AC 2012-5143: INTRODUCING A REMOTELY ACCESSIBLE OPTICAL LABORATORY FOR UNDERGRADUATE STUDENTS

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1. Introduction

Today, online (web-based) learning is receiving more attention than ever before. A key advantage of online learning is that it can provide direct delivery of education at anytime from anywhere to anyone, and thus, enhancing institutional learning to wider student population when resources are limited. Furthermore, online learning can be offered in various dimensions, including distance lecture delivery or remote instrumentation to teach laboratory-based courses [1-3].

Over the past several years a vast number of systems have been developed to provide remote access to laboratory instruments in order for students to conduct online experiments. In fact, today, almost every major instrument has the remote access feature. Web-based experiments allow students to interact with real testing equipment without the need to purchase redundant instruments or dedicate large lab spaces. Another major advantage of online experiments is that, as many researchers have pointed out, it allows students to complete hands-on activities on their own time, resulting in higher level of involvement and overall understanding of the topic [4].

In this project we report on development of a remote laboratory platform that allows students to login and complete different lab experiments in fiber optics and optical communications. Generally, performing such experiments are expensive and require costly instruments. Our setup offers remote access to state-of-the-art optical test equipment. Thus, without having to be physically present, students can remotely receive hands-on training in selected areas in optical communications, such as learning about eye-diagram, bit-error test, and signal dispersion and attenuation in fiber optics.

2. Background

Online and web-based learning continue to expand, thanks to advances in computer, communication technologies, and interactive multimedia on the World Wide Web (WWW) [4]. A vast number of educational software tools and packages are available to educators in order to expand their course delivery beyond traditional face-to-face classrooms. The Adobe Connect[5], Centra system[6], Blackboard, and WebCT are just a few popular examples to mention.

Over the past two decades a large body of works have focused on developing remote mechanical and electrical laboratories, for example, allowing students to carry on a fluid flow experiment, handle wind tunnels, or program special hardware. Our focus in this paper is developing a comprehensive remote optical communications laboratory. Due to their high cost, many universities lack any significant optical testing equipment. As a result, they either avoid offering courses in optical communications or tend to minimize any hands-on activities, limiting the course to lectures only.

In the past, a relatively small body of works have discussed developing remote access to optical instruments. In fact, over the last five years, between 2007-2012, only limited engineering education papers submitted to ASEE have addressed remote optical laboratories. The University of Colorado, Boulder, used a remote access method to teach Introduction to an Optical Communications course in fall of 2004. In the subsequent year, University of Houston, TX, offered an "Optical Circuits" course [13]. In their report on Internet-based approach to laboratory instrumentation, the authors from the University of Huston, presented implementation details and preliminary results of optical source characterization, namely light emitting diode (LED) and laser diode (LD) through remote laboratory access [14]. In a different report the authors introduced the Stanford CyberLab. In their work an example of remote instrumentation using an optical processor was demonstrated. In this experiment students could remotely change and observe the image of a specially filtered object [12].

In our work we primarily focused on developing a robust LabVIEW-based optical communications laboratory that can be remotely accessible to students. We incorporated this experiment within our previously designed unified distance learning platform called the *Integrated Virtual Learning Platform* (IVLP) [15]. In the following sections, we first briefly describe IVLP and then elaborate on details of our proposed Internet-based optical communications laboratory.

3. IVLP Platform Architecture

In our previous work we reported on basic features of the IVLP platform[15], a pilot project developed by the Advanced Internet Technology in the Interest of Society Laboratory (AITIS Lab) at Sonoma State University [7]. We described that a unique characteristic of IVLP is that it is entirely based on LabVIEW software, providing a user-friendly and configurable distance learning development environment. A key advantage of IVLP is that it offers remote access to a collection of online learning tools, such as laboratory experiments, lectures, simulation applets, and tests, while allowing remote students to chat in real-time and participate in virtual face-to-face communication with the instructor.

This project is an extension to our previous work. In this project we developed an integrated distance learning platform that enables course material sharing and collaboration between various institutions and instructors in order to provide a cost-efficient and flexible learning and training delivery to multiple remote users.

In the rest of this paper we focus on architecture of our proposed remote optical communications laboratory, which we developed to fit within the framework of IVLP.

4. Remote Optical Communications Laboratory

Figure 1 shows the basic architecture of the proposed remote optical communications laboratory. The system consists of the following testing instruments: HP 86060 Lightwave Switches, HP 86120A Multi-wavelength Meter, and HP 8156A Optical Attenuator. These devices are daisychained together using GPIB interface. The GPIB cable is then connected to the computer using a GPIB-USB converter. The computer acts as a LabVIEW server, which controls the entire setup.

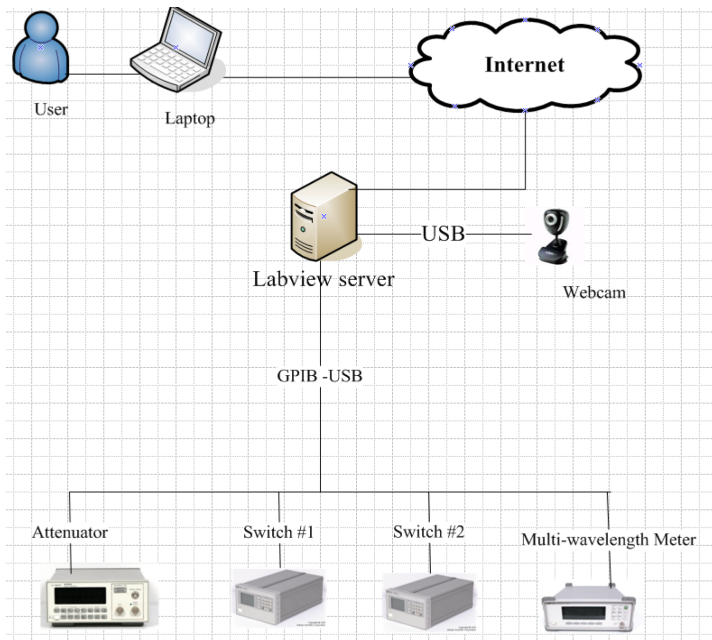

Figure 1: LabVIEW-based remote optical communications laboratory.

The entire remote laboratory platform was designed using LabVIEW software [8]. LabVIEW is a graphical programming language that has become the de facto industry standard for controlling instrumentations. A major advantage of LabVIEW is that it provides a convenient way to setup a PC as a server and establishes client/server environment with a few mouse clicks. Hence, an instructor with limited IT support, and networking and programming knowledge, can easily change the setup. Although, in order to run the remote laboratory the user must have LabVIEW software, a remote student only requires *LabVIEW Run-Time Plug-in*. This program is provided free of charge by National Instrument and it is automatically downloaded when the remote client logs into the system.

In order to establish interface between instruments and LabVIEW software VISA programming has been used. VISA (Virtual Instrument Software Architecture) is a standard input/output language for instrumentation programming, allowing LabVIEW to communicate with instruments using diverse protocols, including TCP/IP, USB, or GPIB.

As we mentioned, the computer acts as a LabVIEW server that controls the entire setup. The actual communication between LabVIEW and Agilent instruments is based on Agilent SCPI commands. SCPI stands for Standard Commands for Programmable Instruments. For example, Agilent SCPI query command to read data out of an instrument called BERT (Bit Error Ratio Test), such as reading eye diagram's height is as follow: *"SENSe1:EYE:HEIGht?"* [16].

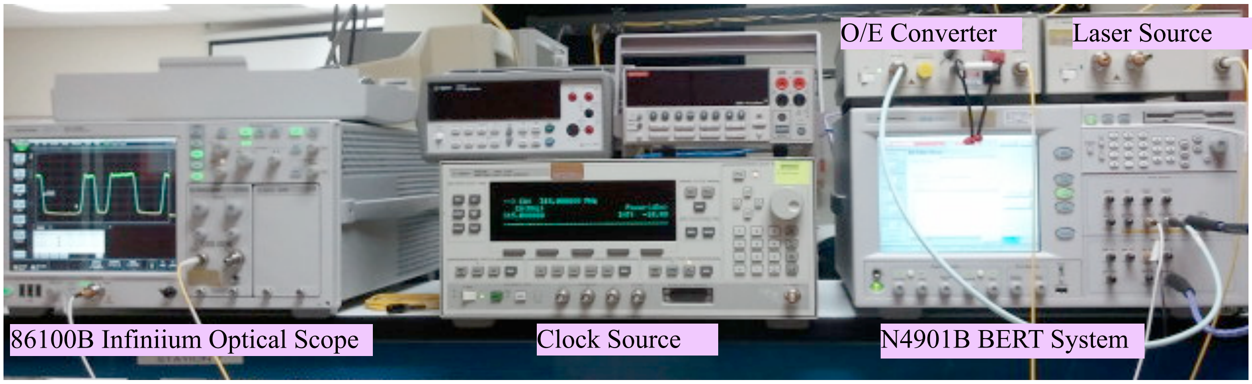

Figure 2: Remote optical laboratory.

A webcam is provided to observe any changes in instruments' displays. Furthermore, in order to create an effective remote laboratory experiment, the platform provides video conferencing capability using Video Conferencing application, accessible from LabVIEW [11]. This feature allows video enabled live conversations, as well as chatting with a group of users. This is an effective environment for instructors to carry out live demonstrations for remote users.

In the following paragraphs we briefly describe each equipment in the setup shown in Figure 1. Note that Figure 2 depicts some of the actual instruments used in our proposed Internet-based laboratory.

HP 8156A Attenuator: This unit is capable of attenuating the output optical signal down to -60dB. The LabVIEW VI for the attenuator module is shown in Figure 3 (a). The instrument also allows adjusting the wavelength of the output optical signal.

HP 86060C Optical Switch: Each switch has 2:4 ports, which can be used as input/output ports. Using our LabVIEW interface optical switching from any input to any output port can be performed individually. In our experiment we used multiple optical switches for providing a more robust setup. The LabVIEW VI for the optical switch is shown in Figure 3 (b).

HP 86120B Multi-wavelength Meter: This instruments offers a number of features, including monitoring the optical power and wavelength of the received optical signal. These measurements are performed using the designed LabVIEW VI, as shown in Figure 3 (c).

Web Camera: The LabVIEW VI for the Web Camera is shown in the Figure 3 (d). The webcam is pointed at front panels of the instruments to give students a more realistic feeling of the physical instruments.

N4901B BERT: In addition to the instruments mentioned above we added an Agilent N4901B BERT (Bit Error Ratio Test) to our setup for more advanced laboratory experiments. N4901B BERT allows measuring eye opening, including its width and height for various optical and electrical signals, including STS-3, OC12, and OC48 signals. A major feature of BERT is its capability to measure signal bit-error-rate (BER). Bit-error-rate can change due to signal integrity, dispersion, and attenuation. Figure 2 shows how the recovered electrical signal from the optical-to-electrical converter is directed to N4901B BERT. In this setup the clock signal to BERT is provided externally.

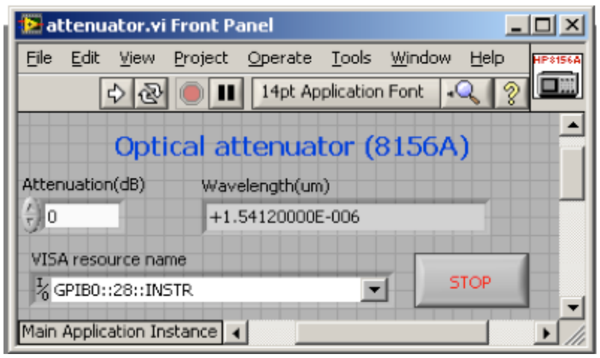

Figure 3(a): Optical Attenuator

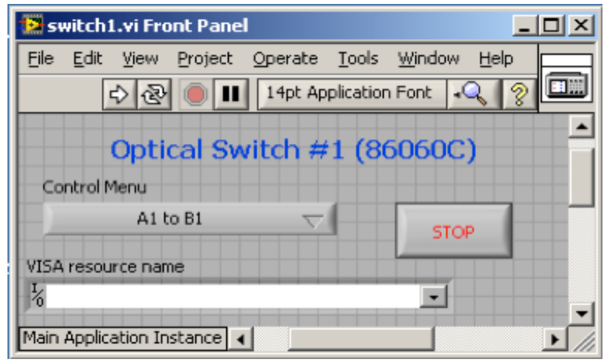

Figure 3(b): Optical Switch

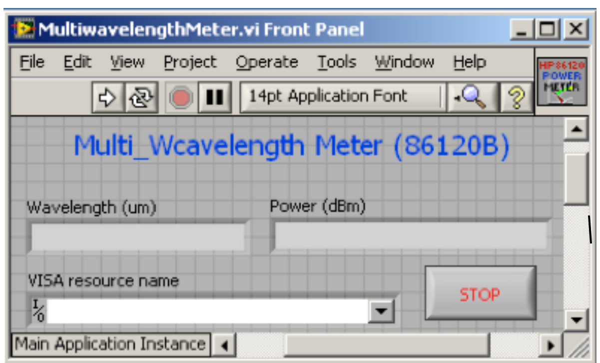

Figure 3(c): Multi-wavelength Meter

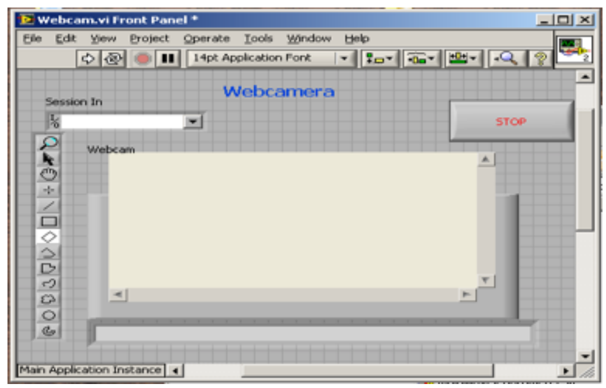

Figure 3(d): Webcam Module

LabVIEW Server: In order to fully control the remote instruments, the server and client sites must be properly configured. Table 1 describes all the components required to be installed and configured on the server and client sites.

On the server end, we used LabVIEW software to establish the Web Server. This was done by publishing the application VI using LabVIEW's Web Publishing feature. Publishing a VI refers to creating a web link to the application VI for remote client access through the web server. In order to provide a web link for the application, the remote laboratory platform requires a static IP address for the server that hosts the application. Moreover, the user has to configure appropriate firewall settings to allow access through the network.

On the client end, when the client accesses the application for the first time through the browser, the browser automatically installs two ActiveX plug-ins for IMAQ Vision[1] on the client PC *and* LabVIEW's Run-time plug-in. ActiveX controls are small programs, or *add-ons*, that are used on the Internet and enhance browsing experience by allowing animations.

Table 1: System configuration.

Server	**Client**
HW Requirement:	**HW Requirement:**
PC Server with a static IP address and High-Speed Internet	PC with High-Speed Internet
SW Requirement:	**SW Requirement:**
LabVIEW 2009 installed with: ➢ Measurement and Automation Explorer ➢ NI-VISA ➢ NI-IMAQdx ➢ NI Signal Express ➢ NI-488.2 ➢ LabVIEW Run- Time 9.0 ➢ Instrument I/O Library Suite	➢ A PC with LabVIEW supported browser e.g. Internet Explorer ➢ LabVIEW Run-time plug-in ➢ Two ActiveX plug-ins for IMAQ Support
Configuration: ➢ Enable LabVIEW's Web Server ➢ Publish Application VI from LabVIEW	

As we mentioned before, in our setup, in order to gain access to the remote laboratory setup over the internet, the client needs a browser, Server's IP address, and login-ID/password. Once the login and password values are checked and authentication is verified, the client is presented with the main menu to make a selection from different available lab experiments.

5. Laboratory Setup

We developed several lab experiments for remote students to complete. These experiments are designed to provide hands-on experience with variety of topics discussed in the first several lectures in an introductory course in optical communications. Thus, through these online activities, students receive hands-on experience in the following areas:

- Group and phase velocity;
- Pulse spreading and chromatic dispersion;
- Splitters and couplers;
- Attenuation and loss in fiber;

[1] IMAQ Vision for LabVIEW is a library of LabVIEW VIs that can be used to develop machine vision and scientific imaging applications.

- Single-mode and multi-mode fibers;
- Fiber bend loss.

Figure 4 depicts a basic laboratory setup, which includes an optical coupler, single-mode fiber, and a long spool of multi-mode fiber. We have created more complex setup, including Agilent 86100b Infiniium Optical Oscilloscope and Agilent N4901B BERT (as shown in Figure 2), however, in this section we limit our discussion to a simple case.

In the experiment shown in Figure 4, we used an ET 42464 Dual DFB light source operating at 1310 nm. In a particular scenario, a remote student can configure switch-1 and switch-2 such that the output of light source is directed to the multi-wavelength meter. To achieve this the output optical signal from the light source transmitter will be directed to port A1 connected to port B4 on switch-1, then form port B1 to port A1 on switch-2, going to the attenuator and then the multi-wavelength meter. As a result, by changing the attenuation value different received power levels can be measured. Similar configuration can be established to characterize the coupler's splitting ratio, and measure the output power from each of its outputs. Using this experiment, students can also configure the setup to characterize the 4.6 km fiber spool. More elaborate configurations, allow students to compare pulse spreading as the signal travels through long single-mode and multi-mode fibers.

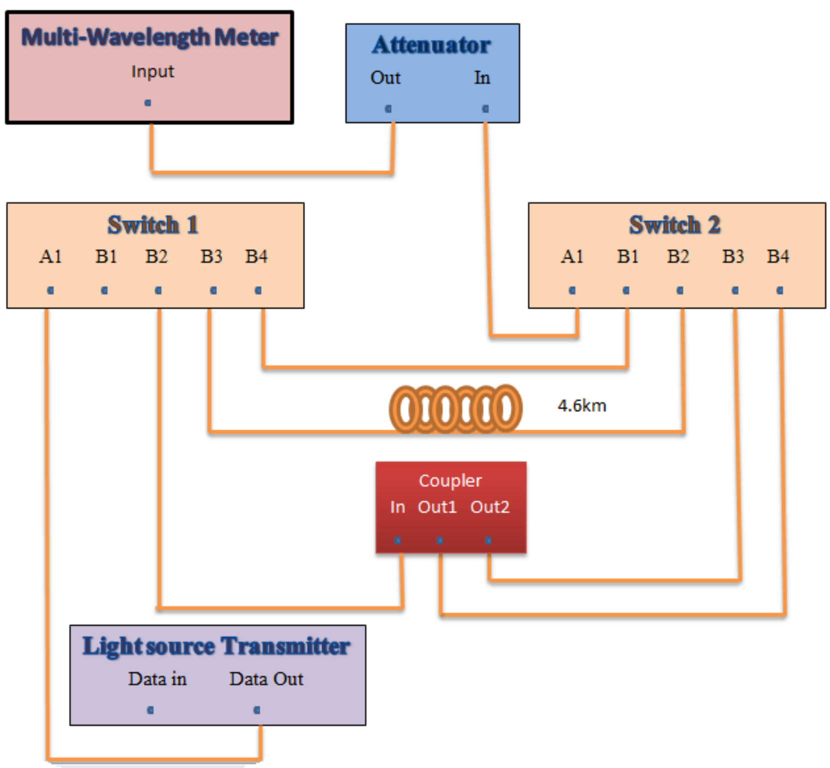

Figure 4: Experimental Setup.

6. Example Modules

In this section we briefly describe a sample laboratory exercise that we asked our students to complete remotely. The exercise includes two parts. These experiments are based on the setup shown in Figure 4.

Part 1: Connect the signal from the source to the input port A1 of switch-1. Connect output port B4 of switch-1 to input port B1 of switch-2 and output port B3 of switch-1 to input port B2 of switch-2 through an optical fiber of length 4.46 km. Connect the output port A1 of switch-2 to the attenuator's input. Connect attenuator's output to the Multi-wavelength Meter. Answer the following questions:

1. Measure the received power using the Multi-Wavelength Meter in dB and mW: Power __________(dB)____________(mW)
2. Measure the received signal power after passing through 4.46 km of fiber: __________(dB) ____________(mW)
3. Calculate the loss in the fiber in dB/km.
4. Record the received power by changing the attenuation level. Plot the results (attenuation vs. received power level (dB).
5. Record the wavelength of the received signal with and without the fiber spool.

Part 2: Connect the signal to the input port A1 of switch-1. Connect the output port B2 of switch-1 to the coupler's input. Connect the outputs Out1 and Out2 of the coupler to inputs B4 and B3 of switch-2, respectively. Answer the following questions:

1. Find out the splitting ratio of the coupler.
2. Calculate the insertion loss due to the coupler.

7. Example Modules

This project was completed by two graduate students over the course of two months. None of the participating students had any prior experience with LabVIEW or SCPI commands. However, the students had already taken the Optical Communications course and completed all the lab activities. The actual time spent on setting up and implementing the remote laboratory was less than three weeks. We note that all the lab activities and setup information were already available.

A number of our students reported random cases of system failure while using the remote laboratory. After making some software modifications, we have been able to improve system performance, considerably. More long term tests are required to ensure 100 percent system reliability. We also realized that remote users with slow computers or Internet connections experience long delays (up to 30 seconds) in receiving data and webcam images.

Another unexpected challenge was obtaining a static IP address from the IT department at the university.

8. Outcomes

All together 12 engineering students operated the remote laboratory over the past 4 months. At the end of the semester, these students were asked to complete a mandatory short survey. The survey was primarily based on quantitative questions with the last question asking for student comments and suggestions. The responses to some of the quantitative questions are shown in Table 1.

Table 1. Responses of students to the survey.

Questions	4. Very much	3. For the most part	2. Almost / Not Sure	1. Not really
Do you feel the remote laboratory experiments helped you to master the related topics better?	**60%**	40%	0%	0%
Were you able to complete the experiment in a timely manner?	40%	**55%**	5%	0%
Did you experience any technical difficulties while completing the experiment?	0%	5%	20%	**70%**
Would you prefer to replace hands-on activities with the remote laboratory?	0%	15%	15%	**70%**
Would you prefer to combine hands-on activities with the remote laboratory?	**70%**	15%	15%	0%

In several cases, our students have reported minor software issues. These problems have been addressed. The way the webcam has been placed can be improved. Based on student feedback, incorporating a controllable webcam can be highly desirable. We asked our students to redo the first three optical communications lab experiments using the web-based setup. Majority of them believed that the remote laboratory can be very beneficial. Several students pointed out that they preferred to physically be present and work with the instruments. Overall, however, based on their feedbacks, most students were satisfied with the remote laboratory setup and expressed interest in being able to complete the laboratory online, rather than having to come to the lab.

Based on the received limited feedback from our students, we believe that remote laboratory should not replace hands-on activities. Instead, remote laboratory can be used as a complement to hands-on activities after the students have become familiar with the physical instruments. Otherwise, the remote laboratory will be perceived as yet another simulation tool.

Finally, it must be noted that a key motivating element in this work has been making the remote instrumentation available to other institutions and establishing collaborations with them. Thanks to continuous support from Agilent Technology, both in terms of providing testing equipment and expertise, Sonoma State University is very fortunate to have access to variety of state-of-the-art optical test equipment. As a result, a unique feature of our remote laboratory setup is to allow remote users from different institutions to request different laboratory experiments; they can describe the setup and specify a suitable time slot to access the server.

9. Future Works

A key improvement for the optical communications laboratory in the future will be enhancing the setup to include more instruments. In this phase of the project we focused on development of remote laboratory using a central server. In our future distributed design, we plan to support multiple seamless experiments from different sites. This is particularly useful when different simultaneous remote users would like to perform different experiments. Another area of improvement in the future is to develop and incorporate online simulation modules. Thus, students can carry out some pre-lab experiments using an online simulation software[10] and then complete the remote laboratory assignments.

10. Conclusion

In this paper we introduced a LabVIEW-based remote instrumentation platform that enables students to remotely perform various basic experiments in an undergraduate optical communications course. The purpose of this experiment was to provide a cost-efficient and flexible learning and training delivery to remote users. This project was designed to be included in our existing unified platform to support a range of diverse learning tools, such as configurable remote laboratory, video conferencing, and simulations.

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