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RECURSIVE HYBRID CONTROL ARCHITECTURE TO DEAL WITH REACTIVITY IN THE CONTEXT OF INDUSTRY 4.0

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ABSTRACT: As a response to unexpected events sourced either from external environment or internal environment, manufacturing companies have to decide and adjust their system autonomously. Indeed, this has brought significant reactivity, adaptability, and stability to disturbances and production changes. However, an ever myopic behavior of locally autonomous entities has led such decision-making process to various drawbacks such as difficulty to get immediate information for performing global decision. Consequently, the interest of hybrid control system has evolved using holonic or multi-agent system paradigms so as to provide an overall and efficient production performance. This paper is aimed to provide state-of-the-art on holonic reference architectures and multi-agent system paradigms and to propose recursive hybrid control architecture by stipulating two decision-making layers namely white-collar layer and blue-collar layer. The decision-making is mainly managed by locally autonomous decision entities incorporated in the blue-collar layer with interfacing and updating role of white-collar entities in the white-collar layer. This layer based control architecture is proposed to fit with the emergence of Cyber Physical System (CPS) and the need of dynamic switching in hybrid control architecture.

KEYWORDS: Hybrid, Cyber physical System, Control architecture, Blue-collar, White-collar

1 INTRODUCTION

In today's competitive world, globally volatile market is one of the biggest troubles for manufacturing industries. Factors such as requirement reactive and adaptive system, shorter life cycle, customized products etc. made this trouble vital. The framework of Industry 4.0 is also urging them to deal with technological advancement in information and communication for effective management of knowledge required for the need to regularly update and reconfigure their system. While struggling to satisfy these factors, the manufacturing industries may impose with new challenges and varieties which in turn these challenges are forcing them to look for new solutions. At this time, it is critical to search for control systems that provide efficient planning of tasks to resources and quickly adapt and react to unexpected events occurred. Accordingly, different control systems in different views, behavioral views (El Haouzi, 2017) and structural views (Dilts *et al.*, 1991; Rey *et al.*, 2013) for instance, have been introduced and implemented so far.

Structurally, the control system can be categorized as central, hierarchical, heterarchical, and hybrid. Each of them has shown merits with capability to react and adapt to unexpected event(s) though the impact varies. Through time, the interest on hybrid control system is increasing as it couples the high and predictable

performance promised by centralized control approach with the robustness of distributed reactive control against disturbances based on the reactivity of Cyber Physical System (Jimenez *et al.*, 2017; Valckenaers and Handrik Van Brussel, 2016). It is studied and proposed by different researchers since the last decade. (Zambrano *et al.*, 2011) and (Rey *et al.*, 2014) for example have presented the need of coupling hierarchical and heterarchical control architectures to manage myopia.

This paper is aimed to provide a state-of-the-art on holonic and multi-agent system (MAS) reference architectures and to propose a Recursive hybrid Control Architecture (REDCA). The novelty is to present the use of two interlinked decision-making layers namely white-collar layer and blue-collar layer in order to minimize impact of unexpected events(s) occurred and to perform a dynamic role switching manufacturing system's autonomous entities. The rest of the paper is organized as follow: Section 2 explicitly surveys related materials. Section 3 follows with proposing the recursive hybrid control architecture and its executability explanations. Finally, a concluding remark and future perspectives are presented in section 4.

2 SURVEY ON RELATED WORKS

The autonomously reactive and centrally predictive behaviors of decision entities in distributed reactive control mode and central predictive control approach

respectively are encouraging for control systems change. As a response to this changing call, coupling these two control approaches is believed to minimize their over shadowing drawbacks. According to (Cardin *et al.*, 2017) and (Jimenez *et al.*, 2017), for instance, minimizing these drawbacks is highly dependent on the way how these two control approaches could be combined. Holonic manufacturing system and multi-agent system paradigms have been handed-over the coupling procedure in order to stabilize manufacturing execution system at glance and performance of whole system then after. Even though both paradigms have a lot in common, the multi-agent system provides multi-domain functions through its cooperative and competitive agents while the holonic manufacturing system is used mainly in manufacturing domain through its inherently cooperative holons. This indicates that the search for an effective implementation of holonic reference architectures and multi-agent system paradigms remains a subject of great attractiveness in the community of researchers working on agile-adaptable system.

2.1 Fundamentals on Holonic Manufacturing System (HMS) reference architectures

HMS provides reactivity to disturbances, flexibility to changes, and efficient usage of resources. It has got much attention due to its fitness to create synchronized control system during unexpected disturbances (Jarvis *et al.*, 2008) and its fitness to satisfy the requirements of industry 4.0. Three main holonic control architectures have been studied and elaborated by different researchers in the previous decades: Product-Resource-Order-Staff (PROSA) reference Architecture, ADAptive holonic COntrol aRchitecture (ADACOR), and Holonic component-based architecture (HCBA).

PROSA is considered as reference architecture for other HMS architectures. It identifies types of holons necessary for any manufacturing system, its responsibilities, and interaction structure in which they cooperate. According to (Van Brussel *et al.*, 1998) and (Valckenaers and Hendrik Van Brussel, 2016), PROSA is built from three holons: product, resource, and order holons. Staff holon is added to assist these basic holons with expert knowledge. Product holon stores process and product knowledge needed to insure the correct execution of the product with sufficient quality. Resource holon is an abstraction of the production means, such as machines, conveyors, pallets, raw materials, tool holders, material storage, personnel, floor space etc. (Valckenaers *et al.*, 2007). Besides, a resource holon offers production capacity and functionality to the other holons. An order Holon is responsible for doing the work assigned on time and in the right way (Giret and Botti, 2006). It interprets a task within a system and hence prepares a work assigned optimally. Meanwhile, it manages the physical product being processed, the

product-state model, and all logistic information related to a job (Valckenaers *et al.*, 2007).

ADACOR, by (Leitão and Restivo, 2006), uses a pheromone-like propagation mechanism to deal with myopic phenomenon by introducing a supervisory holon. It defines a holonic approach for dynamic adaptation and agility in the face of frequent perturbations within flexible manufacturing systems. It is based on a group of autonomous and cooperative holons in order to represent factory components. These holons have an autonomy factor that adapts the holon's autonomy according to its environment (Rey *et al.*, 2013). A low-autonomy factor implies following supervisory advice and a high-autonomy factor allows self-organization and local problem-solving in case of perturbations. Once perturbation is occurred, the locally autonomous holons switch to heterarchical mode and manage their problem (perturbation) without the involvement of supervisory holon. ADACOR groups the holons of a manufacturing system into product holons, task holons, operational holons, and supervisor holons. The supervisory holon introduced in this architecture has specificity over that of the staff holon in PROSA. For instance, it has capability to form group of holarchy and it is in charge of triggering schedules periodically. Each product is represented by one product holon that has all of the product-related knowledge and is responsible for the process planning. To this end, product holon stores information about the product structure and the process planning to produce it. Every manufacturing order is represented by a task holon, which is responsible for controlling and supervising a production execution. The operational holons represent the physical resources of the factory, such as human workers, robots and machines. They manage the behavior of these resources based on their goals, constraints and capabilities, and try to optimize their agenda.

HCBA, much like PROSA, serves as a reference model for numerous implementations and applications of holonic systems. (Chirn and McFarlane, 2000) and (Farid, 2004) have testified that HCBA is derived from the concepts of component-based development (CBD) that provides a guideline for HCBA. As it is presented in (Botti and Giret, 2008) and (Chirn and McFarlane, 2000), HCBA defines two major holons: product and resource holons. The resource holon is an embedded system component that can execute operations such as production, assembly, transportation, and checking. The product holon may contain a physical part such as raw materials, product parts and a controlling part may represent the path controlling a production line, process control, decision-making, and product information.

To sum-up, holonic reference architectures have been studied by the holonic community and clearly showed that they are capable to minimize impact of perturbations on a holonic system. However, the setup for holonic structure requires high effort and hence development of

holonic control applications is sophisticated. This is because modeling of complex dynamic systems is costly and incurs significant processing overhead due to the demand for powerful modeling platforms (Dorri *et al.*, 2018). Hence, the flexibility, autonomy and scalability afforded by agents made agent-based modeling a low-cost and low resource solution for modeling complex systems (Dorri *et al.*, 2018). Subsequently, the developments in multi-agent communication have evolved significant interest and research activity in the area of cooperative MAS.

2.2 Fundamentals on Multi-agent System (MAS) paradigm

MAS consists of society of agents that could potentially cooperate with each other and their outer environment in order to perceive, reason, and converge to a suitable solution (Botti and Giret, 2008; Isern *et al.*, 2011; Wooldridge, 2009). In the intelligent manufacturing system domain, it is well accepted that MAS based control system is a good way to deal with disturbances and production changes. It provides software packages for the implementation of HMS through cooperative algorithm such that each agent's beliefs are brought to negotiation until all neighboring agents reaches at their final offer (Farid, 2004). Agents in such control system are characterized by their autonomy in which decisions at the time of necessity are made by these agents. This helps to create robust system with respect to time-evolving communication. In (Holvoet and Valckenaers, 2006; Isern *et al.*, 2011; Jennings *et al.*, 2001; Leitão, 2009; Maturana Shen and Norrie, 1999; Ryu and Jung, 2003; Wong *et al.*, 2006; Xiong and Fu, 2018), it is clearly presented that the applicability of MAS is characterized by their large scale in terms of number of agents, dynamic nature, and complex functionality. In Ryu and Jung (2003), for instance, the concept of fractals as autonomous cooperating agents to discuss fractal manufacturing systems is introduced. Maturana *et al.* (1999) in turn introduced adaptive multi-agent manufacturing system architecture with capability to facilitate multi-agent coordination by minimizing communication and processing overheads.

2.3 Synthesis and discussion

Plenty of researchers have given owed concentration to holonic and multi-agent manufacturing reference architectures and paradigms to provide efficient production performance and ensure reactivity face to unpredicted events. However, several issues left unsolved such as autonomy of decisional entities and legal aspects to represent sociability challenges, development of interaction mechanisms and protocols, design of decision models and control architectures, issue of introduction and implementation of technological solutions to explain some of them. To emphasize these challenges, Cardin *et al.* (2017) in their state of the artwork, for example have pointed out three

confusing choices by decision entities to reschedule a perturbed discrete manufacturing system: (a) do nothing (b) decide autonomously and (c) decide by shrinking towards central scheduler. Cardin *et al.* (2017) have also presented that three main challenges still need to be investigated in the next few research years: (I) Estimation of future performances (II) Design of efficient synchronization (III) Design of efficient switching strategies integrated into a hybrid control architecture which this work has given attention.

This indicates that further effort and exploration on control architectures with a target to provide all components of manufacturing system decide immediately while they face unexpected events is still a demanding research area. Besides, even though, both the holonic and multi-agent systems have a lot in common to model and implement these control architectures, the applicability domain of MAS is very wider than that of the holonic paradigm. For example, many researchers have given due attention to the applicability of sociability-based multi-agent systems for controlling communication problems in the field of networking sciences, sociology, anthropology, philosophy, economics etc. However, its applicability for manufacturing control problems was highly comprehended with challenges such as difficulty to guarantee minimal level of information and operational performance, difficulty of cooperation, lack of commercial platforms (Jimenez *et al.*, 2017; Rey *et al.*, 2014) etc. Meanwhile, several challenges within the manufacturing systems such as design of decision model, design of interaction protocols, integration of technological solutions, dynamic switching role of entities remains yet unsolved. In the framework of solving these challenges in general and the last point in particular, agent-based recursive hybrid control architecture is proposed and explained in this paper; section 3.

3 PROPOSITION: A RECURSIVE HYBRID CONTROL ARCHITECTURE (REDCA)

In the framework of effort to design and implement hybrid control architecture, REDCA (structurally semi-heterarchical and behaviorally reactive) is proposed with its suitability to create reactive, sociable, cooperative, and adaptable manufacturing systems at the time of perturbations. It is an extended version of VSM-based work proposed by Herrera *et al.* (2011) by taking the recursiveness¹ and legacy system of the work. However, REDCA differs from Herrera *et al.* (2011)'s model by the level of implementability and capacity of adjusting perturbation(s). To adjust a perturbation(s), the different aggregation levels in Herrera *et al.* (2011)'s model were limited to either waiting until final decision is distributed by a central entity or splitting work-in-progress products

¹Recursion inside an operating unit, same configuration exists with local regulation and local management and all decisional entities decide at their own level; Stafford Beer's Viable System Model

to neighbor machines which are working for same lot. This indicates that the model was not able to clearly show a layer-based contribution of each aggregation level. Moreover, it is a product agent who plays all the roles in optimizing the system while the other agents (for example machine agents) have contributing role. Consequently, REDCA is proposed to remedy these limitations by developing a layer-based control and execution system; Figure 1. It follows similar control functions as Viable System Model with self-adaptability in perturbed environment and indefinite repeatability (called recursion in this paper) in order to satisfy control requirements at very local and operational decision levels.

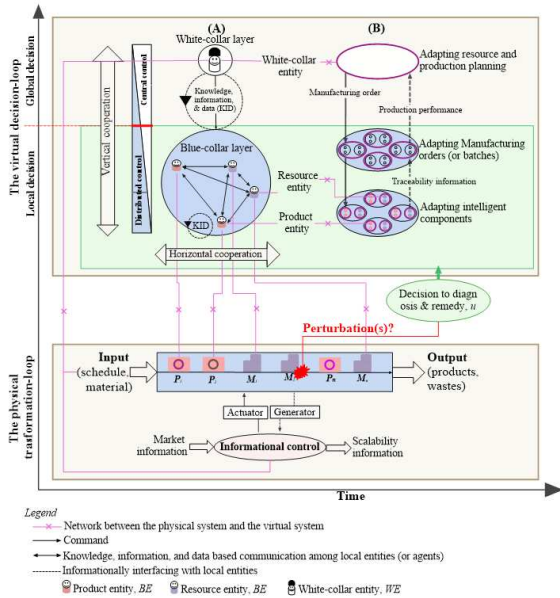


Figure 1: The Recursive hybrID Control Architecture

Meanwhile, REDCA is designed considering the concept of dynamic hybrid control system introduced in Pollux by Jimenez *et al.* (2017). Pollux used a layer-based control system organized into coordination layer, operation layer, and physical layer. Subsequently, REDCA has considered a wider operational specialty of blue-collar layer and an updating and interfacing² role of white-collar layer; see the structural architecture in Figure 1. The operation layer and physical layer of Pollux fall into the blue-collar layer in REDCA. Hence, REDCA is designed to satisfy the requirements (over Pollux and other control architectures) of scalability, dynamic role assignment of decision entities, better closeness to Enterprise Resource Planning, and better level of acceptability by workers of industrial enterprises. The concepts of white-collar and blue-collar, in this paper, are used to represent the role of global and local decision levels in the previously proposed control architectures respectively. Both terms came into common use in the 20th century to mean these who perform office/administrative level and clerical work

²The role of decision entities in the white-collar layer is not as significant as that of decision entities in blue-collar layer

within manufacturing industry respectively (Wroblewski, 2019). Furthermore, the work in white-collar is unstructured and non-routine whereas the work in blue-collar (also named as working class) is manual and/or operational with dirty hands.

3.1 The decision entities

All the execution components within a manufacturing system are installed to perform the required actions proposed by decisional entities (Jimenez *et al.*, 2017). In REDCA, two groups of decision entities namely blue-collar decisional entities (BE) and white-collar decisional entities (WE) are introduced to perform cooperative participations for their common goal and/or objective. In order to make the required decision, all the decision entities consider different parameters, variables, communication protocols (such as broadcasting) etc.

3.1.1 White-collar entities (WE)

They are engaged to prepare production and resource plan through Human-machine interfacing, Enterprise resource planning etc. Once demand management and resource plan are developed at ERP level, a manufacturing order (MO), through MPS, is dispatched using these entities to resources for executing the required operations. These entities are also aimed to declare external changes such as rush order such that if this external change is requested after an online-execution, the locally impacted entities shift their behavior to this white-collar entity in order to declare this change. This proves that white-collar entities decided both in offline and online sub-systems. On the other hand, the layer-based organization of REDCA differs from that of Pollux on the role of these white-collar entities. The decision entities in coordinating layer of Pollux, which are parallel to the white-collar entities in REDCA, are responsible for global production optimization by hosting a predictive decision-making technique to guide the achievements of goals while the white-collar entities in REDCA are used for updating and interfacing role only. That is, once perturbation is occurred, the global decision entity in Pollux has equal decision level with the local entities where as in REDCA, the white-collar entities becomes out of the decision-loop after the perturbation is occurred even though there is dynamic role assignment of decision entities within the blue-collar layer.

3.1.2 Blue-collar entities (BE)

These entities are dedicated to perform the required execution ordered by white-collar entities and to rule a decision-making process at the time of local perturbation occurrence. Each blue-collar entity has its own recursive control kernel and this recursiveness continues until the last operation of a product is completed in a given time horizon (Bae, 2019; Herrera *et al.*, 2011). After perturbation occurred, the decision-making process

begins by sensing the perturbed area through sensors (RFID technology for example) and it uses knowledge, information, and data of the affected decision entities. Then after, they cooperate and diagnose the unexpected event occurred, either through changing their behavior to white-collar entity (the first recursion within the distributed reactive control mode) or acting as blue-collar entities. This behavioral change of locally impacted decisional entities in to white-collar entity makes REDCA dynamic. This continues until the unexpected event is no longer a limiting factor. Likewise, the affected blue-collar entities do not look to be helped either from entities in the white-collar layer or blue-collar entities which are not part of the unexpected event. This confirms the non-universal decision-making process at the time of perturbation. Product entities and resource entities constitute this blue-collar entity with strong horizontal cooperation between them.

Product entities, constructed with different product types for different manufacturing orders, are the leading constituent elements within the entire decision loop shown in Figure 1. The aggregated decision levels in Figure 1(B) are instantiated using knowledge, information, and data provided by these entities. Depending on the required communication with, they organize a production process for their different operations by considering their current state and broadcasting their intention to neighbor product entities or available resource entities. They have informational part to assure they are intelligent enough; the first cyber-physical system. This informational part, which has memory on which data and operational requirements are stored, is in charge of transmission of manufacturing orders to resources, reasoning capabilities, and validation of key performance indicators. Moreover, it is a required function to create and manage other neighbor entities. It also accepts/refuses a configuration change using its environmental knowledge and asks/accepts/refuses to swap its configuration with neighbor product entities.

Resource entities, configured with hardware parts (machines, conveyer, routers, sensors, production controllers etc.) and control parts in order to provide recursive services for product entities. The hardware part executes operations requested by product entities. The control part monitors the hardware operations by hosting attributes such as adaptive capacity and manages tasks assigned to its hardware part. It is shown in the physical transformation-loop of Figure 1 that the sensors and actuators follow commands received from product entities (at this instance, the behavior of the product entity is acting as white-collar entity) to perform the required process. Once the white-collar entities pass a central schedule to these entities for executing, they return inform their availability to execute the required operation. This confirms their role to coordinate the entire system.

3.2 Structural organization of the control architecture

The structural arrangement of REDCA is organized into two layers namely white-collar and blue-collar layers.

White-collar layer is an offline sub-system to coordinate a system towards global performance by preparing production and resource plan through mixed integer programming for example. Once demand management and resource planning are developed at ERP level, a manufacturing order (*MO*) is dispatched to a shop floor by white-collar entities (*WE*) in this layer at periodical time. The manufacturing orders in Figure 1(B) have set of attributes such as order number, due date, quantity etc. and each manufacturing order has its own product classifications defined by its product's current state. Meanwhile, this layer informationally interfaces with the blue-collar layer while the blue-collar entities in the blue-collar layer generate their executed output; see the production performance declaration in Figure 1(B).

Blue-collar layer is an online sub-system for operational execution of the manufacturing orders dispatched by white-collar layer and for controlling the available executing resources. It is represented by blue-collar entities (*BE*) responsible for production performance declaration, traceability information, and agile reactivity to unexpected events occurred in addition to the execution control. Decision entities in this layer have dynamic behavior to assign a role among each other (for example blue-collar entities may change their behavior in to white-collar entities within this layer until the required perturbation is addressed) and this continues until the last operation of a product is completed in a given time horizon. However, after the perturbed sub-system is adjusted, the entities in this layer generate the improved system to the white-collar layer for their informational purpose only.

4 CONCLUSION AND FUTURE REMARKS

This paper has presented state-of-the-art on holonic reference architectures and MAS paradigms and their role in reducing the impact of unexpected events (or perturbations in this paper) on manufacturing systems. It then proposed recursive hybrid control architecture (REDCA) by stipulating two decision-making layers namely white-collar layer and blue-collar layer. The decision-making in the proposed architecture was mainly managed by locally autonomous decision entities incorporated in the blue-collar layer with interfacing and updating role of white-collar entities in the white-collar layer. REDCA was designed to satisfy the requirements (over other control architectures such as Pollux) of scalability, dynamic role assignment of decision entities, better closeness to ERP, and better level of acceptability by workers of industrial enterprises. Two algorithms, through the work of (Mezgebe *et al.*, 2019a), Mezgebe *et al.*, 2019b), have developed and implemented before this work by considering the role of the blue-collar entities but with capability of one of these blue-collar entities to

dynamically act as white-collar entity at the time of unexpected event(s). This dynamism is one of the novelty and applicability roles of these entities. Likewise, these two works confirm the applicability of REDCA in any industrial systems.

However, REDCA is closely positioned to distributed reactive control system. This indicates that even though the white-collar entities are involved in the decision-making process, the basic decisions are made at blue-collar level. This clearly presents the limitation of the proposed control architecture. In order to bring significant impact of all the decision entities, they must equally oscillate towards the distributed reactive control mode and centrally predictive control approach depending on the type of perturbation(s) a manufacturing system faces. The slack interaction of the white-collar entities must be changed to direct interaction and a full study of decision parameters needs to be showed. This will be the significant work expected after this work.

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REFERENCES

- Bae, Sammie, 2019. Recursion. *In JavaScript Data Structures and Algorithms*. Springer, p. 99-115
- Botti Vicente and Adriana Giret, 2008. *ANEMONA: A Multi-Agent Methodology for Holonic Manufacturing Systems*, Springer Science & Business Media.
- Cardin, Olivier, Damien Trentesaux, André Thomas, Pierre Castagna, Thierry Berger, and Hind Bril El-Haouzi, 2017. Coupling Predictive Scheduling and Reactive Control in Manufacturing Hybrid Control Architectures: State of the Art and Future Challenges. *Journal of Intelligent Manufacturing*, 28(7), p. 1503–17.
- Chirn, Jin-Lung and Duncan C. McFarlane, 2000. A Holonic Component-Based Approach to Reconfigurable Manufacturing Control Architecture. *In Database and Expert Systems Applications, 2000. Proceedings. 11th International Workshop on. IEEE*, p. 219-223
- Dilts, David M., Neil P. Boyd, and H. H. Whorms, 1991. The Evolution of Control Architectures for Automated Manufacturing Systems. *Journal of Manufacturing Systems*, 10(1), p. 79–93.
- Dorri, Ali, Salil S. Kanhere, and Raja Jurdak 2018. Multi-Agent Systems: A Survey. *IEEE Access*, 6, p. 28573–93.
- El Haouzi, H.B., 2017. *Contribution à La Conception et à l'évaluation Des Architectures de Pilotage Des Systèmes de Production Adaptables: Vers Une Approche Anthropocentrée Pour La Simulation et Le Pilotage*. Habilitation à Diriger Des Recherches, Université de Lorraine, France.
- Farid, A., 2004. *A Review of Holonic Manufacturing Systems Literature*, University of Cambridge Institute for Manufacturing, Cambridge UK, Tech. Rep.
- Giret, Adriana, and Vicente, Botti, 2006. From System Requirements to Holonic Manufacturing System Analysis. *International Journal of Production Research*, 44(18–19), p. 3917–28.
- Herrera, C., André Thomas, Sana Belmokhtar, and Rémi Pannequin, 2011. A Viable System Model for Product-Driven Systems. *In International Conference on Industrial Engineering and Systems Management, IESM 2011*.
- Holvoet, Tom, and Paul, Valckenaers, 2006. Exploiting the Environment for Coordinating Agent Intentions. *In International Workshop on Environments for Multi-Agent Systems*, Springer, p. 51-66.
- Isern, David, David Sánchez, and Antonio Moreno, 2011. Organizational Structures Supported by Agent-Oriented Methodologies. *Journal of Systems and Software*, 84(2), p. 169–84.
- Jarvis, Jacqueline, Dennis Jarvis, Ralph Rönquist, and Lakhmi C. Jain, 2008. Holonic Manufacturing Systems. *Holonic Execution: A BDI Approach*, p. 7–16.
- Jennings, Nicholas R., Peyman Faratin, Alessio R. Lomuscio, Simon Parsons, Michael J. Wooldridge, and Carles Sierra, 2001. Automated Negotiation: Prospects, Methods and Challenges. *Group Decision and Negotiation*, 10(2), p. 199–215.
- Jimenez, Jose-Fernando, Abdelghani Bekrar, Gabriel Zambrano-Rey, Damien Trentesaux, and Paulo Leitão, 2017. Pollux: A Dynamic Hybrid Control Architecture for Flexible Job Shop Systems. *International Journal of Production Research*, 55(15), p. 4229–47.
- Leitão P., 2009. Agent-Based Distributed Manufacturing Control: A State-of-the-Art Survey. *Engineering Applications of Artificial Intelligence*, 22(7), p. 979–91.
- Leitão, P., and Francisco R., 2006. ADACOR: A Holonic Architecture for Agile and Adaptive Manufacturing Control. *Computers in Industry*, 57(2), p. 121–30.
- Maturana, Francisco, Weiming Shen, and Douglas H. Norrie, 1999. MetaMorph: An Adaptive Agent-Based Architecture for Intelligent Manufacturing. *International Journal of Production Research*, 37(10), p. 2159–73.
- Mezgebe, T. T., Demasure, G., El Haouzi, H.B., Pannequin, R., Thomas, A., 2019a. CoMM: A Consensus Algorithm for Multi-Agent-Based Manufacturing System to Deal with Perturbation. *The International Journal of Advanced Manufacturing Technology*, 105(9), p. 3911–26.
- Mezgebe, T.T., El Haouzi, H.B., Demasure, G., Pannequin, R., Thomas, A., 2019b. Multi-Agent Systems Negotiation to Deal with Dynamic

- Scheduling in Disturbed Industrial Context. *Journal of Intelligent Manufacturing*, 31(6), p. 1367-1382.
- Rey, G. Z., Thérèse Bonte, Vittaldas Prabhu, and Trentesaux, D., 2014. Reducing Myopic Behavior in FMS Control: A Semi-Heterarchical Simulation–Optimization Approach. *Simulation Modelling Practice and Theory*, 46, p. 53–75.
- Rey, G. Z., Cyrille Pach, Nassima Aissani, Abdelghani Bekrar, Thierry Berger, and Trentesaux, D., 2013. The Control of Myopic Behavior in Semi-Heterarchical Production Systems: A Holonic Framework. *Engineering Applications of Artificial Intelligence*, 26(2), p. 800–817.
- Ryu, K., and Mooyoung Jung., 2003. Agent-Based Fractal Architecture and Modelling for Developing Distributed Manufacturing Systems. *International Journal of Production Research*, 41(17), p. 4233–55.
- Valckenaers, P., and Van Brussel, H., 2016. Design for the Unexpected: From Holonic Manufacturing Systems Towards A Humane Mechatronics Society-978-0-12-803662-4. *International Journal of Performance Engineering*, 12(3), p. 240.
- Valckenaers, P., and Van Brussel, H., 2016. Design for the Unexpected: From Holonic Manufacturing Systems towards a Humane Mechatronics Society. *Butterworth-Heinemann*.
- Valckenaers, P., Van Brussel, H., Paul Verstraete, and Bart Saint Germain, 2007. Schedule Execution in Autonomic Manufacturing Execution Systems. *Journal of Manufacturing Systems*, 26(2), p. 75–84.
- Van Brussel, Hendrik, Jo Wyns, Valckenaers, P., Luc Bongaerts, and Patrick Peeters, 1998. Reference Architecture for Holonic Manufacturing Systems: PROSA. *Computers in Industry*, 37(3), p. 255–74.
- Wong, T. N., C. W. Leung, K. L. Mak, and R. Y. K. Fung, 2006. Dynamic Shop Floor Scheduling in Multi-Agent Manufacturing Systems. *Expert Systems with Applications*, 31(3), p. 486–94.
- Wooldridge, M., 2009. *An Introduction to Multiagent Systems*, John Wiley & Sons.
- Wroblewski, M. T., 2019. *What Is a Blue-Collar Worker and a White-Collar Worker*.
- Xiong, Wei, and Dongmei Fu, 2018. A New Immune Multi-Agent System for the Flexible Job Shop Scheduling Problem. *Journal of Intelligent Manufacturing*, 29(4), 857–73.
- Zambrano, G., Cyrille Pach, Nassima Aissani, Theodore Berger, and Trentesaux, D., 2011. An Approach for Temporal Myopia Reduction in Heterarchical Control Architectures. *In 2011 IEEE international symposium on industrial electronics. IEEE*, p. 1767-72