Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 52-10 (2019) 7–12

Semi-heterarchical architecture to AGV adjustable autonomy within FMSs

Sergio Ramiro Gonzalez*. Gabriel Mauricio Zambrano** Ivan Fernando Mondragon***

* *Pontificia Universidad Javeriana (e-mail: sgonzalezb@javeriana.edu.co). **Pontificia Universidad Javeriana (e-mail: gzambrano@javeriana.edu.co). *** Pontificia Universidad Javeriana (e-mail: imondragon@javeriana.edu.co).*

Abstract: A flexible manufacturing system (FMS) is a highly integrated manufacturing system in which there is some amount of flexibility that allows the system to react in case of changes, whether predicted or unpredicted. Automated guided vehicles (AGVs) are suitable for FMSs because they provide flexibility, adjustability and the connection of processing subsystems by handling raw materials, sub-assemblies or finished products. The static level of autonomy granted to AGVs affects their flexibility in dealing with perturbations, efficiency and the contribution to global performance. This paper presents a semi-heterarchical architecture to AGVs' autonomy control to mitigate perturbations of FMS and increase their overall performance. This approach is based on the semi-heterarchical architecture between AGVs using belief-desired-intention BDI model for decision-making under normal and disturbance scenarios. The effectiveness of the proposed approach is demonstrated via a case study. We conclude that adjustable autonomy results in better performance than the classic static version.

Keywords: Autonomy, adjustable autonomy, automated guided vehicle (AGV), semi-heterarchical architecture, cyber-physical systems (CPS), and flexible manufacturing system (FMS).

1 INTRODUCTION

During the last two decades, the market for industrial manufacturing companies has become more and more globalized, highly competitive and presents rapidly changing customer expectations. Therefore, new requirements are imposed on the operation of flexible manufacturing systems (FMS)(Gabriel Zambrano Rey, 2014). Examples of such FMS requirements include the capacity to respond to any disturbance in real-time, achieve fault-tolerance and hardware/software re-configurability, while maintaining the expected global performance. These requirements can be met by proposing innovative control manufacturing architectures, for instance, within the Industry 4.0 concept.

The Industry 4.0 concept proposes smart factories based on cyber-physical systems (CPS) that orchestrate several technologies, such as artificial intelligence, IoT (Internet of Things), big data, and cloud computing. CPS can improve agility and responsiveness to meet the aforementioned requirements. However, the complexity of computing and physical dynamics brings a lot of challenges in the development of CPS, such as interaction and integration of heterogeneous processing subsystems and material handling systems. For that reason, the CPS architecture must describe how the processing subsystems, including the material handling system, are interconnected, interact with each other and cooperate. Additionally, the CPS architecture must guarantee strategic optimization. The material handling system (MHS) is of the highest importance for the CPS, since the material handling can guarantee that raw materials, primary assemblies, and articles ready for shipping are at the right place at the right time, hence affecting directly the production performance indicator.

Automated guided vehicles (AGVs) are used for material handling, aiming for delivering high system integration, provide high flexibility and interaction between processing subsystems in CPS. To deal with disturbances, the AGV must be able to make quick decisions autonomously and recognize and overcome a wide range of perturbations with various degrees of severity (Park & Tran, 2012). Such autonomous behaviour is a very desirable characteristic of advanced systems (KUSTAK, 1985). The definition of autonomy is an essential concept in rational entities that support the reasoning, planning and decision making required to achieve strategic self-directed goals. To be autonomous, a system *'... should have the ability to learn, react, interact, make decisions, and gain information about their environment without human or other entities' intervention ...'* (Dorais, Bonasso, Kortenkamp, Pell, & Schreckenghost, 1999).

A major challenge is to ensure that the level of autonomy is adjusted to meet the global performance expectations imposed by the FMS control and help other entities to fulfil their own local goals. Adjustable autonomy is a property of a decisional entity that allows the changing of the entity's level of autonomy (LOA) from a predefined set of levels, during system operation and particularly during key situations (Dorais et al., 1999). The control allocates responsibilities to decisional entities, determines the relationships between them and establishes the coordination mechanisms for the execution of control decisions. The existing publications on autonomous systems have focused on decision making based on autonomy and decision-making control for autonomous entities (K. Barber & Martin, 1999) (Bob van der Vecht, Dignum, Meyer, & Neef, 2008) (Castelfranchi, 1994) (B Vecht, 2009) (Falcone & Castelfranchi, 2001), (Bob van der Vecht et al., 2008) (Schurr, Marecki, Lewis, Tambe, & Scerri, 2005) (Maheswaran, Tambe, Varakantham, & Myers, 2003) (Pynadath, Scerri, & Tambe, 2001) (Gunderson & Martin, 1999)

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2019.10.003

The LOA can be changed depending on the type of control architecture such as global (semi-heterarchical), local (heterarchical) or reconfigurable control(Hülsmann & Windt, 2007) (d'Inverno, Luck, & others, 1996) (Jensen & Kristensen, 2009). First, when the control is semi-heterarchical, the control is divided into several decisional sub-activities or levels to reduce the complexity inherent in centralized approaches. Dividing the control into hierarchically dependent sub-activities with decreasing time ranges (i.e., strategic, tactic and operational, such as planning, scheduling and supervising) assigned to hierarchically dependent decisional entities allows the maintenance of sufficient optimal global control. For example, Castelfranchi and Falcone in (Falcone & Castelfranchi, 2001), and Barber and Martin in (K. Barber & Martin, 1999) presented an adaptive decision-making framework in which global entities propose strategies to the group and thereby change their own autonomy level. In this way, adjustable autonomy becomes a group process, because other entities can accept or reject proposed decision-making strategies. Nevertheless, such global autonomy control becomes more complicated with the rigidity of the control structure, which implies a weak response to change (i.e., supports less agility and reactivity), particularly when the amount of resources increases, among other factors (i.e., communication delays, complex decision making, and breakdowns) (González, Mondragón, Zambrano, Hernandez, & Montaña, 2017). Second, when the control is heterarchical, it advocates more decentralization of control decisions. The idea is to allow the decisional entities to work together so that they can react quickly instead of requesting control decisions from upper decisional levels. The last type of control, switching control, combines the two aforementioned controls. In this new control, adjustable autonomy is achieved by switching FMS control between local and global. The switching control tries to balance the overall performance with reactivity to perturbations (Leith, Shorten, Leithead, Mason, & Curran, 2003).

The aforementioned studies have investigated various approaches addressing adjustable autonomy from different perspectives, but the authors have mainly focused on five ways to achieve such adjustability. First, the LOA implies satisfactory performance under significant uncertainties due to the ability to compensate for system failures without complicating the operational adaptation. Second, some strategies involve transferring control capabilities between entities or taking shorter-term decisions (Schurr et al., 2005) (Gunderson & Martin, 1999) (Scerri, Pynadath, & Tambe, 2002). Third, extensive literature has dealt with entities' characteristics, such as static autonomy, local views and decentralization of decision making; however, relatively little attention has been directed to studying the influence between entities for designing FMS control structures based on adjustable autonomy (Hülsmann & Windt, 2007) (d'Inverno, Luck, & others, 1996) (Jensen & Kristensen, 2009). Last, the design of FMS control systems does not include the ability to adjust the level of autonomy during system execution. Unfortunately, these approaches reveal three key shortcomings. First, in some implementations, the LOA uses a simple discrete set of levels comprising all states for adaptation and to mitigate the impact of perturbations (K. S. Barber & Martin, 2000). Second, these approaches use rigid one-shot transfers of control that can result in unacceptable autonomy values (Meystel & others, 2000). Last, despite the importance of the autonomy control systems, research has often overlooked this topic, as the related literature is scarce and does not provide developers with a comprehensive framework to achieve more effective control. The first shortcomings are developed in this paper and correspond to the following question: 'How can adjustable autonomy be achieved?' Our hypothesis to answer this question lies in decentralized control architectures because of their benefits in term of the mitigation of perturbations.

This work is focused on a CPS semi-heterarchical architecture that tackles particularly the material handling system. This approach is motivated on granting AGVs dynamic varying autonomy levels of independence. The purpose is that AGVs must perform well under significant disturbances for extended periods of time, and they must be able to compensate for system failures without external intervention to improve the FMS's overall performance. This paper is organized as follows. Section 2 presents the approach proposed for autonomy control, describing the FMS architecture supporting the proposed adjustable autonomy control. The test method is shown in Subsection 3.2. Section 4 describes the experimental results and discussion. Finally, Section 5 presents future work and the conclusion of this paper.

2 DESCRIPTION OF THE ARCHITECTURE PROPOSED

To overcome the aforementioned shortcomings, this section describes a semi-heterarchical approach that focuses particularly on adjustable autonomy. The decisional entity (DE) carry out decision-making activities within a transport decisional process. The problem of decision making within FMSs becomes difficult, requiring the participation of all the DEs, such as processing machines (i.e., processing resources, CNC, industrial robots, etc.), AGVs, conveyor, orders and products. Architecture is a map of the internals of an entity and its data structure, the operations that may be performed on these data structures, and the control of information between these data structures (Farahvash & Boucher, 2004). The architecture defines, how is the information flow? How it is being perceived? How it is being transformed? And finally, how decisions are being made? The architecture has the functional requests of the system and aims to satisfy these requirements (Vuković & Miljković, 2009). The architecture allows vDEs to accomplish activities autonomous with a significant degree of coherence. Due to the design of the architecture, the use of the global knowledge is fortunately not detrimental to the processing requirements of the individual entities. Thus, the use of global knowledge can be incorporated into architecture without impacting the global performance. In order to accomplish the requirements described aforementioned an architecture for vDEs autonomy control is presented in the next subsection. The architecture is constituted by one approach called as semi-heterarchical.