MODELING AND IMPLEMENTATION OF A FLEXIBLE MANUFACTURING CELL (FMC)

Evandro Leonardo S. Teixeira
Universidade de Brasília Departamento de Engenharia Mecânica e Mecatrônica, Grupo de Automação e Controle (GRACO), CEP 70910-900, Brasília, DF.
evandroleonardo@unb.br

Carlos E. Villanueva Cano
Universidade de Brasília Departamento de Engenharia Mecânica e Mecatrônica, Grupo de Automação e Controle (GRACO), CEP 70910-900, Brasília, DF.
cvillanueva@unb.br

Alberto J. Álvares
Universidade de Brasília Departamento de Engenharia Mecânica e Mecatrônica, Grupo de Automação e Controle (GRACO), CEP 70910-900, Brasília, DF.
alvares@AlvaresTech.com

Abstract. *The purpose of this work is to present the modeling and implementation of a Flexible Manufacturing Cell (FMC). The modeling consists in to analyze the main aspects related to the decision maker evaluating the behavior of the system over different conditions. Afterward is described the implementation strategically subdivided by two phases: physical and logical integration. The first one consist in to establish the physics conditions necessaries for initializing the production in the shop floor and the second presents the Management Unit of the FMC and the AGV programming. Such as the last subject is presented a description of the integration and communication structure of the cell describing the hierarchical levels and the protocol communication are used.*

Keywords*: Flexible manufacturing system, (FMS), Flexible manufacturing cell (FMC), CIM.*

1. Introduction

The changes brought by the current global context of the economy, influenced in a decisive way the scenery of the industrial organizations. With a productive system just gone back to the mass production, the industries that until then worried about producing a limited variety of products in large quantities are now facing a new reality imposed by the globalization and competition growth.

In this new context there are three goals to be accomplished by the efficient manufacturing systems: flexibility, reducing cost and increasing the diversity of products. This limits a lot the use of production models based in transfer lines, because this production model does not offer flexibility to produce a variety of products. Therefore, the Flexible Manufacturing Systems (FMS) appear as a new alternative to accomplish these goals using the integration techniques proposed by CIM systems.

A flexible manufacturing system (FMS) is a highly automated GT (Group Technology) machine cell; the cell is a group of processing resources (PLC, NC machines), interconnected by means of an automated material handling (AGV, robots) and storage system, and controlled by a control system (Groove, 2003).

The implementation of the flexible manufacturing cell requires an initial work of modeling, in the sense of to analyze the main aspects related for getting decisions evaluating the behavior of the system in different conditions. Here are described two applications where are utilized in the modeling to define important specifications that will contribute for the implementation of the FMC. The first one, through of a virtual simulation of the workstations operating, is utilized to define the physics layout of the workstations availing the trajectory and movement of the transport and handling unit (manipulator) as well as the Nomad trajectory described working as a AGV, enabling to identify the possible collisions routes.

The second part is used a modeling technical of discrete events (specifically Petri Nets). Petri Nets (Girault, 2002) indicates the workstations state according with the fired transition, showed which of the messages must be changed among the workstations for guarantee the shop floor controller and to avoid the undesirables deadlock (manipulator could be put the part on the turning center with the closed door).

The implementation was strategically divided in two phases: physical and logical integration. The physical integration consists in to establish the physics conditions necessaries for initializing the production in the shop floor, positioning workstations to define the cell layout, connecting the shop floor controllers through the communication and monitoring interfaces, designing and building a claw, a positioning unit for the transport and handling unit and a pallet for storing the blanks and the finished parts. Afterward the logical integration is presented discussing about the development of the Management Unit to the FMC and the AGV programming. Such as the last subject in discussion are presented a description of the hierarchical and the communication structure of the cell showing the hierarchical levels and the communication protocol used for each workstation.

2. Flexible Manufacturing Cell (FMC) Description

The FMC consists of a CNC Turning Center Romi Galaxy 15M (CNC FANUC) responsible for cell machining operation; a transport and handling unit (ASEA IRB6 L2E robot) that handles the parts for the different workstations utilizing a gripper with three controlled positions, through sensor connected in the robot PLC -24V I/O; a blank and a finished storage pallet; an inspection unit (laser micrometer Mitutoyo LM6100) that inspects the machining surfaces and verifies if the dimensions measured agree with the dimensions specified in the project (classifying the parts); an AGV robot (Nomad XR4000) that handles parts and tools and a Management Unit (MgU) that controls, coordinates and manages the resources and the activities in the cell. The illustration 1 shows the main workstations of the FMC. Besides these units also has been implemented a video system for monitoring the FMC as well as the audio monitoring for achieved an optimal teleoperation of FMC.

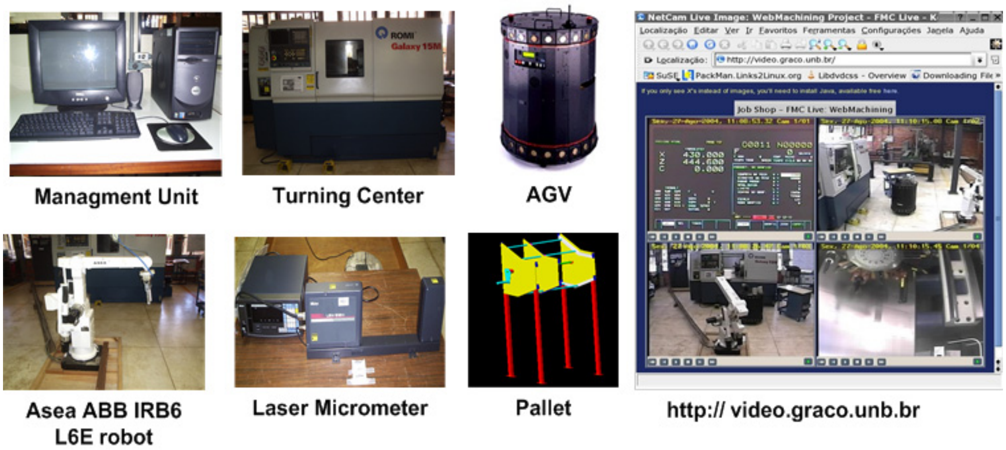

Figure 1. A flexible manufacturing cell

3. FMC Modeling

There’re many modeling techniques and each one of them is destined for a specific application. Yang (1999) utilized a model that works with object oriented techniques for developing a controller model for a shop floor. Feng (1999) utilized the IDEFO methods (functional model) and UML (Unified Modeling Language) for modeling a planning system of conceptual process with a project system attended by computer. Lee (2004) works Petri Nets for analyzed the cyclic escalated with the intention to determinate the time of optimal cycle that minimize the process work.

There’re several aspects that can be related with modeling techniques. The aim of the modeling techniques utilization is to analyze the main aspects that define the system. About these points of view are described two applications where the modeling is fundamental for defining FMC implementation aspects.

3.1 Positioning of the workstations and analysis of interference among the units

To define a physical disposition of the workstations are necessary to evaluate the manipulation and transport unit movement, as well as the trajectory described for the Nomad XR4000 working as AGV. Utilizing a modeling tool was possible, through simulations, to define a position of each workstation that it must to assume in the cell layout and to identify the possible paths and coalitions. Figure 2 shows the FMC simulation modeling in workspace software.

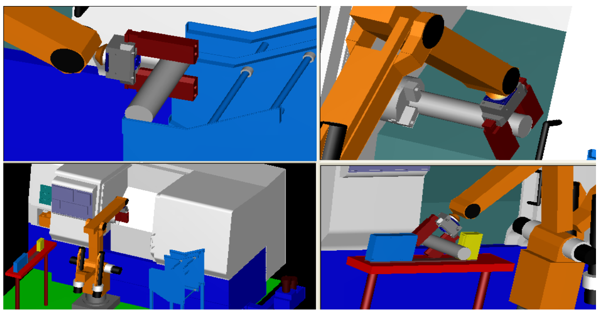

Figure 2. FMC modelling aspects (Workspace, 2005).

This simulation resulted in the identification of the following aspects: positioning of the transport and handling unit to 1000mm of the Turning Center and 380mm of the floor as well as the AGV works area. Specifically the positioning of the manipulator in the established coordinates is very important for the positioning of the parts in the chuckguard. However to assist this specification blocks the access to the station tool turret impeding the setup operation. Therefore the solution adopted to resolve this problem is to build a manipulation position unit.

4. Discrete Events modeling utilized Petri Nets

The Petri Nets generally are utilized in all project and operations aspects in flexible manufacturing systems such as: modeling and verification, performance analyze, schedule, control and supervision (Girault, 2003); besides being a simples modeling tool of parts flow of a manufacturing system it represents the ordered execution of the individual operations (Rembold et al. 1993). A Petri Net is defined by a triple function (Girault, 2003):

$$N = (P, T, \Pr e, Post)$$

Where :
P is a finite set (the set of places of N);
T is a finite set (the set of transitions of N);
$\Pr e, Post \in \mathrm{IN}^{|P| \times |T|}$ are matrices (the backward and forward incidente matrizes of N ($N = Post - \Pr e$)).

The main elements (places, transitions, arcs and tokens) of the Petri Nets possess different meanings when the FMC is been modeling:

- Places: Represent diferents elements as the part state that is been processing, a resort state, etc.
- Transitions: Modelling the event sequences in the systems that modifie the states of some elements (places)
- Arcs: Show the parts flow between the resources.
- Tokens: They are utilized for representing the disponibility of resources.

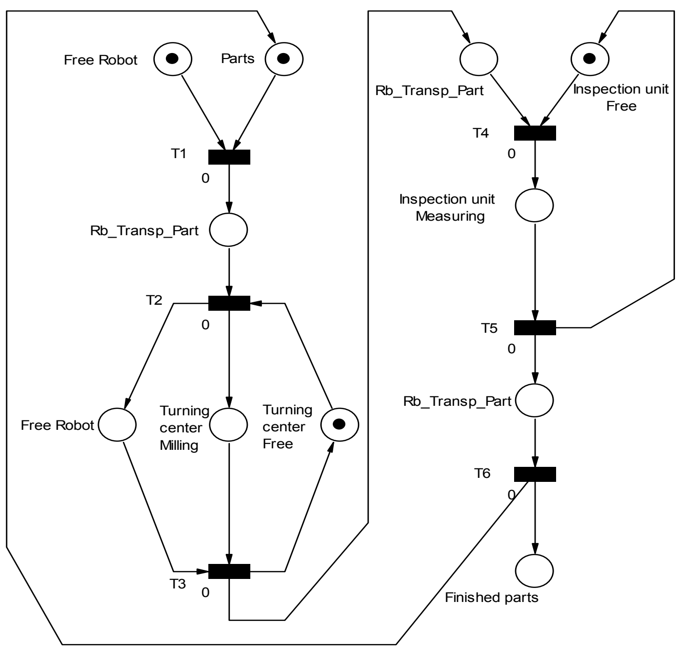

Figure 3. The Petri Net simplified of the FMC.

The figure 3, presents the Petri Net simplified of the FMC. The tokens on the free robot, free CNC (turning center) and free micrometer reveal the necessity of guarantying the availability of these resources when the production is initialized. This availability must be guarantying through the unit manager that is the manager software of the FMC activities when the workstations are initialized.

When the transition T2 is fired the manipulator that was in the part transport state, places it inside turning center for starting the manufacturing (only if turning center was free) passing for the condition of free manipulator. Finishing the manufacturing process, in the case of the manipulator still is in the free condition, the transition T3 can be activated and the manipulator would return to transport the part (getting the free condition) and the turning center passes to assume the free condition again.

For discrete events systems (specifically the control in the shop floor) the transition T2, that initializes the manufacturing process, only can be fired if the manipulator controller sends a message of the turning center confirming the presence of a token in the free CNC place. Using the same idea, the manipulator only carries out the part of the turning center if to receive the confirmation that the manufacturing process was finished. This is very important for guarantying synchronize among the activities and avoiding collisions among the workstations.

The aim of the Petri Nets analysis is to indicate the state of the resources according as the fired transition. This demonstrates which the messages must be changed among the workstations for guarantying the control in the shop floor and to avoid the undesired deadlock (manipulator puts the part with turning center door closed). The map the states achieved with the respective transitions is used for developing the discrete events controller of the Management Unit.

5. Physics Integration

To integrate physically the cell consists in to offer the physical conditions (hardware) necessary for initiating the production in the shop floor. For achieving that is required of the following activities should have executed:

- Establish the cell layout and to positioning the workstations;
- Connecting the stations controllers through the interface communication;
- Connecting the monitoring interface to the workstations controllers;
- Designing and building a positioning for the manipulator;
- Designing and building a gripper for the manipulator;
- Designing and building a parts store (pallet)

Among the established activities, the communication and monitoring interfaces will be presented more specifically, because it is the best important topic of the physical integration.

5.1 The communication and the monitoring interfaces

Lopes (2000), quotes that the most important step for the integration is to connect the machines in the communication net. This will permit the communication between each machine and the extern system obtaining as a result a possibility of to control the machines remotely as well as the information change. This work is the biggest challenge for many researches because of the diversity of the machines and the lack of standard protocols communication

This difficult studied for many researches also influenced in the form to connect the workstations controllers. The limitations imposed by the transport and handling unit resulted in the development of interfaces with the manufacturer of the Turning center (Romi).

The RB-CNC interface connects the manipulator control to the Turning center controller (specifically the PLC) guarantee the change of messages between them. Before putting the part inside turning center, for example, the manipulator verifies the condition of free CNC (chuckguard open, door open, etc). If this condition complies, a message is sending to the manipulator controler ordering to put a blanck part in the chuckguard of the turning center.

For monitoring the cell, the management unit is provided of the monitoring interface connected to the workstations controllers. As the signs of the communication interfaces do not obey to the standard TTL, the monitoring interface has as main goal to guarantee the conversion of these signs in levels TTL for will be read by the management unit server.

6. The logical integration

The logical integration as well as the physic integration, has as a purpose to develop the logic components (software) necessary using to initialize the production in the shop floor. This requires the development of programs for the transport and handling transport unit, the development of the management unit and the development of the AGV navigation system for interacting in the workstations through of an established path.

-

6.1 AGV (Nomad XR4000)

The main functions of XR4000 in the FMC are: 1) Robot navigation through line recognition and landmarks drawn in the shop floor, defining a trajectory of the Nomad as well as its localization during the navigation, 2) Storing of the finished parts through of a "pallet" it placed on top of the robot divided in three spaces that storage the part according it the classification. (Problem: weight limitation), 3) "Material Handling", receiving the pick up and to transport tools during the "setup" the machine and its maintenance and 4) The Nomad XR4000 interact directly with the manager cell.

Figure 5 shows the landmarks that they are represented the main points that the robot should recognize for its localization. These points are point 1 (start functions point) point 2 (zone of discharge of the part manufactured), point 3 (middle point of nomad navigation) and point 4 (zone of charge of the part manufactured) (Beccari, 1997). The landmarks utilized in this work were selected as the best landmarks for its use in tasks such as a precise positioning of AGV or mobile robots in front of loading / unloading (Amat, 2001).

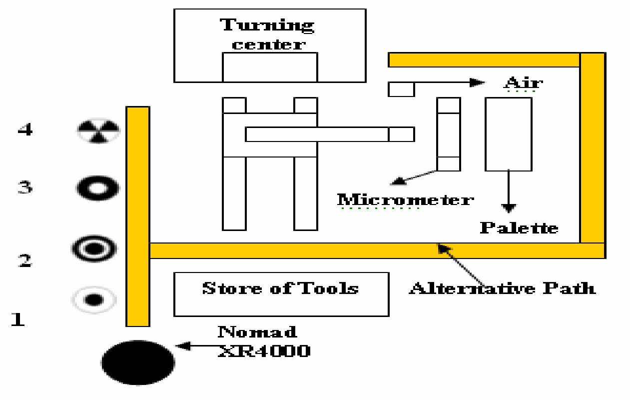

Figure 5. AGV working environment.

6.2. An description of Management Unit

According to Groover (2004) the shop floor control is concerned with the release of production orders to the factory, monitoring and controlling the progress of the orders through the various work centers, and adquiring informações on the status of the orders. This activities should be established by submodules below:

- Scheduler ;
- Dispatcher;
- Monitor.

Scheduler

It receives the production programming and join the necessary information to establish the production and inspection plan. The production planning selects the amont of batches and parts that should be compounded each batch mattering of a common database the necessary information generated by CAD/CAPP/CAM system. When the number of batches and parts were established the production sequencing should be executed. The sequencing consist in to define a sequence method (manual or automatic) and results at the a batch's and workorder's sequence presented in a gantt graphic. The inspection planning complements the Scheduler when establishing the necessary attributes to execute the inspection of the parts. Each surface that will be inspected possesses a program that stores the information used to initialize the inspection unit.

Dispatcher

It initializate the wokstations allocating the jobs and executing the real time control. The machine's setup is done by means dispatching functions that initialize the workstations (loading of the tools list, programs NC list and inspection plan) allowing the start of production (if the setup of all machines were confirmed).When the production is started the remote control is started too. This activity consists in to compare the states received of shop floor with the ideal states previously registered in the database. The presence of an abnormal condition (machine and tools breakdown, power failure) verified by Monitor module initialize the emergency immediately, this, in turn, identify the error and then it researches in the database the possible solutions and reports the control action that must be executed to the workstation, notifying eventual alteration of production and inspection plans to the Scheduler. In the impossibility of treating the identified abnormal condition, a message is sent to the operation notifying the need for human intervention.

Monitor

It accomplish the monitoring and the progress of the workorders in each workstations. This implies in monitoring the activities (events's monitor, virtual monitor and real time monitor) analysing the production system efficiency (quality control) accompanied of the emission of reports. The events monitoring identifies the event (for example, the transport and and handling unit put the parts in the Turning center to be machined) and refreshes the dadatabe; the virtual monitor shows the workstations operating virtually and the real time monitor shows, through of the internet, the images of the four cameras strategically intalled in the cell (theses can be visualized by URL: video.alvarestech.com). This is extremally important to the remote controll of the activities.

The quality control loads the production indicators (processing time, counter parts, counter finished parts, etc) to demonstrate production system efficiency. The reports consists in reporting the productions and inspections aspects investigated (processing time, counter parts, counter finished parts, etc) shows the resuls of the activities ocurring on the shop floor.

7. FMC integration and communication structure

The CIM concepts is that all of the firm's operation related to production are incorporated in an integrated computer system, the output of one activity serves as the input to the next activity, through the chain of events that stars with the sales order and culminates with the shipment of the product (Groover, 2003). The FMC possess an integraded information enviroment (commom database) based on the concepts the CIM philosofy and in the e-manufacturing tecnology.

The figure 6 illustrates the hierarchical FMC structure; the activities will be started when the customer order is registered on the site: http://www.webfmc.com.br/. This order should have the basic informations such as: due date, counter parts, etc, afterward used by the other hierarchical levels, especifically by product design department and the production department.

The product design, through of the system based in the Webmachining methodology (CAD/CAPP/CAM system – http://webmachining.alvarestech.com/) starts the product project and finish with the process plan (PP) (Álvares, 2005) and the production engineering, through of the CAPP system, convert the customs orders in workorders that will be attrached to the Master Scheduler Planning (MSP). The MSP and the PP serve as the input information of the Management Unit.

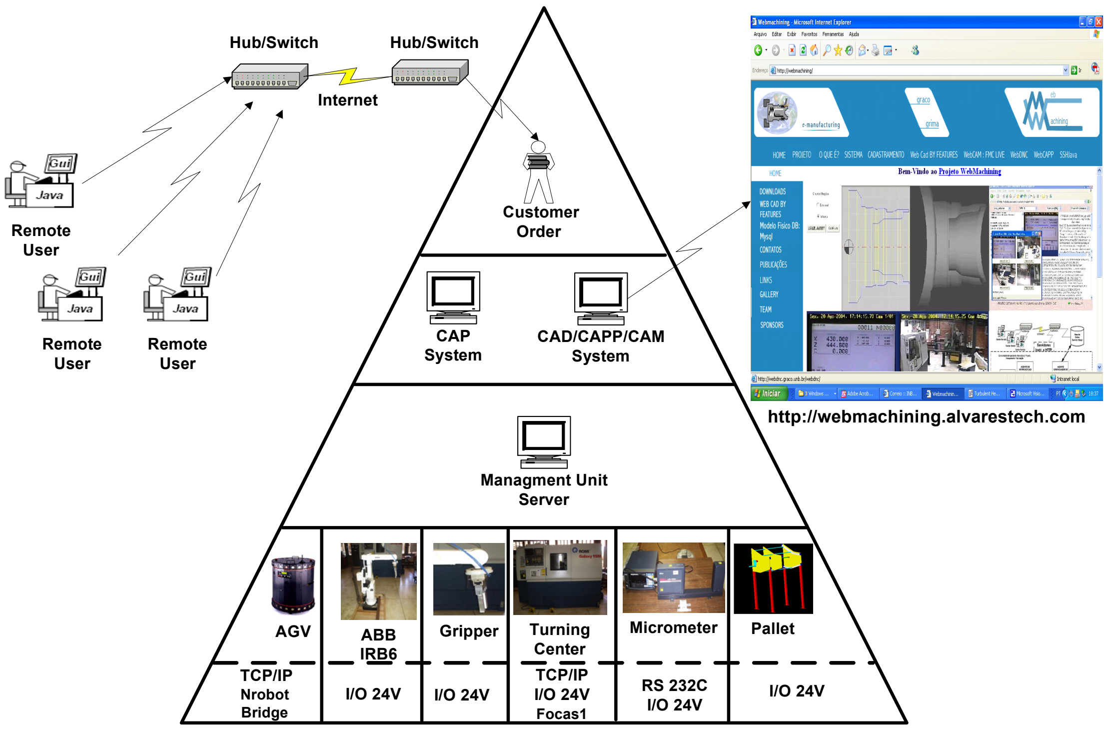

Figure 6. The hierarchical structure of FMC

To allow the communication between the workstations and an external system results in the possibility of remotely controlling the machines, as well as the exchange of data. However, this work has been a great challenge to many researchers because of the diversity of the machines and the lack of a communication protocol standard which can be verified in all the hierarchical level, so much in the shop floor controller as in the Management Unit activities control.

Figure 7 shows the cell communication structure. The focas1 technology is used to establish the communication between the MgU and the Turning Center; the focas1 (Fanuc Open API Specification version 1) programming libraries provide communication and programmable access to PC-base CNC. These programming libraries provide over 300 functions calls which can be used by Microsoft Visual C++ or Visual Basic to develop custom applications (GEFanuc, 2005).

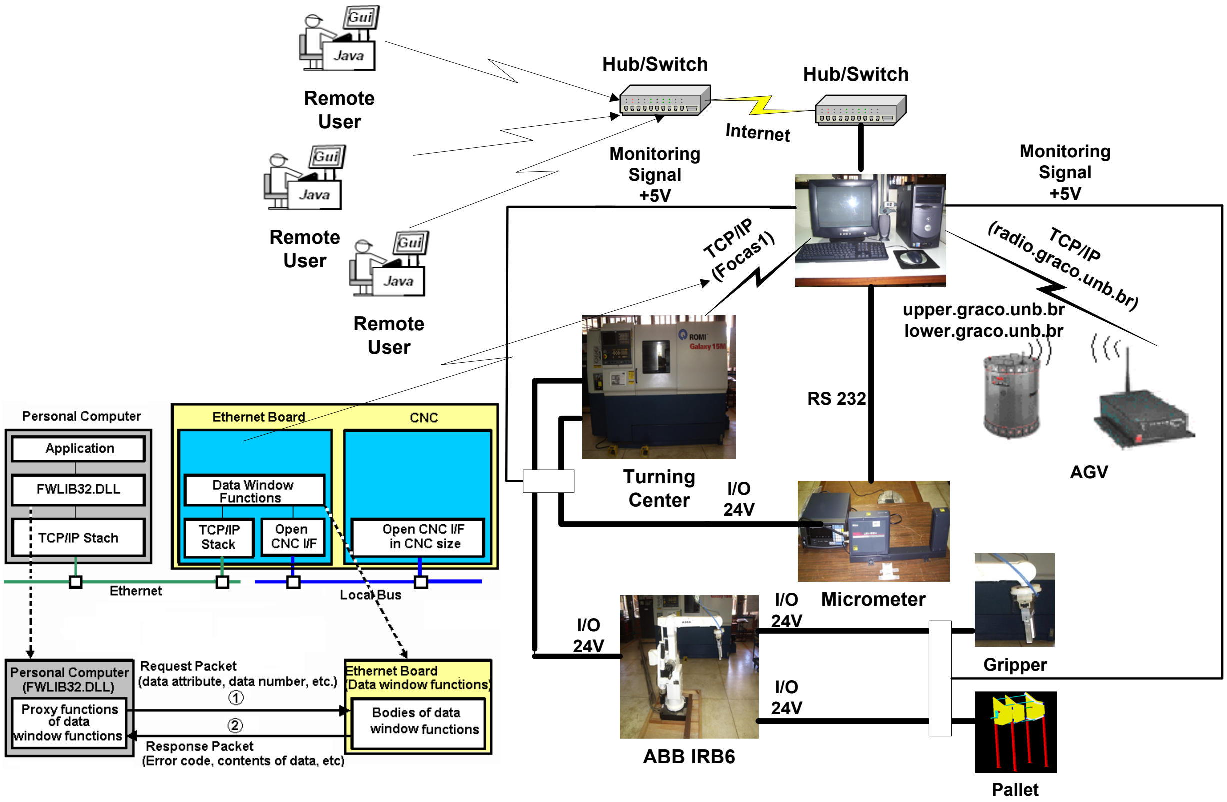

Figure 7. The Cell Communication Structure.

The Radio Ethernet System allows communication with the robot without using an Ethernet cable. The user can use standard network utilities and mechanisms (e.g., ftp, telnet, TCP/IP sockets) as if the robot were another workstation on the network (Nomadic Technologies, 1999). To establish the communication with the robot using radio Ethernet is necessary to have the Access Point Bridge installed in the network.

In reference to the software features, the Nomad XR4000 operating system is Linux, and the daemon Nrobot, it is the software which is "talking" with the hardware. The Nomad has a library (Nhost_client.a) for working with it and giving the opportunity to access the structures, using the sensors, moving, etc. This library is linked with the user program and it is the one who is "talking" with the daemon.

The change of message between the MgU and the inspection unit is established by mean the RS232 protocol and the communication between the transport and handling unit is done indirectly by the CNC-Robot interface thought of signal changes.

8. Conclusions

The aim of this work is to present the modeling and implementation of a Flexible Manufacturing Cell (FMC). The FMC consists of a CNC Turning Center Romi Galaxy 12M (CNC FANUC), an transport and handling unit (ASEA IRB6 L2E robot), a blank and a finished storage pallet, an inspection unit (laser micrometer Mitutoyo LM6100), an AGV robot (Nomad X-R4000) and a Management Unit (MgU) that controls, coordinates and manages the resources and the activities in the cell.

The using of the modeling analyze the main aspects related a decision make to the available the comportment of workstations over different conditions. Therefore are describes two applications in which the modeling is very important to define important specifications necessary to implementation of FMC.

The first model analyze the movement of the transport and handling unit as well as the path used by AGV; by means simulations were defined the position that each workstation must be assumer on the cell layout and identified the possible collision paths.

Afterward the second model was used to identify the reachable states according to the fired transition; this is important to shows what the messages will be change among the workstations to guarantee the shop floor control avoiding the undesirable deadlock. The loading of reachable states is used too for the development of Management Unit controller; software used to control, coordinate and manages the resources of the cell.

The FMC implementation is subdivided in two stages: physical integration and logical integration. The physical integration is related to offer the physical conditions (hardware) necessary for begin the shop floor production, the cell layout (positions of workstation), connecting the workstations controller using the communication and monitoring interfaces, designing and building a gripper and a position unit for the transport and handling unit and a pallet.

The logical integration describes the Management Unit and its main modules and some aspects related with the AGV programmer. As the last subject treatment is discussed the communication structure among the management unit and the workstations shows the protocol communications used. The development of these works could be visualized on the sites: FMC project (http://webfmc.graco.unb.br), Webmachining methodology (http://webmachining.alvarestech.com)

9. References

Álvares, A. J. and Ferreira, J. C. E. WebMachining: Implementation of a Collaborative CAD/CAPP/CAM System for E-Manufacturing through the Internet. In: The 38th CIRP - International Seminar on Manufacturing Systems, 2005, Florianópolis-SC. The 38th CIRP - International Seminar on Manufacturing Systems, 2005

Amat, J., Aranda, J., Casals, A., Fernández, X., 2001, “Optimal Landmark for Precise Mobile Robots Dead-Reckoning”, IEEE International Conference on Robotics and Automation, Seoul, Korea.

Beccari, S. Casseli, F.Zanichelli, A.Calafiore, 1997, “Vision-based Line Tracking and Navigation in Structured Environments” Dipartimento di Ingegneria dell’Informazione University of Parma – Italy

Diltis, D. AndBoyd, N. And Whorms, H., 1991, “The evolution of control architectures for automated manufacturing systems”, in Journal of Manufacturing System Soviero, P.A.O.

Lavagna, L.G.M., 1997, “A Numerical Model for Thin Airfoils in Unsteady Motion”, Vol. 10 nº 1, pp 63-79.

Feng, S.C., and Song, E. Y.,1999, “Information Modeling of Conceptual Process Planning Integrated with Conceptual Design” Manufacturing Engineering Laboratory, National Institute of Standards and Technology Gaithersburg.

Girault, C., and Valk, R., 2002, “Petri nets for systems engineering – a guide to modeling, verification, and applications”. Ed. Springer.

Groover, M. P., 2003, “Automation, Production Systems, and Computer-Integrated manufacturing”, Second edition. Ed. Prentice Hall.

Kals, H.J.J., and Hounter, F.J.A.M, and Tiemersma, J.J. “CIM in small batch part manufacturing” Laboratory of production engineering, University of Twenty.

Lee, J., and Korbaa, O., 2004, “Modeling and scheduling of ration-driven FMS using unfolding time Petri nets”. Computers & Industrial Engineering.

Leitão, P. Quintas, A., “A cell controller architecture solution: description and analysis of performance and cost.” Faculty of Engineering. University of Porto, Rua dos Bragas, 4099 Porto Codex

Lopes, J.R, Leitão, P.J, Machado, J.M, A manufacturing Cell integration Solution. 2000

Nomadic Technologies, “Nomad XR4000 Hardware Manual Release 1.0”, California, USA, 1999.

Nomadic Technologies, “Nomad XR4000 Software Manual Release 1.0”, California, USA, 1999.

Rembold, U., B.O. Nnaji, B.O., 1993,”Computer Integrated Manufacturing and Engineering”, Addison-Wesley.

Restivo, F., and Leitão, P. A. “Layered Approach to distributed Manufacturing”, Faculty of Engineering. Unisersity of Porto, Rua dos Bragas, 4099 Porto Codex.

Workspace, 2005. http://www.workspace5.com/

Yang, C. O., and Guan, T. Y., and Lin, J.S., 1999, “Developing a computer shop floor control model for a CIM system — using object modeling technique”, Department of Industrial Management, National Taiwan University of Science and Technology, 43, Keelung Road, Section 4.

10. Responsibility notice

The authors are the only responsible for the printed material included in this paper.