CHAPTER 1

INTRODUCTION

Laboratories play a paramount role in technical education. Internet based remote laboratories allow online experimentation with real equipment at the user’s location. Online access and control of complex hardware is a compelling issue in remote laboratories and industrial applications. Automation is changing the nature of these laboratories and the system designers now increasingly focus on Internet accessed experiments owing to the availability of several tools to integrate electronic and mechanical hardware with the world-wide-web. Recent years have seen tremendous innovations in integrating remote access hardware or equipment for web-based learning. This is an economical and effective approach in laboratory based course delivery systems, fully exploiting the advances in information technology.

Generally, laboratories can be categorized as hands-on classical laboratories, virtual laboratories and remote laboratories. Classical laboratories are traditional laboratories where the users are physically present in the laboratory. Historically, this was the first type of practical lab requiring systems in their work place or ones location. Virtual laboratories are interactive environments for creating and conducting simulated experiments by means of computers. It is possible to offer “virtual laboratories” to users via world-wide-web [DWB07], through internet access. Remote Laboratories allow users to remotely access equipment and instruments and facilitate to perform experiments on actual lab equipment in real-time over the Internet [FZO08].

The classical or hands-on laboratories are already mediated by computers with the advent of computing technologies. The interactive quality of laboratory participation may not differ much for the experiment involving measuring an output through a computer connected to the experiment apparatus, whether the student is collocated with the apparatus or not. Hands-on labs place a high demand on space, instructor time and experimental infrastructure, all of which are subject to rising costs. Further, owing to the
limitation of space and resources, hands-on labs are unable to meet some of the special needs of differently enabled and distant users. Virtual or simulated laboratories are the imitations of real experiments using computers. Simulation labs are valuable in some cases because it reduces the burden of creating real laboratory infrastructure and reduces learning time [JMJ10]. However, realistic simulations take a large amount of time and expense to develop and still may fail to faithfully model reality [JJ07].

Remote laboratories are characterized by mediated reality where users obtain data by controlling geographically detached equipment. They require space and devices in case of hands-on labs, but the resources are accessed and controlled through a computer network. Remote labs can extend the capability of conventional laboratories by sharing experimental devices remotely using web-learning tools [MBV08].

This thesis presents a web based interface for remote experiments on a communication circuit, electrical machines, a microcontroller based control and a simulated experiment on process control systems. The different experimentation environments are chosen with the objective of bringing different kinds of engineering experiments on to the same platform using a common framework. The emphasis is on the development of computer-interface for the wide-range engineering experiments to support educational features online with learning outcomes on par with the traditional classical laboratory experimentation. The important component to create remote experimentation facility is the LabVIEW Virtual Instrumentation (VI) tools integrated with real hardware to perform tasks in real-time. Graphical programming tool LabVIEW supports a built-in web-server where the virtual instruments used in experiments can be published over the web. It provides a development platform to control experimental system operations remotely and displays measured parameters in real-time [LUN11] [Mer06].

The web based environment for remote experiments is created by developing custom built interface circuits along with the data acquisition system NI (National Instruments) PCI6251 and LabVIEW 8.5. The remote experiment on communication circuit is illustrated with the generation of frequency modulated signal for different carrier frequencies. Web based experiment on electrical machines is presented by developing interface for electrical signal acquisition and control for separately excited
DC motor and generator. The web based interface structure for microcontroller is illustrated with the experiment on stepper motor control. The remote experimentation approach for process control system is described with the virtual instruments (VI) developed using LabVIEW control design and simulation module 8.5.

The remote experiment on frequency modulation describes the web based interface for a communication circuit along with the transistor switching circuitry for the hardware component selection based on the design requirement. The user interface is created to control the circuit components, apply input voltages and to display waveforms and the frequency spectrum. The input and output signals of the circuit is acquired and displayed on the user interface through the LabVIEW graphical display functions.

National Instruments (NI) Data acquisition (DAQ) systems have been used for the design of control and measurement on low power circuits and systems. A web based interface has been designed for a separately excited DC motor and generator, demonstrating the possibilities of flexible operation in complex hardware experimentation with the adaption of VI tools and the custom designed circuits. The novel computer interface techniques are described to create remote experimentation environment on DC machines. The custom built interface circuits extend the data acquisition capacity of NI PCI6251 from 0-10V DC to the range 0-300V DC required for the experiments on DC machines. The designed system supports the web based control of input voltage 0-250V for motor and generator in steps of 1V. The interface circuits for control and measurement links the experiment set-up consisting of 1.5 KW DC motor and 750W DC generator with the web server. The experiment parameters such as DC voltage, DC current and RPM are suitably converted to interface with DAQ card PCI6251 and measured through LabVIEW virtual instruments. The sophisticated computer-interface structure is designed to address safe and user-friendly operations for the remote control and measurement related to the separately excited DC motor and generator experiments. The custom-built circuits for control and measurement of experimental parameters are designed to provide facilities similar to real system operations. Customized modules in electrical hardware experiments provide vital features with ease of operation either using keyboard or mouse offering designers the flexibility to make changes based on the user’s learning curve.
Programming applications have significant impact on engineering studies with the advent of computer technology. Microcontroller-based systems play an important role in engineering design. Experimentations with Microcontrollers are vital in electrical and electronics engineering. Simulation programs are widely used to learn the basic functionalities, but real experiments are essential to design an application optimally utilizing the built-in capabilities of the microcontroller. Remote access and control techniques have been designed for microcontroller based systems. The NI graphical tool, LabVIEW and data acquisition facilities are used to develop control environment for a stepper motor using microcontroller. It is essential that remote microprocessor laboratory developers chose desktop virtualization to provide program debugging [GPA06]. The web based control for microcontroller experiment is implemented by interfacing PIC16F877 development board with NI DAQ PCI6251.

Graphical programming language LabVIEW is the most widely used in the remote hardware experiment on circuits and control systems. The use of virtual instruments in the control of process system parameters leads to extension of control environment from local to remote experimentation practices. The experimentation environment for process control systems is developed using LabVIEW control design and simulation module 8.5. The control simulation module provides rich features and less time to develop control algorithms and system models [UM07]. The process control system is mathematically modeled by considering the real specifications of the physical system and the control algorithms are designed for the bioreactor’s process parameters such as temperature, pH and agitation speed. The remote access features of LabVIEW can be used to integrate the process control features with the WWW (World Wide Web). The LabVIEW GUI facilitates to set the system parameters, PID coefficients and to observe output actuations of the process system.

Design of online learning environment requires various resources to deliver instructions and to enhance the quality of learning. The e-learning tools provide a chance for learners to interact with a trainer or other users and supports group learning. The remote lab facilities are best utilized when the Computer Supported Collaborative Learning (CSCL) tools are embedded with its user interface. CSCL tools have gained increased attention in recent years to enable constructive approaches in web learning.
Learning Management System (LMS) manages training and other educational activities over the Internet with features for online collaboration. LabVIEW virtual instruments and LMS tool such as MOODLE (Modular Object Oriented Dynamic Learning Environment) provide an ideal platform for developing instructional curriculum and for conducting scientific experiments [UHJ07] [MJA09].

1.1 Current Literature

Remote laboratories through the web are in-existence for more than a decade. One of the first online experiments was carried out on ASEA-Irb-6 robot and reported in the year 1994 [SG07]. Literature reveals that there have been successful implementations of remote laboratories on electrical and electronic circuits [CBS01] [DAT09], electromechanical systems [JMT02] [DBV05], power electronics [WC05] [Bau07], embedded systems [GAH08] [GPA06], robots [KPS02], control systems [NOF02] [NZ08] etc., Standalone approaches in remote learning have grown tremendously in the recent years. The ability to combine practical applications with the visualization using the virtual instruments and multimedia tools is the advantage of technology-based learning systems. The major consideration in remote laboratories is to make the user interaction with the distant system as close as possible to the physical work with real hardware.

Virtual instruments are the motivational components for distance education in science and engineering. The Internet revolution has opened up newer approaches and possibilities in remote access techniques. Some of the important tools used for remote experimentations in engineering education are Virtual Instrumentation, Web browsers/Servers, CGI/DataSocket, LabVIEW/Java Programming and MATLAB/Simulink [RLO10] [NOM08] [TLL00]. The use of such software minimizes the requirements of physical facilities.

Various issues and experiences have been presented in web based learning and remote experimentation. It is observed that most of the remote laboratories fall into either the engineering domain or the science domain [JJ07]. Some of the examples of online laboratory websites and the Universities offering online courses in engineering have been listed by John Bourn, et. al., [JDF05]. In the electronics and electrical engineering domain, the laboratories are distributed over a wide range of experiments which include
device characterization, system control and programmable applications. LabVIEW tools with low power data acquisition is available for remote access of electronic hardware which can be used for control applications and remote laboratory experiments [LUN11] [UM03a] [UM06b]. Research articles have been divided into separate categories and presented here.

1.1.1 Remote Experiments on Low Power Circuits and Systems

It is found that most of the remote access techniques described belongs to the experimentation on low power devices and circuits [AAA07]. The data acquisition systems such as National Instruments PCI 6251 and LabVIEW are the major facilitators in the design of web based electronic laboratory experiments.

1.1.1.1 Electronic Devices and Circuits

C.C Ko, et. al., [CBS01] presents a web based virtual laboratory on a frequency modulation experiment where remote users are able to gain access to actual physical apparatus using LabVIEW and through Java applet programming. The web-based experiments on electronic circuits allow remote users to gain access to the actual physical apparatus using standard data acquisition and GPIB interfaces. The use of LabVIEW and GPIB interface in electronic laboratory experiments are also reported by C. C Ko, et. al., [CBC00] and Sanjib Das, et. al., [SSG06]. Generally the remote laboratory experiments are built over pre-fixed readily available components and devices. The flexibility over the experimentation can be increased by allowing the user to make changes in circuit components remotely. This is achieved by operating a remotely controlled switch matrix to replace the traditional breadboard [FKR02] [Ing03]. Virtual Instrumentation tools are used in the remote hardware experiments for control and measurement of various parameters online [SA05]. LabVIEW VI tools used in the development of remote laboratory with multimedia features are described by Amit Chaudhuri, et. al., [ACA03] and Carl Steidley, Rafic Bachnak [CR05] and the specific cases for Digital Signal Processing, analog and digital communication courses are presented by Kalantzopoulos, et. al., [KKZ08] and Yayla, Akar [YA08]. Remote laboratories extended to the field of advanced communication experiments such as optical fiber and antenna laboratory are presented by McKenna, et. al., [MDB05], Sergio Szpigel, et. al., [SEF07] and Nilsson et. al., [NZP08].
1.1.1.2 Control Engineering Experiments

Research on remote experiments on control engineering uses remote access techniques similar to those used in electronic circuits, but with emphasis on control objectives besides measurement and display. Moreover, the first remote laboratory that emerged in mid 90s was control engineering and robotics where the users were allowed to remotely access and control real equipment.

The necessary competencies and facilities to implement real-time control solutions are described by Ch. Salzmann, et. al., [SGH00]. Graphical tool LabVIEW and DAQ boards form an integrated framework for fast prototyping of real-time control solutions along with the control algorithms implemented in C programming and S-functions (MATLAB scripts describing SIMULINK). A distant laboratory using LabVIEW by K. K Tan , et. al., [TLL00] describes an experiment on real-time modeling and control of a pilot-scale DC servomotor. Remote experiments to support learning of controller algorithm and automatic control of physical systems developed using LabVIEW are described by Cvjetkovic, et. al., [CMS08]. Recently new tools such as web and RCP (Rapid Control Prototyping) with great impact on the control systems have been used in the industry and education environment [UHJ06]. The use of DSP-2 Rapid Control Prototyping in the remote control of DC motor is presented by Safaric, et. al., [STH05] and Darko Hercog, et. al., [DMK06]. The PID (Proportional, Integral and Derivative) control algorithm used for the control of almost all the loops in the process industry and also forms the basis for the implementation of many advanced control algorithms. The selection of controller parameters for PID algorithm using LabVIEW and experimented with thermal plant control is described by Nicoleta S Hulea, et. al., [NOM08] and Mohammad A.K. Alia, et. al., [MM04].

A friendly user-interface is required when the control equipments are operated remotely. The development of user interface for remote control engineering experiments using Java scripts & HTML and MATLAB & SIMULINK environment for real-time control is presented by C. Schmid [Sch03] and Carlos A.V.Junior, et. al., [CCA05]. S. Dormido. et. al., [DVS07] describes the development of user-interface for control engineering experiments for virtual and remote laboratories using Easy Java simulation tool and LabVIEW.
1.1.2 Remote Access and Control of Power Experiments

It is found that the idea of remote laboratory has attracted learners to the study of power electronics and electrical drives control theory and practice [VP05] [ERB06]. The use of data acquisition system with suitable hardware and software are frequently used with electrical power system experimentation. These tools allow the users to monitor and interface the experimental assembly to analyze the signals and their harmonics.

William Gerard Hurley and Chi Kwan Lee [WC05] describes the use of simulation tools iPES (Interactive Power Electronics Seminar) & PSpice for pre-laboratory assignments on power circuits and remote laboratory experiment on a dc-dc buck converter using LabVIEW. The measurement of power system harmonics using graphical programming tool LabVIEW is described by Hsiung Cheng Lin [Hsi06]. A software reconfigurable e-learning platform for power electronics courses is proposed by Shun-Chung Wang, et. al., [SYY08]. The use of LabVIEW and multimedia technologies along with circuit simulation software deepens the user comprehension in learning power electronics systems.

Internet technology together with acquisition and analysis tools allow remote access of complex electrical experiments and power systems with visualization and storage of signals for later analysis. The hardware and signal conditioning requirements for laboratories in the institutions may vary and there is no fixed solution for implementation of remote experimentation systems. Development of remote experiments on electrical power systems using Hall tension and current sensors for signal conversion and LabVIEW for signal measurement and display is illustrated by Jose Aquiles Baesso Grimoni [Jos07]. Nesimi Ertugrul, [Nes00] [Nes98] describes a virtual laboratory for electric circuits and machines using LabVIEW for programming, data capturing and data analysis. A Hall Effect current transducer for current measurement and an isolation amplifier for voltage measurement are interfaced with the DAQ card and the measured signals are scaled appropriately using virtual instruments. Power electronic circuits operated with high voltage and current are brought to the level of low power data acquisition systems through a suitable down-conversion circuits or voltage & current transducers. A lab set-up for the real-time study of electric drives using RT-LAB module
and LabVIEW based human-machine interfaces for test and measurement are described by F. Mak, et. al., [MSS08].

1.1.3 Web Experiments on Programmable Systems

Programming concepts are basic to microcontrollers and forms one of the fundamentals in electronics engineering disciplines. The efficient way to introduce these topics in education is through practical exercises instead of theoretical explanations. The available literature in this domain describes the technological tools and exercises which support web learning of programmable systems.

It is essential that remote microprocessor laboratory developers choose desktop virtualization to provide program debugging, which permits the users to download the code, monitor and control registers, memory content and execution. Application virtualization which manages the debugging of microcontroller codes using CITRIX application server and LabVIEW for remote interaction between the system and the user is presented by M. Gilibert, et. al., [GPA06]. Helmut Bahring, et. al., [HJW04] presents a WebLab on microprocessor by combining virtual and remote aspects of remote experimentation under a single user-interface. The remote server is accessed either through a remote shell or web-based VNC (Virtual Network Computing) techniques. In VNC systems, server machines supply not only applications and data, but also an entire desktop environment that can be accessed from any Internet connected machine using simple software such as NC (Network Computer). Simulation tools are traditionally used in the learning process, but they cannot be as effective as that of physically working with the real systems. Computer aided learning system by replacing the simulator with real microcomputer to practice general fundamentals and providing automatic exercise work are presented by H. Cimen, et. al., [CYN08] D. Fuduric, et. al., [FZO08].

Remote laboratories usually are dependent on a computer server that is placed between the experimental system and the remote user. It is required that the integrated learning environment augmented by remote laboratories must successfully achieve the necessary balance between theoretical material delivery and practical exposure. M.J Callaghan et. al., [CHM06] [CHM07] presents a client-server architecture for distant access to an integrated learning environment for remote experimentation on embedded
systems, where web-based e-learning approaches are complemented by utilizing existing on-campus resources.

The fundamental concept of programming is an essential part of computer and software engineering. Virtual laboratories assist in improving the learning process of practical programming and the general structure of a virtual programming lab is proposed by Josep Prieto-Blazquez, et. al., [JJA09]. Remote laboratories on programmable analog devices which allow the implementation of several analog circuits in ASIC (Application Specific Integrated Circuits) using circuit schematics are proposed by D.G Zutin, M.E Auer [ZA06] and Danilo Garbi Zutin, et. al., [DMA08].

1.1.4 Web-based Environment for Education and Training

Web-based learning is closely related to CSCL (Computer Supported Collaborative Learning) and CBT (Computer Based Training) [TJJ07] [GFB08]. Collaborative learning implies team learning, where the users synchronously learn together. Computer network technologies support collaborative learning among globally distributed users by providing space flexibility that distance education offers. More recent developments show the integration of collaborative learning tools with remote experimentation which enhances web-learning in lab-supported courses. Multimedia features have been included in computer-based applications in learning systems to facilitate better learning. With the significant progress in technology, it is possible to combine experimental resources with the web technologies to build pedagogical models for collaborative learning [JSL08].

Many organizations have implemented e-learning solutions using social software such as Moodle, .LRN, WebCT, Blackboard, etc., [ACE08]. In some cases (such as Moodle, .LRN), the organizations can customize the services provided by these social software according to their requirements. E-learning techniques, with the interaction of WebLab and LMS are described by H. Benmohamed, et. al., [BLP06], Fu-Chien Kao, et. al., [FTC06] and E. San Cristobal, et. al., [SMG07] [SMG08]. The instructor uses LMS tools to display the related theoretical material in an organized and controlled manner. The LMS tools can also be used for services such as administration, content packaging, document storage and assessments. WebLab modules with Moodle LMS tool [JH07] is proposed by L. Cirka, et. al., [CKF08] and Kuldeep Nagi, Srisakdi Charmonman [KS08].
A global strategy to introduce social software as a versatile support for collaborative learning in web-based education is proposed by Sandy El Helou, et. al., [SDC09] and C. Salzmann, D. Gillet. [SG08]. The various software tools and techniques for computer supported collaborative environment for engineering education, training and work are presented by F.W Bruns [BEM07], M. Montes, et. al., [MSL06], Salaheddin Odeh, Eiman Ketaneh [SE07] and D. Ursutiu, et. al., [UIC08].

Developing an online learning environment requires design elements to deliver instruction and facilitate interaction between distributed learners. The instructional design elements for web-based learning environment are presented by Alaa Sadik [Ala04]. The modular design for remote laboratory resource management is presented by A. Bagnasco, et. al., [BPP05], Jorgr R, et. al., [JGP06] and H. Hasnim, M.Z Abdullah [HA07]. Modular design allows the system to adapt a range of experiments with little or no changes, while uses of commercial products prove cost effective by sharing resources with multiple applications. J. Garcia-Zubia, et.al, [GOA08] [GDP05] describe the software architectures for remote laboratories which results in a more efficient use of hardware resources.

The rapid expansion of technologies with reference to ICT (Information and Communication Technology) tools are focused on creating communities in which people are brought together to collaborate, learn and build knowledge. Catherine McLoughlin and Mark J. W Lee [CM07] present a Web 2.0 based social software and, the choices and constraints to build pedagogical models for effective learning. Sufficient collaborative features have been provided by the learning management system of Web 2.0 technologies and can be adapted in web education [DSC08].

1.2 Motivation

Majority of the courses in science and engineering are supplemented with the practical activity. In traditional laboratory environment the experimentation facilities are provided to the learners in a specific time frame, which limits over the flexibility in time and place in practicing the actual experiments. The integration of communication technology tools with the laboratory experiments can extend the practical learning environment to the global space with the online access of educational resources, which
benefits the learners to share their experiences among the users distributed throughout the network.

Increase in the automation of learning activity results in quandary to the universities in adapting it, but these technologies can improve the reach of pedagogy by establishing communication among large number of geographically dispersed groups. It is a known fact that the lab-based courses play an important role in technical education and these courses have a strong impact on students learning outcomes. The virtual instrumentation along with the information and communication technology tools have changed the laboratory education landscape by intensive automation resulted in remote lab and simulation lab. These laboratories provide a way to specialized skills and resources, thereby reducing the overall costs to maintain the effectiveness in laboratory education and producing better design engineers by enriching the education experience. The distance approach to education offers benefits such as being accommodative to different learning schedules, allowing the use of various educational media and supporting self-paced learning methods. However to build an experiment is expensive and it is nearly impossible for an educational institute to have a complete set of experiments. Therefore the hardware experiments must be redesigned such that it can be accessed through the web and integrate with the e-learning.

The idea of remote device operation provides opportunities to all students to access experiments using modern technologies. The proposed experimentation systems demonstrate the online accessibility and use of these technologies to a wide variety of hardware experiments. The technology can be scaled up to include much complex hardware to meet the complete laboratory requirements. Hence the demand is ever increasing for remote laboratories in various areas of electrical engineering.

1.3 Problem Specification

The development of web based interface for remote engineering experimentations poses unique challenges in its design and implementations. To avail the benefits of web based experimentation systems on electronic and electrical hardware, a user friendly environment needs to be created for online access, control and measurement operations. A web based experimentation environment is created for engineering experimentations
on a communication circuit, DC machines, microcontroller application and a process control systems. The specific problems addressed in research are listed below.

i) Remote experiments on communication circuits should support for online selection of the design components through the web. The simple and cost-effective technique to perform these operations needs to be investigated.

ii) Remote experimentation system for complex electrical hardware requires sophisticated control and this necessitates the design of novel architecture for the web-interface of DC drives. The design for experiment on separately excited DC motor and generator requires control and measurement over the range of 0-230 V DC voltage and 0-10A DC current with perfect isolation between the server and the electrical hardware. The system should facilitate the option to add controlled load remotely to the web-experimentation.

iii) Development of an interface to web-server which extends the microcontroller experimentation system to web clients through LabVIEW and data acquisition system. The application development platform, the controlling environment and the related technologies used to perform remote experimentation on microcontroller based systems needs to be investigated.

iv) Development of remote experimentation approach to process control system by designing a web based control environment for bioreactor’s process parameters such as temperature, pH and agitation speed by mathematically modeling the system.

### 1.4 Specific Contributions

The research is carried out to develop remote experimentation systems which support web-based learning in engineering education. The specific contributions are listed below.

i. **Novel web based Control Techniques for DC Machine Experimentations**

   A novel web based interface is developed to control the input voltage of the DC machine experiments remotely through the Boolean/digital functions of LabVIEW. The designed system controls the input voltage from 0 to 230V DC in steps of ±1V through the remote computer keyboard or mouse. This feature supports the variation of input voltage to an electrical experiment similar to manual operation, but operated remotely.
ii. **Remote measurement of electrical output parameters**

The custom built interface is developed to measure a wide range of DC voltage 0-300V and DC current 0-10A through a web. The interface circuits are used along with the data acquisition system PCI6251 to measure the experimental parameters online. The measurement circuits perform the down conversion of electric signals from 0-300V DC to 0-10V DC and 0-10A DC to 0-10V DC by maintaining perfect linearity in the operation with isolation.

iii. **Transistor switching circuits for remote experiments**

A switching circuit using transistors to select different design components of the electronic circuits is implemented through *Boolean control functions* of LabVIEW. Web based control environment is developed for remote access and control of circuit experimentation on frequency modulation.

iv. **Web-based control of microcontroller experimentation**

A web-based interface is developed to remotely access microcontroller based experimentation. The interface is developed for the control of stepper motor with the specific features: direction of rotation, number of steps and the delay between the steps. The programming of the microcontroller is remotely managed using a VNC server. The control commands to the microcontroller are generated using the graphical code LabVIEW.

v. **Modeling and Simulation of Process control system**

The control environment for the process parameters such as temperature, pH and agitation speed is simulated using *LabVIEW control design and simulation module*. The process system is mathematically modeled and the controlling is achieved through the design of suitable control algorithms.

1.5 **Thesis Organization**

The design of remote access features for electrical and electronic systems uses advanced techniques in the field of instrumentation, communication and networking. The remote access technologies for web learning and remote experimentations associated with the various software and hardware tools are presented in Chapter 2.
The design of remote hardware experiment on frequency modulation is presented in Chapter 3. It describes the server interface with the custom circuit for the selection of hardware design components of an electronic circuit through web.

The novel architecture for remote experimentation on separately excited DC motor and generator is described in Chapter 4. The web based interface for a complex electrical hardware, custom-built circuits for control and measurements are presented in this chapter.

The integration of remote access technologies with the microcontroller experiment is presented in Chapter 5. It describes the web-interface structure for a PIC microcontroller to access and control the stepper motor along with the remote debugging facilities.

The design of LabVIEW control algorithms for bioreactor process parameters such as temperature, pH and agitation speed are described in Chapter 6. It describes the mathematical representation of the system, methods to obtain the PID controller coefficients and the design of feedback control simulation by considering the real specifications of the process system.

The virtual learning environment and its integration to remote access experiments are presented in chapter 7. It includes the DAQ interface structure to host all designed experiments through web. The chapter 8 presents the final conclusion and the scope for further improvement in the methods used in the design of remote experiments.