THERMAL SCIENCE AND ENERGY ENGINEERING COLLECTION

Derek Dunn-Rankin, *Editor*

Heat Transfer Virtual Lab for Students and Engineers

Theory and Guide for Setting Up

Ella Fridman

Harshad S. Mahajan

MOMENTUM PRESS
ENGINEERING

HEAT TRANSFER VIRTUAL LAB FOR STUDENTS AND ENGINEERS

THEORY AND GUIDE FOR SETTING UP

ELLA FRIDMAN AND
HARSHAD S. MAHAJAN

MOMENTUM PRESS

MOMENTUM PRESS, LLC, NEW YORK

Heat Transfer Virtual Lab for Students and Engineers: Theory and Guide for Setting Up

First published by Momentum Press®, LLC
222 East 46th Street, New York, NY 10017
www.momentumpress.net

ISBN-13: 978-1-60650-548-9 (print)
ISBN-13: 978-1-60650-549-6 (e-book)

Momentum Press Thermal Science and Energy Engineering Collection

DOI: 10.5643/9781606505496

Cover design by Jonathan Pennell
Interior design by Exeter Premedia Services Private Ltd., Chennai, India

10 9 8 7 6 5 4 3 2 1

Printed in the United States of America

HEAT TRANSFER VIRTUAL LAB FOR STUDENTS AND ENGINEERS

Abstract

Laboratory experiments are a vital part of engineering education, which historically were considered impractical for distance learning. In view of this, the proposed book presents a guide for the practical employment of a heat transfer virtual lab for students and engineers. The main objective of our virtual lab is to design and implement a real-time, robust, and scalable software system that provides easy access to lab equipment anytime and anywhere over the Internet. We have combined Internet capabilities with traditional laboratory exercises to create an efficient environment to carry out interactive, online lab experiments. Thus, the virtual lab can be used from a remote location as a part of a distance learning strategy. Our system is based on client-server architecture. The client is a general purpose java-enabled web-browser (e.g. Internet Explorer, Firefox, Chrome, Opera, etc.) which communicates with the server and the experimental setup. The client can communicate with the server and the experimental setup in two ways: either by means of a web browser, which runs a dedicated CGI (Common Gateway Interface) script in the server, or using the LabVIEW Player, which can be downloaded and installed for free. In both cases, the client will be capable of executing VIs (Virtual Instruments) specifically developed for the experiment in question, providing the user with great ability to control the remote instrument and to receive and present the desired experimental data. Examples of this system for several particular experiments are described in detail in the book.

KEY WORDS

armfield, distance learning, engineering education, heat exchanger, heat transfer, heat transfer laboratory experiments, HT-30xc CGI (Common Gateway Interface) script, LabVIEW Player, online lab experiments, remote instruments, virtual laboratory, VIs (Virtual Instruments)

List of Figures

Figure 1.1.	Key elements of a virtual lab	8
Figure 1.2.	How JVM functions	12
Figure 2.1.	Debugging tools in LabVIEW	16
Figure 2.2.	Front panel	19
Figure 2.3.	Block diagram	20
Figure 2.4.	Tools palette	21
Figure 2.5.	Controls palette	23
Figure 2.6.	Functions palette	25
Figure 2.7.	Front panel of simple calculator	26
Figure 2.8.	Block diagram of simple calculator	27
Figure 2.9.	Programming structures in LabVIEW	28
Figure 2.10.	Example run of VI to demonstrate "For Loop"	28
Figure 2.11.	Block diagram of VI to demonstrate "For Loop"	29
Figure 2.12.	Block diagram of a VI to demonstrate "Sequence"	30
Figure 2.13.	Example run of a VI	30
Figure 2.14.	Front panel of a VI to demonstrate "Case structure"	31
Figure 2.15.	Block diagram of a VI to demonstrate "Case structure"	31
Figure 2.16.	Front panel of a VI to demonstrate "Formula node"	32
Figure 2.17.	Block diagram of a VI to demonstrate "Functions node"	33
Figure 2.18.	Data acquisition system components	33
Figure 2.19.	Dataflow in DAQ system	35
Figure 2.20.	USB ports	36
Figure 3.1.	Armfield Heat Exchanger service unit	40
Figure 3.2.	Location of "Call library function" VI	45

Figure 3.3. Function tab setup of "ReadAnalog" function via "Call library function" VI 46

Figure 3.4. Parameters tab setup of "ReadAnalog" function via "Call library function" VI 46

Figure 3.5. Function tab setup of "WriteAnalog' function via "Call library function" VI 47

Figure 3.6. Data representation for the arguments of WriteAnalog function 48

Figure 3.7. Selection of data representation as I16 48

Figure 4.1. Pre-lab instructions tab 53

Figure 4.2. Controls tab 56

Figure 4.3. Readings tab 56

Figure 4.4. Analogy of block diagram and front panel 59

Figure 4.5. Block diagram of the LabVIEW interface 60

Figure 4.6. Schematic of the CSTH 61

Figure 4.7. Sudden increase in Ti 62

Figure 5.1. Concurrent operation flow directions 75

Figure 5.2. Cocurrent operation flow directions 75

Figure 5.3. System response temperature (T1) versus time 79

Figure 5.4. Parameter "P" versus time 79

Figure 5.5. Parameter "I" versus time 82

Figure 5.6. Parameter "D" versus time 82

Figure 7.1. Sustained oscillations in the system response 99

Figure 7.2. Unbounded output of the system 100

Acknowledgments

I would like to express my sincere thanks to my guide Dr. Ella Fridman for her continuous support and encouragement throughout the duration of the project. Her timely suggestions and patience in difficult phases of my project were instrumental in successful completion of the project. Special thanks to Dr. Clark Colton for giving me access to the online experiments at Massachusetts Institute of Technology. The actual online-experiment experience helped me understand my project better.

Successful completion of my project would not have been possible without the initial help of my senior, Viji Venkatachalan. Her initial insight into the project, as well as helping me grasp the "LabVIEW web publishing tool," saved me a good deal of project time.

Sincere thanks to Mr. Allen Rioux for providing me with the required information for FTP access on the web server. Thanks to Al for extending his help in fixing the mechanical problems with the equipment. Last but not least, I am also grateful to all the students who used this project to perform their lab experiments and provided us with their invaluable feedback that helped improve the project.

Contents

List of Figures ix

Acknowledgments xi

1 Introduction **1**

1.1 History of Distance Learning and Concept of Virtual Lab 1

1.2 What Is Virtual Lab? 2

1.3 Analysis of the Project Requirements 4

1.4 Learning Theory and Its Influence on Role Design 6

1.5 System Architecture 7

1.6 Model Hierarchy 9

1.7 Web User Interface 9

1.8 Questions 11

2 LabVIEW Basics **15**

2.1 LabVIEW Introduction 15

2.2 G-Language 16

2.3 Front Panel 17

2.4 Block Diagram 19

2.5 LabVIEW Palettes 20

2.6 Programming with LabVIEW 21

2.7 Programming Structures 27

2.8 Data Acquisition with LabVIEW 32

2.9 Questions 37

3 Hardware: Armfield Heat Exchanger and HT30XC Service Unit **39**

3.1 Operating HT30XC Using Customer-Generated Software 39

3.2 USB Interface Driver Function Calls 42

3.3 Labview Data Logger 44

4 Design of LabVIEW VI Program 49
4.1 Software: Algorithm of the Program 50
4.2 Introduction of LabVIEW Controls Used in the Project 51
4.3 Design of Front Panel 53
4.4 Design of Block Diagram 58
4.5 How Were the PID Parameters' Values Derived for Temperature Control? 60
4.6 Questions 65

5 Experiments 67
5.1 How to Perform an Experiment Using the LabVIEW Interface? 67
5.2 How Would a Student Access the Experiment Over the Internet? 67
5.3 Experiment Results 69

6 Factors Influencing the Virtual Lab 87
6.1 Drivers for Programmable Devices 87
6.2 Concurrent Requirements for Same Experiment 88
6.3 User Authentication 89
6.4 Issues Surrounding Live Training 89
6.5 System Management and Development 91
6.6 Future Developments 92

7 Experiment Instructions 95
7.1 Instructions for the Shell and Tube Heat Exchanger Experiment 95
7.2 Instructions for the PID Control for Heater Experiment 96

8 Related Work 103

Bibliography 105

Index 107

CHAPTER 1

INTRODUCTION

The objective of this project is to design a user-friendly and efficient system for interactive, online operation of remote education laboratory equipment and experiments utilizing the Internet. This chapter introduces the concept and short history of Virtual Laboratory and discusses its needs and advantages. As a part of the requirements analysis for the Virtual Lab project, we touch upon topics such as the overall system architecture and model hierarchy, role design, and web user interface design. This chapter lays the foundation for the rest of the book.

1.1 HISTORY OF DISTANCE LEARNING AND CONCEPT OF VIRTUAL LAB

During the last decade, we have witnessed rapid developments of computer networks and Internet technologies along with dramatic improvements in the processing power of personal computers. These developments make interactive distance education a reality. By designing and deploying distributed and collaborative applications running on computers disseminated over the Internet, distance educators can reach remote learners, overcoming the time and distance constraints.

Besides the necessary theoretical base provided by lectures and written materials, hands-on experience provided by physical laboratories is a vital part of engineering education. It helps engineering students become effective professionals. It not only provides students the knowledge of the physical equipment but also adds the important dimension of group work and collaboration. However, laboratories are expensive to setup, to maintain, and to provide long hours of daily staffing. Due to budget limitations, many universities and colleges can provide only limited access to such physical equipment. Therefore, it is imperative to enable remote access to a physical laboratory, as part of either an onsite or distance-learning course.

Students like it better if given a chance to collaborate in small learning groups. They are more motivated if they are in frequent contact with the instructor. Therefore, the incorporation and reinforcement of collaboration and interaction to support real-time video and audio communication are becoming important features of remote laboratories. The objective of this project is to design a user-friendly and efficient system for the interactive, online operation of remote education laboratory equipment and experiments, utilizing the Internet. Our goal is to introduce a remote lab design that is simple, scalable, and flexible enough to allow users, who may not be computer experts, to use the system to conduct virtual experiments. The particular focus of this work is the design of a real-time, robust, and scalable software system for use in thermodynamics courses to provide students with hands-on experience with a heat transfer experiment for them to compare measured characteristics with theoretical predictions and reflect on discrepancies, limitations, and design constraints. The system must run 24×7 to allow students to access it round the clock.

The heat exchanger unit used was a general-purpose service unit, designed by Armfield Ltd, which supplied facilities and infrastructure and was used in conjunction with a range of small-scale accessory equipment for carrying out specific experiments involving heat exchangers. The service units are operated and controlled via LabVIEW software on a computer that, in turn, functions as a server with LabVIEW software and that enables monitoring and control of the experiment on the Internet. For remote operation of the experiment, it requires a browser and plug-in that supports the Java 2 Runtime Environment (or the preceding) and the LabVIEW 7.0 (or the preceding) Runtime Environment.

1.2 WHAT IS VIRTUAL LAB?

The main objective of a Virtual Lab is to design and implement a real-time, robust, and scalable software system around laboratory equipment that provides a "learner" an easy access to the lab equipment anytime and anywhere over the Internet.

The Internet offers interesting possibilities for disseminating educational material to students, both locally and as part of remote education. Laboratory experiments are a vital part of engineering education, which have so far been considered impractical for distance learning. However, recent advances in Internet technologies and computer-controlled instrumentation presently permit Internet-based techniques to be utilized for setting up remote laboratory access. Also, the use of Internet and studio classrooms is an emerging trend for promoting "individual discovery" as a strategy for enhancing engineering education.

Here, we describe how these techniques can be combined with traditional laboratory exercises to create an efficient environment for interactive online operation of lab experiments over the Internet, to be used either in a studio setting or from a remote location as part of a distance-learning strategy. Our system is based on client-server architecture. The client is a general purpose java-enabled web browser, for example, Internet Explorer, Firefox, Chrome, Opera, and so forth. Web browsers communicate with the server and the experimental setup. In some cases custom desktop software can be used as a client.

Previous versions of remote lab were based on a transmission control protocol/Internet protocol (TCP/IP) solution, which used Java applet technology on the client (i.e., student) side. This was achieved by virtue of a Java virtual machine (JVM) in the web browser that could download and execute Java applet code. The client would see a pop-up window that provided interaction and communication directly with the server. However, unsigned applets make it tough for the client to store and present the measurement data, and to transfer them to other applications (except by "cut-and-paste") because of Java's security structure. An intermittent problem with Java applet is that the functionality of an applet may vary between different browsers.

The LabVIEW software from National Instruments offers an interesting solution for measurement and control system. It also provides the desired Internet access to the lab, out of the box. It has the following interesting features:

1. Graphical programming
2. Simplicity in design
3. Acquire and save the measurements and readings for further analysis in various file formats including xls, csv, txt, and so forth
4. Stand-alone instrument control through vendor-specific or generic plugins
5. Automated tests and validation system

In this solution, the lab-side server runs a "full version" of LabVIEW, which incorporates Internet communication capabilities and functionalities to access/control instruments and to acquire/output data. The client can communicate with the server and the experimental setup in two ways: either by means of a web browser, which runs a dedicated Common Gateway Interface script in the server, or by using the LabVIEW Player, which can be downloaded and installed for free. In both cases, the client will be capable of executing virtual instruments (VIs) specifically developed for the experiment in question, providing the client with great ability to control the remote instrument and to receive and present the desired experimental data. The other solution seeks to exploit the additional functionally of the recent browsers, enabling the server system to respond in many different formats, such as JavaScript, HTML, or eXtensible Markup Language (XML), which gives the client great flexibility in storing, processing, and presenting the data received. This is achieved by creating web solutions based on either the information server application information interface (ISAPI) server extensions, or on a component object model with extensions (COM+) solution at the lab side.

1.3 ANALYSIS OF PROJECT REQUIREMENTS

The project intends to increase its student base through online education aimed at fulfilling the needs of remote students. Remote students need time flexibility, instant guidance, and feedback. This project intends to design a system around virtual labs to achieve exactly that in a perfect pedagogical approach. The project places great emphasis on laboratories that account for approximately 40 percent of program content. The distance-learning program must continue to offer the same quality of interaction with the faculty and the laboratory that it now offers its onsite students. Remote laboratories have been successfully used in electrical engineering education to interact with spectroscopy, measurements, and control systems laboratories. The same is to be achieved for mechanical engineering students.

This book describes the pilot version of a remote interactive laboratory that is used for thermodynamics laboratories by students from remote sites. In a remote delivery scenario, it is important that the delivery mechanism, laboratory course content, and instructional design be tailored to

1. Model an active remote-learning environment that engages the student in achieving learning outcomes
2. Model a collaborative environment for group interactions
3. Design appropriate roles for supporting the collaborative environment
4. Provide unambiguous feedback and instant guidance to the students
5. Match the characteristics of the media (delivery medium) to specific learning outcomes and processes