An Approach to Design Control Systems for Distributed Production Systems as a Collaborative Architecture

Lindolpho Oliveira de Araújo Junior, M.Sc.[1], Diolino José dos Santos Filho, D.Sc.[2]

[1]Paraná Federal Center of Technological Education – Campus of Pato Branco – Department of Electronic
[1]Via do Conhecimento km01, Zip Code 85501-970, Pato Branco, PR, Brazil
[1,2]University of São Paulo – Polytechnic School – Department of Mechatronic Engineering
[1,2]Av. Prof. Mello Moraes 2231, Zip Code 05508-900, São Paulo, SP, Brazil
lindolpho.araujo@poli.usp.br , lindolph@pb.cefetpr.br
diolino.santos@poli.usp.br

Abstract

This paper proposes a control architecture for distributed production systems using a virtual cellular manufacturing and agents based approach, as a natural way for the control of production systems. Actual production system controllers do not have the ability to respond effectively to the system dynamics and complexity. Because of that, much of the planning rules do not occur in the shop floor as planned. This contributes to the gap increase between the planning system and the control system. In order to reduce this gap, control rules and business rules must be implemented together. Here, virtual cellular manufacturing and distributed artificial intelligence (DAI) techniques based on multi-agents are utilized. Agents are modelled using high level Petri nets. Also, it is shown the necessity of applying clustering and planning dynamic techniques to combine virtual cells and DAI techniques to obtain satisfactory solutions of the global control problem.

Introduction

The world competition in goods production with low cycle times has improved the production systems with decision-making capacity to respond to the frequent and rapid changes in demand. The classical product and production oriented manufacturing systems do not have the ability to respond rapidly to these changes, (Drolet, Abdulnour and Rheault 1996). The main drawback is a poor dynamic behaviour that can reflect the shop floor requirements. In this context, there is a need to investigate ways of increasing process restructuring capacity and resources flexibility in order to reduce set up, operation, moving and loading times; together with reducing the Work-In-Process (WIP). In this new scenario, plans are time driven and control actions are event driven resulting in semantic problems and time indeterminism. Moreover, it is necessary to endow these architectures with the capacity of dynamic scheduling and planning.

In this paper, a new control architecture for distributed production systems using virtual cel1ular manufacturing and agents society based approach is proposed. In Section I we outline an extensive scenario of production systems. In Section II a background of flexible systems, cellular manufacturing systems and its related problems to be solved is presented. Section III shows a discussion of control architectures features, its advantages and disadvantages. In Section IV a proposal of control architecture for distributed production systems using virtual cellular manufacturing and multi-agent based approach is shown. Finally, in Section V, we conclude the paper contribution.

Background

According to (Drolet, Abdulnour and Rheault 1996), many terminologies have been used to denote new manufacturing systems. For example, the agile, flexible and intelligent manufacturing systems. The production systems (PS) are a class of systems whose elements are independent and interact among them to produce material goods or to realise services (Santos Filho 1998). These systems can be approached as discrete event systems (DES) (Ho 1989).

The cellular manufacturing emerged to simplify the job shop workflow, where many types of resources necessary to produce component families are grouped in the shop floor forming the production units, also called manufacturing cells (Santos and Araújo Junior 2003). The cellular manufacturing systems (CMS) create part families using clustering techniques defined on sets of parts grouped by similarity coefficients among parts. These similarities can be geometrical, functional, material, by process requirements or necessary tooling, etc.

The contemporary CMS works advocate more flexibility with less commitment to the features used in the past to obtain the parts grouping (Ben-Arieh and Sreenivasan 1999), and also, analyse the effect that lack of information or different orders arrival cause in parts grouping. Some classical CMS alternatives could respond better in situations like little batches and costume-driven productions. These alternatives are the virtual CMS (McLean, Bloom and Hoop 1982) and dynamic CMS (Rheault, Drolet and Abdulnour 1995).

The virtual cell concept was first introduced by McLean, in which a virtual manufacturing cell can not be identified as a physical and fixed workstations grouped in the shop floor, but as data files and processes within a controller. When a job order arrives, a grouping of workstations is needful and the virtual cell controller takes over the control of these workstations and communication among them is realised. The Fig.1 shows a cell shop with two activated virtual cells and no shared resource.

A different kind of system is based on the dynamic CMS concept. This approach is sufficiently efficient in highly turbulent manufacturing environments as in outsourcing industries. In dynamic manufacturing environments, it is hard planning and executing tasks as planned (Irani 1993). The physical configuration of dynamic CMS is subjected to time changes and has as goal minimising the total cost of material manipulation over the planning horizon (PH).

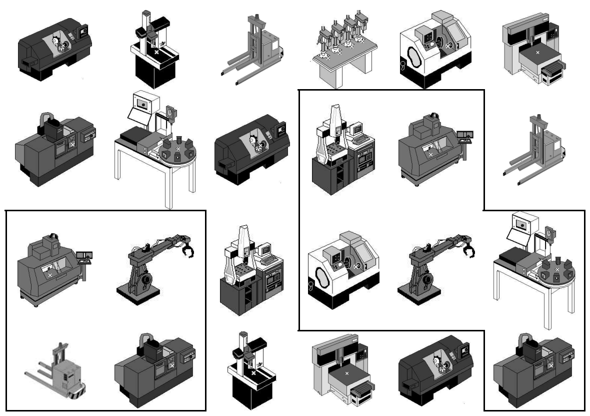

Fig.1 Cell shop with two activated virtual cells.

Control System Architectures

Typical hierarchical control architecture comprises some control modules arranged in a pyramidal form, where each distinct level has its own function and proposal, see Fig.2.

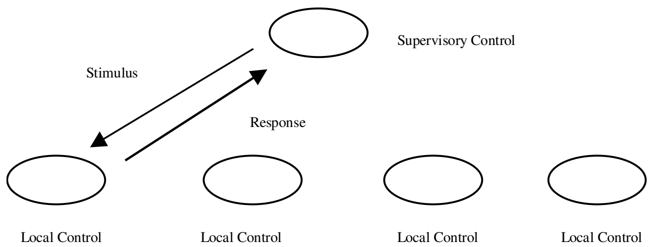

Fig.2 Typical hierarchical control architecture.

The established hierarchy is utilised as a base to system structuring and control. The control flow is typically top-down, and the feedback flow is bottom-up. Recently, the hierarchical control architecture has been modified in different ways, resulting into modified or distributed forms.

In the coordination-control architecture, there is a master-slave relation among subordinate modules and the supervisor module, which can be relaxed to other interactive coordination forms (Darby and White 1988). Modified hierarchical architectures (Senehi et al. 1994) and (Arentsen 1995), also allows the immersion of communication among machine units, where lower levels can better exchange data and synchronise its progress, or react to specific disturbances. Because of the static and deterministic nature of hierarchical control architectures, it turns out to be difficult to modify and incorporate unpredictable changes in the system (Dilts, Boyd and Whorms 1991).

To overcome hierarchical control drawbacks, many researchers as (Hatvany 1985) and (Duffie and Piper 1986) have proposed a heterarchical approach, Fig. 3.

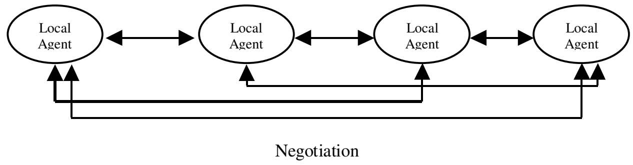

Fig. 3 The Heterarchical control architecture.

The heterarchical control is a highly distributed control form (Lin and Solberg 1994), implemented by an independent processes cooperation system or by agents without centralised or explicit direct control. The control decisions are obtained by mutual agreement and the information is freely exchanged among participant agents (Nwana 1996). Also, the heterarchical control architectures offer scenarios of complexity reduction, high flexibility and robustness against disturbances in the manufacturing environment without the necessity for explicit reactive scheduling (Duffie and Prabhu 1994) and (Bongaerts, Van Brussel and Valckenaers 1998).

However, the system behaviour under heterarchical control is very unpredictable. This can be critical and disastrous to manufacturing control systems. In order to solve this problem some alternative approaches can be realised in the context of distributed artificial intelligence (DAI).

The DAI systems are a class of systems that allows autonomous processes, called *agents*, realise global intelligent actions by local processing and inter-processing communications. An example of modified heterarchical architecture is shown in (Bongaerts et al. 2000), see Fig. 4.

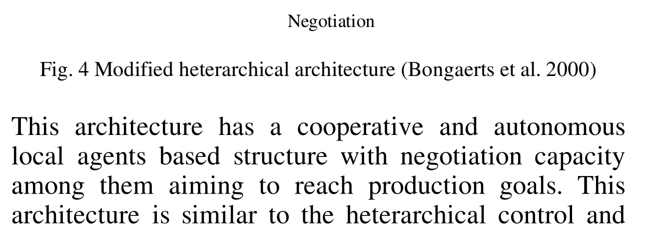

Fig. 4 Modified heterarchical architecture (Bongaerts et al. 2000)

This architecture has a cooperative and autonomous local agents based structure with negotiation capacity among them aiming to reach production goals. This architecture is similar to the heterarchical control and increased by centralised agents as a scheduler agent to coordinate the local agents behaviour. Note that the concept corresponds very well to the holonic systems concept, developed by (Koestler 1989). The *holos* involved in the manufacturing control executes functions as synchronisation, decision-making, deadlock avoidance, coordination, disturbance reaction, optimisation and monitoring. Bongaerts et al. (1997) describes a mechanism that models this aspect using high-level Petri Nets.

The Manufacturing System Control Architecture

The present work claims to design control systems based on *design to control* philosophy. For that occurs, is necessary think about design control systems with reactive and deliberative mechanisms and to adapt them to shop floor real devices. The proposed architecture is modified heterarchical architecture with a centralised hierarchy, based on software agents and virtual CMS concepts see Fig. 5.

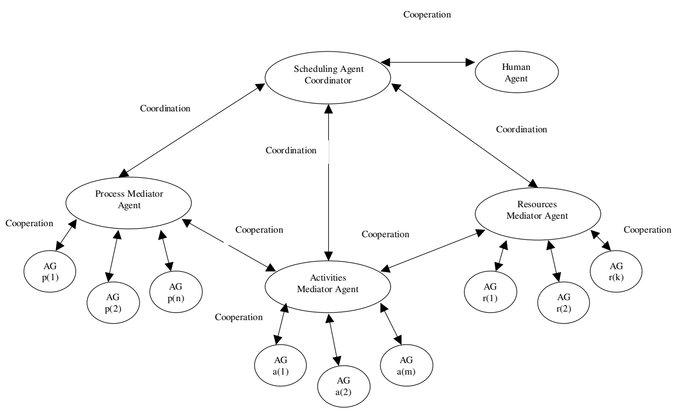

Fig. 5 The proposed control architecture for distributed systems control

Agents are modelled using High-level Petri Nets of the proposed architecture. The global process control is divided into local actions that are realised by specific local domain controllers in order to reach local goals.
The process planning (PP) in this work is referred to the task of process organising for the minimisation of the problem occurrences based on hard resource sharing by current processes which results in resource allocation conflicts.
Also, the PP is responsible to establish the planning horizon and virtual manufacturing cells. The proposed human agent (HA) must realise it. These are complex tasks for a software agent, and therefore, it is proposed an interactive scheduler (the HA) where the communication interface with the scheduling agent (SA) is done by a HA complementary software tool.

Description of the Agents

In this section, the main functional characteristics of the constituent agents in the proposed control architecture and aspects related to the control system dynamics is described.

The HA is the responsible agent by passing the planning information to the SA. The initial planning is designed off-line and must be informed to the SA by a communication interface. All production start up for a PH must be done by the HA. The HA informs to the SA what is the p1anning and the PH activates the planning and control rules to this PH. After production initiates, the control of scenario modifications is assigned by the software agents of the control architecture.
The HA corresponds to the strategic planning agent. By this agent the user can design and verify the PH, decides about business and control rules, implement the rules, activate and finish off processes and periods of the PH and the PH.
The Resource Agent (RA) does the total resource control. One distinct RA controls each resource in the PS. For each resource r(k) there is an associated agent AGr(k). The RA specification is based on the total control of the resource status, on the resource schedule, on the control actions specification for the resource to the realisation of the activities sequences to the processes that utilises the resource.
The Process Agent (PA) is the responsible to assign the activity sequences according to economics and technological criteria. This is a scheduling algorithm feature. The PA also cooperates with the Processes Mediator Agent (PMA) and Activities Mediator Agent (AMA) to inform that one specific process p(n) is requiring the realisation of an activity a(m). The mediator agents execute the scheduling of the activities for all processes in the PH.
The Activity Agent (AA) determines which are the resources that could attend to the required activity for a process using rules established by clustering techniques related to the Virtual CMS, to form independent cells and thus simplifying the resource control.
The AMA receives the AA communication and cooperates with the Resources Mediator Agent (RMA) to assign the resources to the respective processes to realise the respective activities.
The RMA sends and receives information to the RA; cooperates with the AMA to resources assignment for respective processes p(n) by control rules based on agents negotiation and deadlock avoidance techniques. For that, it is necessary cooperate with the AMA, which communicates to the PMA that the process p(n) will realise the activity a(m) using the resource r(k). The sequence specification and execution of the operations for the activity is performed by the resource r(k) assigned. This is a very complex behavioural agent in the architecture.
The PMA receives the PA communication claiming activities to be executed and cooperates with the AMA to inform about these requisitions. Also cooperates with the AMA to receive information from RMA about resources assignments and so inform to the PA about the process status.
The SA coordinates the mediator agents to guarantee that the business rules will be reached. The business and control rules are employed together to reach business and control objectives at same time. Also cooperates with the HA to receive new control rules. The SA behaviour is based on distributed and dynamic

scheduling techniques and it is implemented as the basis to negotiation with the mediator agents and to reach the local goals of the SA.

During the design of the system all alternatives must be defined before. It does not mean to say that the new process, new process routings and new resources cannot be part of the system. For that, a new RA must be inserted for each new resource in the shop floor, such as a new AA must be inserted for each new activity, and a new PA must be inserted for each new process. It is clear that new business and control rules can be implemented within the SA and mediators agents. Due to control architecture is based on agents (distributed) and the interaction form employed in the basis (cooperation), it is turned modular because the agents behaviour is independent and facilitate the new rules implementation. Other important factor is the computational complexity decreasing to generate control rules. It is because the major of the variables involved are locals and independent among them. The agents are implemented into the local domains.

The Planning Horizon

The PH consists of a temporal graphic representation for the time processes distribution for minimising the PP issues mentioned earlier. These problems are: hard resource sharing and resource allocation conflicts. The PH distribution must be done based on virtual CMS principles and dynamic clustering techniques to search independents cell formation. When it is possible, the main goals for each PH period are: independent cells formation to minimise resource sharing and simplify the control planning; optimise the resource utilisation; and to attend business goals without leaving to attend plant control goals following the imposed planning rules.

The Fig. 6 shows an example of a possible PH distribution, where p(n) is the processes for each PH period. This distribution is done considering time and demand constraints and technological similarities among processes.

p(1),p(2)	p(2),p(3)	p(2),p(4)	p(1),p(2),p(4)	p(4)	p(6), p(3)	p(1),p(5),p(4)
1 day	2 days	1 day	1,5 day	1shift	2 day	2 days

Fig. 6 Example of a PH period distribution.

To reach PH formation objectives is proposed choosing a set of process/routing with the smallest number of resource sharing among available routings.

One of the planning system characteristics utilised in this work, reached by virtual CMS that foresee alternatives process routings. The goal is to choose the process routings that have a smaller possible number of sharing among resources to construct a PH based on chosen routings.

Also, it is necessary to form virtual manufacturing cells for each PH period. It consists in creating and/or starting control algorithms within distributed controllers. In the proposed control architecture, in order to select the virtual manufacturing cells control it is necessary to utilise one clustering technique into the mediator and scheduling agents. This technique is a dynamic clustering technique that have a process grouping capacity according to the production system part arrives.

The HA is responsible for passing all planning information to the SA. All planning is off line and must be informed to the SA by a communication interface. Also, all production start-up, according to the PH, must be done by the HA. The HA informs the SA what is the PH and how to activate production and control rules for that planning.

Alternative Process Routings

This step comprises the verification of all processes that will be part of the PH to find one of the alternative routes that results in the smallest number of resources sharing for a PH. After doing it, if some sharing persists which is common in a large production systems, a second step is necessary to divide the PH into distinct planning periods (clusters). The periods must contain only independent processes for total uncouple among virtual cells formed. These steps correspond to the global and local scheduling levels respectively. After doing these two steps, if some sharing still persists, it is necessary to generate control rules to solve the conflictive problems. At the end, the control complexity must have decreased.

Scheduling in the Proposed Architecture

Virtual manufacturing cell formation is done based on Virtual CMS principles, which consider the process life cycle within PH. Future disturbances can occur and the virtual cell might not attend the initial purposes. In this case, it is necessary to utilise techniques to form cells (dynamic clustering techniques) that possess environment perception capacity and decision making-capacity to generate new virtual cells. These requirements must be part of the scheduling and mediator agents processing capacity and must be implemented into the agents' knowledge basis, making-decision and cooperation mechanisms. The main objective is to maintain the performance goal of the PS.

There are two scenarios that must be presented. The first scenario refers to the initial virtual cells formation to the PH and their own PH. It is executed by the planner agent and transmitted to other agents by the human agent. The second scenario refers to the possible re-configurations that are necessary depending on the disturbances in the first scenario. In this case, dynamic scheduling algorithms implemented in a distributed form in the scheduling and mediator agents make virtual cells and PH alterations. The natures of these algorithms are both global and local (Baykasoglu, Gindy and Saad 1998). The aim of the re-configuration is the system performance improvement, whose objective is to satisfy both market demand and administrative goals by better resource utilisation. There are two questions to be answered. When the PH must be re-configured? And, How re-configure it?

The global scheduling algorithms in this work aims to form independent virtual manufacturing cells and synthesise all necessary information to the PH and control algorithm generation. The local scheduling algorithms aim at transforming the information generated in the global scheduling level into a concrete production schedule which represent the PS control rules assignment, such as: transformation, transportation and manipulation resources control rules. Also aim at solving problems as: time, activity sequence and assignment of resource indeterminism, unpredictable events, deadlock of the PS.

Considering the two levels of scheduling presented, a solution by one reactive and predictive approach at the same time is necessary (Sauer, Suelmann and Appelrath 1998). Also, it is necessary to generate scheduling and to adapt them to the actual situations of the PS.

For each period of the PH it is necessary to form virtual manufacturing cells. It consists in creating control algorithms into the agents distributed in the control architecture. In the control architecture proposed it is necessary to utilise some clustering technique in the scheduling and mediators agents to qualify the control of the virtual cells. This clustering technique must be dynamic and possess the capacity of forming new groups of processes or re-organising old processes into the old virtual cells according to the arrival of process in the PS and the necessities generated by unpredictable events. The PH must be done again every time it will be necessary with the purpose to reach business and control goals established before. It must be done every time that performance measure of the PS is under the established standard.

Conclusion

This paper presented a modular architecture for control of distributed production systems. Some model-based simulations have verified some features mentioned in this paper. The partial simulations have shown that the proposed architecture is modular and reacts to the disturbances satisfactory. New results are expected to be published in the near future.

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