FROM E-MANUFACTURING TO INTERNET PRODUCT PROCESS DEVELOPMENT (IPPD) THROUGH REMOTE - LABS

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Abstract. This paper presents the research developed at Universidad Nacional de Colombia about the e-Manufacturing platform that is being developed and implemented at LabFabEx (acronym in Spanish as "Laboratorio Fabrica Experimental"). This platform besides has an approach to virtual-remote labs that have been tested by several students and engineers of different industrial fields. At this paper it is shown the physical and communication experimental platform, the general scope and characteristics of this e-Manufacturing platform and the virtual lab approach. This research project is funded by COLCIENCIAS (Administrative Department of science, technology and innovation in Colombia) and the enterprise IMOCOM S.A.

1. Introduction

Nowadays, technological advantages are important factors for improving competitiveness in almost every economic activity in our global society [8]. Among these economical activities, Manufacturing has been one of the most affected by those new technological advances [4] such as communication technologies, software engineering, algorithms applied to manufacturing, virtual realities, web services and web presentation technologies. e-Manufacturing is becoming the new concept that is currently being applied in today's industrialized world [1]. This is the main reason why At LabFabEx (in Spanish as "Laboratorio Fabrica Experimental" and in English as Experimental Fabric laboratory) in Universidad Nacional de Colombia at the Cam-Mechatronics room Lab, an e-Manufacturing Platform is being developed and implemented. This platform has industrial and experimental machines that are grouped in three manufacturing cells, a communication platform (routers, servers, web cams) and software that supports and manages the information system for centralization of information and for remote operation of these machines.

This platform will provide several facilities regarding to:

- Centralize and synchronize machine performance process information.
- The final user will be able to set machine parameters. This configuration process will be provided through web-services.
- Remote operation of machines, through web VMM[1] interfaces from which the final user can develop product processes.
- Support and implement a collaborative robotic network for performing flexible manufacturing processes.

Experimental tests have been performed with the academic field (professors and students) and with the industrial field (industrial managers and engineers). Although this platform is currently being developed, these tests have shown advantages about remote operation. In fact, the virtual environments or VMM (virtual manufacturing machines) are components that eases the way for operate remotely these machines. The e-Manufacturing platform has been successfully tested through Internet from different parts of the world such as Colombia, Germany, France, Mexico and USA.

LabFabEx project will impact Colombian enterprises by making research about their industrial process and academic and teaching activities by allowing virtual remote laboratories through Internet. LabFabEx is part of the project RC-723 “FITTING OUT AN EXPERIMENTAL FABRIC LABORATORY (LabFabEx) BASED ON E-MANUFACTURING TECHNOLOGY FOR INTEGRATED DEVELOPMENT OF PRODUCTS AND PROCESS AND ITS TRANSFERENCE TO THE PRODUCTIVE SECTOR”. COLCIENCIAS, IMOCOM S.A and Universidad Nacional de Colombia have funded this project.

2. LabFabEx (Experimental Factory Laboratory)

LabFabEx, (for its acronym in Spanish “Laboratorio Fabrica Experimental”) has several industrial and experimental manufacturing machines and equipment. These machines are grouped into three manufacturing cells. The first one contains 6 industrial machines and it is named the Industrial Manufacturing Cell (IMC). The second one has 5 experimental manufacturing machines so that it is named the Experimental Manufacturing Cell (EMC). This EMC’s machines have been designed and developed at Universidad Nacional de Colombia by the Mechanics and Mechatronics Department. The rapid prototyping cell has one industrial 3d printing Machine, one experimental 3D printing machine and one experimental parallel kinematic robot (Orthoglide) for CNC machining. There are two experimental AGVs (Automatic Guided Vehicle) that are being developed at the lab. These two vehicles will interconnect physically all the machines at the laboratory (IMC’s machines, EMC’s machines and rapid prototyping cell’s machines) for several types of industrial processes. Figure 1 shows the IMC and Figure 2 shows the EMC. Besides, this e-manufacturing platform will be able to integrate another experimental and industrial machines.

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[1] VMM (Virtual Manufacturing Machine) refers to a virtual 3D environment that represents the geometric features of the real machine at the lab.

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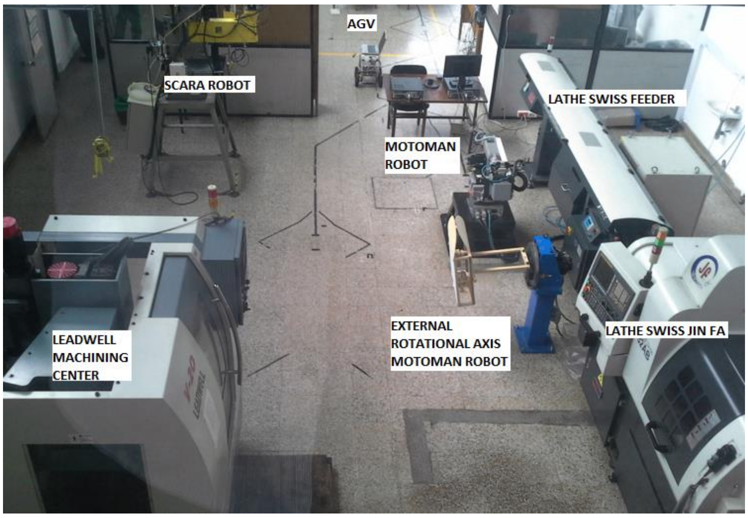

Figure 1. *Industrial Manufacturing Cell's Machines and their physical disposition. Universidad Nacional de Colombia. Mechanics and Mechatronics Department. Cam-Mechatronics room Lab*

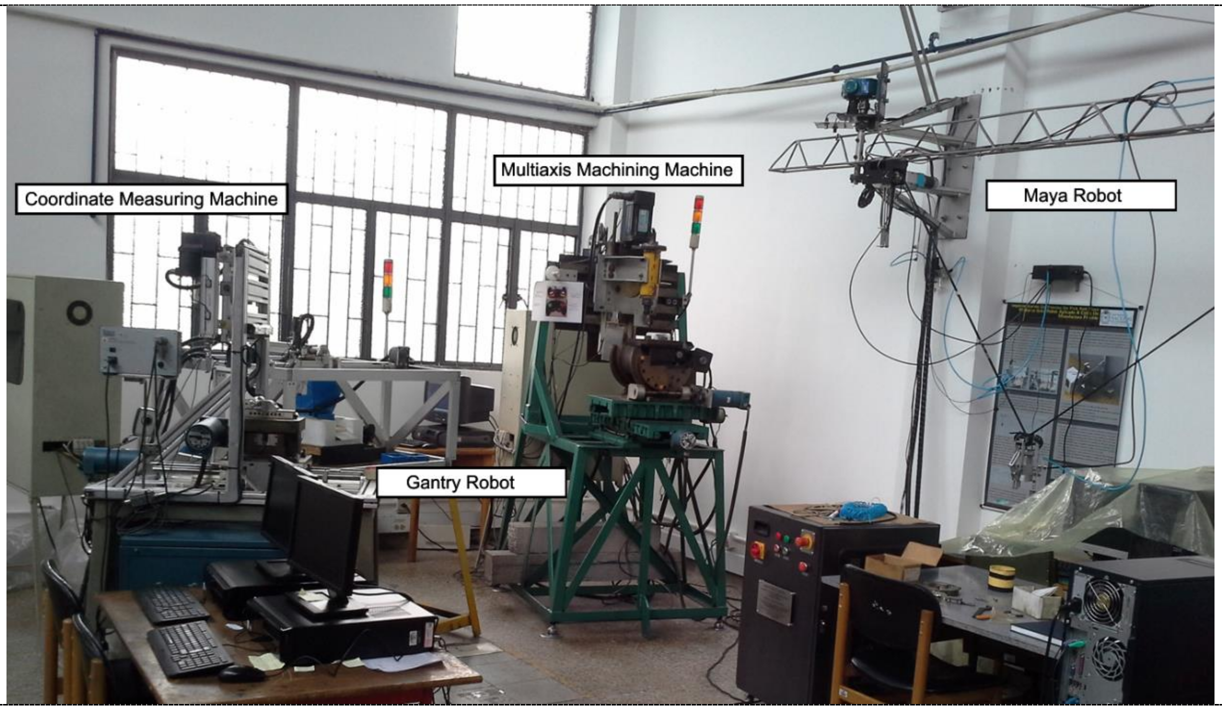

Figure 2. *Experimental Manufacturing Cell's Machines and their physical disposition. Universidad Nacional de Colombia. Mechanics and Mechatronics Department. Cam-Mechatronics room Lab*

The Industrial Manufacturing Cell's machines are listed below:

1. Motoman Robot MH6-DX100: 6 degrees of freedom and one external rotational axis and one external linear axis.
2. Leadwell v20 Machining center: This is a CNC machine that has four axes.
3. Scara Robot: This robot has four DOF and its main function is to pick and place.
4. Lathe Swiss Jin Fa. This machine has seven degrees of freedom (JSL SERIE 32AB)
5. AGV mobile robot: Automatic Guided Vehicle.

6. Presetting machine Zoller smile 400.

The Experimental Manufacturing Cell's machines are listed below:

1. Maya crane Robot: pick and place material around the Experimental Manufacturing Cell.
2. Gantry parallel Robot: three degrees of freedom.
3. Multi Axis Machining Machine: 5 degrees of freedom
4. AGV mobile robot: Automatic Guided Vehicle.
5. Coordinate Measuring Machine (CMM): four degrees of freedom.

3. Experimental Communication Platform

The Communication Platform of LabFabEx has the structure shown in the figure 3. This platform integrates each machine at the lab in a common communication infrastructure.

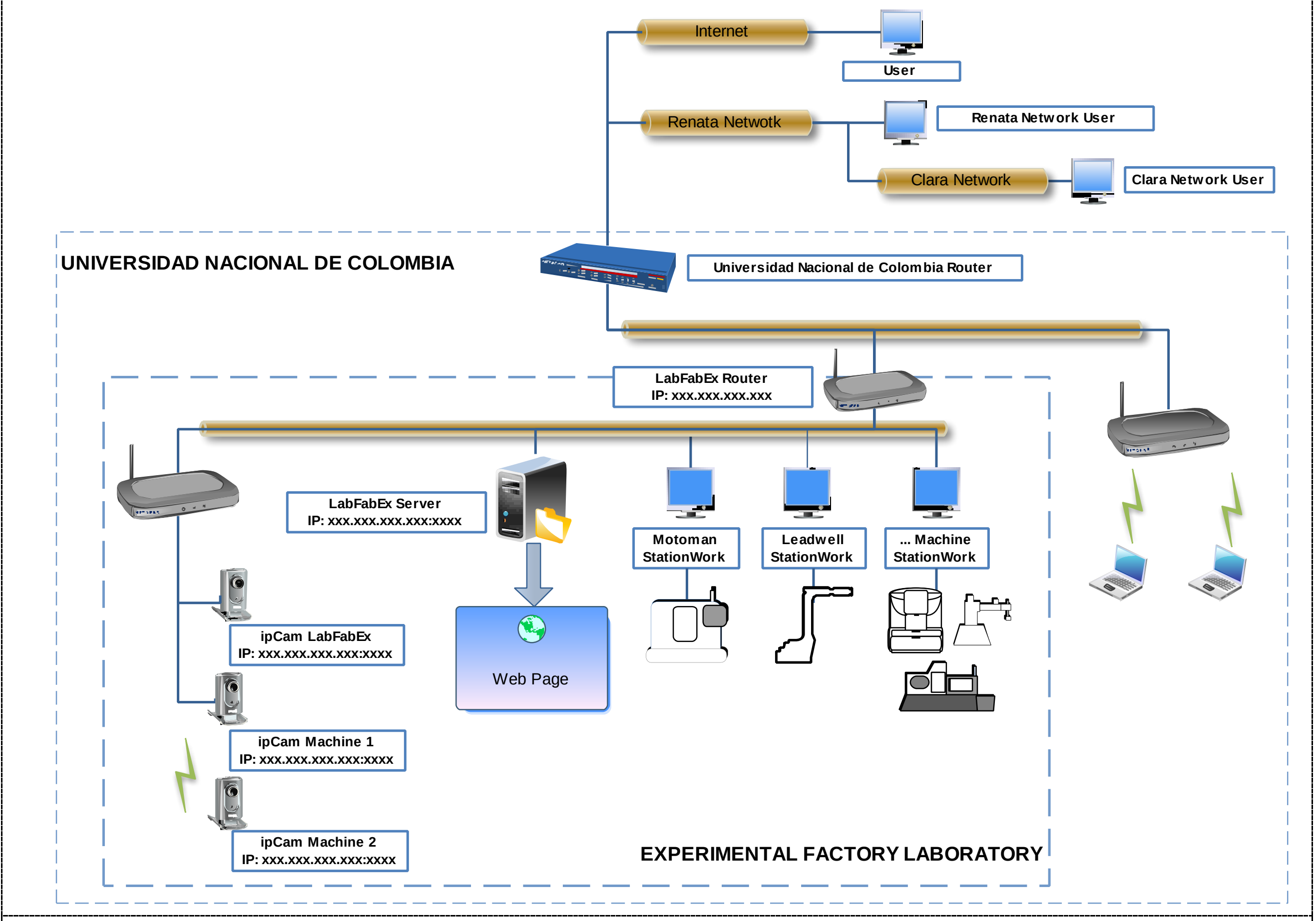

Figure 3. *Experimental Communication Platform at LabFabEx (Experimental Fabric Laboratory). Universidad Nacional de Colombia, Mechanics and Mechatronics Department*. *Cam-Mechatronics room Lab*

4. E-manufacturing platform

e-Manufacturing is a new approach that integrates the manufacturing infrastructure with diverse elements of business systems such as suppliers and customer network systems (refers to [1]). This process of integration is based on synchronization between the transformation system and the business system [1].

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At the Cam-Mechatronics room Lab, at Universidad Nacional de Colombia, there is an e-Manufacturing platform that is under construction. Figure 4 shows the e-manufacturing platform's general architecture scheme with its operation characteristics, the machines located at the lab (and how get access to their controllers) and how the information and interfaces through Internet are presented.

The main idea of this approach is to centralize and synchronize machine performance process information. This information is presented through Internet using graphical computer technologies such as OpenGL (WebGL and processing), Client-Server communication technologies (webSockets, ajax, javaNIO, javaIO) and web presentation technologies (applets, html5, javascript).

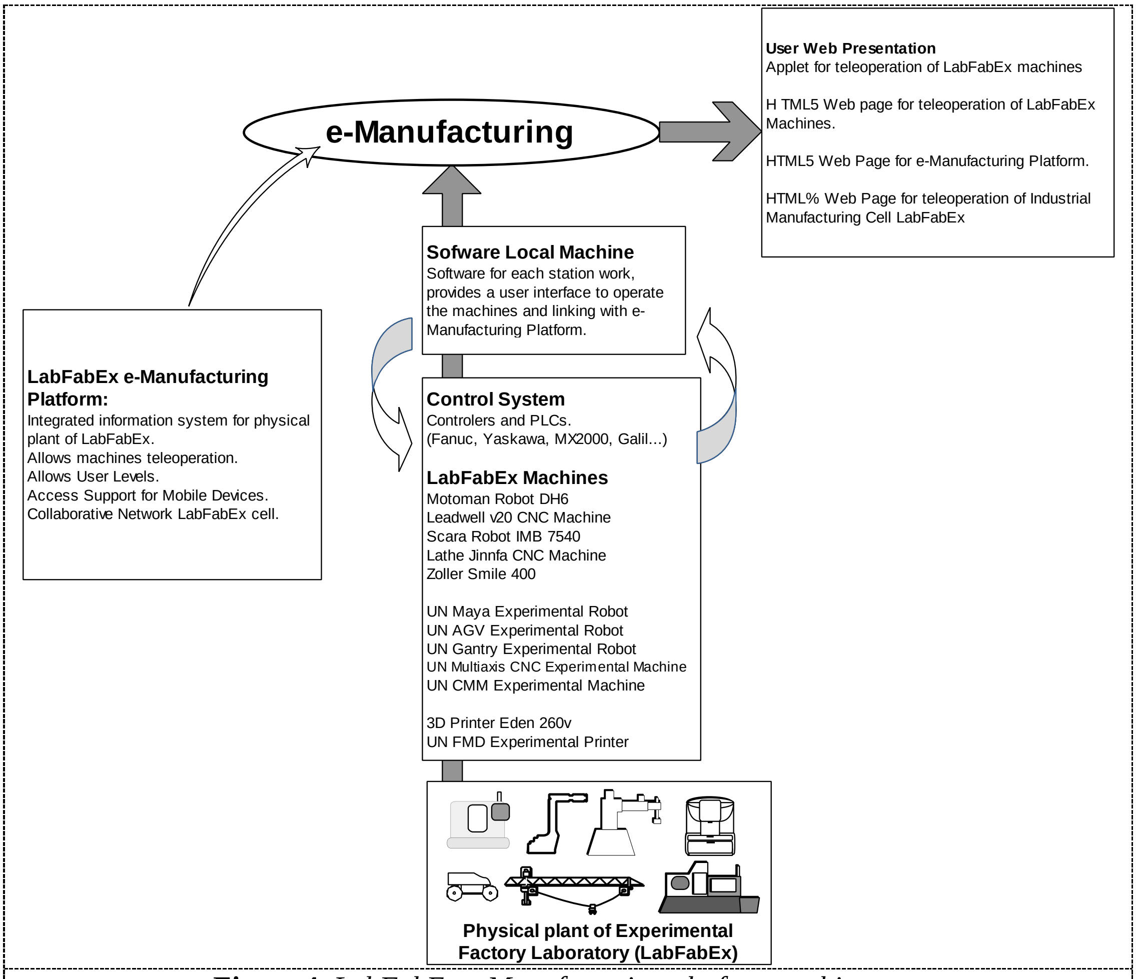

Figure 4. *LabFabEx e-Manufacturing platform architecture*

The virtual lab approach of this platform provides students with technological tools through Internet with which they will be able to access and know how works each machine located at the physical lab.

This e-Manufacturing platform has three modules (see figure 7): 1) Client module for remote access (User Web Presentation), 2) Server module for information management (LabFabEx e-Manufacturing Platform) and 3) station working module for each laboratory's machine (Software local Machine). Each one of these three interdependent modules is designed based on the axiomatic design methodology for software development.

Figure 5 shows the protocols used at each machine for getting communication with the e-manufacturing platform. Machines at LabFabEx have their respective VMM (virtual manufacturing machine that refers to the 3D virtualization of each machine and its environment) and web communication technologies.

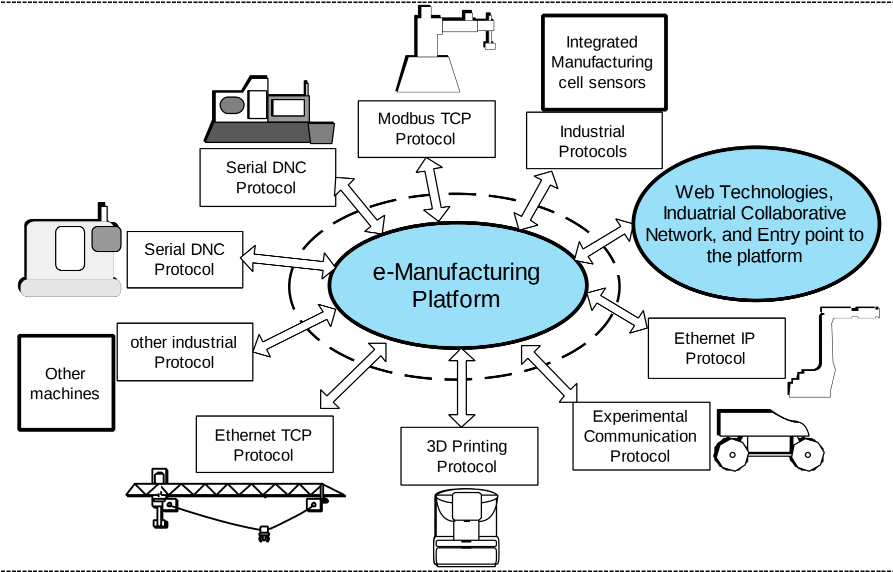

Figure 5. *Protocol used at each machine for getting communication with the e-Manufacturing platform*

The main functions of this e-Manufacturing platform are:

- **Centralize information of each machine:** the current status information of each machine is got, processed and presented to the final user
- **Teleoperation of each machine through internet:** each machine can be teleported through internet, from a typical Computer or from a mobile device (e.g. tablets or smart phones)
- **User access levels:** administrator (Super-user), guest user and operator (see figure 6). Super-User can be Admin User (server Manager that can enable Web Service) or Machine User (Machine manager that can get access to these machines without restrictions). Guest User only had video streaming from the LabFabEx. Operator user has three levels. As beginner user can only move the axis of each machine. As Moderated User can move the axis and send Machine commands. As Advanced User can also load and download Machine programs
- **Industrial collaborative robotic network (ICRN):** The ICRN will integrate three robotic platforms (Motoman Robot, Scara Robot, AGV mobile robot and Maya crane robot) with two machining machines (Leadwell Machining center and Lathe Swiss Jin-Fa) for getting a collaborative robotic network in which automatic industrial processes can be performed (machining, assembly, pick and place and raw material transportation).

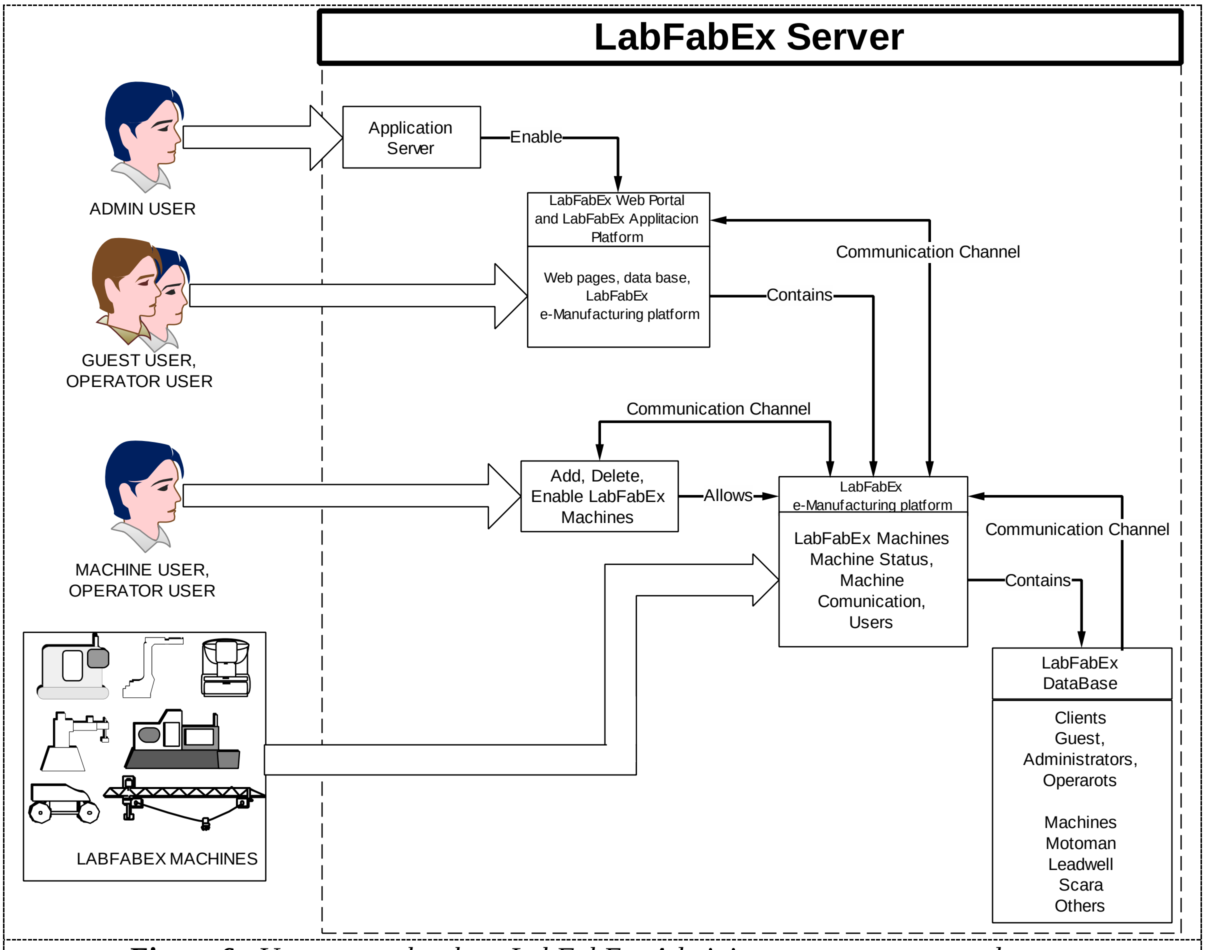

Figure 6. *User access levels at LabFabEx: Administrator, guest user and operator*

The e-Manufacturing platform has three main modules: 1) Client module for remote access; 2) Server module for information management; 3) Work station module for each machine. These three interdependent modules follow the axiomatic design methodology for software development (see figure 7).

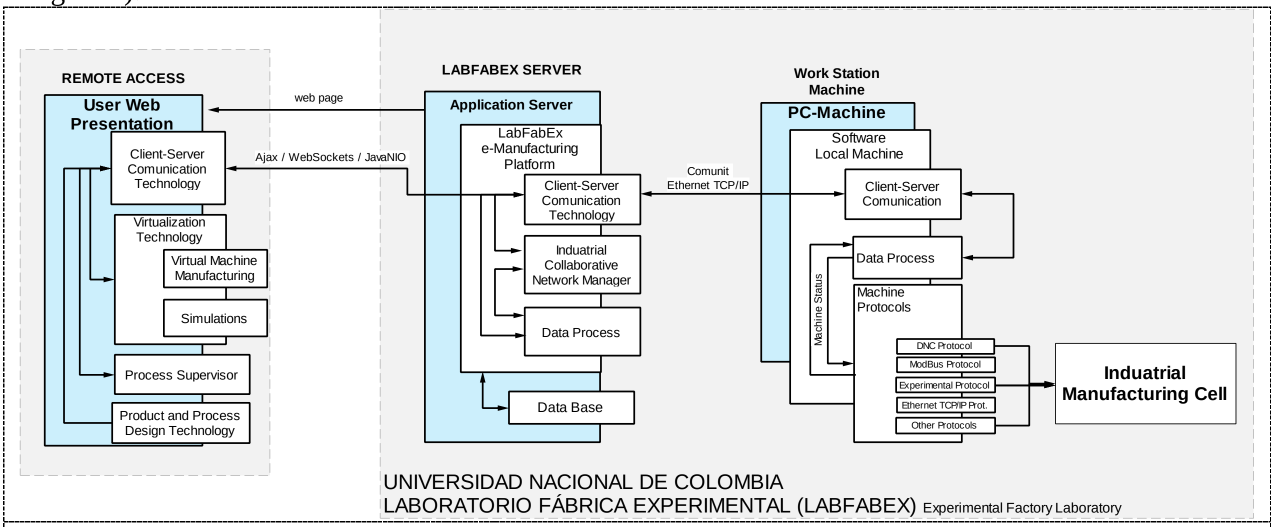

Figure 7. *Methodical diagram. e-Manufacturing platform's modules: 1) Client module for remote access; 2) Server module for information management; 3) Work station module for each machine.*

Through this e-manufacturing platform the final user can develop industrial processes for specific products. The user can operate remotely each machine through the web presentation layer that has several operation features regarding to the industrial process that is going to be perform at the lab

5. Virtual platforms

The physical machines have been mapped to VMM's (Virtual Manufacturing Machine) for developing a virtual laboratory that can be accessed through Internet. Some of these machines belong to the old teleoperation platform (Renata[2] V 1.0) and the other ones have virtual interfaces developed by using new computational graphics technologies. The new interfaces have several features such as programmed task simulations, the VMM (Virtual manufacturing machine), web-chat module for getting an efficient communication between the operator at the lab and the final user, Control panel with commands for teleoperation, Status-Console panel for showing Input/output events. This interface implements APIS of Processing (Programming language for computer graphics), proscene[3], ControlP5 and OBJLoader and manages connection exceptions, data and internal processes.

5.1. Motoman MH6-DX100 Robot

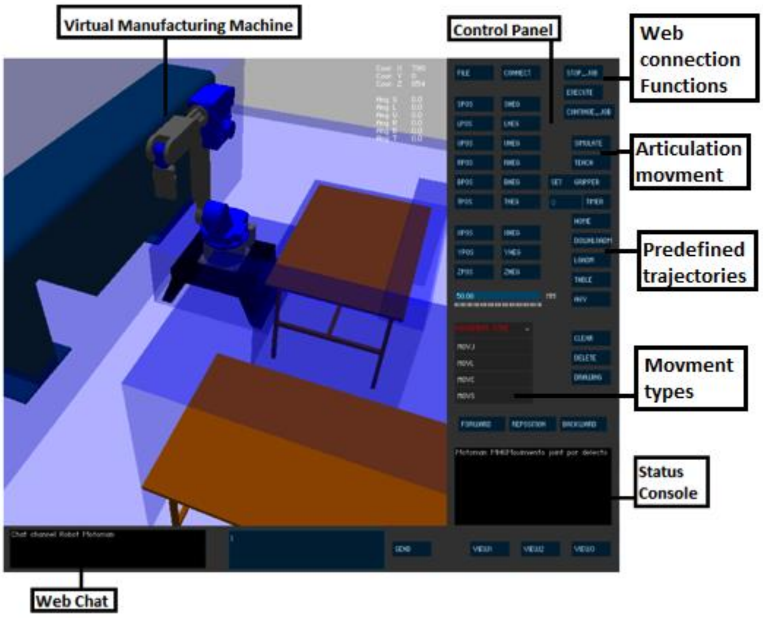

Figure 8. *Virtual interface[4] for operate remotely the Robot Motoman MH6-DX100 trough Internet. This interface shows the virtual environment and its facilities for programming this industrial robot. Universidad Nacional de Colombia. Mechanics and Mechatronics Department. Cam-Mechatronics room Lab*

[2] Renata is the academic network advanced technology in Colombia. Through this technological communication infrastructure, several projects has been developed for getting remote access to the machines at the Cam-Mechatronics room Lab at Universidad Nacional de Colombia. (See [3])

[3] Processing library developed by Prof. Dr. Jean Pierre Charalambos

[4] This virtual interface has been registered in Colombia as "Plataforma virtual para la teleoperación del robot Motoman MH6-DX100 en Internet". Into English it is named "Virtual platform for tele-operating the Motoman Robot MH6-DX100 in internet"

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Figure 8 shows the 3D virtual robot and its environment. This Robot has 8 degrees of freedom (DOF). The first six DOF's refer to the robotic arm (nomenclature: S, L, U, R, B, T) and the last ones are two external axis (one rotational and one linear external axis).

The mathematical modeling (inverse and forward kinematics) has been implemented in order to perform accurate trajectory simulations that can be lineal, circular or spline as it is shown in figure 9. (See [2]).

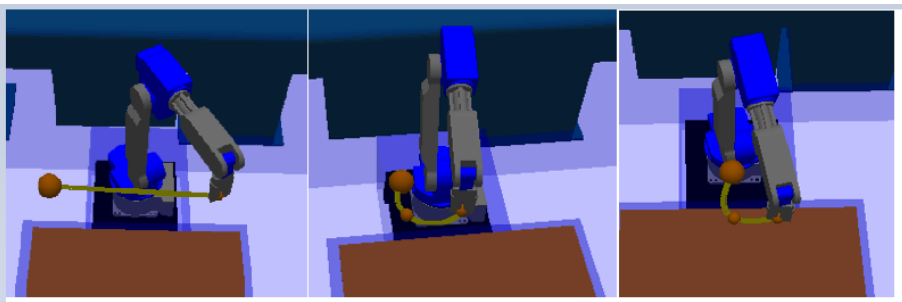

Figure 9. *Trajectory simulations (linear, circular and spline trajectories) based on the mathematical modeling of inverse and forward kinematics of this industrial robotic arm.*

While performing the simulation, if any shock arises, the user must change the trajectory before executing the programed task. If the user does not do that, the 3D virtual interface will not allow the user to execute the trajectory programed. Figure 10 shows a shock between the robot and a security plane.

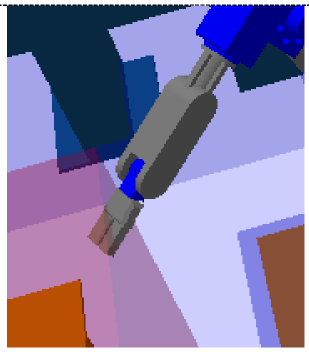

Figure 10. *Security planes get red if there is any shock or mechanical position out of range. A trajectory simulation can be executed only if and only if there is not any chock between the robot and its environment (security planes) or with itself.*

5.2. Scara Robot 7540

This robot has 4 degrees of freedom. Figure 11 shows its general operation diagram.

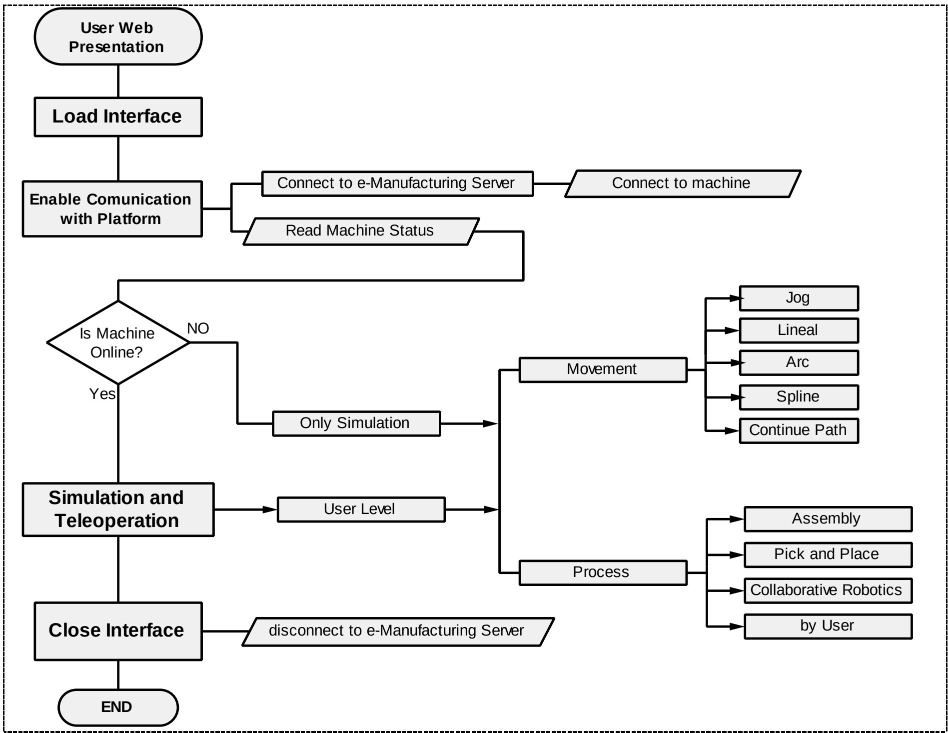

Figure 11. *General operation diagram for Scara Robot 75-40. Universidad Nacional de Colombia. Mechanics and Mechatronics Department*

The figure 12 shows the VMM (Virtual Manufacturing Machine) for operating this machine.

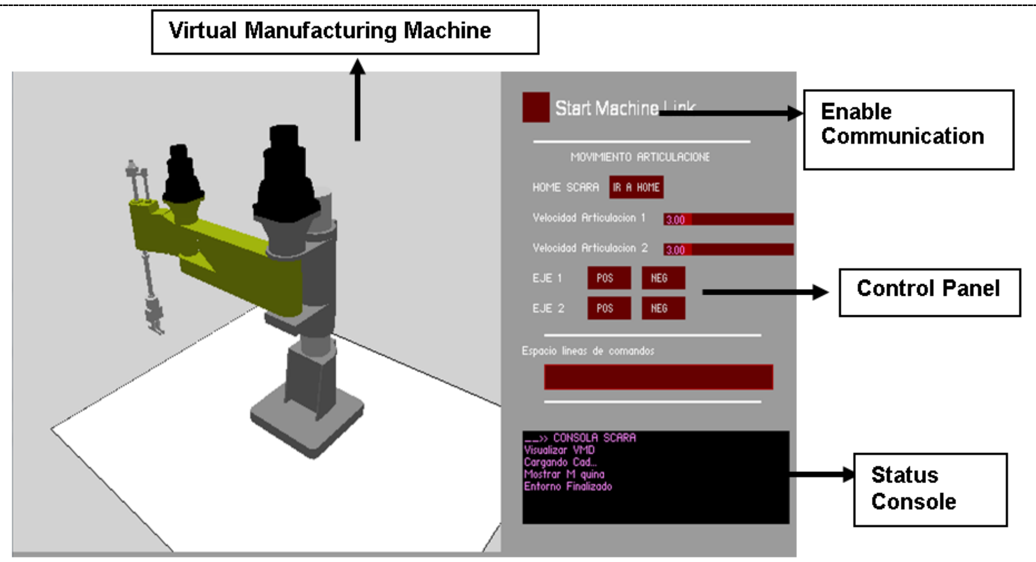

Figure 12. *Virtual interface for operating remotely the Robot Scara 7540 trough Internet. This interface shows its 3D virtual environment and its control panel. Universidad Nacional de Colombia. Mechanics and Mechatronics Department. Cam-Mechatronics room Lab*

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5.3. Leadwell V20i Machining Center

This is a CNC Machining center with 4 degrees of freedom. The figure 13 shows the operation diagram of this Machine in the e-Manufacturing Platform.

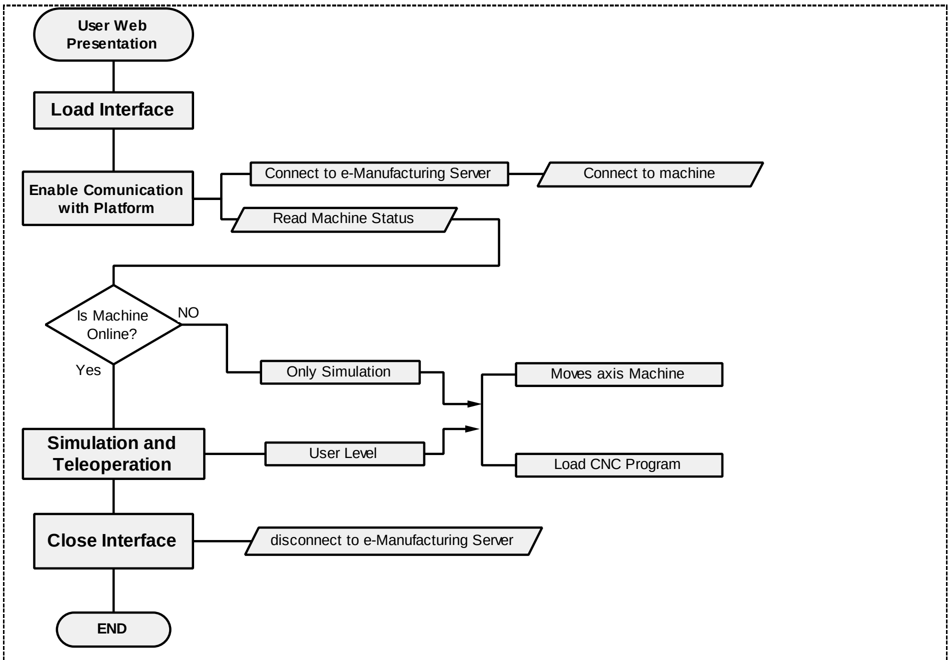

Figure 13. *Operation Diagram of the Leadwell V20i CNC Machining Center. Universidad Nacional de Colombia. Mechanics and Mechatronics Department*

The figure 14 shows the HMI for operating the Leadwell Machining Center through Internet.

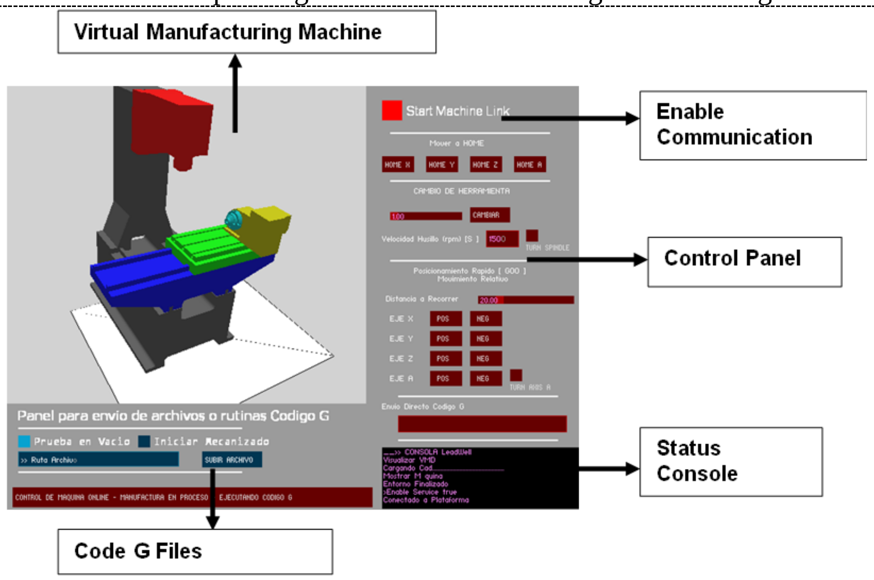

Figure 13. *Virtual interface for operating remotely the Leadwell V20i Machining center through Internet. This interface shows the virtual environment and its facilities with which the final user can program this industrial Machining center. Universidad Nacional de Colombia. Mechanics and Mechatronics Department. Cam-Mechatronics room Lab*

6. Our attempt to cloud manufacturing

While developing the e-Manufacturing platform and after making some validation tests with students and engineers from diverse academic and industrial fields, the platform performed an approach to cloud Manufacturing because product process are developed through internet. The virtual work-stations for each machine and practical exercises implemented by several students have lead to platform model based on the concept of cloud Manufacturing for flexible Manufacturing cells

The Cloud-Manufacturing concept, that came up first on 2010 [5], describes a manufacturing system in the cloud, based on the philosophy of "design Anywhere, Manufacture Anywhere". This platform centralizes and manages manufacturing enterprise's distributed resources for offering support and services in the cloud, based on a model that integrates supply system, business domain and user domain. This model is represented in several layers as shown in the figure 14.

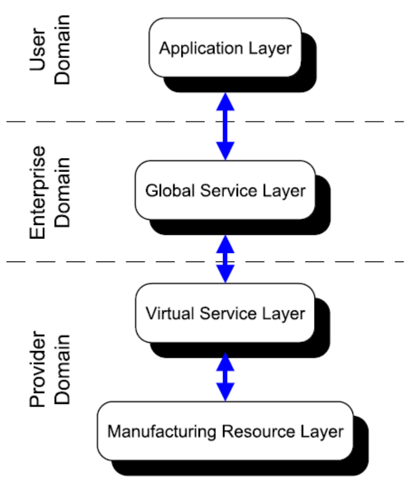

Figure 14. Cloud manufacturing architecture layers [6]

RESULTS

This e-manufacturing platform integrates industrial machines in a 3D virtual environment. The final user can access this 3D virtual platform for operating remotely each machine through the VMM (Virtual Manufacturing Machine) and also for getting centralized information of each machine. This platform has several features such as trajectory simulations, CNC G code compiling, current status information through Internet and software flexible frameworks that can be easily implemented to new machines that are being added to this e-manufacturing platform. This e-manufacturing platform has been tested from several parts of the world, such as Colombia, Germany, France, U.S.A and Australia. Through this testing, several improvements, regarding to virtual interface and robust communication, have been implemented in a continuous way.

DISCUSSION

This platform was initially developed based on only java technologies. However, there are new emergent web communications technologies that have several advantages. Java-applets are technologies that cannot be accessed through mobile devices and have some security restrictions. This has been one of the main reasons for implementing new web communication and computer graphics technologies on the e-manufacturing platform's client side, such as HTML5, javascript, webGL, webSockets, ajax, GWT (these technologies are standardized technologies by W3C[5]). Using these new technologies, the e-manufacturing platform can be accessed through mobile devices and this would be one the most important improvements on this platform

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