A co-Evolving Diagnostic Algorithm for Evolvable Production Systems: A Case of Learning

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Abstract: With the systematic implantation and acceptance of IT in the shop-floor a wide range of Production Paradigms have emerged that exploring these technological novelties promise to revolutionize the way current plant floor operate and react to emerging opportunities and disturbances. With the increase of distributed and autonomous components that interact in the execution of processes current diagnostic approaches will soon be insufficient. While current system dynamics are complex and to a certain extent unpredictable the adoption of the next generation of approaches and technologies comes at the cost of an yet increased complexity. The peer to peer nature of the interactions and the evolving nature of the future systems' structure require a co-evolving regulatory mechanism that to a great deal has to be implemented under the scope of monitoring and diagnosis. In this article a diagnostic algorithm that has the ability to co-evolve with the remaining system, through learning and adaptation to the operational conditions, is presented and discussed.

Keywords: Agile Manufacturing, Diagnostic Systems, Multiagent Systems.

1. INTRODUCTION

Current automation systems are already heavily networked. Their control structures are hierarchical and logically described. These logic signals are propagated trough the industrial networks towards the realization of processes. Logic based control has the virtue that the theoretically behaviour of the system can be predicted. However, in practice, the overall complexity of the control logic in a medium size shop floor renders this task infeasible and the support tools are limited. In addition, the process control is hardcoded in specific components leaving no room for reconfiguration. Even if some modelling and codification patterns are reusable the main reaction to structural changes, either induced by business or disturbances, is time consuming reprogramming.

Emergent control approaches have developed towards the Lego metaphor where self-contained and function-specific autonomous blocks are combined to implement a desired process. The metaphor itself has evolved starting with the notion of flexibility whereby one of these constructs is able to perform many functions and therefore can simultaneously take part in many processes, mostly associated with the production of a specific product line. Becoming agile was the next paradigmatic step in competitiveness. Agility is different from Flexibility. The latter often refers to the ability of producing a range of products (mostly predetermined). It is also different from being lean (producing without waste). Agility implies understanding change as a normal process and incorporating the ability to adapt and profit from it. Agility covers different areas, from management to shop floor. It is a top down enterprise wide effort. The agile company needs to integrate design, engineering, and manufacturing with marketing and sales, which can only be achieved with the proper IT infrastructure (Barata 2003; Ribeiro, Barata et al. 2009).

Current approaches are targeting beyond agility. With a clear focus on Sustainability IT is currently being developed towards the reduction of: energy inefficient processes, mass disposal of equipment and other forms of energy waste.

The notion of Evolvable Production System (EPS) is consolidating in this context, and can be envisioned as a broader umbrella for a wide range of design, architectural and technical considerations first explored under the framework of Evolvable Assembly Systems (EAS). The initial EAS concept dating from 2002 (Onori 2002) was further developed under the EUPASS1 project. The essence of EAS/EPS resides not only in the ability of the system's components to adapt to the changing conditions of operation, but also to assist in its overall evolution in time such that processes may become more robust.

In this context a system is an highly dynamic entity whose structure and processes evolve. From a diagnostic point of view it is somehow difficult to characterise and model such a system using conventional approaches as these have either: been applied within the scope of a specific device (requiring

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[1] EUPASS-consortium, "Evolvable Ultraprecision Assembly Systems," http://www.eupass.org/.

user inspection) or to the entire installation with a constraining freedom regarding evolution or adaptation. To a certain extent, diagnostic systems are "one of a kind" (tailored accordingly to the installation's peculiarities) (Thybo and Izadi-Zamanabadi 2004).

The purpose of the present research is the development of a diagnostic system that actuates locally, at module level, yet capturing the dynamics of the network in which the module is immersed. The approach is to be understood as complementary of the existing technologies adding a comprehensive analysis layer, the network perspective, that plays a fundamental regulatory role in evolvable systems (Ribeiro, Barata et al. 2010; Ribeiro, Barata et al. 2010). The fact that the diagnostic algorithm is self-contained limits its complexity and decouples it from the underlying system's complexity and processes.

The subsequent details are organized as follows: section 2 presents very briefly the related literature; section 3 presents the main architectural considerations on the proposed algorithm; section 4 focuses in the technical details of the algorithm; section 5 discusses the main results and finally section 6 presents the conclusions resulting from the preliminary testing of the algorithm.

2. RELATED LITERATURE

A complete review on diagnostic methods derived from the automatic control community can be found in (Isermann 2006) where the application of: parameter estimation, evaluation of parity relations, state estimation and principal component analysis methodologies is properly covered. These approaches have a strong mathematical background and formulation and present very accurate result in system where it is feasible to devise an analytical model.

When this is not the case but historical and expert knowledge are available other techniques exist that are able to consume that information and generalize whenever a new diagnostic event is triggered as detailed in (Venkatasubramanian, Rengaswamy et al. 2003) where the application of artificial neural networks, probabilistic inference methods and expert systems is discussed and (Venkatasubramanian, Rengaswamy et al. 2003) where qualitative logic based diagnostic methods are covered.

The research being reported in this paper, however, has a close connection with the authors' previous work developed under the Inlife Project[2] where web services were applied to a pilot assembly cell and functionalities including self-monitoring/diagnosis/reporting were implemented at device and process levels (Barata, Ribeiro et al. 2007; Ribeiro 2007). A preliminary version of ACORDA (Lopes and Pereira 2006), a prospective logic engine, that enables the revision of results, trough the encoding of preference rules was used. Although the engine provided an efficient platform to formalize the diagnostic models, the used version did not support modelling uncertainty. With the penetration of IT in the shop floor the development of these infrastructure focused diagnostic systems is attracting a considerable number of researchers and experts from the maintenance domain (Tsang 1995; Yu, Iung et al. 2003; Garcia, Guyennet et al. 2004; Bangemann, Rebeuf et al. 2006; Jardine, Lin et al. 2006; Lee, Ni et al. 2006; Iung, Levrat et al. 2007; Campos 2009)

Probabilistic methods applied in diagnosing industrial systems are reported in (Zhou, Zhang et al. 2004), (Rodrigues, Liu et al. 2000) and in (Son, Park et al. 2000). The first work proposes the application of Hidden Markov Models and principal component analysis to diagnose chemical processes. The second work uses Bayesian Networks to diagnose and study processes in a caravan manufacturing line. The third solution relies on a structured representation of the domain to tackle fault scenarios with multiple causes and fault propagation.

3. ARCHITECTURAL CONSIDERATIONS

As previously mentioned one of the main goals of the present proposal is to ensure the co-evolution of the diagnostic system along with changes in the structure and processes of the installation. The proposed approach is generically applicable to any system as it is based in the decoupling of the diagnostic system and direct system measurements. In this context, rather than interpreting and correlating information collected directly from the hardware being abstracted, that information is harmonized in the interaction domain.

In this sense the system is envisioned and a digraph whose nodes are the modules and the edges denote an interaction (I) with a given direction (D) of some generic nature (N) (Ribeiro, Barata et al. 2010):

$I = (D, N)$ (1)

$n \in$ {Domain Specific Interaction Set} (2)

$d \in \{Inbound, Outbound, Both\}$ (3)

These variables are always evaluated from a module's point of view considering the direct neighbours only (Fig. 1).

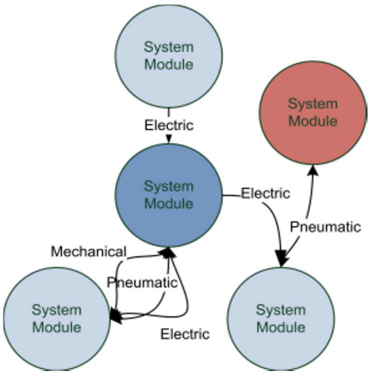

Fig. 1. The central module only considers the states of the direct neighbours. Second order neighbours' influences (top

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[2] InLife project http://www.uninova.pt/inlife/