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Adaptive Services Reconfiguration in Manufacturing Environments Using a Multi-agent System Approach

Nelson Rodrigues[1,2](✉), Paulo Leitão[1,2], and Eugénio Oliveira[2,3]

[1] Polytechnic Institute of Bragança, Campus Sta Apolonia, Apartado 1134, 5301-857 Bragança, Portugal
{nrodrigues, pleitao}@ipb.pt

[2] Artificial Intelligence and Computer Science Laboratory, Porto, Portugal
eco@fe.up.pt

[3] Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias s/n, 4200-465 Porto, Portugal

Abstract. The era of mass customization of goods forces manufacturing systems to promote agility, flexibility and responsiveness, leading to complex and unpredictable systems. Such challenges have an impact in terms of the system responsiveness and adaptation, production costs, product quality, etc. In order to improve those aspects, some flexible control manufacturing paradigms were proposed offering elasticity to change available skills and provide new services. However, the understanding of when and how to (self-) reconfigure the system aiming to perform a fast changeover, is a crucial issue. This work proposes a self-organizing multi-agent system approach for an efficient and on the fly reconfiguration of services in the manufacturing domain. Besides self-organizing techniques, other dimensions, e.g., "social-based" trust and QoS metrics, are used to ensure a constant QoS in an agile production system. The insertion of intelligent agents facilitates the improvement of strategies that perform the service reconfiguration, and in addition, permits to understand when and how self-reconfiguration takes place in order to allow a continuous improvement of the system performance. Additionally, this work addresses solutions for real industrial applications, being aligned with some characteristics of the Industrie 4.0 initiative, namely the distributed intelligence and self-* methods, e.g. self-adaptation, self-organization and self-configuration.

1 Introduction

Nowadays, due to the growing interest of customized products/services, companies are forced to deliver high quality products facing the clients' requirements at short time. These complex and dynamic environments are usually favourable to perturbations, such as broken machines, performance deviations and new product/service demand, which requires adaptive and responsive systems. Given this fact, several researchers suggest tackling this problem by considering new manufacturing paradigms that provide more flexibility, robustness and re-configurability, e.g. Flexible Manufacturing

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Systems (FMS) [1], Reconfigurable Manufacturing Systems (RMS) [2] and Evolvable Manufacturing Systems (EPS) [3]. Typically, the implementation of such paradigms mitigates the performance deviations that will delay the product delivery. To tackle this sort of dynamic environments, mechanisms for service reconfiguration were analysed. The adaptation performed on the demand and the provided services, transforms the way the system works. There are already some projects addressing the service reconfiguration in manufacturing, namely IMC-AESOP (www.imc-aesop.eu) that addresses continuous monitoring and self-adaptation functions and FP6-SOCRADES (www.socrades.eu) that is oriented to smart embedded devices with enterprise applications [4]. More recently, the PRIME project (www.prime-eu.com) relies on a plug and produce architecture for assembly systems, where automatic reconfiguration is mainly performed at the design phase. The proposed approach takes a step forward by evaluating potential possibilities in advance, having the capability to self-reconfigure the multi-agent system by performing run-time adaptation in the agents' behaviours without the need to stop or re-program, reducing the perturbation impact and decreasing the need of external intervention. The analysis of the state of the art shows that it is worth studying "*when should the system evolve*", and "*how should the system be reconfigured in order to adapt and becoming more profitable*", without compromising the quality of the product agreed. Thereby, intelligent agents are designed to manage the device functionalities, which are encapsulated as services and are offered to other agents that can invoke them according to their needs. The agents can improve their functionalities and publish them across the network of agents as new services, permitting new service compositions that allow to meet the desired quality. This approach is not the solution for all reconfiguration problems, but it offers a continuous and intelligent adjustment of triggers for the reconfiguration process, supported by the inclusion of the following main capabilities:

(i) Learning mechanisms to assist the identification of opportunities to perform the reconfiguration.
(ii) Self-organization principles to support the adaptation and evolution of the service composition in a dynamic and automatic manner.
(iii) Quality of service (QoS) provides metrics to quantitatively measure the quality of the generated service compositions. The QoS metrics join several non-functional attributes, such as execution time, cost and availability as well as trust evaluation for the judgment of the dynamic behaviours.

By using the previous capabilities, the system becomes more efficient, adaptive and responsive, and consequently promoting a competitive advantage by offering re-configurability benefits [3, 5].

2 Proposal

Traditional solutions, which rely on centralized decisions, provide good optimization results under static operational conditions but fail to respond promptly to dynamic plan disruption, unexpected disturbances or production changeovers. We propose a dynamic approach consisting in the reconfiguration of services provided and performed by intelligent and autonomous agents. In a simple manner, each agent drives the continuous self-adaptive reconfiguration process based on the potential improvement of the system efficiency. Based on [6], two types of adaptation were selected to drive -the system into a more beneficial state, namely (i) changing its functionalities to provide better services (behavioural adaptation), and (ii) changing the selection of service providers to provide a better composed service (structural adaptation). The strategies about when and how to execute the self-reconfiguration require concepts well known from Service-oriented Architectures (SOA), namely service discovery, service monitoring, service composition and service orchestration. These concepts are logically set up in the behaviour of the agents to support the expected reconfiguration (see Fig. 1).

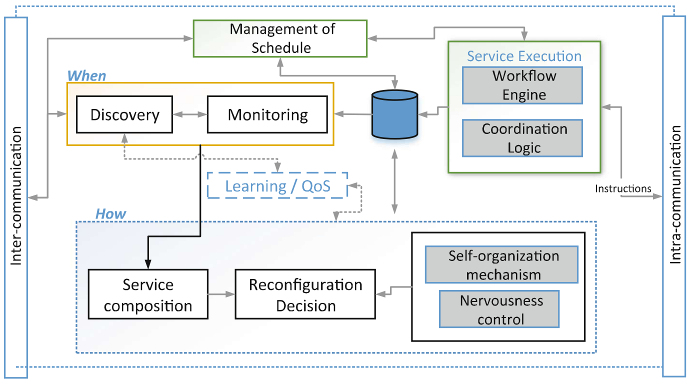

Fig. 1. Architecture for a generic agent

The reconfiguration process can be reached by different triggers from different agent's roles for example: (i) when the agent is performing the role of a service provider, i.e. providing atomic or composite services and (ii) when the agent is performing the role of service consumer, i.e. requesting composite services or atomic services as well. Despite the type of role played, it is vital to recognize when the adaptation should be performed. Four situations were identified:

1. Promote new composite services periodically, triggering the division of the composite services into atomic components allowing to test new combinations of service compositions with different levels of granularity.
2. Discover new services (discovery behaviour), allowing to perceive modification on available services and recognize new service providers, by searching in the service repository or announcing to the other agent's network the intention to discover a specific service.
3. Detect the degradation of the service's efficiency (monitoring behaviour), which needs data analytic methods that are running continuously.
4. Recognize a new service demand (discovery behaviour), which realizes the need to adapt the provided services to meet a new service reconfiguration.

To cope with the "how to make the composition" question, concepts of service composition using top-down approaches with template-based or bottom-up approaches using Artificial Intelligence methods were analysed together with self-organization mechanisms. This inspiration on self-organization techniques allows to regulate the service composition in environments where it is difficult to predict the global behaviour (e.g. the overall production plan). Looking from a high-level perspective, the structural adaptation works at the system level with a strong dependency on the physical layer. The addition or removal of physical components in the system, is another responsibility of the structural adaptation. This type of adaptation also has a larger impact on the behavioural system adaptation that works at the operational level by adjusting the provided services (e.g. add/remove/modify services).

In order to permit the module "when" to recognize unexpected events and react appropriately to them, it was considered a learning mechanism. Basically, due to the impossibility and uncertainty to model the entire world together with the self-organization mechanism, a reinforcement learning algorithm was adopted, in particular the Q-learning for modelling the feedbacks of the service performance. The feedback values results into a set of non-functional criteria, e.g., service response time, throughput and availability. Additionally, different kind of input values, like trust and reputation associated to the provided services, can also be considered by the Q-learning algorithm. The adopted trust model holds the historical knowledge about the services executed in specific contexts, e.g. process plans, set of involved machines, different configurations, etc. The outcome of the learning algorithm allows to select an accurate reconfiguration trigger. In parallel, the same result also represents a context awareness reconfiguration, which is an important characteristic to tune the nervousness module, and allows to decide if continuing using the old settings or to explore potential new solutions. The intra-/inter-communication modules permit the interaction with other agents and physical devices, and lastly the service execution is responsible to execute the requested service.

All these modules are independently designed, creating a generic architecture capable to offer a solution for the dynamic reorganization of the manufacturing system based on the adaptation and reconfiguration of services provided by intelligence of agents. Particularly, a real flexible manufacturing cell [7] has been considered for the evaluation of our proposal, for example, in terms of the downtime impact caused by production variations [8]. Briefly, each machine is controlled by an agent that provides a given set of services that are necessary for the production process; agents are responsible to verify the need for service reconfiguration, adapting their skills and behaviour accordingly and efficiently.

3 Conclusions and Future Work

The described research work explores the automatic service reconfiguration applied to a flexible manufacturing system to cope with the challenges that arises from disturbances or production changeovers. For this purpose, multi-agent systems and service-oriented principles are combined to properly solve the dynamic reconfiguration of services. It is also promoted on the agents, the need for service adaptation in order to meet given requirements in the presence of uncertainty. This implies not only the identification of opportunities when the agents should reconfigure their services, but also how to maintain the desired quality of products and at the same time become more valuable by providing different services. In this sense, the agents adapt and work together as a global behaviour, after recognizing opportunities or after the plug-in or plug-out of hardware components. Such continuous cooperation among the agents reinforce the system towards a better state. As future work, a further specification of the architecture will be conducted as well as its implementation and validation into different case studies.

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