Manufacturing Control Architecture for FMS with AGV: A State-of-the-Art

Sergio R. González[1(✉)], Ivan Mondragón[1], Gabriel Zambrano[1], Wilson Hernandez[1], and Henry Montaña[2]

[1] Department of Industrial Engineering, Pontificia Universidad Javeriana, Bogotá D.C, Colombia
{sgonzalezb,imondragon,gzambrano,hernandez-w}@javeriana.edu.co
[2] Department of Electronics Engineering, Universidad Distrital Francisco José de Caldas, Bogotá D.C, Colombia
hmontana@gmail.com

Abstract. In environments of constant development, the production system is going more complex, focusing on new tendencies about continuous improvement for technologies in manufacturing allows to reduce times and costs of production. The implementation of new Material Handling Systems (MHS) in manufacturing line, allows decrease times for the process of transport. The MHS is utilized principally in the production system for repetitive tasks (i.e., internal and external transport for raw material and goods). Through effective implementation of an MHS, it reduces damages to the materials and risks for workers and the same time increases the efficiency of the operation. In the manufacturing, transport costs is associate to different aspects such as reduced reactivity, recovery system failures, inflexibility, low autonomy and limitation of classical architectures of a MHS, all of this is due to reduced capacities of interaction between control systems (i.e., MHS control and Flexible Manufacturing System (FMS) control). For this reason, the costs of material handling can be reduced through integrated control architectures. In these circumstances, the challenge is to develop manufacturing control architecture for FMS and Automatic Guided Vehicle (AGV) with reactivity to the environment changes, scalability, robustness against the occurrence of disturbances, easier integration of manufacturing resources, and autonomy and intelligence capabilities. Although specific research in this topic has achieved a number of great successes, the general framework for the development on architectural level has not been defined by the community. This paper focuses on the overview over principal development in control architecture literature for FMS, AGV and FMS-AGV, in order to overcome of different aspects of transport and the limitations of classical hierarchical architectures.

1 Introduction

The shrinking product life cycles, globalization, mass customization, market volatility, changing nature of industrial requirements are some of the challenge of

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accomplishing a global optimal performance in current manufacturing systems [1]. A manufacturing system is *"a collection of integrated equipment and human resources, whose function is to perform one or more processing and/or assembly operations on a starting raw material, part, or set of parts"*, (Fig. 1) [5]. A manufacturing system requires various types of inputs (e.g., energy, raw materials, tools, equipment, labor, market information and product design) and inevitably non-desired outputs are generated (e.g., waste and scrap). Manufacturing system involves highly adaptive, reactive and fault-tolerant manufacturing control [4].

In this context, control is *"concerned with managing and controlling the physical activities in the factory aiming to execute the routing plan provided by the manufacturing planning activity"* [2]. In the detailed view of control, each level of the whole manufacturing system is seen as a set of controllers that execute the control function in a *"hierarchical"* level [9]. The control properties allow to produce high quality parts with reduced duty cycles and costs. All of this despite disturbances as tools, equipment and material failures [7,8]. According to industrial requirements it is priority developing an intelligent control in manufacturing systems with properties of flexibility and quick reconfiguration for new manufacturing process.

The flexibility in manufacturing is the *"capability to adapt rapid and frequent changes in flow of materials and parts"* [6]. Therefore, flexibility of a manufacturing system is dependent upon its components (machines, MHS, etc.), capabilities, interconnections, and the mode of operation and control [4]. The flexibility should be inherent to the control architecture (e.g., centralized and decentralized control) being possible to adapt with a minimum effort in the programing. Control architecture is a structure model for the FMS that determines interrelationships and establishes mechanisms among control components (e.g. machines, transport system and equipment control). Depending of such structure, its allow controller coordinated the execution of control decisional for transform raw materials in goods [4,9]. Analyzing a single problem is possible by determining the performance of architecture control. This, under statics conditions while con-

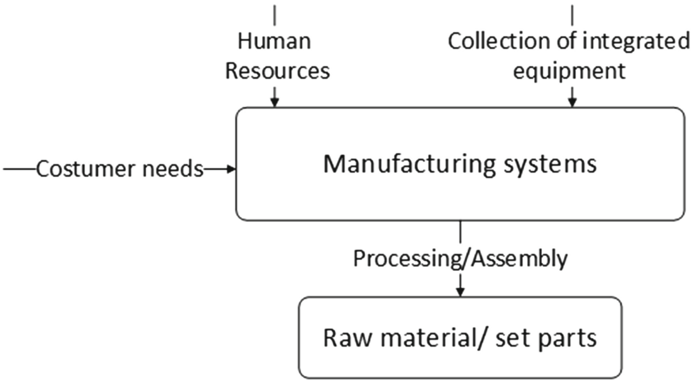

Fig. 1. Manufacturing System.

trol the system is activate. This brings evidence that the centralized control of production system do not accomplish flexibility requirement, manifesting the inadequate the architecture centralized control [4,7,8].

It depends on factors such as quantity of components and the automation level that manufacturing systems can be classified in three groups. The first group is characterized by manual manufacturing with low product variety or similar characteristics. The second group consists in multiples machines, where the manufacturing operations and material transfer between machines are manual proceses. The last one, integrate automatic machines processing with automatic material handling, are known as Flexible Manufacturing Systems (FMS). Roughly speaking a FMS is a manufacturing system in which there is some amount of flexibility that allows react in case of changes. It has recently gained increasing attention becomes an important issue for a growing range of industries.

2 Flexible Manufacturing System (FMS)

Many types of manufacturing systems are currently implemented, including assembly lines, batch production and Flexible Manufacturing Systems (FMS). A FMS is a manufacturing system with a high degree of flexibility, defined as *"...an automated, mid-volume, central computer controlled manufacturing system..."* [10]. Generally speaking, FMS are one of the systems that combine productivity-efficiency of transfer lines and flexibility to react in case of changes, reducing or eliminating problems in manufacturing industries [4]. Flexible Manufacturing Systems (FMS) have become very popular due to the production low level costs and their high levels of productivity [3].

From a systemic point of view, a hierarchical FMS is composed of three subsystems: production system, a material handling system (MHS), and a hierarchical computer system for control purposes [1]. The control system in FMS deals with three types of control decisions in real time: sequencing (i.e., product launching order in the FMS), machine routing (i.e., machine selection among alternative machines for the same manufacturing operation) and material handling (i.e., route selection among the alternative transfer paths allowed by the transportation system that connects the machines) [11]. The final effect on the performance in a FMS is attained if control decisions are appropriately taken by the control system [12]. In FMS, such control decisions are closely related to different types of flexibilities, hence, flexibility and FMS control Architectures are attached for a good performance level [4].

2.1 FMS Control Architectures

In current FMS (Fig. 2), there are two configuration commonly used in classical manufacturing control system [1,13,14]. The control architecture defines the blueprint for the design and construction of FMS control [4]. According to [15], the traditional architectures of the manufacturing system common implemented are: centralized and hierarchical. It is a centralized where a single control simultaneously controls all subsystems (e.g. master-slave configuration). The centralized control architectures can be found in the lowest levels of hierarchical and hierarchical architectures. It is especially in basic process and low complexity where it can be driven by unique central computer.

The second one is a hierarchical structure where each subsystem is controlled separately by one controller based on local information [16]. These subsystems are controller from central control. The capacity of decision-making is distributed to entities (i.e., decisional entities (DE)) or subsystems with below decision in the process [4,15].

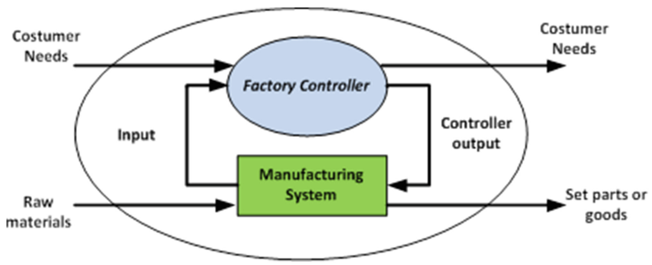

Fig. 2. Block diagram of control manufacturing system, based on [15].

Recent works have integrated dynamic functions on FMS control architectures, specifying how data and control are organized according to the structural and behavioral characteristics that define the elements (e.g. attributes, structure composition and operational) of the control system [1], and how the individual components interact with each other. Such architectures introduced heterarchical relationships in order to respond to changes or perturbations (i.e., reactivity), fault tolerance, scalability, among others [8,17].

In the decentralized control, the process can be considered as a unit functional. In this is allocated an element of control according to system requirements or process. Each one unit is interconnected to the other through a complex system of communication for information exchange [5]. The existence of different unit dont involves complete detection of all process, only one the fail unit [18].

In the early 1970's according to [15], the first class of distributed control in the manufacturing is known Computer Integrated Manufacturing (CIM). This method of manufacturing depends of process of close loop in real time. CIM is a method of manufacturing complete controlled by a computer. This depends of sub process of closed loop control. This approximation is lead to Manufacturing Resource Planning (MRP2) and Enterprise Resource Planning (ERP).

2.1.1 Fully Hierarchical Control Architectures

The perception of hierarchical (Fig. 3) in the complex structure of the organization of an industrial process is taking as base for the coordination of the systems

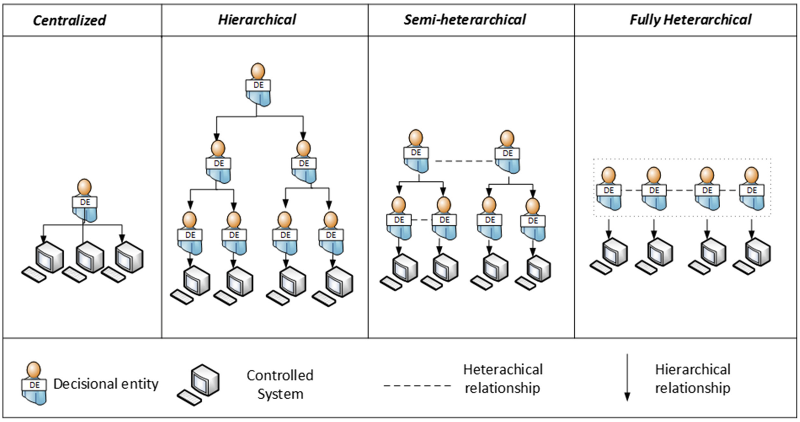

Fig. 3. Architectures of control in the manufacturing, based on [4].

between subordinates and entities of control. Interacting through a constant flow of information in both directions [19]. This is realized by a division of assignment of control and supervision in one level or more of controllers for reduce the complexity of a system centralized unique. This allows a data exchange with a better synchronization with a minimum of disturbances [4].

Typically at the top of the hierarchical, there is no single decisional entity that leads the decisions making of architecture, (Fig. 4). This is responsible for the overall efficacy of the planning horizontal. The planning horizontal is gradually less in the lowest level of the hierarchical [4]. Compared to the centralized architecture, hierarchical allows a gradual increase of control. This resulting in a reduction in development time software allowing to limit (i.e., response times near real time) the complexity of system [4].

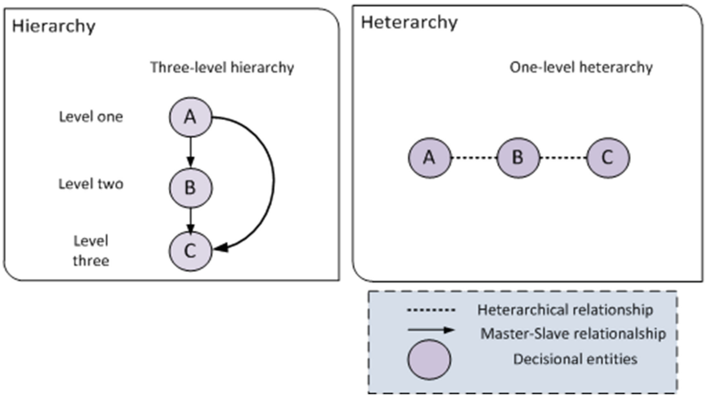

Fig. 4. Hierarchical and heterarchical architectures, based on [15].

2.1.2 Fully-Heterarchical Control Architectures

In control architectures with only one level of hierarchical (i.e., heterarchical architecture), is representing though a distribution of responsibilities of each one decisional entities. The heterarchical structure is based in a descentralized control, (Fig. 4). In this, is eliminating the need of a online control and minimal retention of information. This allows eliminate the use of a data base. The critical response times are handled locally without affecting other entities Adaptive capacity of the architecture heterarchical is guaranteed by the independence between decisional entities and their equal right access to resource [4].

2.1.3 Semi-heterarchical Control Architectures

Semi-hetarchical control combines the advantages of hierarchical and heterarchical architectures avoiding the disadvantage of each one, (Fig. 4). So involve multilevel relations with a low level of autonomy compared with pure structures heterarchicas [4]. According to [20] the systems semi-heterarchical can be represented by a control system. It is designed to perform real time a list of predetermined tasks operated by an active resource (AR). All of this taking account each resource allocation and routing possible [21]. So a semi-hetarchical system can be controlled by a dynamic assignation process (DAP) and dynamic routing process (DRP). These structures can be observed in (Fig. 4). The input to DRP is composed by a pair of nodes (ns,nd), where (ns), is the source node of resources and (nd) is a final node of resources that associate to one or more products in an instant time(t). The output of a DRP is a real time optimized of transport by the routing products. This information will used for a DAP to improve the assignations.

The overall structure of a DAP and a DRP is administrate as a architecture heterarchical unsupervised, (Fig. 5). The relationship between a DAP and DRP is then considerate dependent herarchical [20,21].

In semi-heterarchical control two points are important of stand out. The first one refers to the hierarchical in heterarchical system. This helps in the prediction of behaviors of the control systems. The second one, the hierarchical benefits to

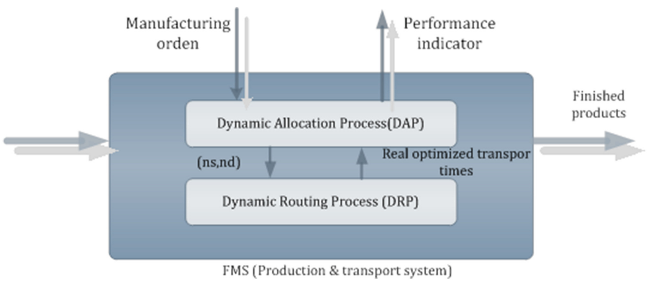

Fig. 5. Semi-Heterachical Control structure, based on [15].

the hetarchical architectures in the migration of the industrial application totally hierarchical to a focusing more descentralized [4].

3 Material Handling Systems (MHS)

FMS require a qualified MHS to transport material (i.e., raw materials, partially manufactured products and goods) safely and with low cost throughout the manufacturing and distribution process. MHS is an important area in a FMS because more than 80% of time is spent in waiting queues or in transportation [22]. Conventional solutions of MHS are based on forklift, industrial trucks, belt, roller and vertical conveyors, elevators, material handling robots and AGV. MHS face some limitations such as the occurrence of bottlenecks, deadlocks, local optimization and low efficiency [6,14].

Automated Guide Vehicle (AGV) defined as *"a material handling system that uses independently operated, self-propelled vehicles guided along defined pathways in the facility floor"* [22] have gained new interest to transport materials between workstations (e.g. load and unload points, machines of processing material) and can be used for the resolution of bottlenecks due to reconfigurable setup that allows AGVs to create new routes. In addition, AGVs are flexible and have the capability to make their own decisions and cooperate with other AGVs [23]. AGVs are employed to maintain flexibility (e.g. diversity of vehicle types, route simplification between processes within complicated networks and the ability to program and retrofit with new tooling to deal with diverse industrial needs), space utilization and efficiency of production and transport [24].

Transport processes required a detailed scheduling for the efficient organization similar to production. In this case, a schedule allocates jobs to available transport vehicles (e.g. trucks, AGV, conveyor, etc.), determines routes, pick-up and drop-off points (P/D) and due dates. The main objective is to minimize the total transportation time required to fulfill the requested jobs [25]. The transportation scheduling problem is decomposed into two sub-problems: AGV allocation and routing.

The industrial use of AGV has grown due to its great potential on the performance of manufacturing environments (e.g. distribution centers, transshipment terminals, warehousing systems, production plants and FMS) being most frequently implemented where they operate alongside humans [14,24]. In this situation, autonomy is vital for the safety of human workers and effective operation of the system. Autonomy in robotics can be defined as: *"within a rational behavior, by the effectiveness and robustness of a robot in carrying out tasks in different and well-known environments"* [24]. Autonomous controls have the ability for self-governance in the performance of control functions (e.g. tracking, regulation and the ability to tolerate failures). A MHS based on an autonomous AGV is known as Flexible Manufacturing Handling System (FMHS) due to its intrinsic ability to accommodate rapid and frequent changes in work-flow [6].

Different approaches to solve problems to optimize the control of AGV systems in FMS were found in the literature: scheduling transport, dispatching of loads, production planning and design of facilities, all related with operational decision, where the main objective for control is to satisfy demands for transportation tasks as soon as possible without conflicts (e.g. deadlocks and collisions) [14,26]. Often, the efficient control and coordination of these decisions is taken to solve different problems, such as: reduce material handling cost, in-process inventories and overall operational cost [14].

The performance measures for evaluating the AGV control system module are: the number of deadlock situations (number of problems that require operator intervention), dispatching rate (i.e. the number of dispatches per hour), quantify the performance of algorithm (i.e. average waiting time of ready parts and the average orders queue length) and AGV utilization (i.e. AGV empty travel rate and AGV idle time) [27]. Embedding autonomous controller structure into AGV releases the higher level production management systems from routing of parts and materials besides provide high level adaptation to changes in the plant and environment [24,28].

There are a number of issues that frequently arise in a typical AGV system. These can occur during the conception, designing, implementation, or operational stages [29]. The AGVs systems design includes problems like: flowpath design, deadlock prevention, conflict-free routing, capacity, fleet size, jobs, traffic management, determination of pick-up and drop-off points (P/D), number and location of points, idle points number and location, battery management, fault management, navigation and guidance and system management (i.e. method of system control used to dictate system operation) [30].

4 Control Architecture of an Autonomous AGV

The control structure (i.e., control architecture) of an autonomous AGV is a framework in which the processes are carried out (e.g. sensing, control, errors detection and recovery, path planning, tasks planning and monitoring of events) during the execution of a particular job. This defines how these should be integrated to get the desired results through decisional capacity [31]. The development of control architecture heavily depends on the environment, jobs, and hardware components [6].

However, due to the inherent complexity of the manufacturing environment, traditional control architecture systems still do not exhibit the capability of adaptation and evolution in terms of production control [6]. In fact, the centralized and hierarchical control approaches present good production optimization but a weak response to change. More, many existing warehouses deploy AGVs use a centralized or hierarchical control paradigm that is integrated with the rest of the material handling systems [32]. With the intervention of a central controller, AGVs require various kinds of guidance for navigation, communication media for transmission of information among AGVs and well-organized jobs definition generated during the system planning stage. With these approaches to material handling, these AGVs cannot be regarded as fully autonomous [6,32].

Autonomous problem arise in that is constrained by rules that are imposed by the strictly specified task execution routines for each resource. Traditional

AGV require costly and rigid changes to infrastructure, typically these utilize a limited drivepath using predetermined routes (i.e., closed loop in one direction), which are frequently demarcated by striping the floor in some manner or by using buried cables or chemical stripes painted on the plant floor. In this case one of the most important problems of deploying AGVs is that the environment around them is not static. These cannot adapt to a changing environment, and are not safe for collaboration with warehouse personnel. AGVs also have limited interaction with the workstations [33].

5 Literature Review

In this section, it is reviewed literature of architecture control for robot, AGV, FMS, and FMS integrated with AGV. The authors provided a list of references this field of control that present either a dedicated or distributed component to the production control.

[34] presented a hierarchical queueing network approach to determine the number of AGVs. Three main issues emerge: track layout, the number of AGVs required and operational transportation control.

[35] proposed a distributed control architecture KAMROs Multi Agent Robot Architecture (KAMARA) that are responsible to overcome coordination problems caused by the independent task execution of systems.

[36] proposed control architecture for autonomous vehicle driving in a dynamic and uncertain traffic environment. The architecture is composed of three levels; the operational level, tactical level, and meta-tactical level, which is the feature of the architecture. The proposed architecture was tested on a highway driving simulator in various traffic scenarios; simulation results show the feasibility of the architecture.

[37] investigated the control system for a robot system with a certain degree of autonomy and complexity. The main specification and design requirements are: Reactivity to the environment, intelligent behavior, multiple sensor integration, resolving of multiple goals, robustness, reliability, programmability, modularity, flexibility, expandability, adaptability, global reasoning.

[38] described an integrated architecture allowing a mobile robot to plan its tasks taking into account temporal and domain constraints to perform corresponding actions and to control their execution in real time while being reactive to possible events. The general architecture is composed of three levels a decision level an execution level and a functional level. The authors proposed a control structure of an autonomous robot must have both decision making and reactive capabilities.

[38] proposed a generic architecture for autonomous robots. The architectural concepts have been justified with respect to the properties required in an autonomous robot. Autonomy in a rational behavior can be evaluated by the robots efficiency and robustness in carrying out various tasks in a partially known environment. The main properties for autonomous robots such as programmability reactivity adaptability or evolutiveness.

[40] discussed how intelligent decision-making is performed for the top Decision Layer of CLARAty architecture for robotic autonomy. This layer provides support for the new trend in planning and executive systems. This layer interfaces with a Functional Layer that provides robot behaviors and control. The interface between these two layers is flexible so that different instantiations of the architecture can use different levels of Decision Layer and Functional layer capabilities.

[41] introduced an architecture that integrates shop floor agents for scheduling, cell control, transportation, and material management. This work introduced a multi-agent system architecture that controls different aspects of a manufacturing environment.

[7] evaluates the performance of alternative control architectures for manufacturing production. The authors evaluated the effect of modifying reactive-based control architecture to incorporate partial hierarchies of agents and planning capabilities. The authors to pose the principal question: what is the most appropriate control architecture for a given system has led industrial and academic researchers to develop a spectrum of decentralised control architectures ranging from hierarchical to non-hierarchical structures? They investigated how increases in planning horizon affect the performance of initially reactive control architecture.

[42] investigated a multi-agent system to architecture control an automated manufacturing environment. The architecture includes functions at the manufacturing cell level, materials handling and transport level, and factory scheduling level. The authors focus attention on the functions of the agents of the transport system, which is composed of a set of AGVs. Agent is an autonomous, computational entity that can be viewed as perceiving its environment and acting upon it. Agents are event-driven objects that can be integrated in automated manufacturing environments to control certain tasks.

[43] investigated decentralizing control of AGVs based on quality requirements such as flexibility and openness. The AGV control system is structured as a multi-agent system. Presented an overview of the agent-based architecture of the AGV system.

[31] investigated on control architecture for autonomous underwater vehicle (AUV). The architecture is organized in three layers: mission layer, task layer and execution layer. The test with real vehicle have been done to validate the architecture. The autonomous control architecture should have well planning or re-planning ability as well as reactive ability to the changing of the external environment.

[44] propose a robotic control architectures. The control architecture defines abilities that should be integrated to develop an autonomous navigation. This could be classified into three categories: Deliberative (Centralized) navigation, Reactive (Behaviour-based) navigation and hybrid (Deliberative - Reactive) navigation.

[45] investigated a hybrid systems framework to behavior control of nonholonomic AGV. This framework has the 3-layered hierarchical structure containing

a hybrid automata of the motion control as the middle process. The hybrid automata has three states, stop, line path following and circle path following.

[46] development an architecture for controlling autonomous mobile robots. The proposed architecture is composed of modules integrates deliberation with a standard planner, execution, monitoring and replanning. The authors present results from experiments that were conducted with the robot Pioneer P3DX.

[47] presents the control system architecture of the autonomous vehicle, called Intelligent Pioneer. The authors investigated the path tracking and stability of motion to effectively navigate in unknown environments. In this approach, a two degreeof freedom dynamic model is developed to formulate the pathtracking problem in state space format.

[48] present a classification scheme that provides a structured mechanism for organizing the relevant information about the design of the AGVS from a control perspective. It allows the system designer to determine how design decisions will impact the control complexity.

[49] investigated the path planning and coordination of multiple Automated Guided Vehicles (AGVs) in an automated warehouse. This paper deals with decentralized coordination of Automated Guided Vehicles (AGVs). The authors propose a hierarchical traffic control algorithm, that implements path planning on a two layer architecture. Describe a coordination strategy for a fleet of AGVs, through an architecture based on a two-layer approach. They treated the planning and the path optimization as a common entity. The path planning is split on the two layers in order to simplify the problem.

[50] propose an architecture for a control system of an autonomous robot as well as an architecture for a multi-robot system in which the robots cooperate in order to accomplish client's tasks. The solution is based on the SOA paradigm and an ontology as a way of representing an environment.

[51] presents the principal components needed in a functional architecture for autonomous driving. They proposed on the division of the architecture into layers, and reasoning on the distribution of the architectural elements across these layers.

[52] proposed a control framework in which a controller is developed for FMS scheduling. This control approach is based on reducing the planning horizon leads to a more stable environment.

[26] discussed the literature related to design and control issues of AGV systems at manufacturing, distribution, transshipment and transportation systems. This paper research perspectives in the design and control of AGV systems in distribution, transshipment and transportation systems.

[1] introduced a framework that includes a governance mechanism in control system architectures that dynamically steers the autonomy of decision-making between predictive and reactive approaches. This paper focuses on architecture of control of FMS, the authors propose a developing a framework that includes a governance mechanism in control system architecture (CSA) that dynamically guide of autonomy of decision making between predictive and reactive approaches. The contribution of this paper is related to the strategy of control

architecture applied in FMS. Although this article focuses only on FMS, it can be a start point to evaluate this framework in AGV.

[53] studied a modeling and traffic control problem of the automated guided vehicle (AGV) system in a container terminal. A set of traffic rules is proposed to ensure the completion of all jobs with the absence of vehicle deadlocks and collisions. Moreover, these rules can be realized almost decentralized requiring little intervention from a central controller.

[8] this article presents a classification of architectures of FMS in the state-of-the-art. These architectures can be grouped in three classes (I, II and III). This paper focuses on the class II hybrid control architecture (i.e., hierarchical and heterarchical) found in the domain of manufacturing scheduling. They propose a dynamic class II architecture called ORCA (dynamic Architecture for an Optimized and Reactive Control). ORCA was applied to a real flexible Manufacturing System (FMS) to prove the applicability of this architecture in an industrial environment. The authors proposed a dynamic architecture, that switching between two functioning modes: normal mode (i.e., the entity is controlled hierarchically) and disrupted mode (i.e., the entity is controlled herarchically).

[23] this paper propose a coordinated control of AGVs in an FMS in areas of group behaviours like formation control, path following maintaining a formation pattern (marching), and collision avoidance between robots or static obstacles. This article proposes a hybrid architecture which objective is to design control architecture that coordinates the AGVs and the process tasks, using Petri Networks (PN). This is based in two levels: in the high level propose a models of FMS using PN, in the low level the control select an adequate AGV, and control laws for process task. Method: decentralized architecture.

[11] these paper propose a semi-heterarchical control architecture is expected to reduce myopic behavior according to current plant conditions (i.e., adaptability) while favoring reactivity and low complexity. Besides the autors explain the control problem in FMS based on the flexibilities (i.e. sequencing, machine routing, and material handling flexibility) and present contributions relevant to pure static heterarchical architectures control, then static semi-heterarchical architectures, and last, they describe contributions which take the dynamic switching between these two architectures into consideration.

This is based in a flexible decision-making technique so as to reduce myopic behavior of local decisional entities. This architecture is a reference for research development in the area of material handling system in FMS, especially the AGV. Method: semi-heterarchical architecture.

6 Discussion

The requirement for adaptable, configurable and reactive control systems for manufacturing has emphasized the inadequacies of traditional centralised control approaches. For this reason, control systems, including FMS control, must incorporate architectures that effectively use the flexibility for reaching better decision-making processes, either before production begins (i.e., predictive phase) and during production (i.e., reactive phase) to deal with real manufacturing needs.

Another feature that current control paradigms prescribe is the autonomy of each component of the system. An acceptable control architecture allows to ensure the quality of the resulting control system and reducing the usually costly and time-consuming development process.

The architecture of a production system has been the most important paradigm for the reduction of complexity in control systems. To meet the objectives of efficient manufacturing, it is necessary to replace the rigid centralized control architecture with heterarchical architectures that have advantages of modularity, extensibility, reconfigurability and fault tolerance.

In these circumstances, the challenge is to develop manufacturing control architecture for FMS and AGV with reactivity to the environment changes, scalability, robustness against the occurrence of disturbances, easier integration of manufacturing resources, and intelligence capabilities. Although specific research in this topic has achieved a number of great successes, the general framework for the development on architectural level has not been defined by the community.

7 Conclusion

This paper presents a literature review of FMS and AGV control architectures. This provides a perspective of the challenges, research needs, and future directions for manufacturing control. In general, they are rigid architectures (i.e., centralized or decentralized hierarchical) and are not simple to modify or configure, being vulnerable to disturbances. In this traditional structures there is limited intelligence for the recognition of stopping points, inflection points or obstruction and reporting of internal conditions or having the limited ability to manage the functions of scheduling, routing and dispatching.

While the literature on AGV design, navigation, routing, scheduling production and transport is extensive, few works has been focused on the adopted architecture for controlling AGVs in FMS in order to overcome the limitations of classical hierarchical architectures, especially the inflexibility for adaptations, low autonomy, and reduced reactivity under perturbations. Despite the importance of the FMS control architecture FMS including AGV, research has often overlooked this topic as the related literature is scarce and does not provide developers with a comprehensive framework to reach more effective FMS control.

From the state of arts reviewed, the authors propose the research question it can be: How to achieve a FMS control framework that includes AGV focused on AGVs autonomy, flexibility, and reactivity under dynamic environments in order to improve the efficiency of the FMS?

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