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A Modular Cell Controller Architecture for a Flexible Manufacturing System

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Abstract
The need to optimise manufacturing systems operation has originated continuous effort in the development of control system architectures. These have been freed from original rigid centralized structures evolving in such a way that atributte more autonomy to each control subsystem. The subsystems have then become specialized in the different tasks needed to control each manufacturing process. In the present work, an architecture for a cell controller, composed of modules with a significant degree of autonomy, is presented.

1. Introduction

Nowadays any manufacturing enterprise is confronted with needs of competition in markets where the product diversity tends to increase, in contrast to the quantities produced which are constantly falling, as well as the reduction of the product lifetimes.

In this way, any enterprise in order to remain competitive has to constantly adapt to ever changing market conditions. This effort implies the use of flexible manufacturing equipment, usually organised into manufacturing cells [1]. These ones contain equipment that are easily reconfigured, in order to allow them to adapt to variations in the process. Eventually, the cells themselves may be reconfigured in order to increase the overall efficiency of the production system. It is therefore fundamental to keep in mind that the manufacturing system structure evolves dynamically.

In order to optimise the overall manufacturing system operation, it is necessary to control the manufacturing system as a whole. So, in turn, it is required the integration of all information related to the manufacturing process. Nevertheless, the complexity of the control system required by manufacturing systems is usually the main obstacle to change of the same manufacturing process.

Therefore flexible manufacturing systems should not be structurally dependent upon the control system architecture.

Recent technological advances in the information and distributed systems fields are being used to achieve this aim. The standardisation of solutions which allow the communication between different equipments has fulfilled the requirements of data flow in industrial environments which is characterised by the high degree of heterogeneity of equipment. It is now possible to overcome interoperability issues among different systems and optimise their use in a flexible manufacturing environment.

2. Requirements

The need to free the evolution of the manufacturing system from dependencies upon the structure of the control system requires the analysis of this structure. A few characteristics of the control system allow us to perform that analysis.

2.1 Reconfigurability

Reconfigurability means the ability of a control system to adapt itself to changes in the manufacturing process. This ability results from the need to manufacture different kinds of products or to recover from failures of an equipment with the consequent rescheduling of tasks among the remaining machines.

The need of this type of flexibility arise from the demand of certain markets where the variety of products and their reduced lifetime dominate.

2.2 Extensibility

Extensibility characterises the simplicity with which the control structure may be extended, i.e. the ease with which it is possible to add elements to the control structure.

This characteristic is of extreme importance when it comes to making changes to the manufacturing system structure [2],[3].

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2.3 Modifiability

Modifiability measures the capacity of an arquitecture to withstand changes to the control structure. This aspect may be evidenced by the ease with which the control structure may introduce new strategies and control methods. For example:

- Adaptation to different control strategies such as hierarchical and heterarchical ones;
- Integration into the control structure of new techniques such as preventive maintenance and quality control.

In order to satisfy these requirements it is necessary to define appropriated modules with a high degree of autonomy. These will be responsible for the different tasks attributed to the cell controller which may vary from the negotiation of tasks to be handled by the cell to the interaction with the equipment that will be processing the tasks.

The autonomy of the several control elements implies the making of decisions at the local level which requires a significant amount of information about the equipment being controlled. The efficient use of this information means that this information should be maintained on a local database dedicated to the equipment. The sharing of information with other modules implies the use of remote database access services.

The interaction with the equipment controllers PLC (Programmable Logic Controller), RC (Remote Controller), CNC (Computer Numeric Controller) should conform to a standard protocol [4]. This increases the portability of the application to equipment of different vendors, in turn freeing the architecture from the need to develop interfaces to proprietary protocols.

3. Cell Controller Structure

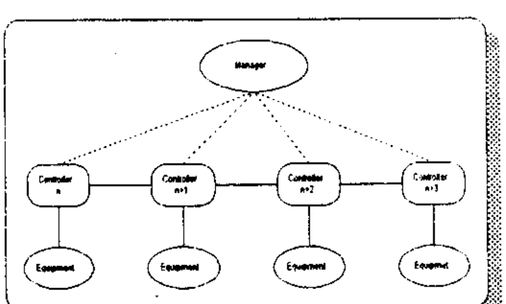

Figure 1 - Cell Controller Architecture

The cell is composed by one or more equipments which need to be coordinated in order to guarantee the completion of the tasks attributed to the cell. There is an individual controller for each equipment (machine, manipulator, robot, transfer tables, etc.) of the cell. These controllers are responsible for the control of the operations attributed to each equipment inside the cell.

The existence of tasks for which more than one equipment is necessary suggests the cooperation of the respective controllers in order to achieve the objective. The concept of grouping autonomous controllers arises for the completion of common objectives. The entity that unites the different controllers is the manager which has, among other functions, the responsibility of trading the tasks to be executed by the equipments associated to the individual controllers. The set of controllers and the manager they contract form the cell controller [5], (fig.1).

The modules that work together for the execution of the tasks attributed to the cell controller requires the definition of interfaces and rules between modules. These definitions are necessary both among peer modules or to communicate with other levels of control.

The correct definition of the interface and the information to be exchanged among the modules ease the development process of the control structure. The addition of a new equipment to the control structure does not require the knowledge of the other modules, but only the rules of co-operating.

The possibility of the cell controller to support different types of interaction (control structure modifiability indicator) and to allow the evolution of its structure (extensibility) cause a modular configuration of the architecture, with each module benefiting from a high degree of autonomy.

Therefore the architecture was based on two main modules: the management module and the control module.

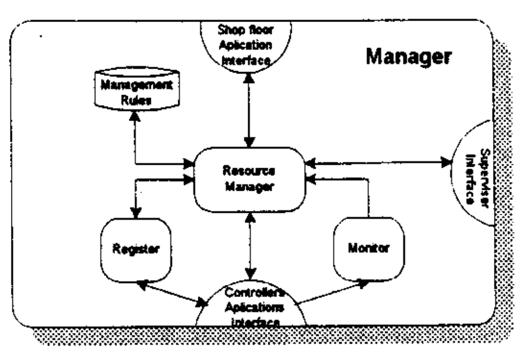

Figure 2 - Structure of the Manager

3.1 The management module

This module is responsible for the cell administration [5]. i.e. it manages the set of controllers that make up the cell, bids its capabilities to the shop floor level and schedules the operations of each controller (fig.2). This module, must work as an interface between the shop floor level and the controllers that make up the cell according to the control architecture.

The shop floor level attributes the tasks that should be completed by the equipments, these then being broken into operations that are forwarded to the equipment controllers by the cell manager.

The use of a registering mechanism in the manager allows the controllers to associate themselves to this manager. This set constitutes the cell controller. The mentioned mechanism establishes a weak relation between the two entities heightens the extensibility characteristics of the architecture. In this case, the addition of a new equipment to the control structure is done by registering the equipment's controller at the manager. All relevant data regarding the equipment is transferred to the manager [5].

A resource management module is used for the interaction with the shop floor level where it bids the capabilities of the controllers to which it is associated. The result of the bidding is made into scheduling plans of the operations which are forwarded to the respective controllers.

The different interactions are hold by the exchange of messages between the parties involved. For this purpose a set of messages were defined, based on the Contract Net Protocol, which support bidding and directed contracts [6],[7]. The interaction with the controllers is processed by a set of messages which correspond to one of three service classes: attribution of operations to the controllers; associations management; and processes supervision.

The interactive interface with the shop floor level allows implementation of different control strategies (modifiability of the architecture). The inclusion of the cell in an hierarchical, heterarchical or mixed control structure may be implemented through change of the cell manager [8].

3.2 The Control Module

The control module has to drive the interior of the cell. It is made by the grouping of the controllers that associate to the manager modules. These modules have a significant degree of autonomy and are responsible for coordinating among themselves all the operations within the cell [5]. The controller should organise the chain of production with the other controllers that take part in the manufacturing process and also drive the equipments under his orders. So the controller should be split into several modules in order to perform the different control actions required (fig 3).

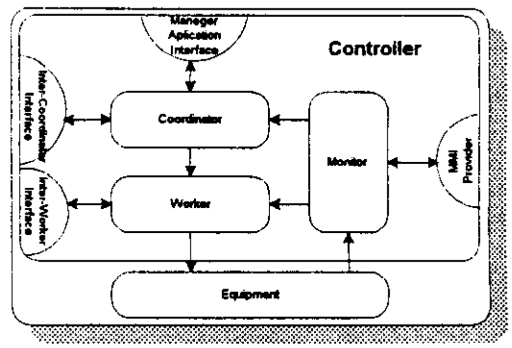

Figure 3 - Structure of the Controller

3.2.1 The coordinator

This module was designed to organise the actions within the cell's equipments. It is responsible for the upper level control and should assemble all the necessary information to it's equipment in order to be able to carry out the operation commanded by the manager.

This module is also responsible for the preparation of the plans for the worker and the coordination of the action of its equipment within the cell's organisation [5].

So, the module must establish associations with the entities which it is interacting with. It uses the registry mechanism as well as the set of messages already referred for the manager module in order to communicate with the manager.

Among similar entities there is a set of messages that allow the coordination of the process between several equipments. This behaviour allows for high autonomy between controllers and, together with registration mechanism, simplify the change in the controller structure.

For the lower level, the messages sent correspond to several orders that the worker must carry out.

In case of disturbances of normal work, the change in the control structure must be avoided but detected. Corrective measures must then be initiated.

In order to avoid deadlocks in manufacturing systems, more frequent in highly automated systems, the coordinator must only send actions to the worker if it is certain that, in terms of the chain of production, every possible condition is met to rule out the possibility of errors. The coordinator of the next equipment (in terms of chain of production) will only accept a request for an operation if this equipment is able to receive the working item into the machine itself or the machine's auxiliary buffer.

This way the controller only issues orders that are guaranteed to continue the production on the following equipment. Also, the following controller will only accept the reservation if all the resources needed to complete the operation are, in fact, available. This is a self-regulation process that avoids the system of accepting more work than what it can carry out, thus ruling out deadlocks [9], [10], [11].

In terms of fault recovery and due to the autonomy of each controller, it is necessary that controllers are on the look-out for errors on the other controllers. The detection of a failure is to be communicated to the manager by the controller that found the situation.

3.2.2 The worker

This module is specified to act as an interface between the coordinator and the local equipment controller. It receives the orders to carry out from the coordinator and transforms them in actions to the equipment. To accomplish this task, a number of messages that are to be sent from the coordinator to the worker were specified. The messages correspond to the several actions possible to the worker and include set-up, work-load, unload, transformation and test. Each action has its own state machine that is translated into basic operation inside the equipment [5].

For the interaction with the local controller, Manufacturing Message Specification (MMS) is to be used as a communication protocol. The choice is made in order to allow standard communication among equipments made by different industrial equipment manufacturers, thus ruling out proprietary protocols [4],[12]. MMS also simplifies access to device functionalities because these are defined as objects inside the Virtual Manufacturing Device (VMD), which represents the equipment to the outside world.

As to recovery from faulty conditions, the worker has two types of recovery: Process fault recovery and controller fault recovery.

Process fault occurs during transformation actions. To recover from such a fault, synchronisation points were established [13]. These are points where the process can be safely interrupted and later resumed without risks for either equipments or materials.

Controller faults occur in the controller itself, a module collaption, for instance. Recovery from this kind of faults must be made by recognising the prime role of the local equipment controller and allowing of to reach a final or interaction time with the exterior. So, the worker has only the tasks of start, monitoring the present action and eventually suspending it. One such command is specified in order to allow the synchronisation between the worker (and his state machine) and the action itself.

3.2.3 The monitor

This module should accomplish the feedback within the control block (coordinator and worker) with the information necessary to allow correct decision-making. It is also responsible for supplying information to the Man Machine Interface (MMI) as well as specific control modules that can be implemented on the controller. Typical examples are quality control and preventive maintenance [14].

4. Conclusions

The work presented describes an architecture for a flexible cell controller. This architecture aims to satisfy the needs of the designing in modern control structures, including to reconfigure, easily adapt and extend the control system itself.

It is required to have a modular construction with a significant degree of autonomy. These modules must co-operate in order to supervise the realisation of the work attributed to flexible cells. The modules were described in terms of capabilities and needs of interaction.

The aim is to contribute to the minimisation of the risks inherent to the flexible manufacturing cells high costs as well as specialisation, both for the purpose of implementing it as well as for changing it.

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