Remote and Real Time Laboratories Network for Engineering Education

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ABSTRACT

Tecnológico de Monterrey as part of Global University Leaders Forum has been developing a strategic project that focus on the application of ICT technologies to implement engineering labs for remote, low cost and mass learning and training. This project is proper for developing countries where the lack of equipment in laboratories used in universities and training centers is one of the main features to prevent the development of professionals to use the last generation technology. The main reason of this lack is the high cost of the equipment. With the integration of telecommunication technologies and computer science with virtual instrumentation, real, remote laboratories can be developed and accessed through Internet in real time, ensuring a richer collaborative experience for the student while avoiding some of the growing limitations of traditional laboratories, such as the lack of enough work area, expensive instrumentation, lack of personnel, time assigned to a laboratory, and their availability in non-working office hours. Under this context, this initiative aims to create new technological platforms for engineering education that fill aspects like the low cost and distributed use of these facilities to include significant quantities of students deal with this kind of instruction.

Keywords: Remote Lab, Engineering Lab, Training, Engineering Education

1. INTRODUCTION

Launched during the Governors Meeting for Information Technology and Telecommunications on the occasion of the World Economic Forum Annual Meeting 2003 in Davos, the Global Education Initiative (GEI) with a primary objective to raise awareness and support the implementation of relevant, sustainable and scalable national education sector, plan and develop innovative models to address these challenges.

GEI implementation is based on technological interventions, particularly Information and Communication Technologies (ICT), for modernizing educational service delivery, skill development and quality learning; and enhancing the enabling environment and providing social empowerment. As for GEI, technology is the most powerful tool we can employ to rapidly improve education. Some technological issues of GEI implementation are (Global Education Initiative, 2008):

1. Improve channels of lifelong learning through e-learning and content delivery centers.
2. Establish a connected learning community that removes traditional obstacles related to time and place, allowing all to realize their full potential.
3. Prepare all school and university students for the digital workforce.
4. Equipping all universities with an e-content development lab and a training/accessibility lab.

5. Connecting all public universities and private universities to Internet II.

GEI model suggests improving the quality of education, aligning knowledge and skill outcomes and changing teaching–learning practices and the learning culture in schools. One important highlight is the relationship between ICT, Physical facilities, curriculum and pedagogy (Cassidy, T. and Paksima, S., 2007). An opportunity area arises related with topics concern educational technology development to reach the world trends in education and social issues.

Tecnológico de Monterrey's proposal shows the definition and implementation of a Remote Laboratories Network based on telecommunication technologies and computer science that allow the use of the technology to develop laboratory stations with remote access in real time which can be share by a great number of universities and/or training centers from distant geographic places having a variety of machines and/or processes that otherwise will be impossible to have due to high cost of real machines or lab equipment.

The present document is a recompilation of the Tecnológico de Monterrey's efforts evolution to reach the main targets expressed by GEI, especially the issue related with equipping all universities with an e-content development lab and a training/accessibility lab. Currently, a Remote Labs Network project lets to connect learning communities of Tecnológico de Monterrey Campuses around the country.

2. ANTECEDENTS

The constant and accelerated growth of computing and telecommunication technologies, along with its also grown availability, is creating a new bond between the teaching and learning processes, and the way they are carried out together. As a result, knowledge transmission is being accomplished in many new ways, such as online courses, tutorials, information pages and network resources, among many others. On the other hand, practical knowledge transmission platforms are very limited in number and available resources. Nevertheless, real and practical experience must not be excluded, since it would allow this trend to have more impact and to accomplish a better teaching-learning process. Likewise, collaborative work and at-a-distance projects are beginning to attract more interest among the engineering world.

The interaction between virtual-remote world and real experiments can be accomplished by exploiting the advantages of modern data acquisition equipment, network-ready hardware, and their ability to provide development bench top equipment for measuring, instrumentation and access platforms that can be easily connected, controlled and processed with specialized software. Once a workstation is connected to a computer, it can be easily controlled with virtual instruments created with the software which, at the same time, can be published into the network or as a standalone application, and that can be not only accessed but controlled via Internet, allowing for the lab application to be used from any network connection.

The overall experience, together with the fact that the process to study is being taken from a real experiment, the ease-of-use of the graphical interfaces, the remote access from virtually any place and any time, and, most importantly, that it is all done in real time, give the user a richer real experience. To laboratory coordinators, this allows for the elaboration of better practices with a far lower cost than traditional labs, the creation of remote laboratories with a minimal space required, and the ability to implement customized instrumentation based in software and low-cost hardware.

The advance towards tele-engineering projects, educational laboratories, and collaborative development of projects has been advancing and integrating new data acquisition technologies, digital manipulation, and software-applied measurement instrumentation. Examples of this type of software-applied measurement instrumentation are the so called Virtual Instruments. Through a specialized software tool, graphical user interfaces (GUIs) that allow the control of an entire automated system can be easily created. Besides, the functionality to allow a GUI to be published as a web page immediately is available in certain software packages, giving access to the students to a remote process in real time and with no commercial software needed, only a web browser.

By integrating electronic, computing and communication technologies, and by taking advantage of the National Networking System implemented at Monterrey Tech, the present project develops Remote Education Technological Platforms that allow knowledge transmission and its application in real and practical experiments. Monterrey Tech possesses one of the most suitable infrastructures in the world to allow the development and implementation of these Technological Platforms, representing an element that provides the Institute a leadership role internationally.

3. REMOTE AND REAL TIME LABORATORIES

This project started in Monterrey Tech, Campus Monterrey, and consisted on the construction of laboratory workstations accessible via internet. Two types of remote laboratories were achieved this way: Remote Automations Lab and Remote Electronics Lab. The implementation of these remote labs is similar in each case, with the exception of the particularities that each one of them has due to its nature. Next, the details of their development and implementation are presented.

3.1 REMOTE AUTOMATIONS LAB

An automation station was built, consisting of a network-accessible PLC, a server computer, a scale model of transport and sorting line (with a 3-axis crane-like portal), and two network cameras that has been set up to work remotely through proprietary, remote, stand-alone GUIs. This was accomplished by integrating this automation equipment controlled through a port in a computer, with today's internet technologies, making the configuration and control of the entire system fully available through the network. The structure of the remote lab can be seen on figure 1.

In automation and control laboratories, remote experiments are hard to set up online, since they require advanced knowledge of the system in order for the user to avoid fatal errors to the system, an audio-visual feedback structure to allow the user to actually see and hear what happens when he makes a change in the experiment, and a way to control access to the experiment itself, since two simultaneous user cannot operate the experiment. Once connected to the remote workstation, the GUI allows the user to modify input variables to the control hardware and provoke certain actions in the scale model such as the movement of a specific motor. The interface also provides audio-visual feedback via a video display in which the user may select different angles of the model and also control camera movement and zoom.

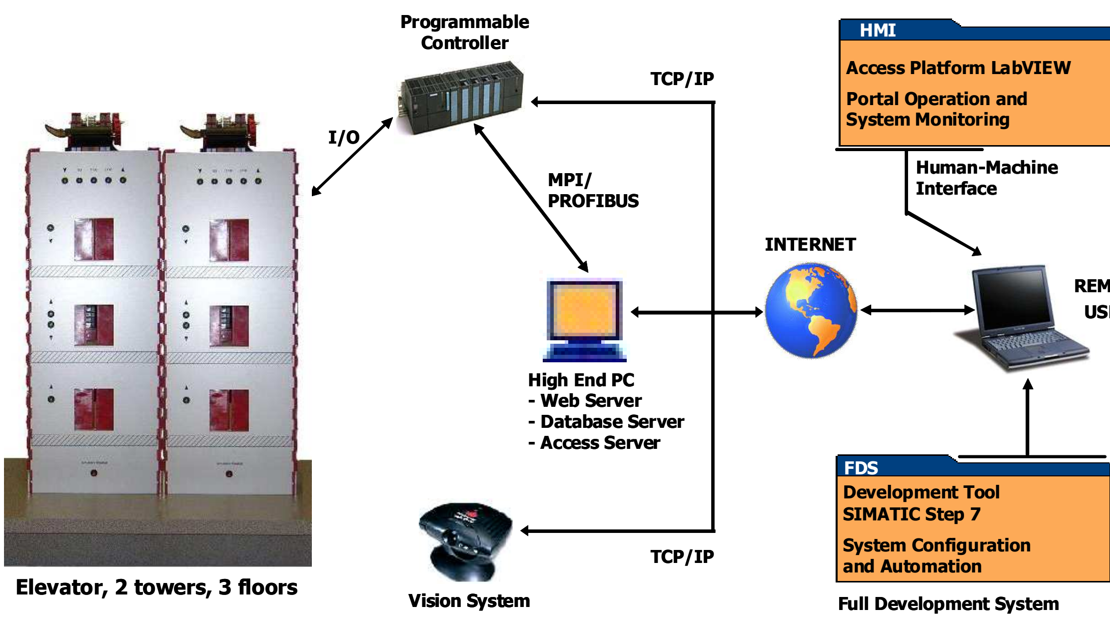

Figure 1: Remote Automations Lab Structure

But the main approach of a remote automations lab is precisely to let the user control the automation process, which immediately implies access to the control hardware's programming, in this case, a PLC. The user may change the PLC's main routine by uploading a new program to it. This is done via hardware-specific software.

However, such ability is precisely the one where a new, special need arises: a safety monitor. When an automation lab is set up to be remotely used, even during non-working hours, the need for a safety system becomes critical. Such system has to monitor the process and the control hardware constantly, making sure that a fatal error is not performed, like leaving a motor running for too long, trying to force the crane out of range, etc. This system would also ensure that, even when the user makes a programming error in the control hardware, such error does not lead to any damaging actions to the model. To avoid programming errors, however, new tools have been developed which enable the user to emulate the process to be accessed and test their program in a safe, virtual environment without having to connect to the physical equipment. Such emulations allow the user to correct programming errors before they are loaded into the remote laboratory in their practice time, adding to the safety of the entire system.

The implementation of a remote laboratory with this kind of equipment reduces implementation and operational costs in a significant way, mainly because instead of building a lot of stations for a traditional lab, only a few are set up and they can be shared. For example, the average cost of a basic work station in an automation and control laboratory, consisting of a PLC, a PC with a suitable interface card, multiple connectors, and a scale model of a certain process, goes higher than US$14,000, but an average automation lab consists of 5 of these stations, exceeds the cost of US$71,000 per lab; this comparison can be briefly seen at Table 1. The application of a remote laboratory, on the other hand, requires the same basic hardware but implemented through a network and a shared scheme, reducing the needed stations to one, reflecting a cost reduction of about 76 percent.

Table 1: Remote Automations Lab vs. Traditional Lab, cost comparison

Traditional Automations Lab		**Remote Automations Lab**	
Equipment	Cost (USD)	Equipment	Cost (USD)
High end PC	$1,500	Common Automation Station	$15,100
Scale Model	$8,000		
PLC Training Package	$3,500		
Communications Card	$700		
Cables and connectors	$200		
Development Tools	$1,200		
		Network cameras	$1,600
		Student Licenses	$400
Subtotal (1 Station)	**$15,100**	**Total (1 Remote Station)**	**$17,100**
Total (4 Workstations)	**$60,400**		

This cost comparison, however, does not take into account that, in the traditional laboratory costs there are not only those generated by the equipment needed, but also those for the space required for it and the working personnel, as well as the infrastructure costs, laboratory personnel, maintenance staff and administrators. So, the cost savings go way far from those achieved on the reduction of required equipment.

3.2 Remote Electronics Lab

Likewise, Monterrey Tech, Campus Monterrey, implemented an Remote Electronics Lab, by integrating data acquisition equipment controlled through a port in a computer, software specialized in measurement and control, and a network/matrix of digital solid-state components, relays, and digital switches with today's internet technologies, similar to a traditional laboratory, making measurements and control of the circuit fully available through the network without having to be physically present in front of the experiment.

A Data Acquisition (DAQ) station was build, consisting of an NI-ELVIS set, a DAQ card, variable power sources, function generators, and a relay system has been set up to allow the student to measure different points in different circuits as well as to modify the input parameters in such experiments and it has also been set up to work remotely through proprietary, remote, stand-alone Graphical User Interfaces (GUIs). Once the user is connected to the workstation, the GUI allows the modification of input variables to the control hardware to provoke certain reactions in the circuit such as changing the input of a voltage amplifier and see the results of such an input change at the circuit's output. Inside the interface the user is presented with various controls and displays, depending upon the current practice and circuitry available. Examples of these controls and displays are variable DC power sources, function generators, switches to allow for specific parts of the circuit to be activated or disconnected, temperature readouts, and a 4-channel oscilloscope-like display with multiple measurement points. Other functions, depending on the current practice, may be activated.

With the practice interface, the user is given control of the circuit in its entirety and is able to reconfigure it in real time. However, the way each user carries out each practice is not predefined, but dependant of every user. During a practice, each student may get to the final result taking several different ways, many of them including errors and mistakes. It is a known fact that the user must be permitted to have mistakes during the practice for, after all, learning usually arises from making errors. These mistakes, however, do not necessarily require being lethal to the circuit. This control given to the user via the practice interface calls for an extra effort from the instructor's side: safety. When an electronics lab is set up to be remotely used, the need for 'safe' circuits becomes critical. This safety criterion has to be implemented before the user can perform fatal operations in the circuit. Some of the safety criteria include limiting the input signals, preventing dangerous connections during remote re-wiring, and choosing circuits components correctly.

The implementation of a remote laboratory with this kind of equipment reduces implementation and operational costs in a significant way, mainly because of the low cost of instrumentation and application of measurements through software and not specific hardware. For example, the average cost of a basic work table in an Electronics laboratory, consisting of a DC power source, multimeter, function generator, and digital oscilloscope is around US$6,300, while the application of a remote laboratory, with the same generation and data acquisition capabilities but implemented through a data acquisition card can be less than US$4,000, reflecting a cost reduction of approximately 45 percent. However, it has been established that the use of real instruments may present a better performance, so, as a high performance option, the lab can be implemented using real instruments connected to the DAQ card of the computer rather than virtual ones. This option, however, elevates the cost of a remote lab considerably, becoming a secondary option. Table 2 shows a brief, detailed comparison between the cost of a common workstation in a traditional laboratory and the cost of implementing a similar workstation but in a remote way with DAQ equipment and virtual instrumentation in a low-cost implementation, and with a remote scheme with commercial instrumentation in a high performance development.

Table 2: Remote Electronics Lab vs. Traditional Lab, cost comparison

Traditional Lab Cost		**Remote Laboratory Cost**			
		Low-Cost		High-Performance	
Cost	Equipment	Cost	Equipment	Cost	Equipment
$1,200	Power Source				
$500	Digital Multimeter	$2,200	Data Acquisition System	$5,800	Common Station minus Multimeter
$1,800	Function Generator	$1,200	Server Computer	$1,200	Server Computer
$2,800	Digital Oscilloscope	$100	Digital Components	$100	Digital Components
1 Workstation		Low-Cost		High-Performance	
Subtotal: $6300		**TOTAL: $3500**		**TOTAL: $7100**	
5 Workstations					
TOTAL: $31500					

As for time efficiency, a remote laboratory (in both cases, automation and electronics labs) would allow access to it in non-working hours, which is not common in traditional laboratories, such as weekends and night-time. This allows for a better use of the resource and for better service to a greater number of users in a greater number of hours, since the laboratory is available in these time slots. Table 3 shows a comparison of the efficiency of use of a remote lab against a traditional lab.

Table 3: Remote Lab vs. Traditional Lab, time availability

Traditional Lab	**Remote Laboratory**	
9 hours/day	**14 hours/day**	24 hours/day
3 hours/session	**2 hours/session**	2 hours/session
5 days/week	**6 days/week**	7 days/week
15 sessions/week	**42 sessions/week**	84 sessions/week

It is important to note that, although very effective, a remote lab is not meant to replace traditional labs at all, but to enhance the learning process by supplying a remote, flexible laboratory for those basic subjects that lack a traditional one.

4. REMOTE LABORATORIES NETWORK

The construction of the so called “Society of Knowledge” requires a constant growth on the use of Remote Educational Technological Platforms, to accomplish a better and more effective knowledge and information transmission. Regarding the Engineering field, these platforms require the inclusion of means to, not only transmit information and knowledge, but also to allow the development of technical abilities gained with the realization of real experiments to apply that knowledge.

The main objective of the project at Monterrey Tech is to create a Collaborative Intercampus Network for the development of remote lab platforms in the areas of Electric, Electronics and Mechatronics Engineering, and their extension into other knowledge fields. Also, the following goals are seek to be achieved:

- Allow students to have remote access to the lab resources.
- Allow teachers to bring lab experiments into the classroom.
- Share lab resources among the involved Campuses.
- Promote a Collaborative Network of Virtual and Remote Labs.

The Network is intended to have three main remote lab platforms:

1. eLab. Remote access laboratories for the analysis and/or design of electrical, electronic and digital circuits. Integrating computational and telecommunication technologies with data acquisition systems and virtual instrumentation, these remote access laboratories can be accomplished, which can be operated in real time, ensuring a positive learning process for students.

2. teleLab. Remote access laboratories for monitoring, diagnosis, automation and control of continuous and discrete systems. Based on PLC’s, standard communication protocols, audio and video feedback systems, databases and web servers, teleLab platform establishes a remote connection at real time.

3. ASMLab. Remote access laboratories for the automation, monitoring and control of manufacturing cells. Real-time connection to accomplish PLC, Robot, CNC machines, artificial vision systems, material handling and AS/RS remote programming and control.

The first step in the path to develop the Collaborative Intercampus Network was taken in Campus Monterrey, it included the implementation of two main platforms: eLab, Remote Electrical and Electronics Engineering Lab in Real Time; and TeleLab, Remote Automations and Control Lab in Real Time.

These technological platforms consist of three main parts:

- A free Web accessible **Portal** containing the necessary information about the platform.
- A **Scheduling system** to organize the use of the remote work-stations correctly; the access is restricted to the users of the platform.
- An **Access Interface** needed to remotely execute the experiments on the reserved time slots.

The **Web Portal** contains all the necessary information about the remote laboratories, including concepts, workstations descriptions, detailed instructions, downloads, practice documents, teacher information and the links to the Scheduling System and Access Interfaces (figure 2).

Figure 2: Web Portal for TeleLab – Remote Automations Lab

The implemented **Scheduling System** consists of an access web page in which the user, having previously requested a user account and being validated by the lab administrator, logs in and selects up to two hours to access the automation station. Once the user has secured these time slots, they don't become available for any other user, thus avoiding double reservations. The system also validates that each user account can only reserve up to two time slots and can only change any existing reservations or select new ones with up to two hours prior to the selected time slot. Any time slot before that becomes immediately blocked for all users.

A very plausible advantage (and one of the best features) of a remote lab is precisely the freedom of the user to select appropriate time slots, therefore, not being tied up to a fixed weekly schedule and being able to adapt the lab to the user's own schedule; the user timing can include non-working hours, such as weekends and night-time, which allows a higher efficiency on the use of the workstations. Also, the two available time slots per user do not have to be necessarily selected in succession; this means that a user may select one time slot one day and the second one in another, adding to the flexibility feature.

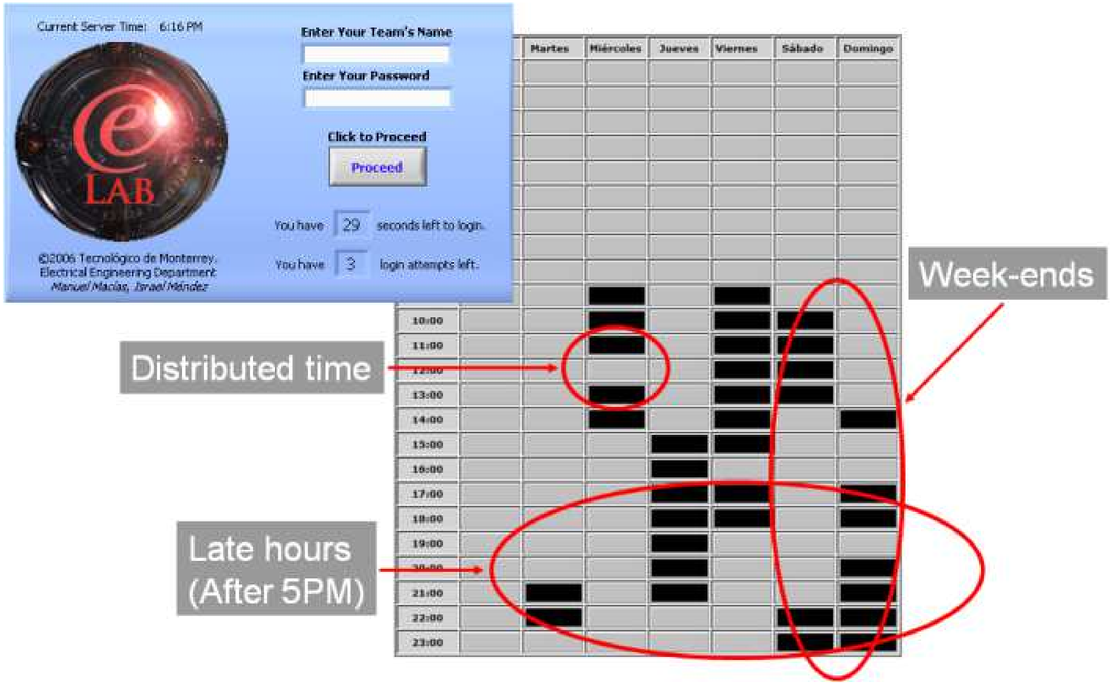

Figure 3: Scheduling System

The **Access Interface**, as shown before, allows the user to access the remote workstation at his reserved time slots; once its credentials are checked, and only if a valid reservation is active at the current time, the user can connect and interact with the equipment, having the ability to modify input variables to provoke certain actions with audio-visual feedback and control over the movement and zoom of the cameras.

The first approach gave as a result the main web Portal *RemoteLabs.itesm.mx*, which contains a general description of the concept of Remote Labs and the Intercampus Network; also, the domains *eLab.mty.itesm.mx* and *TeleLab.mty.itesm.mx*, for the two developed platforms at Campus Monterrey. Once these domains were implemented and fully functional, the two platforms were used in an electronics class (eLab) and in an automations class (TeleLab), showing excellent and promising results. Once the platforms were implemented at Campus Monterrey, these same stations were used to teach lab courses at several different Campuses around the country. It was then time for Monterrey Tech to look at the bigger picture and begin extending the project through the entire system to accomplish a **Collaborative Intercampus Remote Labs Network**.

The second step was taken to build up the Remote Labs Network, the following campuses were included: Campus Estado de Mexico (CEM), Campus Santa Fe (CSF), Campus Laguna (LAG), Universidad Virtual (RUV), and, of course, Campus Monterrey (MTY). Besides, the Network is open for the inclusion of those smaller Campuses with not enough financial resources to afford a workstation by themselves, to allow them to remotely use the workstations provided by the former in their engineering courses. This initiative is intended to bring benefits into several academic programs, such as:

- Electronic and Communication Engineering
- Mechatronic Engineering
- Electronic Systems Engineering
- Electronic Technologies engineering
- Computer and Information Technologies Engineering
- Biomedicine Engineering

The next step consisted on the consolidation of the Network, with the materialization of two new eLab workstations, at Campus Estado de Mexico and Campus Santa Fe. Likewise, the workstations built in these campuses consisted of different type of equipment between them, as well as the one on Monterrey. The workstation at Monterrey is intended to teach Electronics classes, while the one at Estado de Mexico is for Digital Circuits and the one at Santa Fe for Electrical Circuits. This way, instead of having three different laboratories to teach the three different classes, the workstations can be remotely accessed from anywhere, bringing a lot of benefits and saving to Monterrey Tech, and bringing the teachers and students a wider and more complete teaching-learning experience.

Nowadays, there are a total of seven workstations in use in a total of five participant Campuses in the entire Collaborative Intercampus Remote Labs Network: **three eLab workstations**, at Campuses Monterrey, Estado de Mexico and Santa Fe; and **four TeleLab workstations**, at Campuses Monterrey, Laguna, Estado de Mexico and Virtual University. Each one of these workstations has its own website, which can be accessed by going to *RemoteLabs.itesm.mx***.** The Network's performance is due thanks to the Infrastructure available at Monterrey Institute of Technology, which brings the most suitable environment for its development. The intention is to include more campuses to the Network, as well as the third platform, ASMLab. This will allow cost saving though the entire Monterrey Tech system, permitting the sharing of resources between campuses that have them, and its use to the campuses that don't.

5. CONCLUSION

The Intercampus Remote Labs Network allows to have shared resources among the different campuses at Monterrey Institute of Technology, to extend the resource available for each one of them, and reduce the amount of investment needed for it. This scheme allows the whole system to share resources between them and take advantages of the already existing equipment on each of the participant Campuses, and use it by all the Network members.

Future development on the Remote Labs Network at Monterrey Institute of Technology is threefold. It is meant, on one hand, to integrate new workstations at different Campuses so that all National territory can be covered by the Network. Also, it is intended to integrate eLab and TeleLab platforms to the teaching of other courses, e.g. to use TeleLab platform in Control Lab remote courses, or eLab for Instrumentation and Digital Systems.

On another hand, ASMLab platform will be incorporated to the network. This platform will allow students to learn topics on industrial automation by remotely accessing, on real time, manufacturing cells for its supervision and remote control; this allows automating and controlling the laboratories with the use of cameras to combine real-time images with digitally processed signals, and with the use of software and hardware tools for data acquisition and control.

Finally, these technological platforms will be transferred to other Universities around the country and around the world. Nowadays, this transference is already being accomplished, searching for the formation of a National Remote Lab Network on Tec Milenio University, which possesses campuses on 37 cities around the country.

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