20

A Manufacturing Cell Integration Solution

Paulo J. Leitão [1,2], *José M. Machado* [1], *José R. Lopes* [1]
[1] *Engenheiro Electrotécnico, Investigador do CCP - Centro de CIM do Porto, {pjl,jmm, jrl}@ccp.up.pt*
[2] *Assistente do Instituto Politécnico de Bragança - Departamento de Informática*

Abstract
This paper intents to describe the work of integration developed in the metalwork manufacturing cell of CCP (Centro de CIM do Porto). It focus on the manufacturing cell philosophy, the structure of the cell controller, and the integration work with the MMS communication standard. The present work was developed at CCP as a part of the ESPRIT 5629 Project, concluded in October 1995.

Keywords
Cell Controller Architectures, Flexible Manufacturing Systems, CIM, MMS.

1 INTRODUCTION

World market competition is rather strong, so many enterprises are being confronted with increasing market demands by competitiveness, reduced prices, better qualities, minimal response times and a rise in product diversity. The development in *Flexible Manufacturing Systems* (FMS) has emerged to fulfill the requirements of efficiency, quality and flexibility simultaneously. A flexible manufacturing system consists of numerical control machines, industrial robots, automatic assembly and automatic inspection devices, interconnected by means of an automated material handling and storage system, and controlled by an integrated computer system. The reference model for a factory automation is characterized by a hierarchical control architecture, whose layers are *Facility*, *Shop Floor*, *Cell*, *Machine* and *Equipment*. These layers contains modules, each one receiving commands from only one higher level and coordinating the activity of several others at the next lower level.
The integration of several machining resources with different functionalities and different protocols is the key of Flexible Manufacturing Systems, increasing the flexibility of the production systems and improving the control quality.

L. M. Camarinha-Matos et al. (eds.), *Balanced Automation Systems II*

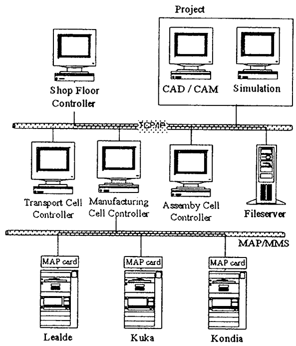


Figure 1 Model for a factory automation

The biggest step to integration is connecting the machines in a communications network. This allows the communication between each machine and external systems, making possible remote machine controlling and information exchange. It also makes possible downloading NC programs to the CNC machines, generated automatically by a CAD system with post-processors, and the RC programs generated automatically by an off-line robot programming (e.g. IGRIP) in case of robots.

Having all the machines integrated, we can develop software (cell controller) for the direct control of these machines. This software would work as an interface between the machines and the Shop Floor Control (SFC). This high level software (SFC) is responsible for the integration of the several existent cells through their own low level controllers (as the manufacturing cell controller). The Shop Floor Control makes the scheduling tasks and the management of the global resources.

2 THE CCP MANUFACTURING CELL IMPLEMENTATION

Our metalwork manufacturing cell has two CNC machines and an anthropomorphic robot for the load/unload of the machines.

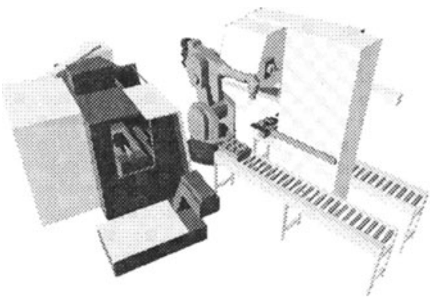


Figure 2 Manufacturing Cell Layout

One of these machines is a turning center *Lealde TCN10* with a SIEMENS *Sinumerik 880T* controller; the other machine is a milling center *Kondia B500* model with a FANUC *16MA* numerical control. The robot is a KUKA *IR163/30.1* with a SIEMENS *RC3051* controller.

All the machines have MAP (Manufacturing Automation Protocol) / MMS (Manufacturing Message Specification) interface boards. The manufacturing cell has two transfer tables, where the containers arrive. These containers bring to the cell the material to be operated and take away the pieces produced in the cell.

Manufacturing Cell Philosophy

For the normal operation of the cell, there are a set of rules :

- The cell comunicates only with the SFC (Shop Floor Controller), receiving manufacturing or setup orders, positions of the materials in a container, etc.
- Possibility of two different orders, one for each machine, at the same time; the robot a resource shared by the manufacturing cell orders.
- Each manufacturing order has one input workpiece, and one or more CNC and robot programs. The result is another workpiece different of the input.
- Each order can have more than one operation in the same machine. The robot must remove, turn and load the machine again to a new operation.

3 MANUFACTURING CELL INTEGRATION

Hardware Layout

The manufacturing cell is connected to the controlling room by a LAN with a bus structure topology, based on a base band transfer media (10Mb/s). The LLC protocol used is 802.3 (Ethernet CSMA/CD). The machine running the Cell Controller software is a SunSpark 10 workstation with O.S. Solaris2.4. This workstation also uses a TCP/IP network that servers the CAD/CAM/CAE and SFC infrastructure. All the manufacturing machines have MAP/MMS boards to implement the communication with the cell controller.

MMS, A Standard Protocol

Flexibility and open systems concept lead us to the application of an open systems communication standard protocol at the manufacturing process control level. MMS (Manufacturing Message Specification) is an internationally standardized message system for exchanging real-time data and supervisory control information between networked devices and/or computer applications in a manner that is independent of the application function to be performed and the developer of the device or application. MMS is the international standard ISO 9506, based upon the Open Systems Interconnection (OSI) networking model.
The key feature of MMS is the "Virtual Manufacturing Device" (VMD) model. The client/server relationship between networked applications and/or devices is a key aspect of the VMD model. In our work cell, the CNC machines act as server applications to the control applications. In general the VMD model defines the objects contained in the server, the services that a client can use to access and manipulate these objects and the behavior of the server upon receipt these services requests from the client. There is a distinction between a

real device (e.g. PLC, CNC, Robot) and the real objects contained on it (e.g. variables, programs, etc.) and the virtual device and objects defined by the VMD model. Each developer of a MMS server device or MMS server application is responsible for "hiding" the details of their real devices and objects. The manner in which these real objects are modeled to MMS objects is critical to achieving inter-operability between clients and servers among many different developers. In many cases the relationship between the real objects and the virtual objects can be standardized for a particular class of device or application (PLC, CNC, Robots, PCs). Developers and users of these real devices can define more precisely how MMS is applied to a particular class of device or application. The result is a Companion Standard. The Companion Standard is a companion of the MMS standard as an additional part.

4 MANUFACTURING CELL CONTROL PHILOSOPHY

The conception and the development of cell control philosophy was based on two important factors :

- a modular structure, which allows the expansion of the cell controller, if the number of machines grows up;
- a maximum flexibility of the cell controller related to the Shop Floor and control architecture.

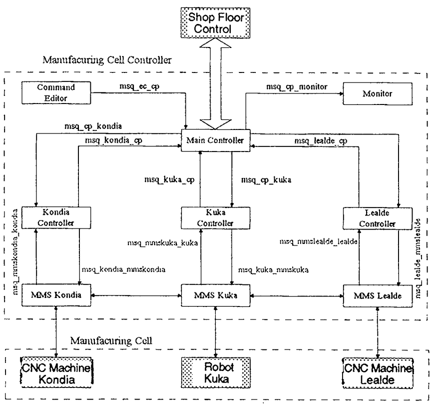


Figure 3 Cell Control Structure

The cell controller is a blend of centralized and hierarchical control architecture. It isn't a centralized architecture because the functions are distributed between the several levels of control; it isn't a hierarchical architecture because the machine modules executes services, and not the full orders, required by top level. This architecture is adapted and customized to our specific problem and could be extended if the number of machines grows up by adding one machine module and a communications module for each additional machine. The option for this architecture control is to free the main controller for executing communications and

management functions. MMS services are confirmed; when one service is required by the controller, the response is not immediately available. So, it's necessary to wait for the service confirmation and this wait can't be executed by the main controller because this will stop the cell controller loop.
The structure of manufacturing cell controller was separated in three hierarchical levels, each one with several modules, performing the necessary functions. This modular structure allows the integration of *n* different machines by adding new modules for each new machine.

Hierarchy control structure

The first level is the brain of cell control, designated by *main controller*, having the following functionalities:

- communications with Shop Floor;
- scheduling and dispatching of the manufacturing orders to the machines;
- dialog with all the machine modules;
- management of the manufacturing orders which are running at the moment at the cell;
- monitoring of cell status;

This functions are performed in separate modules, allowing more flexibility of control.
In the second level, there are several modules, one for each machine. These modules (*kondia_controller*, *kuka_controller*, *lealde_controller*) receive jobs from the *main controller* and are responsible for their execution in the corresponding machine. For job execution, these modules require several MMS services. When the job is finished, this module informs the main controller about its result.
The third level is responsible for the communications between the cell controller and the machines. This level uses the MMS protocol to execute the required tasks. There are three MMS modules, one for each machine, allowing the execution of the MMS services required by the second level modules.

5 DESCRIPTION OF MAIN CONTROLLER FUNCTIONS

This level is the most important of the manufacturing cell controller. The main functions of this level are :

- Receive, treat and store the manufacturing and setup orders from the Shop Floor.
- Receive, treat and store the information of the containers that arrived to the cell.
- Dispatch the orders to the three machine modules.
- Receive and treat the results of services execution by the machine modules.
- Notify the Shop Floor about the evolution of the orders.
- Notify the Shop Floor whenever an alarm occur in the cell.
- Notify the monitor module about the evolution of the order and the cell state.
- Read and execute the commands from *Commands Editor* module.
- Update the cell state in a permanent file (to allow the recovering after a power fault).

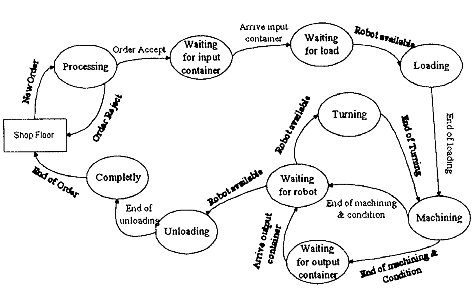
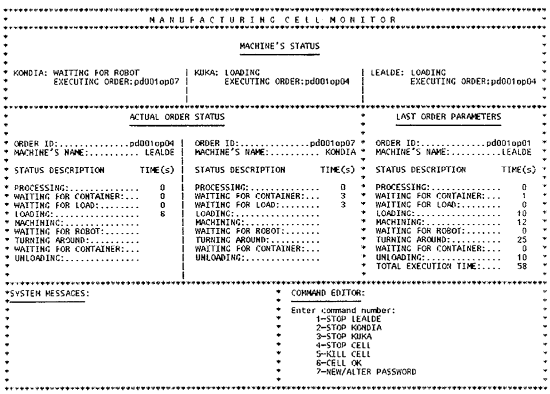


Figure 4 States of an Order

The management of the cell is based on information tables where all necessary data for the orders execution is stored. While an order is in execution, there is a correspondence between its logical state and the real state (order in the cell).



MANUFACTURING CELL MONITOR

MACHINE'S STATUS

KONDIA: WAITING FOR ROBOT EXECUTING ORDER:pd001op07	KUKA: LOADING EXECUTING ORDER:pd001op04	LEALDE: LOADING EXECUTING ORDER:pd001op04

ACTUAL ORDER STATUS

ORDER ID:..............pd001op04		ORDER ID:..............pd001op07	
MACHINE'S NAME:.......... LEALDE		MACHINE'S NAME:.......... KONDIA	
STATUS DESCRIPTION	TIME(s)	STATUS DESCRIPTION	TIME(s)
PROCESSING:.............	0	PROCESSING:.............	0
WAITING FOR CONTAINER:...	0	WAITING FOR CONTAINER:...	3
WAITING FOR LOAD:........	0	WAITING FOR LOAD:........	3
LOADING:.................	6	LOADING:.................	
MACHINING:...............		MACHINING:...............	
WAITING FOR ROBOT:.......		WAITING FOR ROBOT:.......	
TURNING AROUND:..........		TURNING AROUND:..........	
WAITING FOR CONTAINER:...		WAITING FOR CONTAINER:...	
UNLOADING:...............		UNLOADING:...............	

LAST ORDER PARAMETERS

ORDER ID:.............pd001op01	
MACHINE'S NAME:..........LEALDE	
STATUS DESCRIPTION	TIME(s)
PROCESSING:.............	0
WAITING FOR CONTAINER:...	1
WAITING FOR LOAD:........	0
LOADING:.................	10
MACHINING:...............	12
WAITING FOR ROBOT:.......	0
TURNING AROUND:..........	25
WAITING FOR CONTAINER:...	0
UNLOADING:...............	10
TOTAL EXECUTION TIME:....	58

SYSTEM MESSAGES:

COMMAND EDITOR:

Enter command number:
1-STOP LEALDE
2-STOP KONDIA
3-STOP KUKA
4-STOP CELL
5-KILL CELL
6-CELL OK
7-NEW/ALTER PASSWORD

Figure 5 Monitor of manufacturing cell controller

The monitor module of the manufacturing cell deals with the visualization, in real time, of the manufacturing orders evolution running at the moment, as well as the current state of the several machines (Kondia, Lealde and Kuka). It is a virtual image of the Manufacturing cell.

Description of Machine Modules Functions

The machines modules (*Kondia_Controller*, *Kuka_Controller* and *Lealde_Controller*) receive from the main controller, jobs to execute in the correspondent machine (examples: load_machine, unload_machine for the robot; start_machining_program for the CNC machines). Each of these jobs are separated in elementary services for execution by the MMS modules. These elementary services are sent to the correspondent MMS controller using *mailboxes*. When all the elementary services of a job are finished, the main controller is informed about the success or failure of the job execution.

Description of MMS Communications Level Modules

The Manufacturing Cell devices early described are equipped with MAP/MMS interface boards supporting Ethernet 802.3 CSMA/CD connections enabling them to communicate with the control computer via the referred protocol profile.
Such interfaces are: the *CP 1475 MAP* and *CP 1476 MAP* for the *Sirotec* Robot and *Sinumerik 880T* RC/NC controllers respectively and *GE FANUC OSI-Ethernet Interface* for the *GE FANUC 16MA NC* controller.
All these interface boards are microprocessor based 7-layer OSI stack implementations fitting into the backplane of the controllers with industry standard bus systems. These three boards implements MMS server applications on the top of OSI stack, responding to a total of approximately 25 services.
It is possible to note the missing of some implementations that would be useful from the control application point of view. There is a gap between the MMS functionalities specified in ISO 9506 and the objects and services provided by the MMS server applications for the controllers that we worked with. As an example the end of execution of a NC/RC program can be asynchronously reported by the server application by means of an event notification unconfirmed MMS service. This feature is only implemented in the MMS server application for the *Sinumerik* NC controller. The MMS server application for the *GE FANUC* NC controller reports this occurrence with an unsolicited status unconfirmed MMS service. In the case of the robot MMS server application there is no mechanism for the reporting of this occurrence which implied the development of a polling function with a lost of efficiency.
It has also been possible to note different solutions in the modeling of some real objects to MMS objects between the MMS server application for the two NC controllers. We expect that in the future this problem is solved with the application of MMS Companion Standards in all MMS server implementations.
Our cell control computer employs a standard two-layer Ethernet board and executes MMS and the remaining OSI stack in the computer under the operating system. The MMS software was provided by SISCO and the OSI stack by SUN. The SISCO's MMS software designated MMSEASE is a C language API for developing MMS compatible applications. This API, which is not in conformance to the MAP 3.0 MMSi specification, provides primitive level service access similar to MMSi and "higher level" functions that helped in the development of our application.

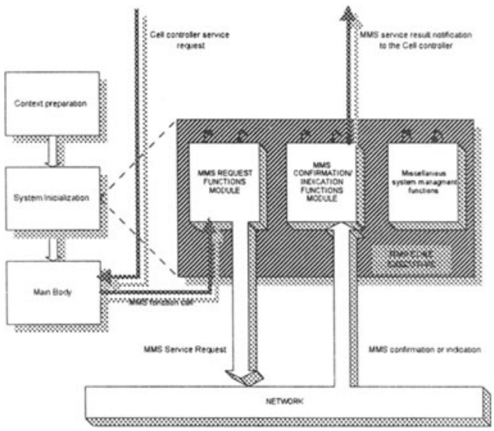


Figure 6 MMS Client Application Module

The MMS application modules are responsible for the communication with the machine controllers, receiving from the higher level elementary requests together with particular information needed for the execution of MMS services and responding with information about the result of the network request issued or with some asynchronous information sent by the MMS server application of the machines controllers.
Only a small subset of the MMS services are implemented by the MMS communication modules due essentially to the limitations on the objects and services implemented by server applications and the needs of the control application.
The MMS objects implemented in the server application and accessed by the client modules are:

- MMS Domains, which are used for the standardized transmission of data or programs (NC/RC programs)
- MMS Program Invocation, used to manipulate NC/RC programs
- MMS Variables, used to map typed data (e.g. Tool offsets, NC data, PLC data, etc.)
- MMS Events, reporting the end of program execution

6. CONCLUSIONS

The manufacturing cell integration here described was successfully completed.
This implementation allowed us to prove inter-operability between equipments from different MAP/MMS vendors and to make some performance conclusions.
This experimental metalwork manufacturing cell is now producing in a autonomous mode integrated in the CIM platform of CCP.

7. REFERENCES

Lee, K., Sen, S. (1994) *ICOSS:A two-layer object-basead intelligent cell control architecture*, in Computer Integrated Manufacturing Systems, Vol 7 N°2, pp 100-112

Leitão, P., Machado, J.(1995) *Flexible Manufacturing Cell Controller Architecture,* in Presentation Day - Proceedings of ESPRIT 5629 Project, pp 190-206

Leitão, P., Martins, C., Rocha, R. (1995) *Integration of CNC Machines in Flexible Manufacturing Cell,* in Presentation Day - Proceedings of ESPRIT 5629 Project, pp 207-217

Lopes, J., Pinto, P. (1995) *Manufacturing Cell Integration using the MMS Communication Protocol,* in Presentation Day - Proceedings of ESPRIT 5629 Project, pp 218-241

Machado, J., Silva, M. (1995) *Integration of load/unload Robot in a Flexible Manufacturing Cell,* in Presentation Day-Proceedings of ESPRIT 5629 Project, pp158-168

Pimentel, J. (1990) *Communication Networks for Manufacturing*, Prentice Hall