of sensing the environment (i.e., data from sensors, other possibly connected modules, etc.) as well as publishing its own identity and capabilities, therefore providing a suitable information for identifying the production context and communicating its presence to the external world.

In this talk, we specifically describe the current work on a Knowledge-based Control Loop as a key feature of a generic control architecture for nodes in a Reconfigurable Transportation System (RTS). In particular, two main aspects are presented: (i) the design of an ontology-based representation of information related to both internal configurations/capabilities of a node and the active connections with its neighbors in the plant; (ii) the definition of a relationship between the ontology and the abstract model exploited by an temporal planning and execution module to implement intelligent control strategies of a single node. An ontological analysis of the shop floor's agents and processes has been performed to identify relevant information flows and types of information that are potentially needed. The ontological analysis was based on the methodologies used to develop DOLCE, see [6], and to evaluate ontological taxonomies, e.g., [7]. From the control perspective, the objective is to exploit P&S technology in order to control complex systems acting in real world environments. In particular for planning and execution we rely on the timeline-based approach [8, 9] that allows to deal with the temporal aspects of the control problem (see also [10]).

The main contribution we are pursuing concerns the connection between a ontology-based representation and the planning and execution model. The goal is to enable dynamic inference of control models so as to adapt control strategies while facing mutating shop-floor scenarios. The paper presents this connection in operation during two phases when the node controller is adapted: (1) the *set up phase* in which the ontology provides the controller with the key information about the initial physical configuration of the specific node, i.e., the internal equipment and the associated functional capabilities, and (2) the *reconfiguration phase* in which the ontology is exploited to capture dynamic changes occurring either in the internal configuration, e.g., due to a failure of a component, or in the connections with other nodes in the RTS, e.g., given some due maintenance activities. The generic control architecture is then to take advantage of such knowledge dynamically inferring and adapting the planning and execution model and, thus, (re)establishing a suitable control configuration both at startup time and after any possible disruption. To illustrate our technology at work, we refer to a real pilot plant of the GECKO project: a manufacturing system for Printed Circuit Boards (PCB) recycling.

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