

A Novel Web-Based Laboratory for Remote Control of Power Lighting Processes

FELIX PAUNE

EEAT (Electrical, Electronic, Automation and Telecommunication) Research Laboratory
Advanced Teachers's Training College for Technical Education, University of Douala
BP 1872, Douala, CAMEROON
felix.paune@laposte.net

JEAN MBIHI

EEAT (Electrical, Electronic, Automation and Telecommunication) Research Laboratory
Advanced Teachers's Training College for Technical Education, University of Douala
BP 1872, Douala, CAMEROON
mbihidr@yahoo.fr <http://www.cyberquebec.ca/mbihi/>

Abstract: - The novel *Web-Based Laboratory* (WBL) presented in this paper is a multimedia framework for engineering education practice. It is designed and built for remote control of power lighting processes via Internet. The real lighting plant consists of : fluorescent lamps associated with dimmable electronic ballasts, a controllable lighting disturbance, a working space for visual activities, a light sensor, two wireless IP video cameras, and an Ethernet multifunction data acquisition board. In addition, a wireless router is used as a centralized access point for local IP equipments (wireless Internet link, web server computer, data acquisition board). For the sake of easy implementation of automated control tasks, Labview is used as an integrated tool for building the digital control software. From a virtual instrumentation panel of the application software, a variety of experiments could be remotely conducted via Internet. A sample of experimental results obtained and captured by independent authorized remote users operating from Cameroon and from France are presented. These results show the effectiveness of the proposed WBL, for remote experimentation of most control engineering concepts (e.g. *open loop test*, *input time delay*, *PC-based PID controller*, *stability*, and *robustness*), from anywhere in the world wide web via Internet.

Key-Words: Traditional Laboratory, Web-Based Laboratory, Lighting Processes, Experimental Modeling, Time Delay System, PC-based PID controller, Remote Control, Disturbance Rejection, Robustness.

1 Introduction

Traditional laboratories encountered in engineering education provide a number of crucial weaknesses ([1]-[2]). These weaknesses could be summarized as follows:

- a) Limited capacity for users;
- b) Physical presence of users and instructors during laboratory works;
- c) Availability constraints of laboratory on the basis of 24 hours per day;
- d) Chaotic management policies when sharing specialized equipments or workbenches among users;
- e) Complexity of sharing laboratories among institutions;
- f) Lack of flexibility and lost of time when switching among experiments;
- g) Low security level of users since they should be absolutely present in the laboratory before to conduct experiments;

- h) Rigid scheduling of the duration and starting time of laboratory works;
- i) Higher risk for laboratory failure due to direct manipulations of equipments;
- j) Higher costs of startup and setup times, and more.

These weaknesses have motivated over years a rapid development of Web-Based laboratories (WBLs). The WBLs are a subclass of remote control systems, in which the intermediary communication media between the experimental site of a real laboratory and the authorized remote workstations, consists of Internet network. Following the state of the art about remote laboratories reported in [3], many types of WBLs are in use nowadays in a wide variety of disciplines including automatic control ([4]-[11]), robotics ([12], [13]), automation ([14]-[16]), industrial electronics ([17], [18]), Chemistry [19] and a number of multidisciplinary topics ([20]-[23]).

Furthermore, WBLs have become increasingly attractive products for both publishers of patents ([24]-[26]) and scientific editors of engineering education books ([27]-[30]).

Surprisingly, according to our best knowledge, most Web-based laboratories created for control engineering education, are focused only on dynamic processes involving mechanical motions of fluids or parts (e.g. [4], [7], [9], [10], [12], [13], [14], [19], [22]), resulting from digital control of position/speed or level/flow variables via electric, hydraulic or pneumatic actuators.

However, in most professional jobs, there is a growth of new emerging and preoccupying problems requiring control engineering solutions. This is the case of the lighting comfort of workers for visual activities in offices and workshops. The mayor interest to regulate the lighting comfort of workers, is to respect normalized lighting levels dictated for each type of visual activity according to modern lighting norms ([31]-[33]). In addition, the resulting great benefits being to reduce risks of accidents due to visual fatigues, while offering significant energy saving under additive ambient lights if any. Although the lighting comfort of working media is a potential research area for control engineering, it is surprising that lighting control systems have received little attention of researchers in control engineering education. This fact has motivated us to consider the feasibility of a prototyping power lighting control laboratory, for remote engineering education.

Although the general concept of WBL is not new in online control engineering, the mayor aim of this paper is to present a pioneering well tested WBL for dynamic power lighting control systems. Unlike traditional lighting control laboratories, the proposed WBL is normally designed for autonomous services since the physical presence of instructors and users in the real experimental site is unnecessary. In addition, it might be available for remote users on the basis of 24 hour per day. Furthermore, the installation and setup of local equipments to be used for a given experiment, are instantaneous processes implemented in the instrumentation software. As a resulting benefit, even though many persons cannot conduct the same experiment simultaneously, it offers over time a very high capacity under an automated management policy of remote users in the queue if any. Thus,

for the same capacity of service and the same experiment, the number of physical workbenches should be significantly reduced under a WBL.

The second novelty of the proposed WBL is that, it is designed for high flexibility, and built using high performance multimedia technology as it will be shown later. In addition, for the authorized remote users with active Internet connection from anywhere at any time in the world wide web, it offers a variety of independent experiments, allowing real time tests of most important concepts taught in control engineering education.

It is important also to outline the great interest of the proposed WBL in our specific context. In the Advanced Teachers's Training College (ATTCO) for Technical Education of the university of Douala (Cameroon), the control engineering courses are taught at all training levels (bachelor, Master, Ph.D.) to EEAT engineering students. However, given the great lack of flexible and reliable didactic equipments and laboratory instructors, it becomes almost chaotic to conduct practical experiments, allowing to a growing population of students to discover and understand the realistic nature of control engineering concepts and technologies. Therefore, the proposed WBL is installed at the second floor of the AMPHI 500 building in the campus of ATTCO for Technical Education of Douala. It has been created for didactic use as a new multimedia framework, for control engineering practice via Internet.

The remaining content of the paper is organized as follows: In Section 2, the architecture of the proposed Web-based control laboratory for power lighting processes is described, whereas the real local lighting laboratory to be remotely accessed is presented in Section 3 according to a control engineering vision. In Section 4, more details are provided about the setup of the Web-based laboratory, whereas the remote experimentation results obtained are presented in Section 5. Finally, Section 6 stands for the conclusion of the paper.

2 Architecture of the proposed Web-based control laboratory

The architecture of the prototyping Web-based laboratory for remote experimentation and control of dynamic lighting processes, is organized into three main blocks as shown in Fig. 1. It results

from significant improvements of a local architectural scheme initiated in a recent research work [34]. In addition to improvements due to wireless technology, the second great challenge of this paper results from the extension of the local control architecture studied in [34], to a Web-based multimedia framework for advances on control engineering education .

The first block of the WBL, is the real local laboratory for digital control of power lighting processes. As shown in Fig. 2 where a physical view is provided, it consists of two fluorescent lamps with dimmable electronic ballasts, a controlled light disturbance source, a working space for visual activities, a light sensor, a fixed wireless IP video camera, a rotating wireless IP video camera, an Ethernet multifunction data acquisition (MDAQ) board, and an UPS (interruptible power supply).

The second block is a local area network (LAN) consisting of a wireless router, used as a centralized access instrument for other TCP/IP equipments including the wireless Internet connection, the web server computer, and the EDAQ board connected to a router using an Ethernet cable since an equivalent wireless model was not available in our toolkit.

The last block is Internet network, from which authorized remote users, can access to the local real laboratory, in order to remotely control the dynamic lighting system, from a variety of independent experiments provided on the virtual control panel.

3 Real laboratory for remote control of the power lighting system

3.1 Equipments required

The technical characteristics of the local equipments used to build the WBL are summarized in Table 1, where the main blocks observed in Fig. 1 are numbered as follows :

- 1: Real local laboratory with lighting plant;
- 2: LAN;
- 3: Internet network.

3.2 Physical view

Fig. 2 shows a physical view of the prototyping Web-based laboratory for remote experimentation and control of dynamic lighting processes. Except remote workstations connected to Internet, most equipments predicted earlier in the architectural scheme of the proposed WBL (see Fig. 1), are visible in Fig. 2. They are adequately identified using corresponding labels. At this point, it is important to indicate that the lighting disturbance

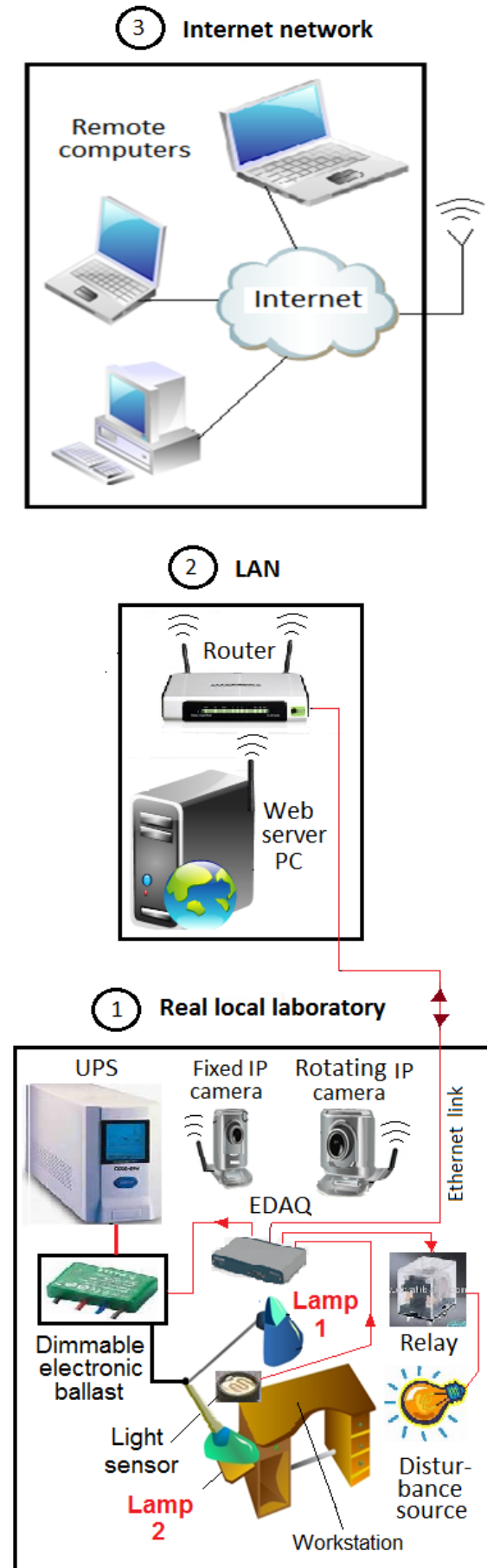


Fig. 1 Architecture of the proposed WBL .

Table 1. Characteristics of equipments

N°	Equipments	Characteristics	Price (€)
1	Fluorescent lamps	1.2 m, 36 W, 220 V	4
	Electronics ballast	2 x 36 Watts, Dimmable 10 Vmax	300
	Disturbance	Lamp, 60 W	1
	Light sensor	Photo resistor	
	standard IP camera	Wireless, IP, 100 m, LinkSys.	120
	Rotating IP camera	Wireless, IP, 100 m LinkSys,	400
	EDAQ board	Labjack UE9-Pro, 10 Mbits/s, 16 bits	1000
	UPS	1200 VA, 230 V, 50 Hz	130
2	Internet connection	Commercial Public DNS required for full remote access	Annual basis
	Wireless Router	Wifi 300 Mbits/s 2.4 GHz, 1 WAN port, 4 LAN ports	250
	Web server PC	HP Proliant, 2.4 Mhz	1200
3	Run time engine (RTE) + web browser	RTE (LabView) or RTE (TeamViewer)	0 (Free)

is an electrical lamp (60 W, 220 V) observed in Fig. 2, where it is fixed in the neighborhood of the main lighting source, and is connected to the main contact of an electromagnetic relay (not visible on Fig. 2) as indicated earlier in Fig. 1. This relay can be switched ON or OFF via a digital output of the EDAQ board (see Fig. 1), from a case select visual component labeled “disturbance control” in Fig. 4.

3.3 Dynamic models

For the sake of good understanding of many concepts to be handled later from remote experiments using the Web-based learning technology, it is important to perceive the real local observed in Fig. 2 according to a control engineering vision. Professionally speaking, the power lighting control plant observed Fig. 2, falls into the class of complex dynamic processes. This complexity results from various factors including the heterogeneous nature of its constituents, the input time-delay behavior, the lack of exact knowledge about the dynamic behavior, and the effects of uncertainties (age of lamps, lighting disturbances, optic properties of the lighted medium). However, in the pioneering research work conducted in [34], the dynamic behavior of the whole lighting process has been modeled from Strejc’s identification method, as a second order process with input time delay.

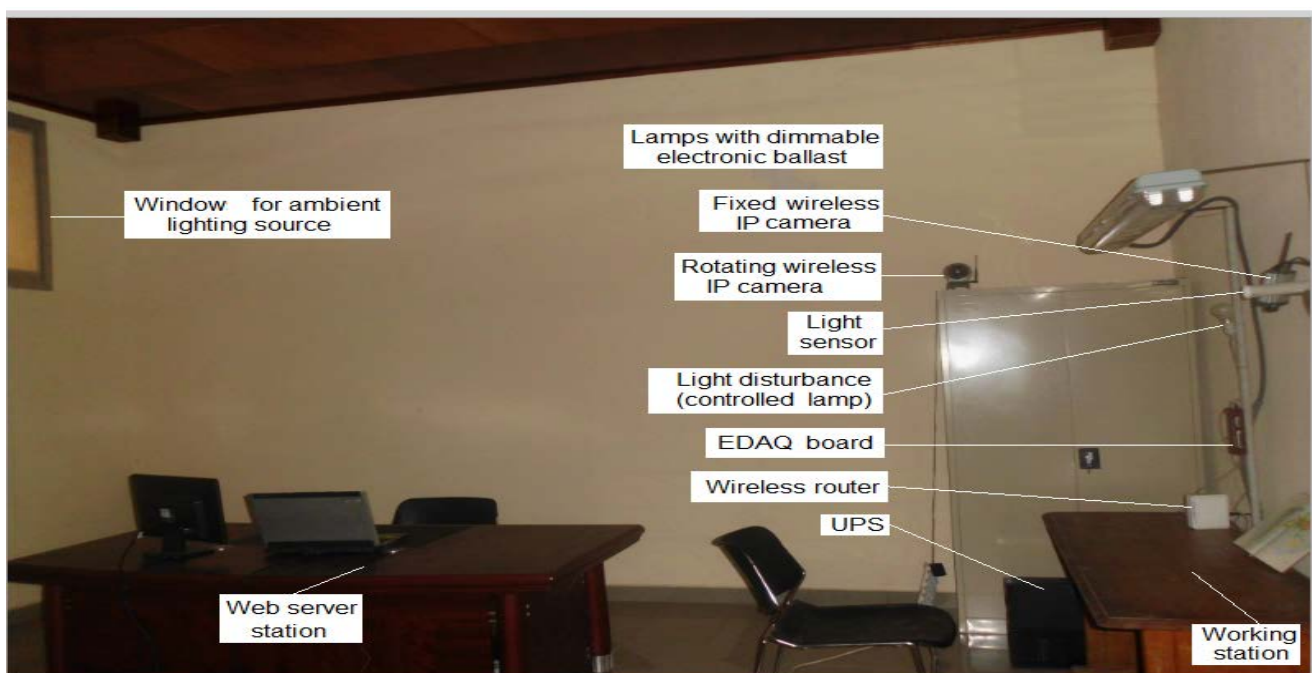
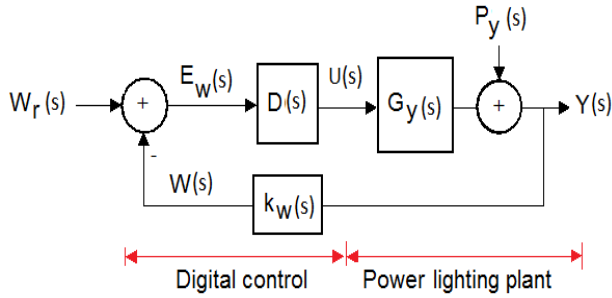


Fig. 2 : Physical view of the real WBL.

In addition, the great robustness and high performance of the closed loop lighting control process under PID control policies, have been proven and well-tested. Fig. 3 shows the block diagram of the closed loop control process,



$W_r(s)$: Set lighting level;
 $Y(s)$: Lighting level returned by the sensor installed near the main lighting source where ;
 $W(s)$: Lighting level at the work station;
 $E_w(s)$: Lighting Error ; $U(s) \rightarrow$ Control signal
 $P_y(s)$: Lighting disturbance

Fig. 3 Block diagram of the lighting control Process

The main transfer functions involved under the PID control policy, are given as follows:

$$G_w(s) = \frac{W(s)}{U(s)} = G_y(s) k_w(s) \tag{1}$$

$$= \frac{K_y(s)}{(1 + T_w s)^2} k_w(s) e^{-a_w s}$$

$$D(p) = K_p \left(1 + \frac{1}{T_i s} + T_d s \right) \tag{2}$$

$$W(s) = \left\{ \frac{\overbrace{k_w D(s)G_y(s)}^{L_w}}{1 + k_w(s) D(s)G_y(s)} \right\}_{\tau_w} W_r(s) \tag{3}$$

$$+ \left\{ \frac{k_w(s)}{1 + k_w(s) D(s)G_y(s)} \right\}_{s_w} P_y(s)$$

In discrete time, the PID control model (2) is transformed using Tustin's discretization technique to obtain :

$$D(z) = K_p \frac{\left(1 + \frac{T}{2T_i} + 2\frac{T_d}{T} \right) z^2 + \left(\frac{T}{T_i} - 4\frac{T_d}{T} \right) z + \left(\frac{T}{2T_i} + 2\frac{T_d}{T} - 1 \right)}{z^2 - z} \tag{4}$$

and the equivalent digital PID control algorithm is given as follows:

$$u(k) = u(k-1) + a_0 e(k) + a_1 e(k-1) + a_2 e(k-2) \tag{5}$$

where

$$\begin{cases} a_2 = K_p \left(1 + 2\frac{T_d}{T} + \frac{T}{2T_i} \right), \\ a_1 = K_p \left(\frac{T}{T_i} - 4\frac{T_d}{T} \right), \\ a_0 = K_p \left(\frac{T}{2T_i} + 2\frac{T_d}{T} - 1 \right) \end{cases} \tag{6}$$

Although Equations (5) and (6) are fundamentally important for the digital control policy, their real time versions are implemented using Labview application control software. However, the main decisions making of a remote user from the control panel, is limited to the choice among available experimentation types, and to a change on input data if any.

4 Web-based laboratory setup

4.1 Web server computer setup

The following specialized software are installed in the software computer :

- a) *Labview Web Server* used for sharing visual instrumentation data and images as well as videos from wireless IP cameras among authorized remote users. It is important to recall in this case that, the access from outside our Internet campus network, required a registered DNS to be paid to the Internet provider.
- b) *Teamviewer Web Sever* is an alternative freeware solution. Although it behaves as console departing tool and provides low performance, its use don't require a registered public DNS for remote users located. Therefore, it is a good solution for testing from anywhere the effectiveness of the web laboratory, without additional connection costs.
- c) *Labview application software*, designed and implemented for virtual instrumentation and real time control of the light comfort in a multitasking workstation context. This digital control software has been built from the basic control software developed in [34], by implementing new virtual instrumentation objects required for advanced remote learning tools.
- d) A *Web explorer*, since it is useful for locally testing the Web-based capabilities using the web server computer as a local host workstation.

4.2 Setup of remote workstations

For authorized remote workstations with active connection to Internet, their specific needs are limited to :

- a) A Web browser such as Internet Explorer, Mozilla or FireFox, from which shared local resources of the Web server PC including the virtual instrumentation control panel, can be requested by remote users according to HTTP norms and protocols.
- b) The connection data sent by the web server administrator: IP address of the server, user name, and pass-word.
- c) A *Run-Time Engine (RTE)* viewer to be installed in the remote PC. It is useful for displaying virtual instrumentation Web pages transmitted almost continuously under request from the web server.

Let us provide more information about two types of RTE viewer tools, which have been successfully experimented in order to prove the effectiveness of the proposed WBL. The first RTE viewer tool is Labview RTE viewer tool (*nplv2012win32.dll*), available for free downloading in the National Instrument web site. As mentioned earlier, for authorized remote operators connected to the Internet network of the campus, their access to our WBL in this case is quite reliable even from any office or standard classroom. Otherwise, a full access from anywhere via Internet, requires that Labview server runs under a qualified DNS account, to be paid from the local Internet provider according to an annual basis. Although this solution is the best technically, it is costly for our research team with little budget.

The second RTE viewer product considered is *Teamviewer_setup_fr.exe*. It falls into the class of advanced console departing tools. It is easy to be installed and used, and don't require a qualified DNS account for using Labview control application. While waiting for a financial sponsor for buying a registered DNS (if any), this approach is more suitable for publication of our WBL to an unlimited web space, without additional Internet costs.

In all cases, our WBL server runs under the unqualified (unregistered) DNS www.gr2ia.com, in which case, if www.gr2ia.com is typed in a web browser, then the resolution name is found in the hosts file or in the set of network parameters of the operating system.

4.3 Web-based equipments setup

The IP addresses of communication equipments mentioned in Table 1, are as follows: 192.168.1.209

for EDAQ board, 192.168.1.100 for Fixed IP camera, 192.168.1.101 for rotating wireless IP camera, 192.168.1.150:8080 for the Virtual server redirection in the router.

Under the activated Web server (Lview server or Teamviewer server) originally selected by the WBL administrator, multiple remote users might attempt to simultaneously control the power lighting plant. However, only one remote user can be allowed to control the real front panel, while the others (if any) are placed in the waiting queue. Fig. 4 shows the screen view obtained after start-up. Appropriate identification labels are assigned to input-output visual objects provided on the virtual control panel. More specifically, the mouse-based control switch labeled "Operation mode" on the visual control panel presented in Fig. 4, is used for switching from PID to open loop operating mode. In open loop mode, the digital PID regulator is just bypassed, whereas the sensor remains in service since the open loop response should be acquired and monitored without taking into account the feedback error.

4.4 Experimentation modes

The proposed WBL enables remote users to easily and quickly test the following set of independent experiments :

- a) Open loop tests without disturbance;
- b) Open loop tests under disturbance;
- c) PID control without disturbance;
- d) PID control under disturbance;
- e) Change on the lighting set point;
- f) Switching from open loop to closed loop;
- g) Switching from closed loop to open loop;
- h) Change on control data including the PID parameters and the sampling period.

The main control configurations are summarized in Fig. 5, where Fig. 5(a) shows the open loop test modes, given a set of lighting flux levels (specified in Lux), with possible digital activation of the light disturbance source. In Fig. 5(b), the emphasis is on closed loop configuration modes, under the same input and disturbance conditions.

As mentioned earlier, a real time switching between both open loop and closed loop configurations, is realistic and safety (i.e. no technical risk) as it will be shown from experimental results. The default operation mode is a closed loop control without disturbance, associated with nominal input data such as the parameters of the lighting plant from which the controller has been designed, the parameters of the PID controller, and the sampling period.

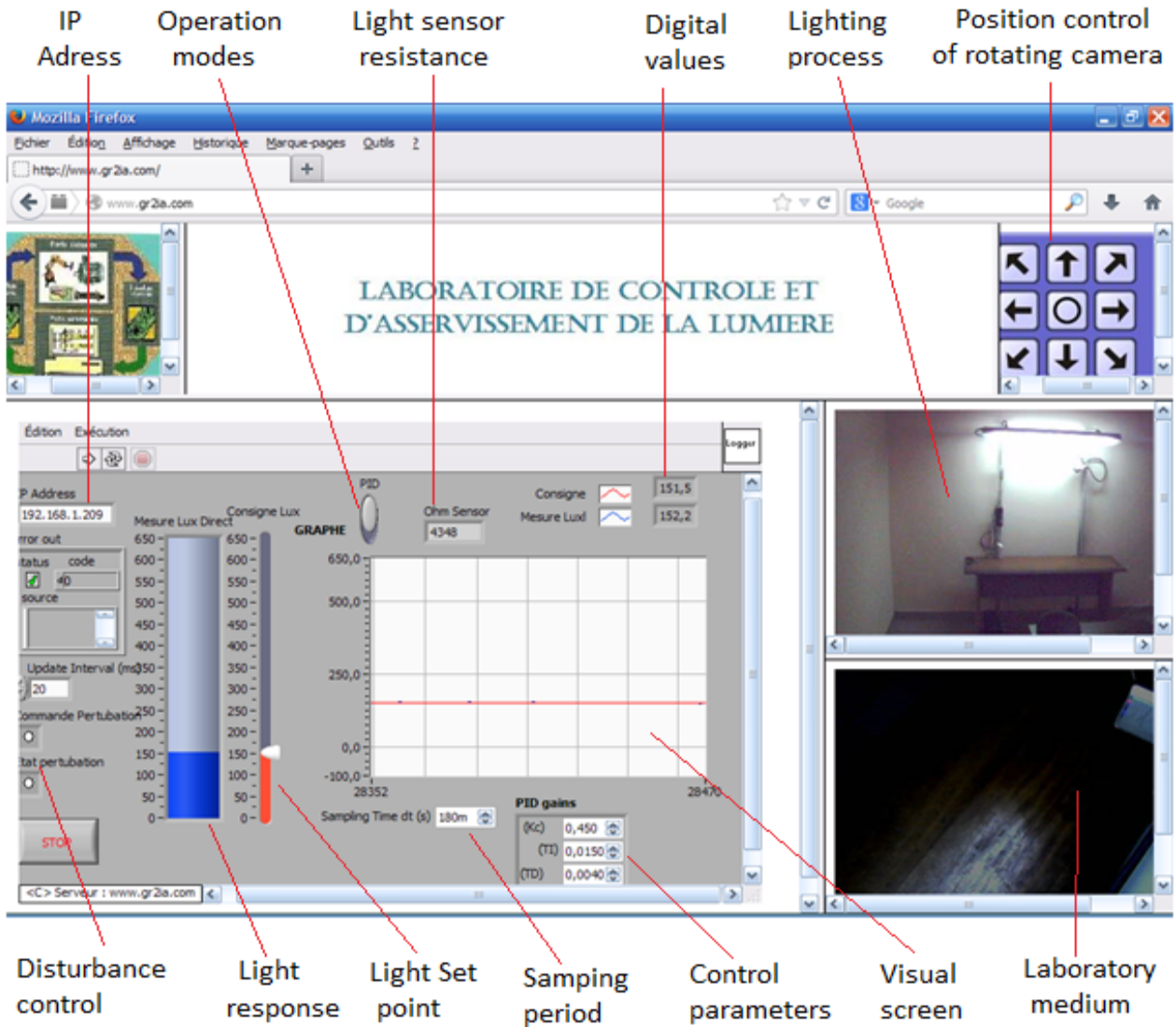


Fig. 4: Visual Control panel of the proposed

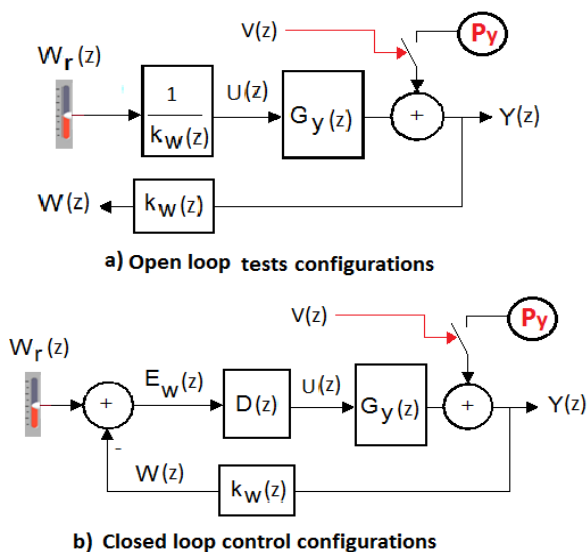


Fig. 5 Main control configurations

4.5 Practical lesson organization

For undergraduate students, experimentation sessions are frequently organized in a standard classroom, where a remote PC with preinstalled Web browser and RTE software, is connected to Internet network of the Campus. The number of student is just limited by the capacity of the classroom. A video projector is connected also to the remote PC for the sake of better visualization of remote experiments on a wide white board placed in front of the classroom. When the instructor starts up the RTE software under an active WBL server, and enters the identification data (user name and password), the virtual instrumentation control panel of the WBL server, is deported and displayed continuously on the remote wide white board.

Then, the experiments retained for the didactic session, are realized easily and quickly.

For each experiment, sufficient explanations are given by the instructor in order to help student to handle the realistic nature of concepts taught in the theoretical session of the related control engineering course. In addition, the graphical results obtained are captured and save in the hard disk of the remote PC for further distribution by the instructor to students via their E-mail contacts. Finally, it is recommended for each student to produce in his free time period or at home a technical report about the WBL session, then to submit this report to the instructor within 7 days for evaluation.

However, the organization of experimentation sessions for our graduate students and researchers in control engineering, is done according to the individual basis since their total number is low. In this case, the RTE tool recommended by our WBL administrator, along with a Web Browser and an active Internet connection, should be preinstalled in the Laptop PC of each authorized graduate student.

Thus, from anywhere in our campus, a graduate student can quickly starts up the RTE, enters his identification data (username and pass word), and explores our WBL or conducts control engineering experiments, at a predefined date and time period allocated by our WBL administrator.

5 Remote experimentation results

5.1 Results obtained in the campus

The proposed WBL is frequently tested successfully from offices and standard classrooms (outside the real laboratory), via Internet network of our campus. A sample of experimental results obtained under an active Labview server is presented from Fig. 6 to Fig. 8.

A few instructive phenomena which emerges from Fig. 6, are related to the open loop step response under a lighting disturbance.

Following are the most important phenomena observed:

- a) The real lighting plant and lighting surface, are quite visible on the video frames as though the remote operator is present in the real site of the WBL.
- b) The real control and instrumentation panel as viewed from a remote station, behaves as a direct interactive man machine interface.
- c) The step response is initially delayed before starting up after a few milliseconds for the sake of clarity;
- d) The transient shape of the step response

shows that the power system considered behaves as a dynamic system with order less or equal to 2;

- e) In the open loop control mode, a wide gap is observed between the set lighting level and the resulting steady response;
- f) The mutual effects on the step response of both the reference input and the disturbance appear to be cumulative. Therefore, under a lighting disturbance, it is necessary to reduce the main lighting flux in order to maintain the resulting flux at the lighting surface as a constant using a regulator. In such cases, the compensation of the lighting surplus might offer over time a significant energy saving.

As a learning activity, the mayor attractive knowledge arising from these remote experiments is that, the power lighting processes to be remotely controlled, behaves as a *time delay uncertain dynamic system*, with weak open loop performance to be improved using a PID controller.

Conversely, in Fig. 7 where the closed loop step response is plotted, although the time delay remains almost unchanged, it is obvious visually that the transient behavior is significantly improved since the steady error tends to zero. This result indicates that, the presence of a well designed PID controller in a closed loop lighting process, yields stability, good dynamic performance and great robustness as expected.

However, an arbitrary choice of PID parameters might lead to undesired behaviors, including instability.

A set of additional experimental results obtained is presented in Fig. 8, where only the instrumentation display of the virtual control panel is shown in each case for the sake of clarity.

Fig. 8(a) shows that the closed loop response under a negative step input reference remains very satisfactory. In addition, Fig. 8(b) and Fig. 8(c) indicate that, it is quite safe to switch from open loop to closed loop control and from closed loop to open loop control respectively. This behavior is not surprising since it has been shown in [34] that, the transfer functions of both open loop and closed loop lighting processes are stable, at least within the nominal robustness range.

Furthermore, the rapid *disturbance rejection* property is shown visually in Fig. 8(d) for the sake of better understanding. It is important to remark that the dynamic effect of the lighting disturbance on the output flux to be regulated is cancelled rapidly.



Fig. 6 Open loop step response under disturbance (125 Lux)

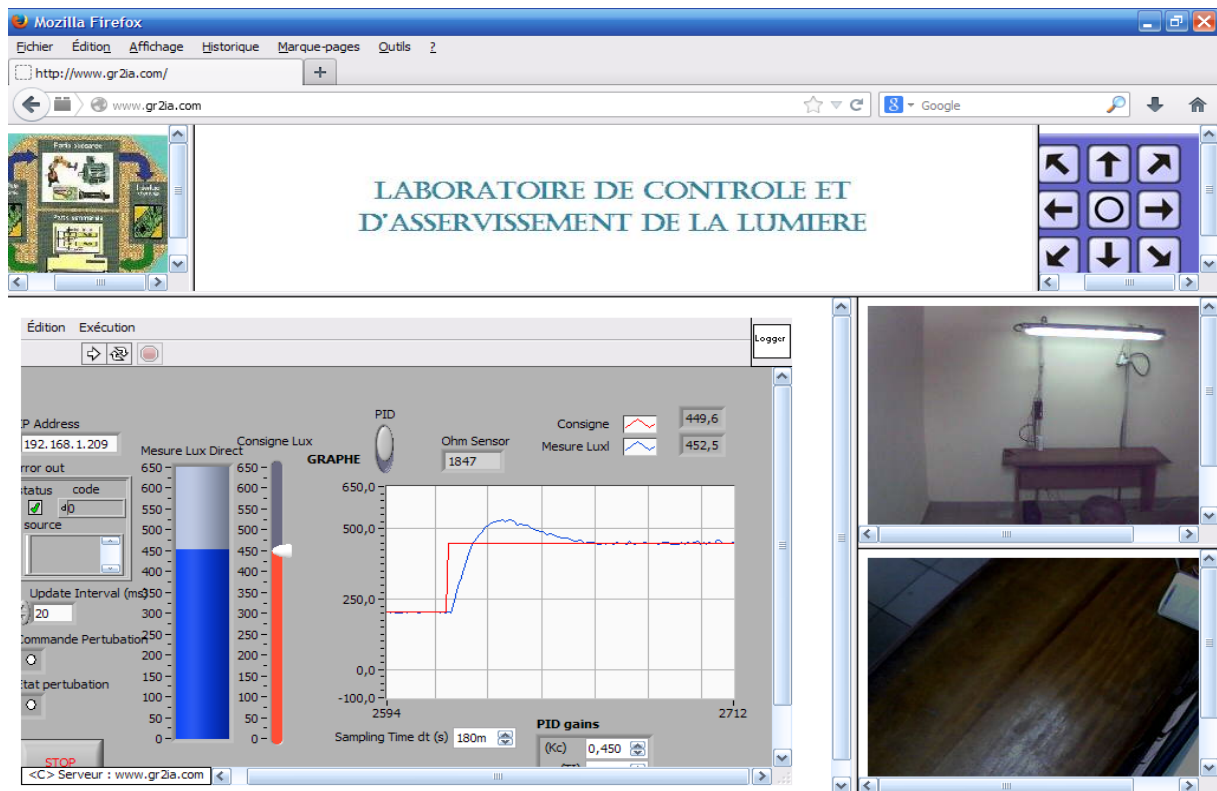
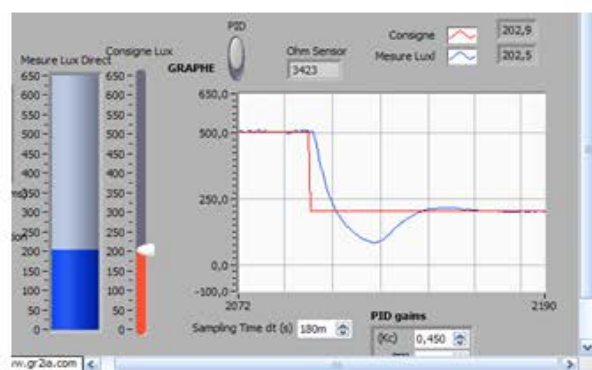
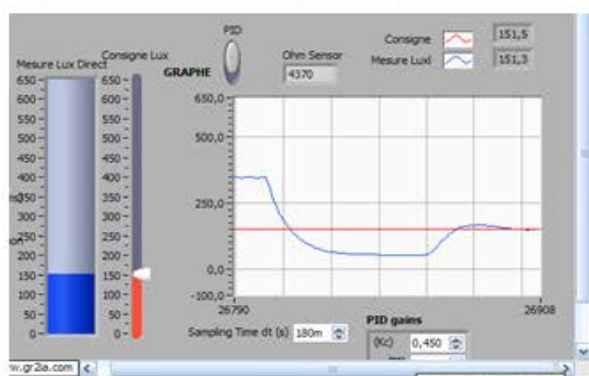


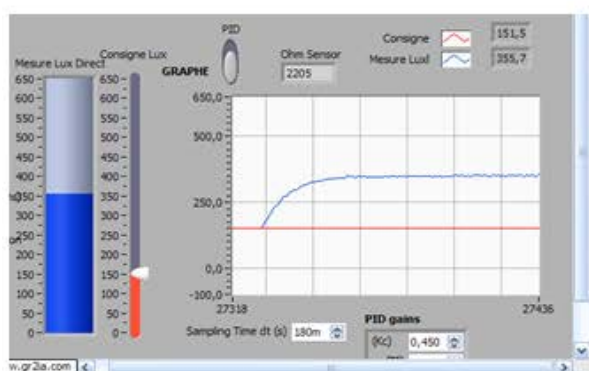
Fig. 7 Closed loop step response without disturbance



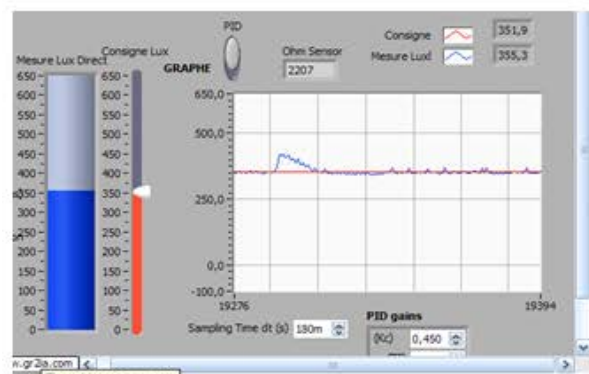
a) Step response (closed loop control)



b) Switching from open to closed loop



c) switching from closed to open loop



d) Switching on disturbance

Fig. 8: Other types of experimental results.

5.2 Results obtained outside the campus

Under the active Teamviewer Web server, the proposed WBL has been also tested successfully via Internet, by remote users located geographically outside our campus and even abroad. A sample of recent experimental results obtained by an authorized remote user operating from France via Internet, are provided on the Appendix in Fig. 9. Under our request, these results have been captured as PNG images and sent to us by E-mail. In Fig. 9(a), the step response obtained under PID control of the power lighting system (without lighting disturbance) is plotted, whereas the steady state behavior of the perturbed control system is shown in Fig. 9(b).

The last important finding emerges from the whole experimental results presented in this paper is that, when using our novel WBL for real time experimentation of control engineering concepts, there is no difference between local users and remote users operating independently from anywhere in the world wide web.

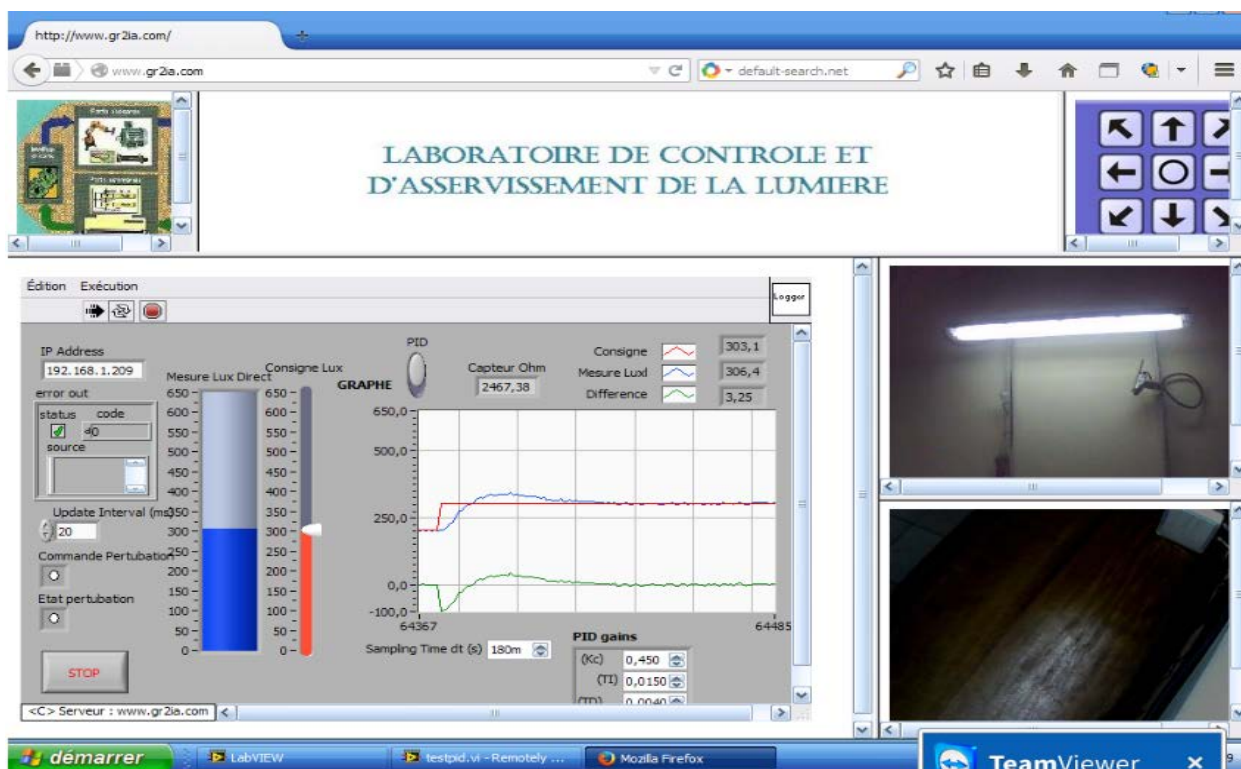
6 Conclusion

The Web-based control laboratory for power lighting systems presented in this paper, is a novel e-learning multimedia framework. It has been created, well tested and still remains in use for control engineering practice via Internet, by authorized education and research partners, located geographically anywhere at anytime in the World wide web.

Since the related real laboratory it is built according to wireless technology standards, the setup required for replacing any failure equipment is less demanding. In addition, the real site of the local laboratory can be deported geographically in minimum time if necessary. Since only the visual control panel of the Labview application is uploaded to remote computers as image objects, it would be very important to create an automated database for each remote user profile. It can be downloaded and saved into the hard disk of the corresponding remote workstation for further use or analysis.

Furthermore, it might be an impressive contribution also, to provide an appropriate quiz module with automatic corrections, in order to help users to evaluate their learning activities themselves. These aforementioned potential extensions, will be investigated in future research works.

Appendix : Experiments conducted from France



a) PID control : Step response without disturbance



b) PID control : Steady state with disturbance

Fig. 9 : Experimental results obtained from France

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