DESIGN AND IMPLEMENTATION OF REMOTELY CONTROLLED

LABORATORY EXPERIMENTS

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DESIGN AND IMPLEMENTATION OF REMOTELY CONTROLLED

LABORATORY EXPERIMENTS

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To those who have supported me unconditionally

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DEFINITIONS

Control Group - The group of test subjects left untreated or unexposed to some procedure and then compared with treated subjects in order to validate the results of the test[1].

Distance Education or **Distance Learning** or - Education in which students take academic courses by accessing information and communicating with the instructor asynchronously over a computer network[2].

Effectiveness - Refers to how Remote Laboratories compare with traditional laboratories in terms of student perception and attainment of learning objectives.

Experimental Group - A group of subjects that are exposed to the variable of a control experiment[3].

Local - Refers to the location of a student or apparatus that is stationed in the same place as the experimental equipment or host institution.

Remote - Refers to the location of a student or apparatus that is connected to the experimental equipment or host institution through the internet.

Remote Desktop Software or **Remote Desktop Program** - A software program designed to enable a user to control a computer at a remote location as if the user was stationed at the remote computer.

Remote Laboratory Experiment or **Remote Laboratory** or **RL** - A physical or practical experiment where an individual or group of students use specially adapted mechatronic machinery to manipulate equipment from a remote location to obtain and process experimental data.

Template - A model for grouping laboratory experiments with similar student interactions and data acquisition requirements.

Traditional Laboratory Experiment or **Traditional Laboratory** - A physical or practical experiment where an individual or group of students manipulate equipment locally to obtain and process experimental data.

Traditional Student – A student who completes an experiment by hand on campus.

SUMMARY

Laboratory experimentation plays a critical role in the education of engineers. With the increase of students choosing to obtain their education online through Distance Learning programs, something must be done to allow them to gain practice with experimental techniques. Remote Laboratories (RLs), or laboratory experiments specially constructed for remote use, have the potential to fill this void.

In a "traditional" laboratory experiment, students physically interact with an apparatus to obtain experimental data. Remote Laboratories are meant to offer a similar learning experience that is equivalent to, or as close as possible to the physical one, by allowing a user to control the apparatus from a remote location using mechatronic control hardware, integrated with data acquisition software. Studies have shown [4] there is no significant difference with regard to meeting educational outcomes between students who performed an experiment remotely versus those who carried out the same experiment in-person.

The focus of this thesis is on the development of a framework for developing and implementing Remote Laboratories. To do this, this research introduces advances in the following areas:

a) Identifying the educational differences between traditional and Remote Laboratories.

b) Developing a method for comparing student perceptions about RLs and their laboratory reports through surveys and laboratory report grading.

c) Creating a standard Information Technology protocol for hosting and conducting remote experiments.

d) Investigating alternative uses for RLs.

e) Proposing new methods to best mimic the physical interactions of traditional laboratories.

f) Creation of functioning Remote Laboratories.

g) Analyzing the findings of their use in a classroom setting.

A comparison of surveys and laboratory reports between groups that conducted remote experiments and those which conducted traditional experiments over a period of 4 semesters suggest that RLs have the potential to be used to achieve the same educational outcomes as traditional laboratories.

CHAPTER 1: INTRODUCTION

1.1 Foundations for Remote Laboratory Experimentation

Generations of engineering students of the past have permanently changed the way we presently live and work with technology. Advancements in telecommunication practices have made learning from remote locations viable, thereby granting access to information and education for people who would not otherwise have the privilege [5].

1.1.1 Background

Distance learning has been implemented for decades and has proven to be a viable alternative to traditional learning practices [6]. A major bottleneck occurs when a student must obtain his or her own data through an experiment or laboratory work instead of interpreting data that is provided in a lecture or homework problem. This presents a problem, as it is important for a student to get hands-on learning when preparing for a future in industry[7]. There is currently no system in place that allows a remote user to have exactly the same experience as a student who is physically able to participate in an experiment. As a result, the remote user is not able to develop the essential problem solving. Many individual **Remote Laboratory experiments** have been created, but there has been little development on making an entire sequence of hands-on laboratory experiences accessible to remote users [8].

Before this can happen, guidelines for creating a single and a set of Remote Laboratory experiments need to be created to better inform an institution which wants to implement them. Successful setups can provide evidence for the practicality of Remote Laboratories and could contribute to a consensus that they are a firm way to conform to Globalization 3.0, an era in which individuals collaborate and compete on a global level [9]. In this thesis, the author

discusses implementation procedures to assist in the creation of Remote Laboratory experiments that could mimic those offered in typical engineering laboratory courses.

There are two potential approaches for developing Remote Laboratories. One involves the adaptation of current set-ups to be accessible via the internet. This could involve the integration of sensory inputs (webcams, microphones, thermometers, ect.) and simple data-management inputs. Achieving this integration would allow the institution to provide use of laboratory equipment for on-campus and off-campus students while avoiding substantial development costs. An experiment that requires frequent connection changes with wires or replacement of samples could not utilize this approach, due to their complex control requirements

The second approach is to develop a new apparatus from scratch since some procedures in a typical undergraduate laboratory experiment include steps that would not easily adapt to robotic control. An advantage to this approach is that the developer would be able to design the experiment with both groups in mind.

Evidence of the capacity to integrate Remote Laboratory setups with **traditional experiments** needs to be shown before an institution can decide to put it to use [10]. If proven successful, Remote Laboratories have the potential to engage additional students than those currently interested in Distance Learning. The inclination of Remote Laboratory technology to be fused with current practices and how measurement of success could be made is outlined in Table 1.

Table 1: Measuring the Need for Integration of Remote Laboratories

Driver	Metric
Distributed Education	Number of available Distance Learning courses
Graduate Aptitude	On the job training requirements
Technological Advancement	Relevance of equipment and methodology to industrial practices
Specialized Equipment	Opportunities for collaboration with industrial equipment
Increased Collaboration	Interaction between geographically distributed individuals
Fiscal Limitations	Resources available for laboratories
Educational Impact	Test scores

Once the need for alternative educational techniques is presented, there must be an understanding of how Remote Laboratories will resolve critical problems. The following Table 2 is an outline of the motivations and measurements of how and why to integrate Remote Laboratory technology with current practices.

Table 2: Motivation for Implementing Remote Laboratories

Driver	Metric
Lower Cost	Return on Investment
	Income Generation Potential
Increase Process Efficiency	**Effectiveness** of Development
	Use with Local and Distant Students
Increase Process Speed	Time of Development
Workforce Reduction	Number of Automation Solutions
	Number of laboratory Assistants Needed
Increase Workforce Aptitude	Increase of Advanced Degrees

1.1.2 Motivation

The use of Distance Learning technology in distributed educational environments has allowed engineering courses to be delivered to locations and populations that have historically

not been afforded opportunities for involvement. However, efforts to incorporate Distance Learning principles into physical laboratory exercises have not yet led to a general mechanism or procedure for performing physical laboratories remotely.

In the absence of sufficient laboratory resources at remote sites, the usual practice is as follows: either replace the exercises with virtual laboratories, replace the exercises with experiments that can be done with an inexpensive laboratory kit, have a mobile laboratory that can be taken to various sites, or completely remove these exercises from the course. Removing the exercises or replacing them with virtual exercises is not an ideal solution since physical laboratory exercises are a vital component of any educational curriculum in virtually every major field of engineering [11], and other sciences.

In Distance Learning environments, such as the Georgia Tech Regional Engineering Program, any traditional lecture course can be taught remotely between participating institutions. However, it is still not feasible to cover physical laboratory exercises. Thus, at present, students attend pre-laboratory classes remotely but have to meet at a specific location on a campus to carry out the practical parts of the various laboratories. To overcome this barrier of contemporary Distance Learning, faculty can turn to the development of Remote Laboratories which involve the user conducting physical experiments by controlling laboratory equipment from a remote location.

1.2   Significance of Remote Laboratories

Physical laboratory exercises are the most critical gap in Distance Learning education today [8]. While there has been an increase in development of individual online laboratories, little has been done to develop sets of Remote Laboratories to accommodate entire courses or programs. The ability to provide these is of key importance to institutions offering Distance

Learning programs in major engineering disciplines and/or cross-disciplinary short courses in the educational service sector.

The opportunity to be able to fully cover physical laboratory exercises in a Distance Learning setting would not only significantly enhance the student learning experience, it would enable educational institutions to offer programs to a much broader target group of potential students who under no circumstances are able to travel to and attend on-site sessions. Consequently, educational institutions offering this opportunity could benefit from increased revenue through tuition fees. On a larger scale, if proven successful in the higher education sector, the introduction of physical laboratory exercises could also significantly impact the advancement of student learning in the high school sector. Smaller or financially underprivileged schools could offer their students access to first-class education through Distance Learning collaboration with so-called magnet schools that have the physical laboratory facilities and equipment available for use by others.

1.3   Literature Review

The earliest modern Remote Laboratory initiatives known to the author started in the mid to late 1990s. A laboratory that supported a variety of remotely operated laboratory exercises in control systems and chemical, environmental, and mechanical engineering was developed at the University of Tennessee at Chattanooga [12-13]. A remotely controlled physics experiment to determine the speed of light was developed by Enlo et al.[14]. Experiments involving semiconductor characterization were developed by Shen et al. [15]. Hamza et al. [16] developed a prototype Remote Laboratory system; their initiative led to the development of the Florida Atlantic University CADET (Center for the Advancement of Distance Education Technologies) [17]. They developed proof of concept prototypes and at present claim to have laboratories that

are under development, including Electrical Element Characterization (for Electrical Engineering), Logic Design (for Computer Engineering), Motion and Friction (for Mechanical Engineering) and Metallic Elasticity (for Physics and materials in engineering).

One of the first comprehensive surveys of online higher education was published by Sloan-C and the Sloan Center for Online Education in 2004 [18]. At that time, their main finding was that the Associates degree granting institutions had the largest number of students taking at least one online course, representing about half of all the students studying online, while they were followed, in order, by Masters, Doctoral/Research, Specialized and Baccalaureate institutions with the smallest number.

Based on the Sloan-C survey, Ibrahim and Morsi [19] conducted a discipline specific review of undergraduate and/or graduate Electrical and Computer Engineering degrees offered completely or partially online. They reviewed instructional technologies and different systems for offering electrical, electronics, and digital laboratories via Distance Learning to facilitate online education for engineering disciplines. It was concluded that although simulation may be used to reinforce concepts, practical experiments are needed for undergraduate electrical engineering education to develop students' skills in dealing with the physical instrumentation. They discussed if virtual laboratories are a valid alternative to the practical experience and postulated that laboratories should include the required hands-on control. A proposal was mad to use a technology available with National Instruments (NI) LabVIEW Remote Panels, which enabled a user to publish the front panel of a LabVIEW program for use in a standard Web browser.

Other literature assessing the **effectiveness** of Remote Laboratories has generally indicated that the achieved learning outcomes are comparable to those obtained from laboratories

performed in person [20-23]. However, learning outcomes in some areas have been degraded. Students who performed the Remote Laboratories versus simulations were able to identify the nonidealities in the experimental results. There is no known method to allow students to obtain the same hands on experiences in areas such as assembly or fine tuning. Early attempts at developing Remote Laboratories were hindered by Internet connectivity, hardware reliability, and the difficulty of controlling the instruments remotely with a web interface and control software.

As web tools and instrument control software have become more advanced and easier to use, there has been increasing development of Remote Laboratories. Jodl et al. of the Technical University of Kaiserslautern, Germany [24] have started an initiative for the distribution of remotely controlled laboratories (RCL) in Physics teaching. They have set up classic physics experiments, including Electron Diffraction, Photoelectrical Effect, Voltage-Current Characteristics, Diffraction and Interference, in various European locations that can be executed through the Internet. A user at a location "A" is allowed to conduct an experiment at a distant location "B" via his or her computer. Controlling the experiment is enabled by accessing an interface and a web server. Web cams allow the user to observe the ongoing experiment. The researchers directed these RCLs to K-12 students (and as a prototype model to build-up RCLs in school projects) and to the lay public, but these Remote Laboratories could be immediately used for university teaching as well.

In a recent paper, Gröber et al. [25] review the existence and status of physics experiments in Remote Laboratories worldwide. By 2006 they found approximately 60 projects offering about 120 remote experiments. More than half of these projects were located in the USA and Germany, and some of the projects were joint ventures between universities in different

countries. Some recent examples of engineering Remote Laboratories are: controls [26-27], electric motors [28] image acquisition and processing [29], robotics [30], PLC control of manufacturing cells [31], telecommunications [32], photonics [33], power electronics [20], and fluid mechanics [22].

There is also a growing number of remote electrical and control engineering laboratories, more so than other types of laboratories. This may be because electrical and control laboratory equipment typically supports external control and monitoring via RS 232 or GPIB (IEEE-488) interfaces and thus requires less alteration to be performed remotely. In 2003, Ogot et al. [22] carried out a study on assessment of in-person and remotely operated laboratories. Their results showed no significant difference with regard to meeting educational outcomes between students who performed an experiment remotely versus those who carried out the same experiment in-person [4].

Many universities and colleges lack the funding initiatives to provide extensive setups and are forced to compromise [8], by providing less experimental opportunities to Distance Learning students. If an institution were to develop a Remote Laboratory program for their own uses, they could also become a magnet school for others to use as a synergistic resource. The host facility could collect a fee to cover maintenance and overhead, and the accessing entity would avoid development and storage costs.

1.3.1 Alternative Laboratory Delivery Methods

Most users who can only connect to a university through Distance Learning enabled programs have no other choice than limit the experimental side of education. The goal of Remote Laboratory implementation is to grant these students access to laboratory equipment. This would not only increase the type of courses that could be offered through Distance

Learning, it could also broaden the type of clientele that would participate. As a remote student's ability to mimic the actions of a traditional student strengthens, remote education will become increasingly reputable. It can be assumed that as a result, more people may associate remote education with being a viable alternative to traditional education for full time undergraduate and graduate students.

Complementary Benefits of Remote Laboratories

Remote Laboratories are not limited to use by remote students. A university can benefit from a partial to full scale implementation of Remote Laboratory experimentation for the use of their on-campus students. The following list describes just a few of these possible uses:

Interdepartmental Collaboration

Multiple programs may teach similar theories in the early stages of their respective disciplines. Laboratory equipment which one department employs could be utilized by other departments to teach similar principles without having to relocate the apparatus.

Interinstitutional Collaboration

Colleges and Universities with similar programs and accreditation boards, such as ABET [34], often promote the use of similar practical experiments. Instead of individually creating and maintaining their own procedures, they could collaborate and share their equipment through a network of Remote Laboratories. Assuming the partnering institutions have computer laboratories connected to high speed internet, this would allow them all to save on development and maintenance costs. As an added benefit, professors that monitor laboratory classes would have an increased network for collaboration and continuing improvement of the experiments.

Instructional Use

Courses that do not currently include laboratory experimentation can utilize a Remote Laboratory to help provide an example for a theoretical lesson. In the case of interdepartmental or interinstitutional collaboration, an instructor could access a Remote Laboratory during a lecture to give the students a quick demonstration. Since it is not pre-recorded experiment, students would be able to interact with the instructor and ask questions about a physical response and the instructor could show them the answers while discussing the theory behind it.

Laboratory Locations

Some equipment can be located in different buildings or campuses that would require students to commute large distances to perform an experiment. Employing Remote Laboratories would reduce the complications in scheduling and transportation by allowing students and professors to work from a centralized location.

Safety

Experiments that deal with equipment that could present a physical threat to students could potentially be improved with remote control. Such laboratories often have specialty personnel on hand to train and monitor students' actions. Remote control of laboratory equipment would allow personnel to monitor equipment while circumventing the need for timely training exercises.

Special Needs

The Americans with Disabilities Act of 1990 requires that students who are differently-abled must have the opportunity to participate in the similar exercises as all other students [35]. Creating a mechatronic interface for an experiment would make these exercises accessible to all

students regardless of their needs by simplifying the physical interaction required for equipment use.

Scheduling Conflicts

As enrollment increases, so does the complexity of scheduling long periods of time that would be suitable for students, faculty, and laboratory staff. Allowing an experiment to be remotely controlled could make this task simpler by giving the students a set of times to sign up. The schedule could be altered based on availability throughout the semester. In the case of an emergency, the student or staff could more easily reschedule the experiment instead of missing it or calling it off.

Variations of Remote Laboratory Experiments

This thesis refers primarily to Remote Laboratory experiments as those where a **remote** student takes control of a **local** computer to control an apparatus. The following are alternative methods to provide laboratory experimentation via Distance Learning.

iLabs

Although many institutions host a variety of programs called "I-laboratories", the only one related to this thesis is the MIT "iLabs" [36] program that enables online laboratory experiments. iLabs has made variety of laboratory experiments available online and created a shared architecture to allow open innovation for future Remote Laboratory experimentation. By being "dedicated to the proposition that online laboratories … can enrich science and engineering education by greatly expanding the range of experiments that students are exposed to in the course of their education", they promote the same ambitions of most Remote Laboratory designers.

Remote Access Laboratories

The "Remote Access Lab" term is often considered synonymous with Remote Laboratory, although no specific definition has been found. They have the same goal as a Remote Laboratory of providing physical laboratory experiences for students in Distance Learning. The uniqueness of the term seems to deal with the fact that Remote Access Laboratories often involve large network systems or have a connection with Cisco Academics®.

Teleoperated Laboratories

Laboratories that deal primarily with remote robotic control and programming are often referred to as "Teleoperated Laboratories". The term is otherwise similar to remote Access Laboratories in that is frequently used to describe any experiment preformed remotely[37].

Web Laboratories

A "Web Lab" is an online step-by-step visual guide to a laboratory experiment, often used as a reference for traditional laboratory experiments. Students use them to make sure they are correctly setting up complicated procedures and to verify their. They grant no additional control over equipment nor can they be used to replace an experiment for remote students.

Virtual Laboratories or Simulation

Simulation is a powerful means to aid traditional and Remote Laboratories by using internet enabled computational software. Students can use them simulation for pre-laboratory familiarization with equipment, developing a better understanding of theoretical fundamentals, and quickly analyzing a hypothetical situation under various conditions. Many institutions use flash based programs to allow students to calculate and view the cause-effect relationship of a variety of physical, electrical, and chemical phenomena. However, since they do not involve any

interaction with physical components, there is a definite loss of user control/confidence with simulations [6], making them unfit as an alternative for Remote Laboratories.

1.3.2 Gap Identification

Based on the literature review conducted, there is no known method to guide the creation of Remote Laboratories from the educational considerations to IT protocol to equipment configuration. This must be available to facilitate the creation of multiple setups which can be utilized to instruct a series of laboratory experiments. Additional data must also be gathered that provides evidence as to the effectiveness of Remote Laboratories.

1.4 Scope and Focus of Work

1.4.1 Research Questions

The questions listed in Table 3 were used to guide the research and development activities presented in this thesis. Primary Questions deal with the broader spectrum of Remote Laboratories, where Secondary Questions focus on more specific topics.

Table 3: Research Questions

Primary Question 1	(PQ1)	**What resources are required for Remote Laboratory experimentation?**
Primary Question 2	(PQ2)	**How can Remote Laboratories be created to provide a similar educational experience to traditional laboratories?**
Secondary Question 1	(SQ1)	What tools and practices can be used to enhance distance education through Remote Laboratories?
Secondary Question 2	(SQ2)	What are the limitations of traditional and Remote Laboratory experiments?
Secondary Question 3	(SQ3)	How can current instructional techniques be amended to compliment Remote Laboratories?
Secondary Question 4	(SQ4)	What types of courses can utilize Remote Laboratories?
Secondary Question 5	(SQ5)	What are the non-university applications for Remote Laboratories?

Table 4 can be used to locate the sections where the research questions are addressed in this thesis.

Table 4: Research Question Content Matrix

Relevant Sections	Chapter 2					Chapter 3				Chapter 4				Chapter 5	
	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.5	5.1	5.2
PQ1			X			X	X	X		X					
PQ2	X		X	X			X				X	X	X		
SQ1		X		X	X	X			X	X					X
SQ2	X		X					X							
SQ3	X	X	X		X									X	X
SQ4				X						X	X	X	X	X	
SQ5															X

1.4.2 Understanding Instructional Techniques

There has been much discussion regarding the differences between traditional and Remote Laboratories, often centering on the experience itself rather than the experiment's ability to produce usable data. It is true that students have different interactions with machinery when they are in a remote location, but that does not mean they should not be able to pull similar value from it.

Students perform practical laboratory experiments for various reasons; learning experimental procedures, generating experimental results, and learning how to interact in a laboratory or research environment are just a few. Many of these can be ascertained through the use of Remote Laboratories with no concern as to their validity. Those experiences which result from indirect interactions in a traditional laboratory are more difficult to imitate.

Although there currently does not exist a way to perfectly emulate these encounters, there are many practices and tools that help match a traditional kinesthetic environment in a Remote Laboratory [38]. For example, employing webcams with microphones would allow a student to see and hear many perspectives simultaneously. Furthermore, in certain experiments, a remote

student might be able to see more than a traditional participant if the camera were to be placed inside an enclosed area. These concepts are expounded in Chapter 2.

Tactile sensation can be addressed in through multiple means. The simplest solution would involve a Graphical User Interface (GUI) that is designed to simulate the physical responses of a machine when activated. Here, when a user sees a button, knob, or lever they can locate it on the GUI and press the appropriate button, rotate the mouse around a knob, or manipulate a lever graphic, respectively. A more complex method could transmit a vibration or temperature signal to a remote location that would be converted into a proportional response [39]

The use of such devices could allow students to participate in a larger variety of experiments while reducing the financial burden on the host institution. Institutions which decide to collaborate and share their laboratories would grant their students more opportunities while reducing costs. Liability would be reduced since potentially dangerous procedures could be performed in a way that gives students freedom to witness the ramifications of their actions, without causing major damage.

Remote Laboratories can be preprogrammed so that the interaction options for a participant are known ahead of time so the laboratory designer may have an understanding of the potential combination of actions. This would allow them to add or reduce functionality or add additional safety information if necessary. In many instances the use of Remote Laboratories could prevent equipment from unanticipated wear and tear, and more importantly keep students safe from hazards such as pinch points or electrocution.

1.4.3   Generalized IT Overview for Remote Laboratory Applications

There are many considerations that must be made when configuring an apparatus for remote access. One such consideration is that many institutions have multiple firewalls for data

to traverse, which can complicate communication between machines by denying access or slowing down the transfer of information. For a Remote Laboratory to be successful there must be a reliable way to connect local computers in a facility to those connecting remotely from the outside.

Specific procedures for creating these connections vary depending on the laboratory requirements and institution policies. Thus, more specific instructions that generally apply across the board are not made here. Specific methods to facilitate a link between networks for similar uses have been patented [40]. The simplest way found to securely connect computers is to use **remote desktop software** which is discussed further in Chapter 3.

1.4.4   Practical Examination of Remote Laboratories

Laboratory setups are similar to each other in many ways [41]. Parallels between them can be used to group experimental setups into abstract collections that generalize the physical requirements of a lab. These collections are then modeled as **templates** for Remote Laboratory implementation procedures. A summary of the data collection outputs from laboratory experimentation is displayed in Table 5.

Table 5: Typical Laboratory Experiment Output Data

Generic Outputs
      Temperature
      Audio
      Video
      Mass
Signal Outputs
      Voltage
      Amplitude
      Frequency
Specialized Equipment Outputs
      Strain
      Flow-rate
      Angular velocity
      Vibration
      Pressure
Computer Generated Data Outputs
      Random numbers
      Code printouts
Hardware Outputs
      Pre-programmed equipment
      Proprietary equipment

These outputs are the primary means to gain data in a traditional and remote experiment. All of the methods in Table 5 can be configured for remote use without much intervention as long as an appropriate data acquisition system is used. Tasks such as measuring an objects dimensions or mass could prove difficult when creating a remote lab. Traditional students can easily complete these tasks by hand, while a remote user would need to interface with a robot. It is possible to provide the students with these measurements before hand to avoid programming additional interfaces.

The following Table 6 is be used to illustrate how these outputs can be generalized collections to provide a solution pattern for creating Remote Laboratories. Examples of common laboratory experiments and a program of study which might perform the experiment are included. These templates should be viewed as a starting point, providing enough information to

start the laboratory building process but leaving enough freedom for adaptation for various

circumstances.

Table 6: Templates for Remote Laboratory Experiments

Template 1: Electrical response/signal/display
        Oscilloscope (Electrical)
        Function Generation (Mechanical)
        Amplification (Electrical)
Template 2: Measurement
        Temperature (Civil, Mechanical)
        Sound/Light (Mechanical)
        Current/Voltage/Power (Electrical)
Template 3: Simple movement
        Stress/Strain (Civil)
        Physics Experiments (Mechanical)
        Pendulum Effect (Mechanical)
        Friction (Mechanical)
Template 4: Complex movement
        Controls Laboratory (Electrical)
        Vibrations (Civil)
        Spring-Mass-Damper (Mechanical)
        Tensile Test (Civil)
Template 5: Mass Flow
        Wave Simulation (Civil)
        Inlet/Outlet Calculations (Mechanical)
        Air Flow/Heat Rates (Mechanical)
        Viscosity (Mechanical)
Template X: Simulation
        Computer Generated Data (All)

A few points need to be understood as this list is reviewed. The potential difficulty to

incorporate an experiment with a Remote Laboratory setup increases as the list progresses.

Creating a Remote Laboratory experiment is an art as much as it is science, leaving much room

for interpretation. These templates are intentionally without specificity since each institution has

varying policies network configurations. Many of the ideas overlap between templates, but they

can still be used for problem framing exercises. Experiments that are similar across disciplines

(such as temperature effects) still have critical differences in how the lesson is presented.

1.4.5   Templates as Solution Patterns for Creating Remote Laboratories

This section is used to elucidate the template concepts introduced in Table 6.

<u>**Template 1: Electrical Response/Signal/Display**</u>

Many basic experiments deal with the understanding of signals and how they are created. Students currently toggle buttons and alter switches on various apparatuses like function generators and view the response on an oscilloscope. Technology exists that allows a student to control these machines and others via a computer connection [28], usually with a USB. Assuming there is no need to alter connections, the best case scenario allows the equipment to be accessed through remote desktop software. If altering the equipment is necessary (for example, switching polarities of a diode), a robot could be programmed to handle this task, or much more simply, a laboratory assistant could make the switch. More information on the use of a laboratory assistant is discussed in Chapter 2 (pg. 29).

The following is an example of a Signal Response lab:

Example Measurement Lab

Measuring the speed of light
A setup has known, fixed distances between a signal origin and a receiver
The student controls when to activate the signal

In this case, the students can view most of the data is available on a computer screen, but still needs to apply critical reasoning skills to interpret the data [30].

Template 2: Measurement

Many forms of measuring equipment are available in digital forms, allowing simple assimilation with computers. Cameras could be used to monitor a display on tools like an oscilloscope if there is a reason to avoid computer-equipment integration. An experiment can be designed to give a student control while fixing certain parameters. Students can then take the data derived from their observations and perform their analysis.

In Figure 1, an acoustics laboratory is hypothesized to provide an example of a Measurement lab.
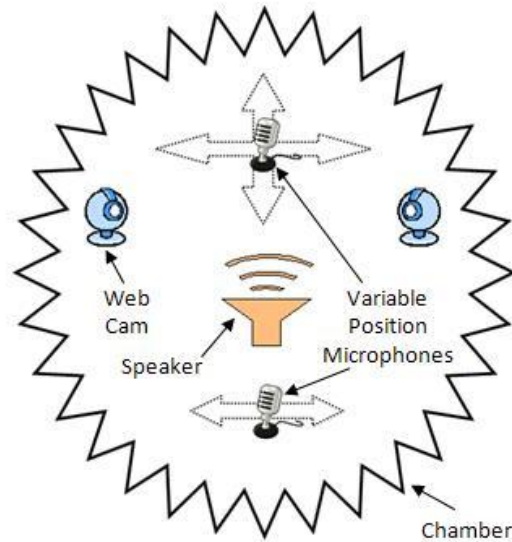
Figure 1: Acoustic Measurement Lab

Acoustic anechoic or reverberant chambers are used by many institutions to measure vibrations and calibrate equipment. These chambers require financial, special and other resources to be used and, therefore, are not able to be installed by all who need them. Experiments that involve monitoring of various pre-defined sounds could utilize a camera/microphone/speaker setup similar to the one in Figure 1. Placing multiple microphones

at varying distances from the speakers could provide remote students with the opportunity to discover various phenomenon like the speed of sound or noise attenuation.

Template 3: Simple Movement

Experiments that require a Simple Movement such as a flick of a mass, pull of a bar, or opening of a gate can be assisted by a simple actuator like a solenoid or an electric motor. The speed or power of an articulation can be controlled through various methods, allowing variance when required.
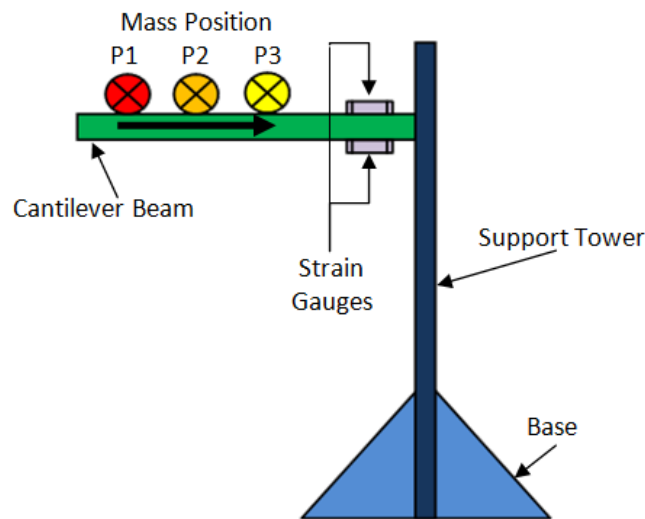
Figure 2: Use of a Remotely Controlled Mass to Alter Stress on a Beam

In this example (Figure 2), a cantilever beam is affixed with strain gauges to measure the effect of a change in the mass position. Control can be maintained by a single motor that translates the mass moved toward and away from the edge of the beam. The mass of the object, wires, and motor as well as the other constants could be given to the students, and they could be would required to calculate the theoretical bending moment and compare it with experimental data.

Template 4: Complex Movement

Success in engineering requires an understanding in Complex Systems. Those with more intricate movements or relationships require more robotic intrusion than the others and possibly a laboratory assistant to initiate steps or replace components.
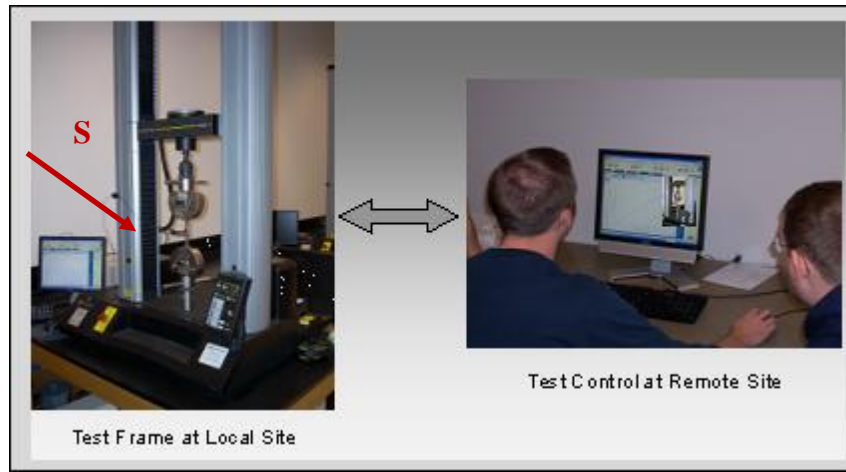
Figure 3: A Remote Laboratory for Tensile Testing

In the example of a simple tensile test shown in Figure 3, Remote desktop software application can be used to control the machine and receive all pertinent data. A laboratory assistant would need to replace the sample after it reaches critical failure. Alternatively, this process could be automated, but would require a complex robotic system which might cost more than employing a TA.

In the example shown in Figure 3, a prefabricated machine with built in computer control would makes integration easy. Most complex setups, however, would require more adaptation, rebuilding, or monitoring to be practical as a Remote Laboratory. An example of how a multi-dimensional robot was used to model a controls experiment and how it can be used to evaluate it as a Remote Laboratory is available in the in Chapter 4 (pg. 57).

Template 5: Mass Flow

Mass flow also involves complex movement of matter, but the need for containment and possible mixture of masses separates these laboratories into another template. A Mass Flow laboratory presents the most difficulty for adaptation for remote use due to the higher pressures and temperatures involved. Automated pressure regulators and sensors need to be monitored by a fail-safe to make sure unintended flow is minimized.

Template X: Simulation

Simulation is included with the other templates because if its ability to convey laboratory-like information by animating various interactions and generating data. As mentioned earlier (pg. 12), simulation can be used to aid the instruction of experimental theory, but should not replace the practice.

1.5   Overview of Implementation Strategy

This thesis covers a wide spectrum of topics starting from a literature review of the state of the art of Remote Laboratory experimentation, through the development of working RLs, to the final analysis of the effectiveness of Remote Laboratories.

Before any work could be completed on the development of new experimental procedures, it was necessary to review what has already been accomplished in the growing field of remote communication for laboratory experimentation. The review discussed alternative methods that would allow remote users to gain supplemental knowledge to their regular Distance Learning coursework such as virtual laboratories and web laboratories. Remote Laboratories have an outstanding potential to overcome the bottleneck in distance education, so they became the main research focus for practical development. The research plan for this thesis is depicted in Figure 4.
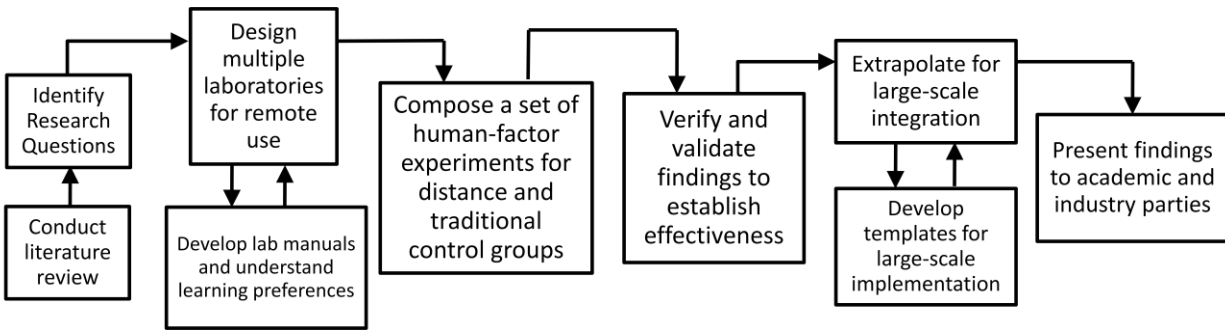
Figure 4: Research Plan

Three experiments were created to be completed by undergraduate students. Survey findings and laboratory reports were used to analyze the capacity of Remote Laboratories to be integrated with current coursework. These experiments are discussed further in Chapter 4 (pg. 55).

The 3 Axis Gantry Control Systems Remote Lab was an original development to instruct various controls system parameters. This experiment helped identify some best practices for the IT interfaces and connection practices for Remote Laboratories, discussed further in Chapter 3 (pg. 43).

Two additional experiments were developed based on the findings of the 3 Axis Gantry Control Systems Remote Lab. These were the Heat Transfer by Convection Remote Lab and Flywheel Control Systems Remote Lab. These two experiments were adapted directly from the Experimental Methodology course in Georgia Tech's Undergraduate Mechanical Engineering curricula.

Along with the design of the equipment for each remote experiment came a supplemental reference to aid the student in set-up, provide background information, explain experimental procedure, and a description of the required analysis of the acquired data. Surveys were also

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distributed to gain feedback about the students' perception of RLs and attain suggestions as to how the experiments could be improved.

The latter two Remote Laboratories were tested with undergraduate students, where the prior was constructed solely for research purposes. Participants were selected to take part in the traditional (control) and remote (experimental) trials based on how they scored in a 'Learning Assessment' survey, which is discussed further in Chapter 2. After completing the experiment, the participants were required to submit a report and complete an exit survey. Reports from previous semesters were added to the control data since they were also preformed traditionally. Once all the data was collected, it was analyzed and used to compare and contrast traditional and Remote Laboratories.

CHAPTER 2: EDUCATIONAL BROADER IMPACTS

In this chapter, the education related concepts of Remote Laboratories are addressed. This includes a comparison of traditional and Remote Laboratory instructional practices, a discussion of techniques that promote problem based learning in the context of laboratories, and an introduction to a method for identifying learning styles.

2.1 Creating a Remote Lab for a Distance Learning Student

To understand how to write a Remote Laboratory experiment manual, one must understand the viewpoints of the potential students.

2.1.1 Characteristics of a Distance Learning Student

Students who choose to receive their education through Distance Learning commonly have different schedules than traditional students and need to be more self-motivated [42]. They must manage their time to read or write assignments, review lecture slides or videos, and study for tests. Some choose to be online learners to fit with their schedules, where others may not have a choice. Students located on a campus also choose to take classes online for similar reasons.

The number of distance education participants is has grown tremendously over the past few years [43], and this trend is likely to continue. This is based off the assumption that the reputation and quality of DL will continue to enhance. A key player in these advances could be the adaptation of Remote Laboratories into the curriculum. It is reasonable to believe that current distance education students will welcome the opportunity to engage themselves in this additional online activity.

2.1.2 Characteristics of a Traditional Student

Students who have worked with traditional laboratories and have no experience with Remote Laboratories are often skeptical of the RL's capability to provide an adequate level of interaction with an apparatus[36]. People form ideas about how the experiment might go and what they might be missing by not physically interacting with the equipment. A study explained on page 41 is used to provide evidence that students look more favorably at Remote Laboratories after taking part in one. This does not change the fact that those without experience might refuse to try a Remote Laboratory based on their preconceived notions. There are two ways to combat these opinions: explanation and demonstration. Remote Laboratories must be tested on a larger scale in order to change the conception that they only work in theory, not in practice.

2.1.3 Laboratory Instruction

Before a student begins their first remote experiment, they should be introduced to the general procedures of the remote control software and the experiment itself by a video or brief tutorial. It is important to make the connection instructions clear and without superfluous detail as it might be perceived as a challenge to setup the initial remote connection. Screenshots and other figures help student become comfortable with the remote connection procedure and not worry about managing the connection while operating the local equipment. An appendix should include advanced instructions if the students would like to better understand how something works.

The procedure for the experiment itself should be similar to that used by the traditional students. Since remote and traditional experiments have the ability to produce the exact same data, the only procedural differences should be the adaptation of remote control. For example, if a traditional manual calls for the student to turn on X and connect Y, a remote manual should say

use the A button to turn on X and move B to connect Y. Screenshots of the buttons and

commands would be useful when called for or in an appendix.

2.2 Identifying Learning Styles

Students learn in different ways. Some work best when they are told information, some

might need to read before understanding, others might need to see examples and work them out

[11]. Each individual varies on how they are best able to gain knowledge. Since a person's

perception on what works best for them might be different than what they have actually

experienced, there ways to qualitatively discern their learning styles.

Findings of two questionnaires based on the Myers-Briggs Type Indicator® [44] and

Fleming's VARK® model [45]were used to identify learning styles of Remote Laboratory

participants, and can be found on page 39. These series of questions provide a perspective on the

learning preferences of an individual according to how they answer generic questions. The

following Table 7 is used to show the learning styles according to each test and some example

questions.

Table 7: Learning Preferences

Assessment Type	Learning Style	Description
VARK©	Multimodal	Multiple strong learning preferences
	Visual	Prefers visual examples and descriptions
	Aural	Prefers to hear examples and descriptions
	Read/Write	Prefers to learn by writing information
	Kinesthetic	Prefers to participate or be hands-on
Myers-Briggs©	**E**xtroversion or **I**ntroversion	Where a person directs their energy
	Sensing or **I**ntuition	How a person perceives information
	Thinking or **F**eeling	How a person processes information
	Judging or **P**erceiving	How a person implements information

The VARK model uses a numerical scale to rate the degree of preference for each learning style. A person might score a V:2, A:10, R:1, and K:2, classifying them as a "Aural" learner, where someone with a score of V:12, A:10, R:1, and K:2 could be classified as a "Multimodal" learner. A person could also be rated from "mild" to "very strong" in a particular category, depending on their score.

Myers-Briggs evaluates perceptions differently. Instead of a numerical scale used to determine if a person has one of five learning preferences, it evaluates which area a person tends to act in four different categories. Results are listed as the first letter of the predominant area in each category. For example a person could be ISTP for Introversion, Sensing, Thinking, and Perceiving. Someone with a learning preference of EIFJ would have the opposite preferences.

These learning preference assessments are separately used (pg.38) to identify a connection with learning preference and students' perceptions about Remote Laboratories and compare their experimental understanding based on report grades.

2.3   Managing the Practicality of Remote Laboratories

2.3.1   Teaching Assistants

Teaching assistants (TA) are used in traditional laboratory classes to provide three main services. The following Table 8 is used to highlight these tasks and their main purpose.

Table 8: Teaching Assistants' Role in Laboratory Experimentation

Function	Description
Safety	Ensure safety of students
	Promote proper use of equipment
Guidance	Lead students through laboratory procedure
	Manage equipment malfunctions
	Answer calculation or technical questions
	Advise students on experimental procedures
	Trained to understand theory, not setup equipment
Grading	Grade reports or worksheets

Many Remote Laboratories can be carried out with absolutely no interaction with a TA. Universities often employ graduate students with sufficient experience to work as these laboratory moderators for their courses. If a TA is requested for a Remote Lab, the assistant could interact with the students without having to dedicate the full laboratory period as they must in traditional experiments. They may even be able to work from any remote location as opposed to within close proximity to the local equipment. It is important to note that a teaching assistant cannot be available at all times of the day, so labs that require a TA would need to be scheduled accordingly.

Laboratory Safety

A TA that oversees a traditional experiment must be familiar with all of the laboratory equipment and safety procedures before students begin a lab. They must be aware of the potential accidents that could occur as well as the first aid and administrative procedures that would need to be followed if a mishap did occur. In some cases, this could require special training to grantee the TA has the required knowledge to handle delicate apparatus.

When working remotely, there is no threat to the student, and potentially none for the TA. If the laboratory is set up to be 100% self sustaining, the TA might only need to be available for

guidance and grading, easily carried out with any variety of online communication tools. Students could have the ability to ask questions through an online chat, video conference, a phone call, and even remote assistance.

Since Remote Laboratories are designed to use robotic control to replace the inputs of a human hand, it is likely that more experiments will have built-in fail-safes so the equipment does not fail prematurely. This allows students to access the equipment completely unsupervised without danger of accidental or intentional harm to the experiment. That being said, it is best to include emergency contact information in the instructions or limit access to certain laboratories.

Laboratory Guidance

Laboratory manuals intended for Remote Laboratory use should have enough explanation for students to be able to complete all tasks without needing operation assistance from a TA. It might be beneficial to have a posted schedule of times that an assistant could be available. This would allow remote students to have the freedom to work when they are available and have the opportunity to receive guidance if necessary.

Some laboratories inherently have more complex instructions depending on the experiment being performed. Those that follow the 'electrical response' or 'measurement' templates will likely need no TA interaction due to their simple nature. As the experiments demand more moving parts, the possibility of malfunction increases. Laboratories that are known to stop working as expected should have a live TA available to troubleshoot any issues.

Another instance requires a TA when an experiment requires a multiple samples to be evaluated. In a common tensile testing experiment, for example, students use machinery to find a stress/strain curve of various materials and differing cross-sections. This often requires a test piece to be manually loaded and unloaded into the equipment. Automation of this kind of

procedure would be expensive and require extensive development time. A TA could be on hand to simply replace a piece at the remote student request.

Laboratory Grading

Grading procedures should be no different in a remote environment than a traditional one. Laboratory reports could be electronically submitted and processes from whatever location the grader is available. Special considerations would need to be made to augment attendance and participation policies, but this would vary depending on institution policy and teacher preference.

In summary, A Remote Laboratory TA would be used similarly to a traditional laboratory TA by being available to manage the equipment or provide assistance on demand. Remote Laboratories have an inherent fiscal benefit to their more automated control since it is more likely to make the need for a TA obsolete. Many experiments do not require help from a live person. Even when a TA is needed, their time commitment and therefore cost to the university, should be less than with traditional experimentation. This allows them to work on homework, other research activities, or even proctor additional Remote Laboratories.

2.3.2 Human-Computer Interfaces

The human computer interface (HCI) is the main connection between a remote student and an experimental apparatus. It is critical that the HCI is configured to provide a user with an understandable purpose and life-like interaction.

Specialized Haptics

There is no known method for providing remote students with the same tactile experiences as they would encounter when manipulating an apparatus in a traditional lab. It is possible for an institution to ship specialized equipment that replicates all of the interactions of the local machinery, but it is not practical.

Haptics equipment can be used with the existing audio/video feeds to provide additional sensory information. Temperature, resistance/pressure, or vibration feelings could be used to substitute some of the interactions a student would undergo in a traditional environment. A device such as this could be similar to a video game controller that plugs into the remote students' computer and interfaces with the remote desktop software. It could also allow unique control of the local equipment using the features common gaming controllers have, such as a potentiometer or gyro control. A small piece of equipment like this could be shipped inexpensively to the students.

Graphical User Interfaces

A more simple way of closing the gap between the physical experiences for the student would be through specially developed HCIs. Remote students' inputs are often limited to keyboard and mouse commands. Assuming there is no special equipment available like the haptics controller mentioned in the previous section, the best way to imitate various commands would involve mimicking the local equipments actions in the interfaces. Examples of such actions are given in Table 9.

Table 9: Using a GUI to Mimic a Physical Response

Action	Interface
Knob	Virtual knob that students spin with mouse
Button	Virtual button that students press with a specific key
Switch	Virtual switch that students activate with click-drag of the mouse
Move object	Image of that object and its path, click and drag image on path
Plug in/connect	Image of male and female ends, click and drag the images to connect
Add Material	Virtual beaker or graduated cylinder, select desired level
Tip	Image of object being tipped and a fulcrum, click and drag to desired angle

For example, if a student is working on a function generator and wanted to change the output voltage, they would likely turn a knob. Even if the Remote Laboratory is able to automatically respond to a numerical input, the GUI should be designed to look and respond like a knob. When the remote student uses the mouse to spin the virtual knob in circles, their hand moves similarly to a local student's, thus creating physical interaction in a Remote Lab. Creativity is required to program more complicated imitations.

2.4   Additional Benefits of Remote Laboratories

2.4.1   Higher Value of Equipment

A traditional class commonly has 10-20 students working in groups of 5-10. This means that classes must have at least 5-10 stations with all the equipment necessary for the groups to complete their work. Depending on the required equipment and the number of different experiments that take place in a year, this can be a large expense. Remote Laboratories can provide these students with a full laboratory session using only one laboratory station. A schedule could be put together that allows each group to alternate use with the same equipment. Each station could also be Remote Laboratory accessible if for any reason the laboratories need take place at the same time.

2.4.2   Greater User Access

This thesis in not used to claim that Remote Laboratories give students more control over laboratory equipment than if they were working with it locally. There are some things like feeling the texture of polished metal that are currently near impossible to provide remotely. On the other hand, Remote Laboratories are able to provide experiences that local users are not.

Many experiments involve a factor of concern for students such as pinch points, high temperatures, or closed systems. A local experimenter could have to stay clear of a section of an apparatus, or they might not physically have access to it. The use of Remote Laboratories creates the ability to easily place cameras, microphones, or other sensors in precarious locations. A remote user would have the option of selecting which camera angle to view or which sound to hear. They could even see multiple shots at once to compare a cause-effect relationship.

It is possible to allow a local user to access the options a remote user can after it has been configured. They would able to move around an apparatus to see from different perspectives or use a computer to see them, but it would be very difficult to selectively hear one noise source in the way a microphone can.

2.4.3   Progress Tracking

Traditional experiments occur in real time just as remote experiments do. The difference is that a student operating remotely only uses a computer for the entire experiment. All signals, responses, and commands are sent to and from the students' location enabling them to make an audio/video recording of their entire session.

Observations are important to many experiments. A student needs to remain vigilant to take note of any peculiarity like a flash of light or unexpected physical response. This bit of information can vanish if the student's focus was elsewhere when something happens. Remote users whom record their sessions can review an experiment for errors and better learn from the experience. An instructor might also choose to view the recorded sessions to understand how the student work and how they arrived at their conclusions.

2.4.4 Better Reliability

It has been noted [41] that Remote Laboratories must be more stable than traditional experiments. A local student has a much better chance of fixing a problem if a piece of equipment fails. They might be able to locate a replacement part or use their hands to find some other solution. The only options for a remote user are to contact a TA or switch to an alternative apparatus if available.

To best provide a reliable Remote Lab, the initial design must be robust. It should be able to undergo accidental or intentional abuse by design or by limiting unnecessary functions. All plugs, button, switches, etc., should be secure and stable so they are not inoperable after frequent use. Each laboratory requires varying levels of robustness.

Since this special care is designed into a Remote Lab, they are most likely able to outperform identical equipment that is operated by local students. A major cause of equipment malfunction is user error. Obviously the students should be allowed to make mistakes, just not those that can harm the apparatus. If the damaging error is taken out of the experiment, the reliability may improve. If this is proven in application, some traditional experiments might be controlled remotely by a local student. This would allow the local student to interact with the equipment in person while still maintaining the high level of reliability.

2.4.5 Problem Solving Built into Experiment

Many laboratory experiments are constructed to promote Problem Based Learning. This instructional strategy requires students to use their problem solving skills and reach conclusions by analyzing their observations or raw data. In traditional experiments, a student or group may encounter a problem with limited information provided for them. They must use their understanding of the subject matter to formulate a solution plan and carry it out. It is through

this process that they are able to understand how the equipment works and gain a higher comprehension on a technical subject matter.

Remote Laboratories provide the same opportunities with a slightly different approach. Depending on the GUI and controls that are built into the experiment, the user can be guided down a specific path of actions or left to understand everything from the video and signal responses. If a laboratory is designed for the latter approach, the GUI would have minimal labels and require the student to see how a button or knob affects the local apparatus. This allows the participant to gain a higher level of understanding of how the local equipment works by forcing them to put extra consideration into how and why they make an action. For example, a student would need to put more thought into spatial physical interactions before deciding to move an object.

When the laboratory designer believes the experiment could use some simplification, they could provide extra detail on the GUI to help the student focus on only the intended problem. Students could then focus their attention on a signal response or on the calculations necessary to achieve the desired results. These options provide Remote Laboratories with the extra ability to augment the path to an experiment's completion.

2.5   Student Learning in a Remote Laboratory Setting

This section is used to show the findings of a series of tests studying various aspects of Remote Laboratory experiments. Participants were asked to take the VARK and Myers-Briggs learning preference assessments as well as a survey before (Presurvey) and after (Postsurvey) their experiments. These surveys included generic questions about their perceptions of RLs and how they compared to traditional experiments. Only one Presurvey was collected from each

student even if they performed multiple Remote Laboratories since their opinions were noted after each experiment in the Postsurvey.

Candidates were selected to participate in either a Remote Laboratory (**Experimental group**) or traditional laboratory (**Control group**) based on their group's average kinesthetic (K) score in the VARK model. This was chosen so the unintentional favoritism for a student who prefers to learn kinesthetically would detract from a positive Remote Laboratory experience. In other words, kinesthetic learners are most likely to prefer traditional over Remote Experimentation. It would be better to get favorable results against the odds than with them. Future works should randomly select the experimental groups for more statistical accuracy.

The Experimental group and Control group apparatus were designed from the same equipment, where the Experimental group apparatus was fitted with Remote Laboratory technology. Two laboratory types were utilized for these tests. One was a heat transfer experiment that would fit with the 'measurement' template, and the other was a controls experiment that fits in the 'complex movement' template.

2.5.1   Learning Style Comparisons

As discussed on page28, students were asked to complete two questionnaires to determine their learning preference. Table 9 through Table 12 are used to present the results of these questionnaires.

Code Name	JUNG	VARK Visual	VARK Aural	VARK Read/Write	VARK Kinesthetic	VARK Learning Preference
SA1	ENTJ	5	11	8	**11**	Multimodal
SA2	ISTJ	4	6	11	**8**	Multimodal
SA3	ENTJ	8	3	3	**2**	Multimodal
SA4	ENTJ	10	12	13	**8**	Multimodal
SA5	ENTJ	12	4	10	**9**	Multimodal,
SB1	ESFJ	5	4	10	**7**	Mild Read/Write
SB2	INTJ	4	3	9	**5**	Read/Write
SB3	ENTJ	3	4	4	**6**	Mild Kinesthetic
SB4	ESTJ	7	5	6	**8**	Multimodal
SC1	ISTJ	3	2	10	**1**	Read/Write
SC2	INTJ	1	1	12	**2**	Read/Write
SC3	INTJ	2	2	10	**8**	Multimodal
SC4	ENTJ	14	9	11	**14**	Multimodal
SC5	ISTJ	4	3	5	**4**	Multimodal

On average, the class demonstrated a multimodal learning preference, but there was a wide range of responses for both the VARK and Myers-Briggs tests.

Table 11: Spring 2010 VARK Kinesthetic Averages

Group Name	VARK Kinesthetic
SA	7.6*
SB	6.5*
SC	5.8

*Selected for experimental group

A group was chosen to perform an experiment remotely based on their average VARK kinesthetic score. In spring 2010, two groups were selected to conduct remote experiments.

Table 12: Fall 2009 Learning Preferences

Code Name	JUNG	VARK Visual	VARK Aural	VARK Read/Write	VARK Kinesthetic	VARK Learning Preference
FA1	ESTP	7	12	8	**9**	Multimodal
FA2	ISFJ	7	9	12	**9**	Multimodal
FA3	ENFJ	10	11	13	**8**	Multimodal
FB1	INTJ	3	5	9	**9**	Multimodal
FB2	ISFJ	11	13	12	**15**	Multimodal
FB3	INTJ	1	6	5	**4**	Multimodal
FB4	ESTJ	8	10	10	**11**	Multimodal
FC1	ENTJ	8	6	11	**9**	Multimodal
FC2	INTJ	7	2	5	**5**	Visual
FC3	ENTJ	3	11	6	**7**	Aural
FC4	INTJ	6	4	13	**4**	Read/Write

As with spring 2010, the fall 2009 class demonstrated a multimodal learning preference since most students scored high in multiple categories.

Table 13: Fall 2009 VARK Kinesthetic Averages

Group Name	VARK Kinesthetic
FA	8.7
FB	9.75*
FC	6.25

*Selected for experimental group

Only one group was selected in fall 2009 to execute the laboratory remotely. This decision was based on the intention to have a large Control group to compare with a single Experimental group.

2.5.2 Report Comparisons

Comparison between the report grades for traditional and remote experiments are discussed in Chapter 5 on pages 78 and 80. In summary, groups who performed a remote experiment received a lower grade than those who did the experiment locally but gained a

stronger than average theoretical understanding of the material taught in the lab. Note that the sample size 6 groups, three taking the laboratory remotely.

2.5.3   Survey Analysis

Surveys were distributed to all students before an experiment to gain perspective on their initial perceptions of Remote Laboratory experimentation. Students who executed a laboratory remotely were given the same survey after the experiment, with additional questions. These surveys are available on in Appendix A (pg. 93).

Table 14 is used to demonstrate the tendency of students' favorable perceptions of Remote Laboratories to improve after performing a remote experiment.

Table 14: Changes in Traditional or Remote Laboratory Opinions

Presurvey				
Participants	**Favoring Traditional (Procedure)**	**Favoring Traditional (Concepts)**	**Favoring Remote (Procedure)**	**Favoring Remote (Concepts)**
Full Class	93.3%	93.3%	60.0%	60.0%
RL participants	100.0%	100.0%	55.6%	66.7%
Difference (RL - Full)	*6.7%*	*6.7%*	*-4.4%*	*6.7%*
Postsurvey				
RL participants	90.0%	80.0%	90.0%	80.0%
Difference (RL Post - RL Pre)	*-10.0%*	*-20.0%*	*34.4%*	*13.3%*

Results from the Presurvey indicate that the students chosen to execute a RL believed traditional experiments would be more useful for understanding experimental procedures and technical concepts by 6.7% compared to the full class response. The results for remote experiments were more mixed with RL participants favoring remote procedures 4.4% less and remote concepts 6.7% more.

After completing a remote experiment, the perception of the usefulness of traditional procedures and concepts dropped by 10% and 20%, respectively, for the RL participants. Their believe that Remote Laboratories are useful for understanding experimental procedures and technical concepts increased by 34.4% and 13.3% respectively.

Table 15 is used to present the favorability of the usefulness of Remote Laboratories to traditional experiments by comparing each group's responses before and after the experiment. This was evaluated by taking the percentage of favorability for a traditional experiment and subtracting the favorability from the same category of remote experiments.

Table 15: Favorability of Remote Laboratory to Traditional Experiments

	Presurvey	
	Difference in (Procedure)	**Difference in (Concepts)**
Full Class	33.3%	33.3%
RL participants	44.4%	33.3%
	Postsurvey	
RL participants	0.0%	0.0%

It is shown that on average, students prefer traditional experiments by at least 33.3% before completing a remote experiment. Once an experiment is completed, the RL participants indicate no difference in the usefulness of a Remote Laboratory compared with a traditional lab.

CHAPTER 3: IT REQUIREMENTS FOR REMOTE LABORATORY

IMPLEMENTATION

The purpose of this chapter is to provide an understanding of the complexities involved with the remote connections required for Remote Laboratory deployment. To do so, an overview of firewalls, modern secure networks, and latency is provided. A method to overcome the challenges associated with establishing and maintaining a connection through multiple networks by utilizing remote desktop connections is then proposed.

3.1   Network Connections and Security

Several information technology managerial challenges need to be addressed in order to create Remote Laboratory environments. This section includes various aspects of network security management as well as a description of it's two primary functions; to allow seamless remote access for remote users to communicate with local machines within highly complex and secure enterprise networking systems (such as a university network), and to retain high-levels of security for the RL environments. A brief discussion of how latency can affect a Remote Laboratory is also presented.

3.1.1   Firewalls and Network Security

Firewalls are network devices that filter incoming and outgoing network traffic based on a network security policy by partitioning networks into secure regions. All traffic flowing between these regions must be scrutinized by the firewall. For each communication connection traversing the firewall, the firewall may use a network data packet contained within the data and compare it against the firewall's security policy. If the policy is defined to allow the particular

type of traffic, then the firewall can provision the traffic and allow it to continue its flow. Otherwise, the firewall filters the traffic and not allow (deny) it to continue flowing.

Communication traffic flows from the inside network through the firewall to an outside network and vice versa. Common enterprise networks and their firewall systems allow most traffic that is initiated inside the network to flow outside. However, the firewall acts as a modulated switch for traffic that is initiated outside, where the modulation is provided by the security policy.

Example Security Policy

> *"Allow all Internet connectivity to the web server located within the inside network."*

This policy is implemented via a firewall filtering rule, which is a translation of the high-level security policy into a filtering language understood by the firewall. The "switch" closes for traffic that matches the firewall's security policy and opens for traffic that does not match the policy.

There are two types of firewall security policies: static and dynamic. Static policies are the formal policies defined by the enterprise. Dynamic policies created by the firewall when an inside node initiates a communications connection to an outside node. Note that when an inside node communicates with an outside node, the outside node will reply to the inside node. Hence, there can be traffic flowing from the outside to the inside network.

In order to allow a reply from the node to the internally initiated connections, the firewall employs stateful packet filtering technology. With stateful filtering, the firewall stores connection tracking state information for every internally initiated connection. Once the external node replies to the internal node, the firewall inspects the connection tracking state table. If the

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reply connection matches information stored in the state table, then the connection is allowed to pass through the firewall.

3.1.2   Latency

As with any computer network connection, latency causes a delay in response after a signal is sent. Factors which contribute to this latency are not limited to network load and speed of the remote, local computers' internet connections, and distance between them. This can cause a varying and mostly unpredictable delay in signal when a remote user is connected to a local computer. In most laboratories, the local computer which is directly connected to a piece of equipment apparatus has virtually no latency which needs to be corrected for.

An example of an error caused by latency is as follows:

Example of Latency Related Errors

A student is learning about the pendulum effect using a Remote Laboratory with a camera to display movement. He wants to find the time it takes for the pendulum to oscillate for one full cycle.

He presses "Go" on the GUI, which sends a signal to the apparatus to release the pendulum and automatically starts a timer. Once the student observes that the pendulum has completed the cycle, he presses "Stop" which stops the timer.

Since the timer initiates at the SAME TIME as the pendulum (since the signal is sent from a local computer to local apparatus) and the student stops the timer when he OBSERVES the cycle is complete, there will be a timing error equal to the response time of the student and the latency of the video from the local computer and "Stop" signal being sent to the local computer.

If performed locally, this experiment would have the error from the student response time only. A potential remedy for this would be to automate the timer completely or have the student discover and/or approximate the latency error and consider it during data analysis.

3.2   Software

3.2.1   Computer Networking

Certain software is required to establish communication between the local and remote computers. Three widely used methods that are currently being used are through the use of internet browsers, remote access programs, and remote desktop connections [4, 16, 41, 46]. This thesis focuses on latter since they provide the maximum control for the user.

Remote Desktop Connections

Remote desktop connections can be established using software that comes with an operating system, or third party programs. Some Virtual Network Computing (VPN) packages require the IP addresses of the connecting remote computers to be verified before a connection can made, where other full access remote desktop programs allow access to a local computer as long as the remote computer verifies an identification number and password. Each method has varying levels of functionality and security associated with them which should be taken into consideration when a Remote Laboratory designer is selecting an option.

Once a connection is established, the remote student has access to everything the local computer is allowed to control. This grants the student maximum access to utilize advanced controls or troubleshoot computer problems without requiring expert level programming to allow this much access through other connection types. Many remote desktop programs allow a user to view the remote desktop in a window on the local screen instead of taking the full monitor and quickly transfer files between the computers. Some programs, such as Teamviewer®, have a video conferencing option that can be used to send video and audio at a faster rate than if watching solely through the remote desktop connection.

Internet Browsers

Some laboratories are operated by a remote user entirely through an Internet browser, such as Internet Explorer or Mozilla Firefox. These laboratories are linked to a local computer which sends and receives information from the equipment and broadcasts in over the internet [47]. This allows a remote user to simply access a website and run the laboratory as desired.

Remote Laboratories operated through internet browsers often have a filter which limits unauthorized people from access, or only allows a certain number to connect at a time. If configured and programmed correctly, this option provides an easy method for remote learners to get experimental experience[48]. A drawback with this method is that the students have minimal control over that data collection and are strictly limited to what is available on the website.

Remote Access Programs

A Remote Laboratory designer might choose to create a single or set of programs that are downloaded and installed on a remote computer and used for the entire laboratory process. Once installed, they search for the local computer, usually by IP, and establish a connection. Remote access programs have a mix of the benefits of internet browser access and remote desktop connections. They may allow greater control of the equipment or data flow than can be managed by a single website and provide better security for the local machine than remote desktop applications. The two main drawbacks are that they can be difficult to program for the complex signals which must be sent and each computer must have the appropriate firewall and port settings.

3.2.2 Data Collection and Robotic Control

Almost every Remote Laboratory experiment requires some form of computer controlled data collection or operation of equipment. Some experiments might utilize one software package

to manage these tasks, where others use another. This could cause a problem for a remote

learner by requiring them to continually learn new programs instead of focusing on the

experiment. Without understanding the variables in network capability, institutional policy, and

laboratory equipment, there is no way to predict what single type of programming will work best

for a set of experiments.

It is better to leave the options open than to commit to a single type of program for each

experiment. Many robotic controls come with pre-programmed interfaces that might be able to

communicate with other programs[49]. It would not be logical to scrap a functioning program

only for the sake of consistency. Instead, it would be best to integrate these programs into a
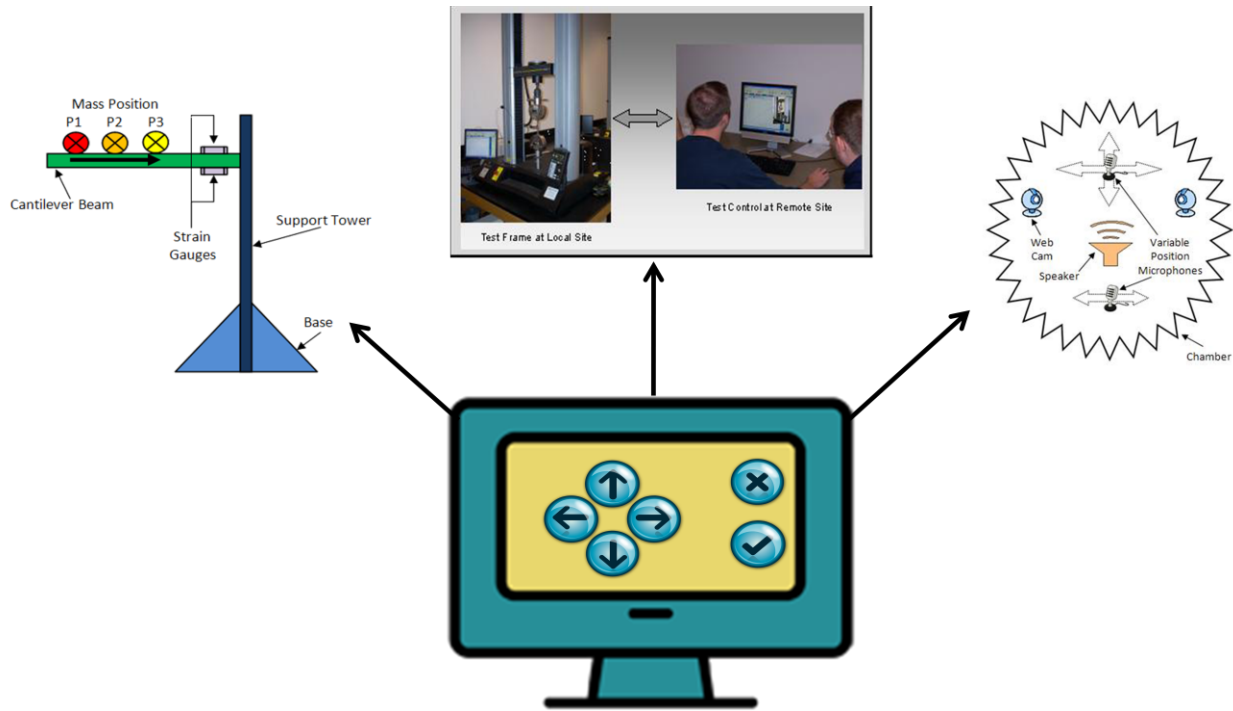
familiar GUI, as exhibited in Figure 5.

Figure 5: Exhibition of Using a Single GUI for Multiple Laboratories

When there is a need for a Remote Laboratory designer to create a HCI, it must be able to

be accessed through a small number (preferably one) of GUIs so the user does not get confused

by needing to operate multiple programs simultaneously [50-51]. Uniformity of control type can then be easily configured for all experiments by using just one program as the terminal for the others to work with. Existing Remote Laboratory experiments have had success by utilizing National Instruments' LabVIEW® ELVIS [36].

3.2.3 Laboratory GUI

Utilization of graphical user interfaces for improving the user experience was previously discussed in Chapter 2 (pg. 33). This section is intended to highlight some of the technical considerations for a GUI with respect to remotely controlled machinery.

There are two objectives one must consider when creating a GUI for a Remote Lab. One is to provide a student with full control of the local apparatus as needed to complete the laboratory while providing the most realistic user controls possible. The other is to minimize any errors which could occur due to the nature of the remote connection. As discussed earlier (pg. 45), latency can cause errors in Remote Laboratories. Building the GUI to prevent such problems or instructing students how to manage them can have a significant impact on the laboratories' ease of use.

A Remote User is not expected to download the GUI software and run it from their location. All control is made through the Remote Desktop connection, including data gathering and apparatus control. GUIs should be constructed so that a student is able to interface with it from any computer, no matter the speed or operating system. This means there cannot be a need for a rapid input of commands or operating system specific input commands (i.e. Ctrl+Shift+T, Apple key, etc.).

Another source of error could occur when the students are using a broken piece of equipment. Accidents are bound to happen in local or Remote Laboratories, but the GUI can be

created to help minimize them. If ordering two commands at the same time could damage the equipment or alter results, the GUI can be programmed to restrict duplicate commands. It is advised that this is done directly instead of automatically. Providing the students with a "switch" to allow one command type or the other may give them a better understanding of the system as opposed to limiting operation in the background.

There is also the option of creating an adaptable GUI that students could improve after conducting an experiment. Open-sourcing the GUI could lead to better student interactions with the equipment, and reduce development costs[52].

3.3   Network Connections

3.3.1   Allowing Remote Desktop Access

The means to connect a remote student and local apparatus must include a network connection through the Internet. Due to the amount of data that is transmitted during an experiment, both computers must have a high speed connection. The local computer controls the commands to an apparatus and performs most of the calculation, so it must be able to process information fast enough to support whichever actions are required of it. A remote computer must only needs to support web browsers or remote access programs.

3.3.2   Alternatives to Conventional Network Connections

A conventional network includes two or more computers which are connected to share information. The communication can take place via a set of transmission lines, routers, servers, or many other means. A university network usually includes servers which communicate with each other through an intranet, and allows them to communicate with computers outside the

network through the internet depending on firewall settings. This section is used to summarize two server types which could be used grand alternative access to outside computers.

Command and Control Centers

A centralized server, known as a command and control center (CCC), is used to interface between the local and remote computers and equipment. The CCC can act as host for various functions that control the Remote Laboratory including routing, synchronization, and providing the security features and communications between computers. The Remote Laboratory program polls the CCC periodically and "asks" it for any commands that it needs to execute. Then the CCC will reply appropriately.

The ultimate goal is to establish communications between the remote user and the local remote control program. To accomplish this, the remote user logs into the CCC and chooses the appropriate laboratory system. All communications are managed via the CCC which acts as a virtual switch. Since all communications are initiated from the local equipment and remote users to the CCC, the architecture provides the ability to essentially bypass any firewall change management process for a Remote Laboratory apparatus.

Portable Servers

Some laboratories might be designed to be portable. There can be a need for portable laboratories if the room where the equipment is stored can only support a limited number of setups at a time, or if the laboratory is to travel from place to place. Instead of configuring a computer at each location, the laboratory could be connected to a portable server, one that could additionally serve as a CCC. This allows the equipment to have a consistent connection process independent of its location.

3.4   Remote Desktop Implementation

3.4.1   Initiating a Remote Connection

Remote desktop software programs have varying connection requirements. Programs like the one included with Windows 7 provide multiple methods to create a connection. Some connections can be timed or allow access in a certain time frame, where others can allow unlimited access. It is advised that whichever program is chosen, it allows a remote user to access the computer without requiring a live person on the local end. Requiring a person to be stationed at the local computer would take away one of the autonomous benefits of Remote Laboratories.

A user is given a wider range of options by using a remote desktop program other than the ones included with an operating system. They can have more open access to the local machine while still maintaining the security associated with a user ID and dynamic password. Commercial programs also tend to be more user-friendly and grant connections between multiple operating system versions and types.

Teamviewer® granted a free trial of their software for these Remote Laboratory purposes, so it was used for each of the experiments in Chapter 4 (pg. 55). This tool assigns a 9 digit numerical identification number and creates a dynamic password for each computer on which it is installed. A user defined password can also be created and edited as needed to provide greater security, such as "RLExperiment2" or "TensileTestLab".

Laboratory instructors can provide students with the local computers' user IDs and passwords as they deem appropriate. Remote students can then download and install the licensed software and input the information to establish a secure connection. This allows the remote user to freely perform the experiment, view multiple monitors, and transfer data files

between computers. Teamviewer® can be programmed to start with the operating system so a remote user can reconnect with the computer in the case of an operating system crash or other potential power downs.

Single Computer

The most common implementation with a remote desktop connection is when one computer joins another. It provides simple access for any user if they follow the steps outlined in the previous section. Any laboratory where one or a group of students perform an experiment in the same location will utilize this type of connection.

Multiple Computer

Many Distance Learning students are used to working alone [53]. Remote Laboratories give them the opportunity to share control over an experiment and interact with each other through a voice-over IP. Students can connect to the local computer simultaneously when an experiment requires group work. The connection protocol is the same as with a single connection except there are multiple users who have access to the machine at the same time. As with a traditional lab, students need to communicate and choose who should be in charge of operating the GUI at a given time.

3.4.2 Need for Simple Remote Connections

Remote Laboratories should be designed to focus on the equipment and data. A laboratory manual can be written to minimize any confusion associated with establishing a remote connection. This task is made much simpler by using a software package that is as user-friendly as possible. Ideally, a student should be able to install the remote desktop software,

access the local computer, locate or open any required software, and begin the experimental procedure.

The local computer should be free of unneeded programs and have only the required software icons available on the desktop. When the remote user connects to the local computer, they should be able to easily understand what needs to be done to prepare for the experimental side of the lab. Unnecessary programs or icons may confuse the student, slow down the system, and increase the potential of a crash.

CHAPTER 4: REMOTE LABORATORY IMPLEMENTATION AND EXAMPLES

This chapter includes descriptions regarding the three Remote Laboratory experiments constructed to understand previous examples and provide further evidence of remote experimentations suitability to modern laboratory environments.

4.1 Steps for Remote Laboratory Implementation

The implementation described in each of the three following Remote Laboratory examples involves four key steps:

1. Configuring the IT infrastructure
2. Initiating a Remote Laboratory experiment
3. Completing Remote Laboratory experiment
4. Assessment and evaluation

These models were used for the creation of the three example experiments. It is assumed that the descriptions listed here were used for each experiment unless otherwise stated.

4.1.1 Configuring the IT Infrastructure

IT infrastructure, as it relates to remote connections, must be taken into consideration before a laboratory is designed. Understanding the concepts from Chapter 3, such as a networks firewall policy or which software is used for the connection and interface, is vital for this initial stage. A Remote Laboratory can only be preformed after these technical aspects are identified since user control can vary between different programming and configurations.

These laboratories utilized a remote desktop connection to gain remote access. Once connected, the students had the ability to control everything that a local student could control through the computer. LabVIEW® was used as the GUI for controlling experimental equipment when there was no commercially available software included with the lab.

4.1.2 Initiating a Remote Laboratory Experiment

An experiment is ready to be run after the equipment controls are tested and the GUI is complete. As long as the students have been made aware of the policies and procedures for setting up and working with a remote connection, they should be fully prepared to begin. It may be necessary to have a video tutorial to ease them into the process, but a laboratory manual should have enough description for them to follow.

A student must have been provided with the local computer's remote ID and password to initiate the remote desktop connections. These should be distributed as needed by the teacher or TA so the student could enter the information and be granted control of the local computer. GUIs were only run on the local computer so there would be no need to install laboratory specific software for each experiment.

4.1.3 Completing Remote Laboratory Experiment

Students must be given background information on the technical background of the lab, as well as a procedure to follow. These are needed for any experiment whether or not it is preformed remotely. The "3 Axis Gantry Control Systems" experiment was created from scratch, so there was no existing procedure or background information available for student use so they needed to be developed with the lab. The "Flywheel Control systems" and "Heat Transfer" experiments were directly adapted from an existing traditional laboratory experimentation class, so the procedure and background were virtually the same. Details on how the individual experiments were operated and monitored are included in the following sections.

4.1.4 Assessment and Evaluation

Student reports following their experiments were compared between the groups who completed the laboratory remotely and those did so locally. Surveys were given to students

before and after the experiments to gain an understanding of their opinions regarding Remote Laboratory experimentation and to gain feedback on the setup and procedures. Indicators from each experiment are outlined following the experimental descriptions and detailed in Chapter 5.

These findings should be viewed as insights to the effectiveness of Remote Laboratories, not as hard evidence since there have been a limited number of tests performed. It will take a larger research setup to obtain enough samples of reports and surveys to provide proof reliable that Remote Laboratories can be an effective means to teach laboratory experimentation.

4.2   3 Axis Gantry Control Systems Remote Lab

4.2.1   Purpose of Experiment

This Remote Laboratory was created to apply the theoretical knowledge gained from this thesis to create an experiment based off of the Complex Movement template (pg. 22). Practical experience with the key models to identify best-practices was only achievable by creating an experiment from scratch.

It was designed to allow students to use their background knowledge of control systems to complete the procedure and answer the provided questions. The laboratory manual for this experiment is available in Appendix B.

4.2.2   Equipment

A CAMotion® 3 Axis Gantry Packaging Robot was used to provide students with first-hand experience with control systems concepts. It utilized a PID controller to translate the position of the "head" on 3 planes, as shown in Figure 6. Only the X and Y planes of space were used for this experiment.
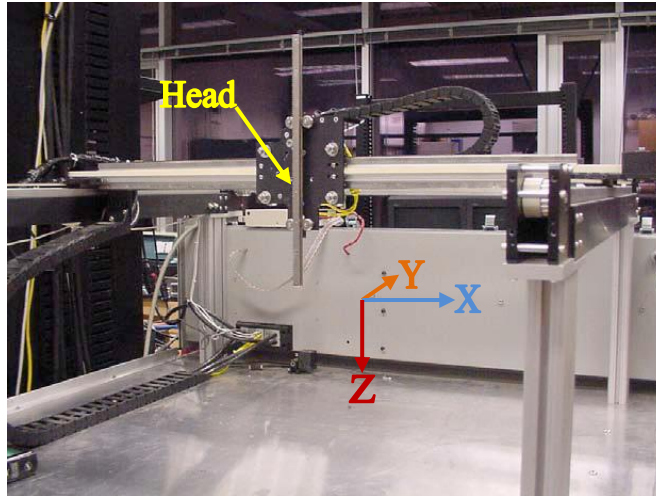
Figure 6: CAMotion® 3 Axis Gantry Packaging Robot

A LabVIEW program was created to control and track the head position. Students had

the ability to force a sawtooth, square, or sine wave function in either or both axes, where the

response and settling times would be subject to the gain variables. They were required to use

background knowledge of control systems and the provided equations to calculate which gain

values to select to optimize these times. A webcam and microphone was mounted above the

robot to provide students with an audio/video feed of the experiment.

4.2.3 Adaptation for Remote Use

There was no need to make alterations to existing laboratory equipment since this

experiment was created directly for remote use. Traditional experiments that are to be used for

remote use require some kind of adaptation to allow remote users to view and access the

apparatus.

4.2.4 Communication Protocol

This experiment was designed to use the Windows XP® remote desktop tool. Initial

trials lead to this decision since tools like Virtual Network Computing would require multiple

firewall exceptions to be made through the university's IT department. The Windows® remote

desktop tool was able to provide a secure and stable remote connection without altering the

firewall, but was not able to send sound with the video feed displayed on the GUI.

Skype® was used to connect the audio signal to the remote students' location by

installing the voice over IP program on the local and remote computers and connecting a "call"

between the two. Preliminary tests demonstrated a lag between the audio and video signals, so

the video signal was also sent via Skype® to provide synchronization.

4.2.5   User Interface

The LabVIEW® program running on the local computer was also used as the graphical

user interface (Figure 7) for this experiment. It contained 6 tabs where the students could control
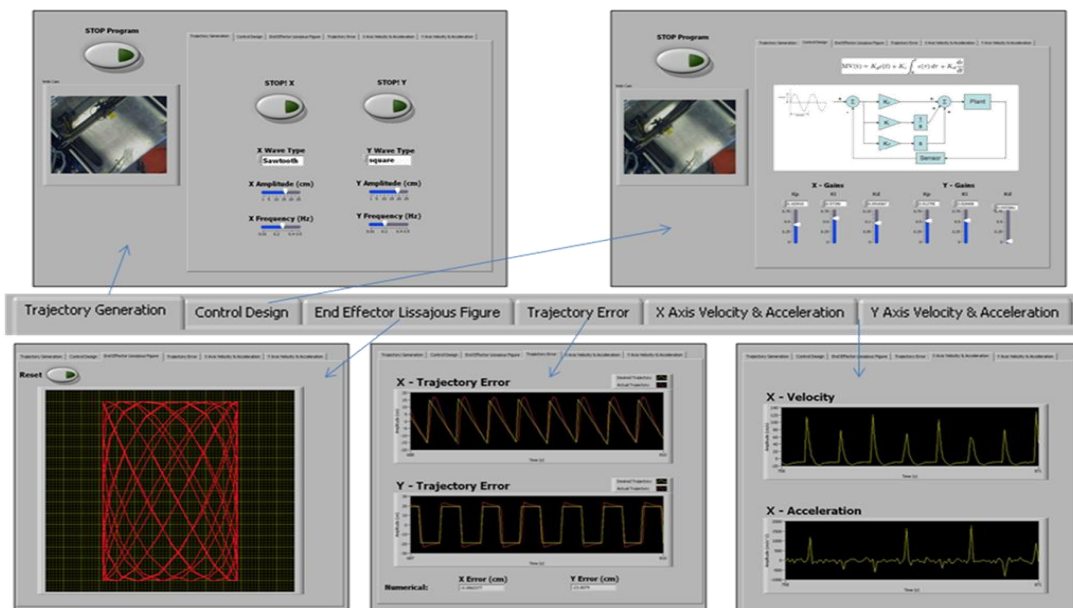
or view various components of the lab.

Figure 7: 3 Axis Gantry Controls System Remote Laboratory User Interface

- Trajectory Generation – Allowed the student to choose a waveform and its amplitude and frequency
- Control Design – Provided the X and Y Gains for student control based on their calculations
- End Effector Lissajous Figure – Illustrated the position of the head in real time

- Trajectory Error – Displayed the theoretical and actual trajectory of the head on both axes in real time
- X and Y Axis Velocity & Acceleration – Presented the head velocities and acceleration on the X and Y axis

A local student would look at the robots movements while tracking the information on the computer screen. For a remote student, selecting a tab would change the information in the right side of the GUI, while leaving the left side open to display the video feed. This allows them to make a visual link between the video of the head and the End Effector (Figure 8) or other plots. To more closely emulate a traditional laboratory experience, the camera could be rotated to provide alternative viewing angles for the student.
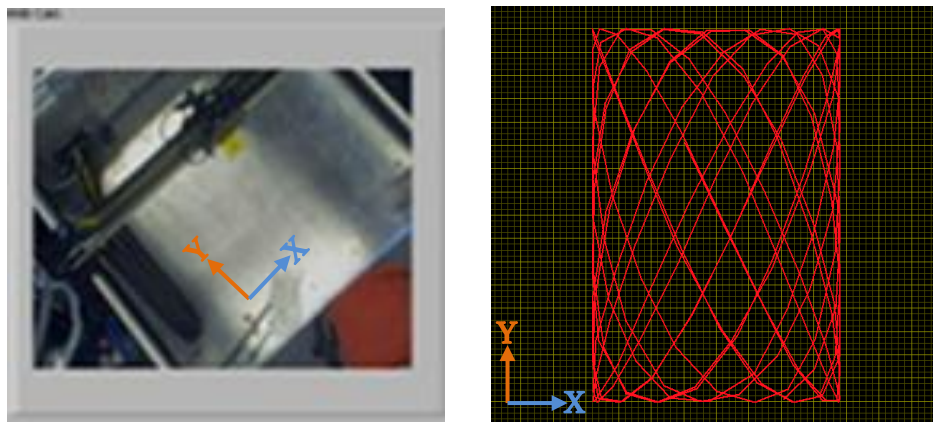
Figure 8: Traced Display of Head Location

Commands available for student interaction were buttons, pull-down menus, and sliders. Buttons were chosen to simulate the real-world requirement to push a button to turn a machine or component on. A power button was available in each tab so the system could be powered off in case of an unforeseen mechanical problem. The pull-down menu was selected since there was a list of waveforms available for use and they should have been able to see which is active at any time. Sliders gave the students a range of values to work in, without allowing them to cause any damage to the system.

4.2.6 Findings

Volunteers were asked to conduct the experiment and provide feedback about the system from a technical view point and discuss their observations of the GUI and ease of creating a remote connection with the intention of pointing out problems. The feedback received is summarized in Table 16.

Table 16: Feedback from 3 Axis Control Systems Experiemnt

Topic	Response			
User Interface	Difficult to understand initially, but makes sense after use	Good, but too many tabs	Liked being able to see real time changes	More description needed in each tab
Ease of Remote Connection	Easy if directions are followed	Did not like how remote desktop program took over entire monitor	Simple	Noticeable delay between mouse commands
Observations	Remote Laboratory felt more like traditional than expected	Liked having an option to do an experiment remotely		
Other	Opposed to installing Skype® on remote computer	Wants better synchronization between GUI video and Skype® video		

These responses were used to help develop future experiments. Since this experiment was an intellectual exercise, there was no graded trial run which would provide data on the participants' level of technical understanding.

4.3   Heat Transfer by Convection Remote Lab

4.3.1   Purpose of Experiment

An Armfield® Heat Transfer Laboratory Experiment was used for another Remote Laboratory based off of the Measurement template (pg. 20). Georgia Tech Savannah's Mechanical Engineering 4053 laboratory experimentation class was performing this experiment

traditionally. Since they had already been evaluated to conform to the institutional and ABET

guidelines, there would be no need to recertify the experiment before it was tested. There would

be years of laboratory reports to serve as Control data (See Student Learning in a Remote

Laboratory Setting, pg. 37) and opportunities to collect Experimental data. Additionally, a

manufacturer provided software package could be used as the GUI for this experiment, making it

was a prime candidate to Remote Laboratory integration.

The laboratory procedure involved temperature collection at different locations on a

metal rod with an applied heat source. Students analyzed the data to determine the rod's material

composition and understand the temperature response over distance with natural convection and

radiation. There was no difference between the manuals for traditional and remote experiments,

but slides were distributed to remote students as a reference for controlling the laboratory

remotely, available in Appendix C.

4.3.2   Equipment

This experiment required three different apparatus, an Armfield® HT10XC Computer

Controlled Heat Transfer station, an Armfield® HT15 Extended Surface Heat Exchanger, and a

computer. The Armfield® equipment setup is shown in Figure 9.
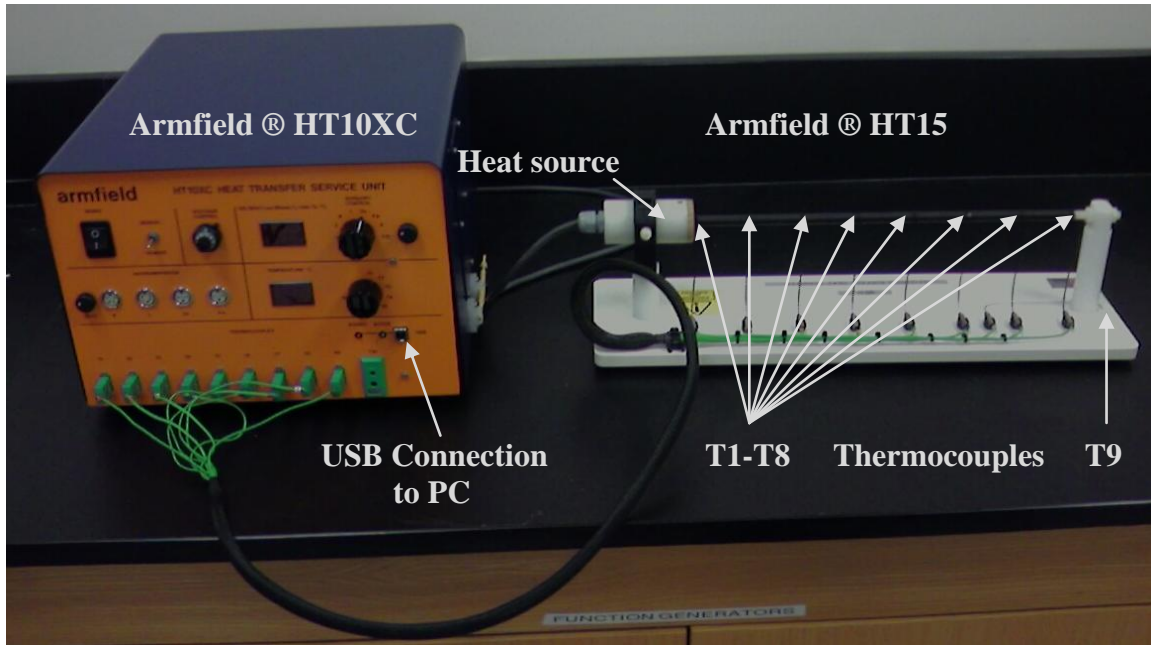
Figure 9: Heat Transfer by Convection Remote Laboratory Setup

These responses were used to help develop future experiments. Since this experiment was an intellectual exercise, there was no graded trial run which would provide data on the participants' level of technical understanding.

There are 9 different thermocouples along the HT15. Thermocouples T1-T8 are located 50 mm apart along a heated rod and T9 measures the ambient air temperature. It connects with the HT10XC to control the heat source and receive temperature data. When connected to a computer through a USB, the Armfield® apparatus communicates with software to send and receive signals.

4.3.3 Adaptation for Remote Use

When an existing laboratory experiment is selected for Remote Laboratory use, there is often a need for some adaptations to provide the remote user with a full experience. A webcam and microphone should almost always be installed to provide more feedback for the students. This experiment generated no sound, but an audio signal was sent with a video feed to allow the

students to come to that conclusion on their own. There was no need for any extra signal

conditioners or mechanical components for this experiment, just the webcam with built-on

microphone.

Software to connect the HT15 to a computer had been available since the equipment was

purchased, but was never installed since students could obtain all of their readings from a display

on the HT10XC15. To enable the laboratory for remote use, the Armfield® software was

installed on the computer which would be connected remotely.

4.3.4   Communication Protocol

A remote connection was again made via a remote desktop software package where the

teacher or TA would provide the ID and password as needed. Having implemented the feedback

from the 3 Axis Control Systems Remote Lab, the software was changed to Teamviewer® since

it would it allow the user to control the local computer without taking up the entire remote

monitor and it has a built-in VOIP function. These features allowed the remote user to manage

their own computer and the local computer at simultaneously and view/hear real-time signals

without running any extra programs.

4.3.5   User Interface

Armfield® provides software to control their equipment through a computer. The

module for working with the HT15 shown in Figure 10 was used as the primary interface with

the equipment. A webcam and microphone was also setup to let the students see and hear any

changes in the equipment.
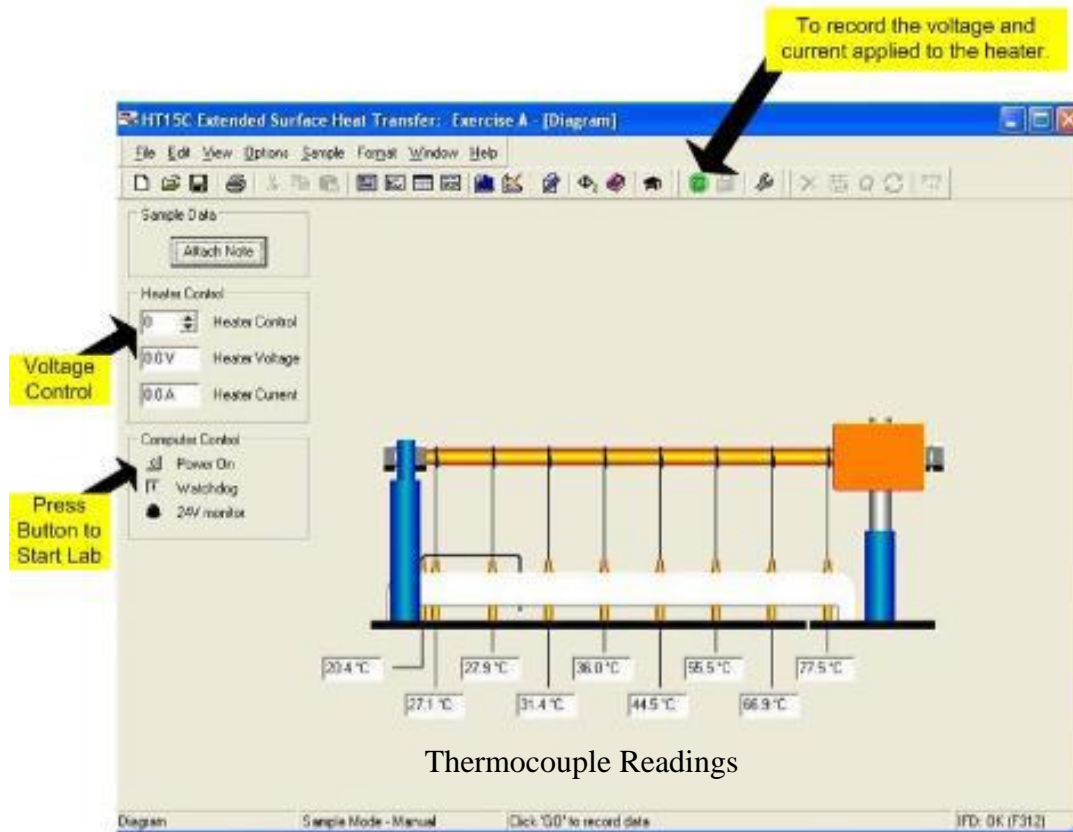
Figure 10: User Interface for the Armfield® HT15 Software

Traditional students were only required to take temperature and voltage measurements displayed on the Armfield HT15. Remote students must use this GUI, so they have the benefit of working with the extra features of the Armfield® software such as watching a graphical representation of temperature changes in real time as opposed to simply watching numbers change. These extra features can be accessed by selecting to "view" different windows that include tables or graphs.

Students were only required to take temperature measurements and change the voltage output after the temperatures have settled. This happened after approximately 15 minutes since heat would only move along the beam through convection. Traditional students manually input sample readings into a spreadsheet or notebooks; remote students have this option too. The

software allows the remote student to automatically take sample readings, but this option is not encouraged to maintain similar results between traditional and Remote Laboratories.

This Remote Laboratory is an excellent example of an experiment that is enhanced when adapted for remote use. Many other experiments could benefit from automatic and accurate data collection which is standard with Remote Laboratories. Students have more exposure to numerical trends when they use an apparatus which is interfaced with a computer. Traditional students would also have the option to view the same information, benefiting everyone involved in laboratory experimentation.

4.3.6   Findings

Students were asked to take a survey before and after completing the

These responses were used to help develop future experiments. Since this experiment was an intellectual exercise, there was no graded trial run which would provide data on the participants' level of technical understanding.

Heat Transfer by Convection Remote Lab experiment to understand their perceptions of Remote Laboratory experimentation. These surveys are available in Appendix B. A class of 14 students, divided into 3 groups, completed this experiment and surveys in the spring semester of 2010 with 2 groups doing the laboratory remotely.

Presurvey and Postsurvey comparisons are displayed in the following table and figures. Figure 11 includes the Presurvey data taken from the entire class, while Figure 12 only includes the students who participated in the laboratory remotely. Figure 13 displays the Postsurvey findings from the 2 Remote Laboratory groups.

Table 17: Traditional and Remote Survey Comparison Questions

Legend Title	Question
Traditional Procedures	How useful do you believe a <u>traditional experiment</u> will be with helping you understand *experimental procedures*?
Traditional Concepts	How useful do you believe a <u>traditional experiment</u> will be with helping you understand *technical concepts*?
Remote Procedures	How useful do you believe a <u>remote experiment</u> will be with helping you understand *experimental procedures*?
Remote Concepts	How useful do you believe a <u>remote experiment</u> will be with helping you understand *technical concepts*?

Table 17 is used to summarize the questions asked in the Presurvey and Postsurvey. The legends of Figure 11 through Figure 13 relate to how the students believe experimental procedures and technical concepts are affected for either laboratory delivery method.
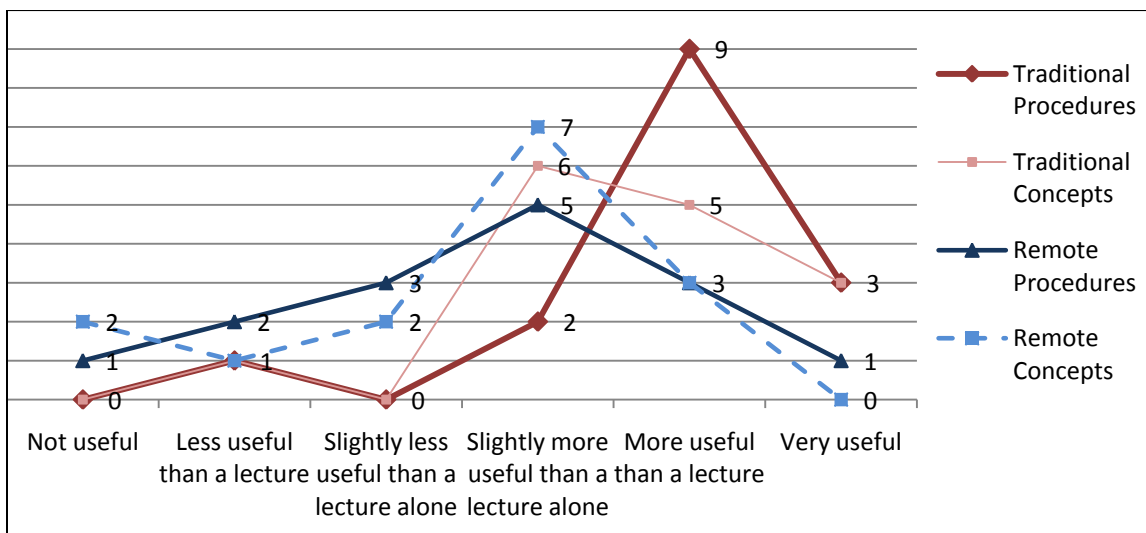
Figure 11: Spring 2010 Full Class Presurvey

Note that the initial student perceptions shown in Figure 11 tend to favor traditional laboratories over Remote Laboratories.
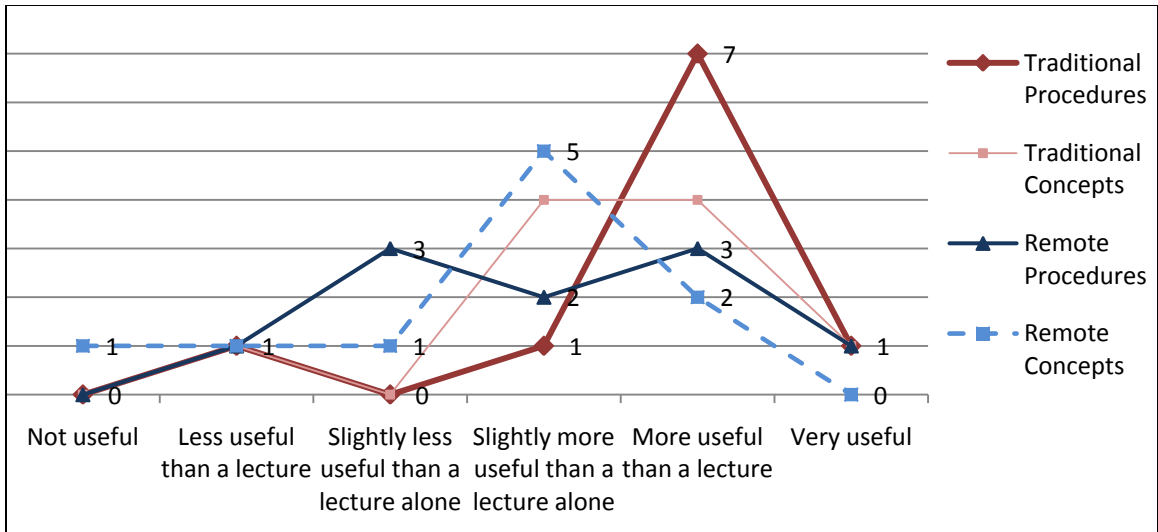
Figure 12: Spring 2010 Experimental Group Presurvey

A similar trend is noticed in Figure 12 after the traditional laboratory groups are removed. Here, students who would perform the laboratory remotely seem to have a more negative opinion as to the usefulness of Remote Laboratories.
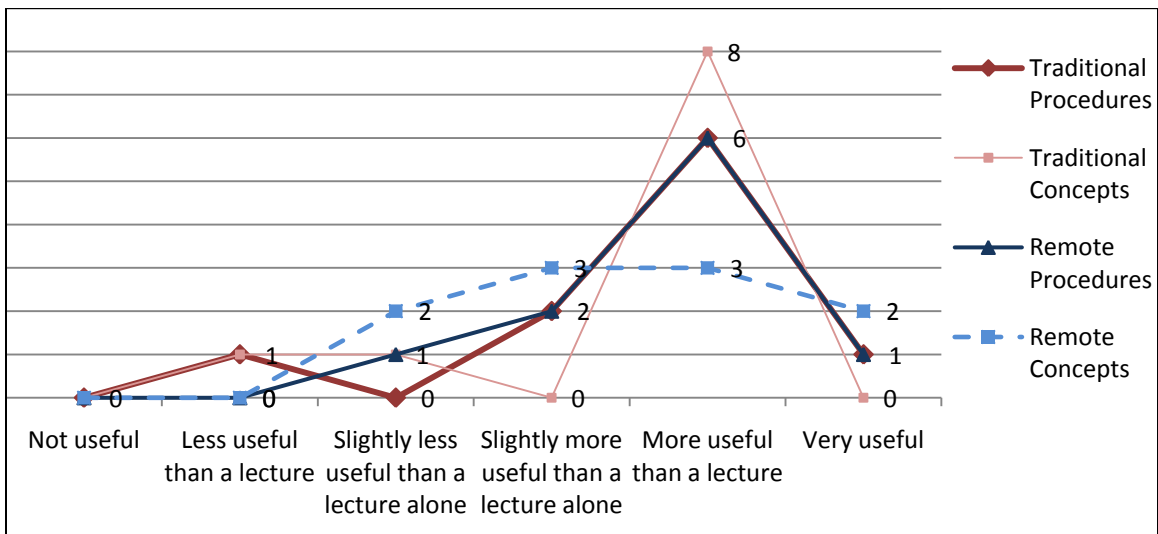
Figure 13: Spring 2010 Experimental Group Postsurvey

After the students complete the experiment remotely, their opinions regarding the usefulness of Remote Laboratories increased, as displayed in Figure 13. Note that the perceptions of traditional laboratories became more negative after completing the experiment remotely.

4.4   Flywheel Control Systems Remote Lab

4.4.1   Purpose of Experiment

A third Remote Laboratory utilized the same template and instructional concepts of the 3 Axis Gantry Control Systems Remote Laboratory with alternative equipment. This experiment was also a part of Georgia Tech Savannah's ME 4053 laboratory experimentation class, so it could quickly be implemented and tested.

Students were required to send various programs from the computer to the QET and experiment with the response time in certain conditions. They would then calculate theoretical values to reduce any difference in signal responses and make observations about assorted phenomenon.

4.4.2   Equipment

A Quanser® QET DC Motor Control systems apparatus, shown in Figure 14, served as the experimental equipment and the manufacturers GUI was utilized to control the devise.
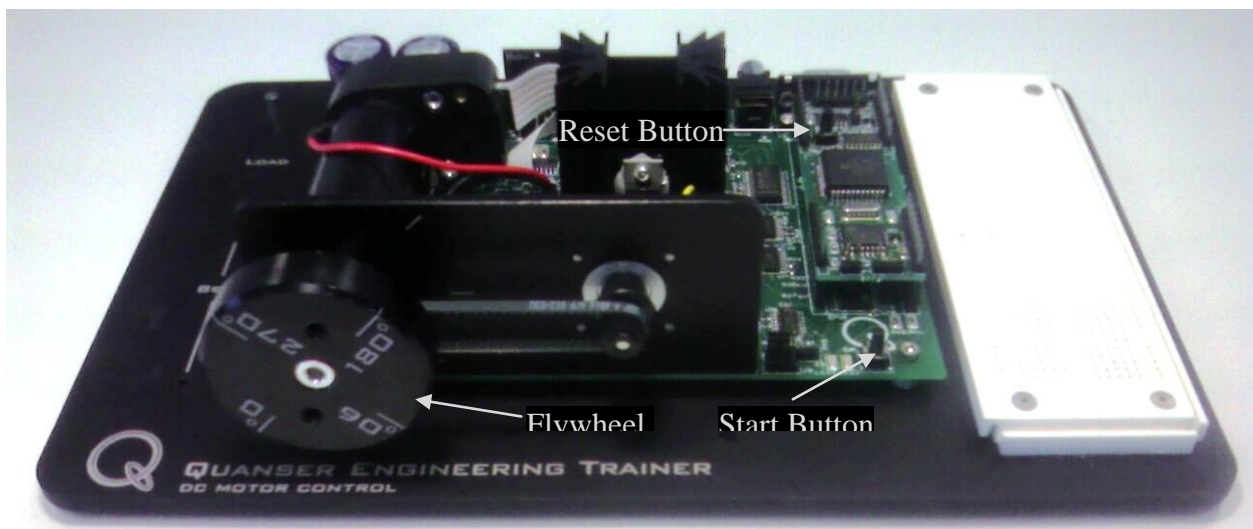
Figure 14: Quanser® QET DC Motor Control Systems Apparatus

The QET DC Motor Control utilizes a computer-controlled motor which spins a flywheel by rotating a belt. Students would reset the equipment, select the appropriate program on the computer, and press a start button to begin control. For one section of the experiment, students are required to manually apply a load on the wheel with their finger.

Local and remote users were able to control the QET DC Motor Control by manipulating the Quanser® GUI shown in Figure 15.
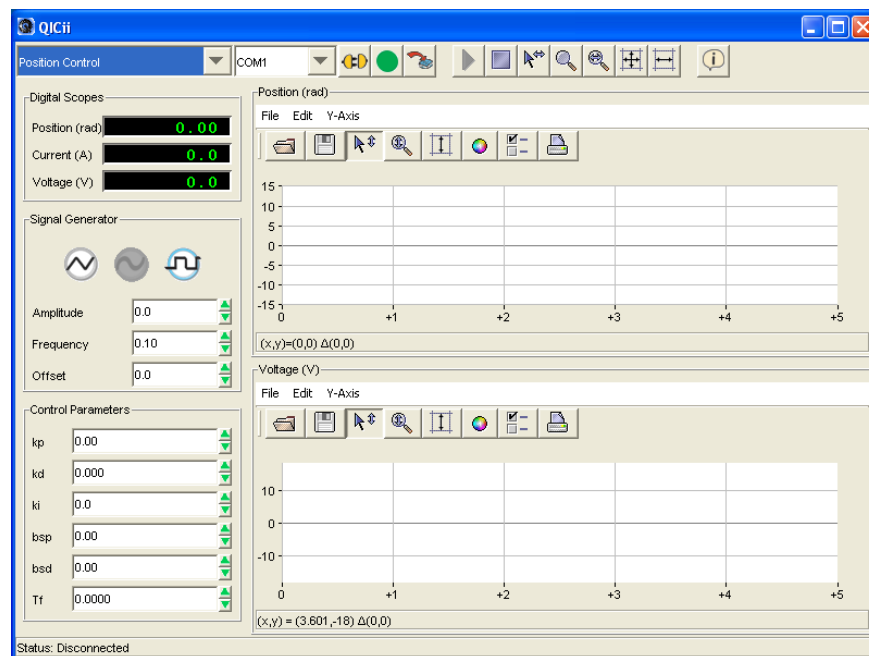
Figure 15: Quanser® QICii Control System User Interface

Students have the option to use this interface to:

- Change program type
  - o Speed control
  - o Position control
  - o Timing
- Change Signal Values
  - o Wave functions (Signal Generator)
  - o Control Parameter
- Read Values
  - o Instantaneous position
  - o Instantaneous current
  - o Instantaneous voltage

- Read Graphs
  - o Voltage over time
  - o Position over time

4.4.3 Adaptation for Remote Use

The three manual functions enabled for remote use are illustrated in Figure 16. These

modifications included:

- Pressing the Reset Button
- Pressing the Start Button
- Applying a Load
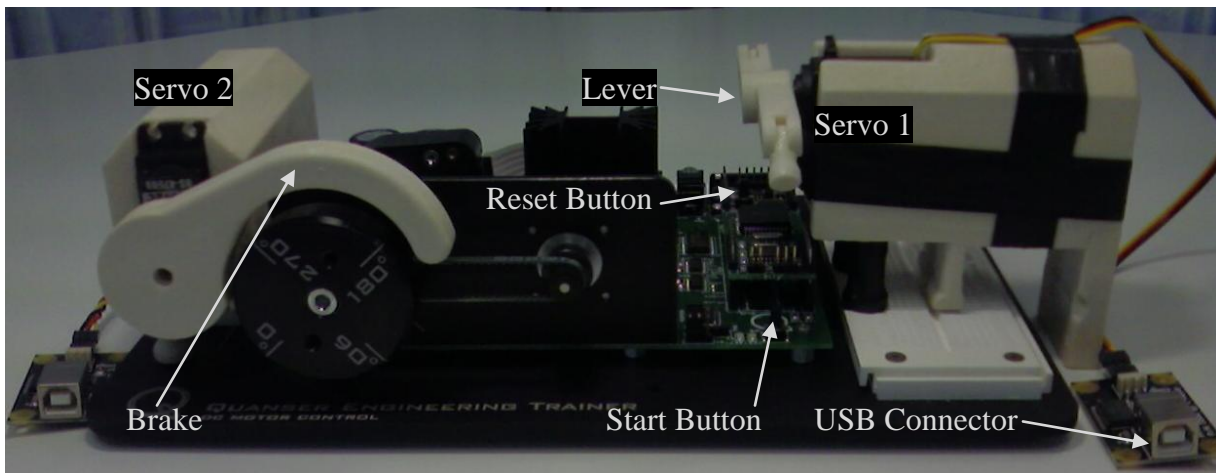
Figure 16: Quanser® QET DC Motor Control systems Adapted for Remote Use

A servo motor was programmed with Visual Basic® to actuate a lever. The "Reset" or

"Start" buttons would be pressed if the lever was rotated clockwise or counterclockwise,

respectively.

A second servo was fitted with a brake and was programmed to apply a load on the

flywheel. When rotated, the break would cover the flywheel until a predetermined load was put

on observed on servo. At this point, the break would not be able to rotate further to avoid

damage to the flywheel, break, or servo.

Multiple camera angels were setup to provide the student with more than one perspective of the moving components. Two were configured for this experiment, so they were merged side-by-side so they could be viewed by one camera viewing program (Skype® or Teamviewer®).

4.4.4 Communication Protocol

Remote desktop connections were used for this Remote Lab. Just as in the

These responses were used to help develop future experiments. Since this experiment was an intellectual exercise, there was no graded trial run which would provide data on the participants' level of technical understanding.

Heat Transfer by Convection Remote Lab, a student would gain access to the local computer and work with the provided software. They would watch and listen to the video and audio feed on their desktop as they manipulate the remote apparatus.

4.4.5 User Interface

Visual Basic® was used to program the servo operations as well as a few other functions designed to provide the user with more simple interaction with the software. A Java applet served as the final GUI by providing commands that opened programs and actuated the servos, shown in Figure 17. The code used to develop this interface is available in Appendix D (pg. 105)
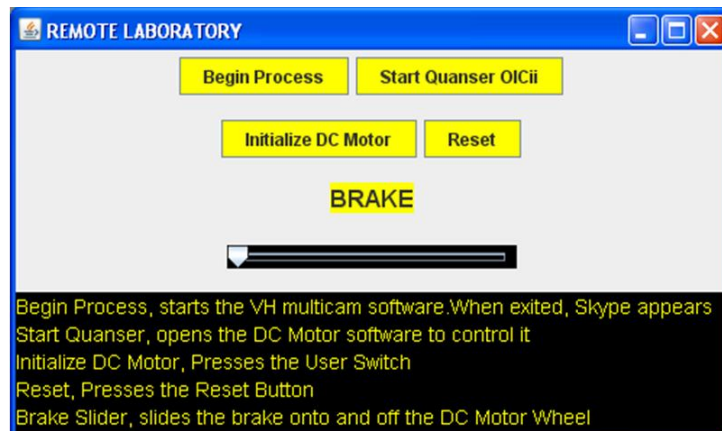
Figure 17: Java Applet for Flywheel Control Systems Remote Lab

- "Begin Process" opened all the background software required to run the Visual Basic® program and setup the webcams for remote use. One minute wait time allows the programs to fully open without the student interfering.
- "Start Quanser OICii" initiated the software which was also used by the traditional students.
- "Initialize DC Motor" and "Reset" actuated the lever which pressed the Start or Reset, respectively.
- The slidebar actuated the break to apply a load on the flywheel.

Students were asked to create the remote connection, open the Java applet, press button 1, wait one minute, press button 2, and begin the experiment as described in the laboratory manual. The traditional manual was only augmented by replacing, 'manually press the Reset/Start button' with, 'press buttons to start/reset on the Java applet."

Buttons were selected for most of the user interaction since the laboratory equipment required the students to press buttons. The decision to use a slidebar was based on the concept that resistive force will increase linearly as an applied force increases, as in a spring. A student can more easily relate the movement of a bar to the compression of a spring than they can by arbitrarily inputting values to rotate the break.

CHAPTER 5: DISCUSSION OF FINDINGS

This chapter includes a discussion of the findings from the three remote experiments discussed in Chapter 4, presents the contributions of this thesis as a whole, and suggests additional benefits of Remote Laboratories.

5.1   Findings

5.1.1   3 Axis Gantry Control Systems Remote Lab

The objective to create a Remote Laboratory to identifying potential difficulties and discover best practices was successfully completed by working through the 3 Axis Gantry Control Systems Remote Lab. The method for classifying experiments as templates was also formed through this exercise. Put simply, experiments that require similar amounts of adaptation for remote use can be modeled closely to each other. The feedback gained from Table 16 was used to improve the other laboratories and strengthen the best practices for creating Remote Laboratory experiments.

5.1.2   Heat Transfer by Convection Remote Lab

The survey indicates that that students have a stronger preference for using a Remote Laboratories after performing a "simple measurement" laboratory remotely. The exact reason could not be determined through the distributed surveys, but it could be a combination of many factors, including but not limited to:

- Students like having an alternative to traditional laboratories
- Students prefer the freedom to travel to campus
- Students like the idea of working on their own schedule
- Students prefer to work in non-traditional laboratory environments
- Students can better focus on the theory since the GUIs are designed to reduce contusion

Postsurveys taken by the Remote Laboratory groups included a section where students were asked to answer specific questions. Although only one student answered Question 5 twice, they were not limited to one response per question. The findings from these questions are shown in Figure 18 through Figure 24.

How well could you understand the instructions?

10%

90%

☑ They gave too much information
☑ More detail would have been helpful
☑ They were adequate
☑ There was not enough information
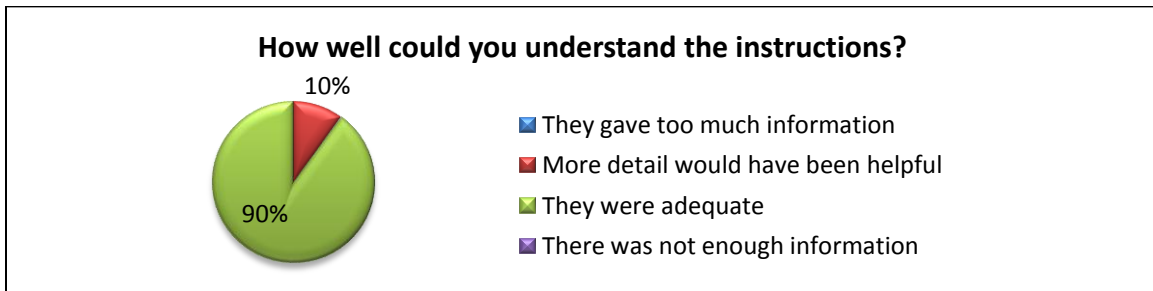
Figure 18: Postsurvey Question 1

When asked if they could understand the instructions included with the laboratory manual, 90% of students believed the instructions were adequate, where 10% thought additional detail would be helpful.

How do you feel your experience relates to other experiments you have done?

10%

40%

30%

20%

☑ This seemed like a video
☑ There was not enough interaction
☑ It felt similar, but less hands-on
☑ There were some benefits and failures
☑ It felt exactly the same
☑ It felt more beneficial
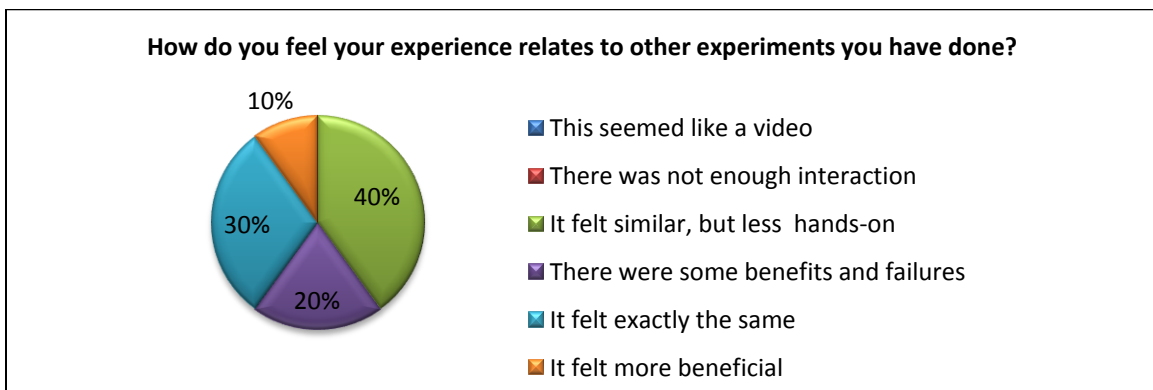
Figure 19: Postsurvey Question 2

60% of students had a positive response to the question asking if their remote experience related to others they had performed. 10 % believed the RL was more beneficial than others, 30% perceived it was the same, and 20% thought there were equal positive and negative aspects

of the RL. The remaining 40% of those surveyed indentified that the experiment was similar, but they felt less physical interaction with the equipment.
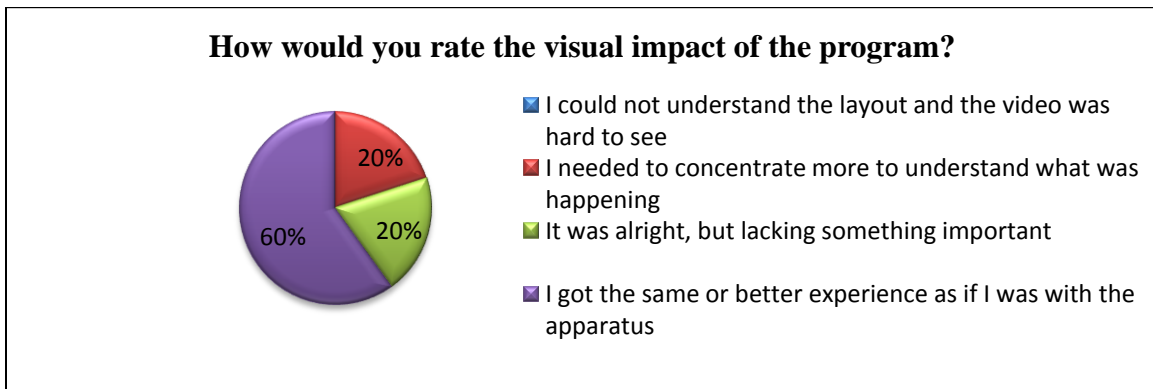
Figure 20: Postsurvey Question 3

After being asked to rate the visual impact of the experiment, 20% felt they needed to concentrate more and felt it lacked "something important", where 60% stated they got the same or better experience as if they were physically located with the apparatus.
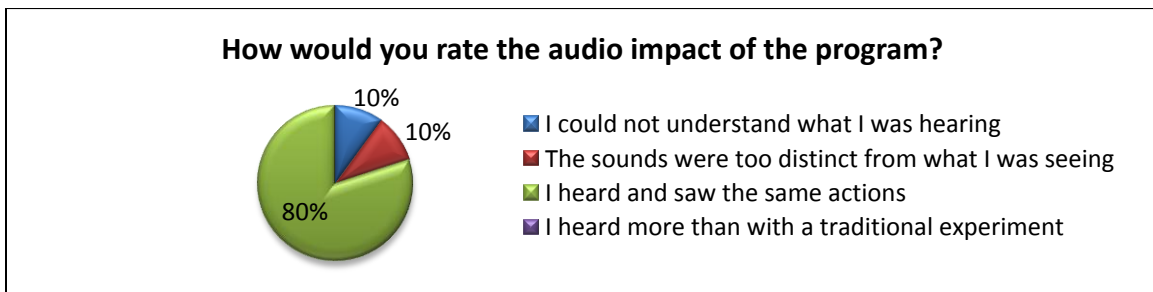
Figure 21: Postsurvey Question 4

80% of students believed they were able to hear the same as if they were performing a traditional experiment. 10% could not understand what they were hearing and 10% believed the sounds were too distinct from what they were seeing.

How would you rate the kinesthetic, or physical interaction of the program?

- I sensed no correlation with a physical system
- I understood it was a physical system, but it did not seem like I was interacting with it
- I understood I had control over the system
- I believe I had a better experience as if I were manipulating a physical system

9%
18%
73%
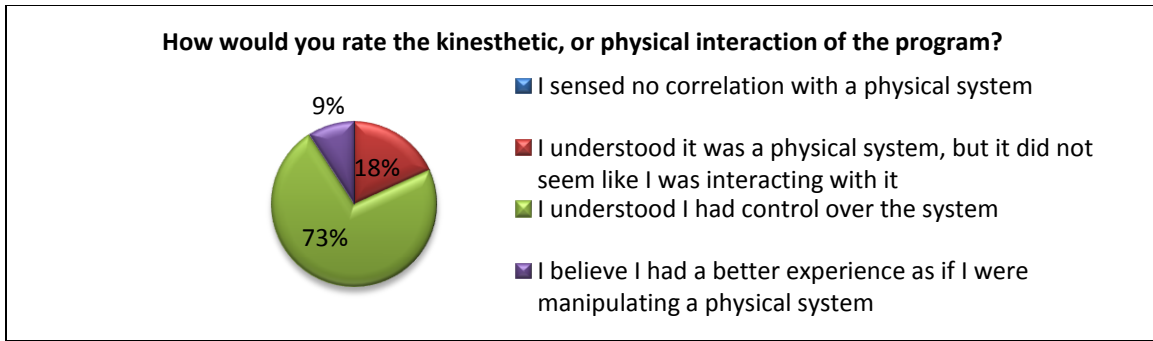
Figure 22: Postsurvey Question 5

Students were not limited to one response per question, so one student provided two replies to the question asking them to rate the kinesthetic interaction of the experiment. 73% of responses signified that students understood that they had control over the system, where 9% believed they had a more positive experience with the RL compared to a traditional experiment. The remaining 18% did not feel as if they were physically interacting with the equipment.

What did you think of the controllable functions?

- Too many options
- Not enough options
- Difficult to manipulate
- Easy to work with

100%

Figure 23: Postsurvey Question 6

Every student believed that the controllable functions were easy to work with.

How would you classify the user interface?

- Impossible to understand
- Complicated yet functional
- Too much visual stimulus
- Concise and practical

100%
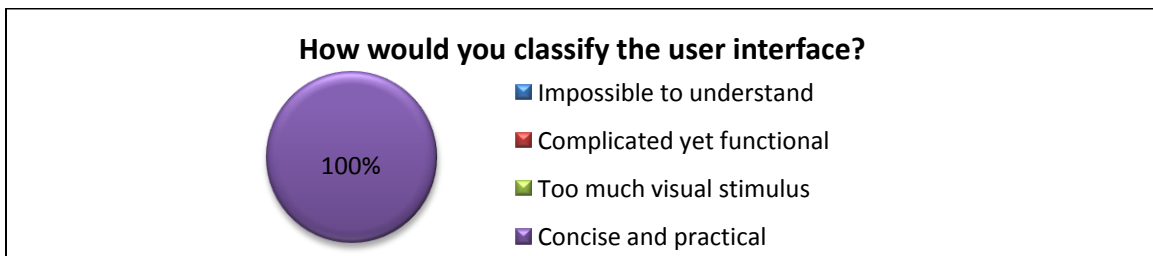
Figure 24: Postsurvey Question 7

The user interface was deemed "concise and practical" by every student.

Students provided a response which implied they liked the remote experiment as much, or more than a traditional experiment. This indicates that the students enjoyed their experiences and believe that their interactions with the experimental equipment were similar to being able to personally see it.

Laboratory reports were required for every laboratory experiment throughout the semester. Remote and traditional group reports were graded and compared in Table 18. Names and indicators that a laboratory was preformed remotely or locally were removed before reports were graded. 8 group reports from previous semesters were added to the local experiment average for the Heat Transfer by Convection Remote Lab to increase the sample size.
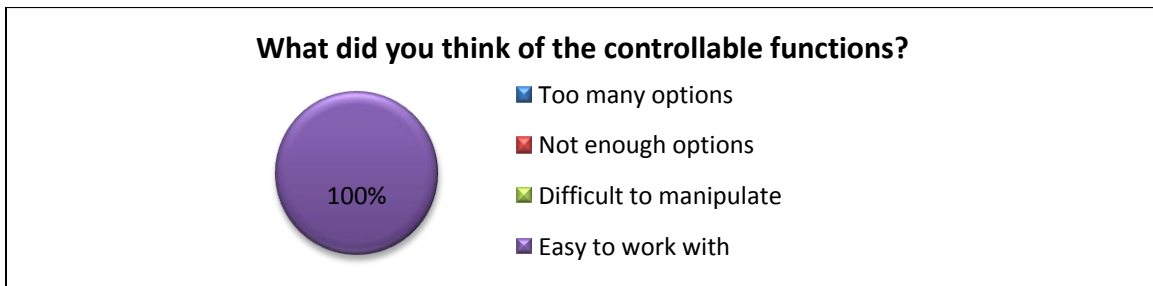
Table 18: Report Grades for Heat Transfer by Convection Laboratories

Traditional Experiment Group Report Grade	Remote Experiment Group Report Grade*
95%	70%
89%	95%
80%	
80%	
75%	
95%	
80%	
20%	
90%	
Average	
78%	**85%**

*Only two groups have completed this experiment remotely

It is apparent that the average report grades of 85% from remote experiments are higher than the 78% score from with traditional experiments. If the 20% outlier is removed from the traditional experiment report column, the average becomes 86%. This means that students who performed the experiment remotely earned at similar grade on their reports as those who had a traditional experience. It is impossible to conclude that this trend will continue based on this

data alone due to the sample size of this experiment. When taking the findings of previous studies into consideration [35], there is strong evidence that this trend will continue.

Table 19 provides additional detail as to how the grades for the spring 2010 trial were determined and Table 20 displays the comments associated with each report.

Table 19: Detailed Grades for Heat Transfer by Convection Remote Lab

Group	Remote	Data score	Theoretical Understanding	Report Score
A	Y	10	8.5	7/10
B	Y	9	10	9/10
C	N	9	9.5	9/10

Although the Report scores were the only metric compared in Table 18, a few other metrics were noted for the spring 2010 Heat Transfer lab. A sub-score that tracked the accuracy of the collected data showed that Group A was best able to observe and analyze the data. An additional sub-score noted the level of theoretical understanding of the groups.

Table 20: Report Comments for Heat Transfer by Convection Remote Lab

Group	Comments/Notes
A	Did not use appropriate format guidelines or show data Apparent lack of background heat transfer knowledge
B	Great physical understanding Average communication skill
C	Good understanding of topic Lacking understanding of physics

Group A received a grade of 70% mostly due to an apparent lack of background knowledge in the subject matter their and inability to follow the formatting conventions required by the class. These issues would have resulted in a similarly low grade if they preformed the experiment traditionally. They showed an understanding of the theoretical information gained from the experiment and produced outstanding data through observation and calculation.

Taking the information gathered from the Postsurveys and report, and recognizing that there is only a small number of data to be referenced, it can be concluded that Remote Laboratories are a viable means to instruct laboratory experimentation, but require further study to verify this claim.

5.1.3 Flywheel Control Systems Remote Lab

Laboratory reports were compared for this experiment similarly to with the Heat Transfer by Convection Remote Lab, as shown in Table 21. No additional details were considered during the grading of these reports.

Table 21: Report Grades for Flywheel Control Systems Laboratories

Traditional Experiment Group Report Grade	Remote Experiment Group Report Grade*
100%	85%
85%	
85%	
90%	
90%	
85%	
100%	
85%	
85%	
Average	
89%	**85%**

*Only one group has completed this experiment remotely

The findings from the fall 2009 Flywheel Controls RL resembled those from spring 2010 Heat Transfer RL in that the remote students received similar an average to the traditional experimenters with a grade of 85%. Since there was only one remote report graded, there is not much evidence to support a different conclusion than from the Heat Transfer by Convection

Remote Lab.   As a note, the group who performed this RL had the lowest average grade in the class.

5.1.4   Conclusions

Through the creation of three separate Remote Laboratory experiments, best practices were identified and data was collected which suggests they can be a viable means to teach experimental procedures to students who do not have access to traditional equipment. Since the three groups tested were traditional students that preformed the experiments remotely, and the sample sizes were small, more trials must be made to better understand the value of Remote Laboratories.

5.2   Ramifications of Findings

This thesis was created to provide motivation and best practices for setting up Remote Laboratory experiments for university applications. There is no reason the topics discussed here cannot be augmented for use with other schools or companies. In this section, the potential benefits Remote Laboratory implementation can provide for various institutions is addressed.

5.2.1   Impact on Universities

If further testing verifies the applicability of Remote Laboratories for instructing laboratory classes, Distance Learning and traditional learning are able to provide much more opportunities to students. Students without the ability to commute to a campus are able to share experimental experiences with other students' independent of their locations. There is a greater opportunity for collaboration wherein students complete group work with people from other universities, or even other countries. Universities might be able to offer full degrees which are not currently available for students who can only take classes online.

In the "real world", people often have the ability to run experiments over a period of days to check and reverify results. Current practices commonly involve a single time slot for an experiment to be preformed. Students who participate in traditional experiments would be able to take advantage of the added computer controlled data collection required for remote access or access an experiment to verify results if there is a discrepancy in their findings.

As the internet continues to be more user developed [54], universities must be able to stay on pace with technological trends. Remote Laboratories can be provided in a way that encourages feedback from users to improve laboratory manuals or details on how to enhance the experiment in other ways. With enough input and user support, a university could enhance the level of participation and feedback a student receives. As technology advances and the average consumer has access to more technological equipment, advancements can be made to Remote Laboratories that are implausible today.

5.2.2   Impact on K-12 Schools

Not every school can provide their classes with equipment to perform experiments to supplement the topics taught in class. Just because they might not have the room or the means to support the apparatus, does not mean the students should not be deprived from experience with physical equipment. A host school or university could allow access to equipment through a basic internet connection to schools in their district or beyond.

Imagine a trigonometry class where a student cannot comprehend the difference between a sine and cosine function. Instead of solely listing examples, the teacher could pull up a Remote Laboratory designed to demonstrate the uses of the functions and allow the students witness a cause-and-effect relationship.

Schools could collaborate and share experiments configured for remote use. The apparatus do not need to be located in a single location. Instead, School A could create a single or a set of laboratories, and School B could access them and maintain their own experiments to be shared with others. In this scenario, schools would be able to have a comprehensive set of experiments and only need to commit resources to maintain a few.

5.2.3   Impact on Companies

Companies can spend up to 3% [55] of their payroll budget on employee training. This often includes transportation expenses for employees to interact with equipment that is located outside their home office. Some may purchase ancillary equipment to provide their employees with the opportunity to interact with it, even if it had no other use at a given facility. Much of these costs could be eliminated by implementing Remote Laboratories for training purposes. A company with offices in varying venues, or a supplier of equipment which requires training before use could use Remote Laboratories to quickly and economically instruct the use of an apparatus.

A company that supports continuing education may fund tuition costs for an employee. They may have no other option than to take classes online and might be required to gain experimental experiences, something that is currently unavailable without Remote Laboratories. Additionally, they could be used to keep an employee up to date with more general concepts by allowing them to access a variety of setups to test and improve theoretical understanding.

CHAPTER 6: CONCLUSION

This chapter is used to summarize the information presented in this thesis by providing answers to the research questions and recommend future work.

6.1 Critical review of work

In this section, answers to the questions proposed on pg. 13 of Chapter 1 are provided to summarize the conclusions of this thesis. Table 4 can be used to locate the sections where the research questions are addressed in this thesis, reprinted here in Table 22.

Table 22: Reprinted Table 4: Research Question Content Matrix

Relevant Sections	Chapter 2					Chapter 3				Chapter 4				Chapter 5	
	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.5	5.1	5.2
PQ1			X			X	X	X		X					
PQ2	X		X	X			X				X	X	X		
SQ1		X		X	X	X			X	X					X
SQ2	X		X					X							
SQ3	X	X	X		X									X	X
SQ4				X						X	X	X	X	X	
SQ5															X

Primary Question 1

> *What resources are required for Remote Laboratory experimentation?*

Remote Laboratories require a computer network connection and a robotically controlled experimentation apparatus. Software promotes communication between the apparatus, the local computer which controls it, and any remote computer used by the laboratory operator. This software must be able to provide the operator with a human-computer interface which allows signals to be sent and received from the apparatus.

Primary Question 2

> *How can Remote Laboratories be created to provide a similar educational experience to traditional laboratories?*

Remote Laboratories are designed for situations wherein a user is unable to directly manipulate experimental equipment. To best resemble the experiences of a traditional user, remote users should be enabled to work with equipment much like if they were able to physically touch it. Users should be able to interact with the apparatus the way a traditional student does and the interfaces must be created to mimic the command.

Secondary Question 1

> *What tools and practices can be used to enhance distance education through Remote Laboratories?*

- Remote Laboratory experimentation could allow a host institution to provide experimental experience through Distance Learning. If the experiment is fully automated, users could access the equipment any time of any day, allowing them to work on any schedule from any time zone.

- A remote desktop program should be used to grant a remote user control of the local computer. This localizes the apparatus control programming at the local computer and reduces the software needed to be installed on a remote computer.

- Allowing the user to zoom or change camera views, or listen to multiple microphone locations provides a heightened feeling of control and could enhance the understanding of an experimental phenomenon.

- Providing feedback via physical sensation is a potential way to enhance a user's feeling of control over an apparatus, but could increase the cost of conducting experiments.

- Teaching assistants can be used to provide guidance for experimenters. They can use voice over IP software or simple text-chat windows to communicate with a remote user.

Secondary Question 2

> *What are the limitations of traditional and Remote Laboratory experiments?*

Institutions that offer traditional lecture courses through Distance Learning cannot currently provide experimental experiences to their students. Traditional laboratory experiments can only be accessed by users who are geographically located near the equipment. This limits a potential participant's ability to obtain real-time understanding of experimental procedures.

Although Remote Laboratories can provide experimental access to remote users, they cannot precisely replicate the exact experiences of a traditional student. Remote users are unable to feel the weight or textures or temperatures of an apparatus, they can only see or hear data from webcams and other sensors. A Remote Laboratory can also be difficult to fully automate if it involves mass flow or complex movement.

Secondary Question 3

> *How can current instructional techniques be amended to compliment Remote Laboratories?*

- Remote Laboratory manuals should include information about the remote connection and user interfaces as well as what is included in a traditional laboratory manual.
- Universities could offer more online degrees due to the added experiences available with Remote Laboratory experimentation.
- Teaching assistants can be better trained to answer technical questions instead of being trained to operate the equipment.
- Laboratory experimentation will no longer need to conform to a schedule according to when an entire class, the professor, and TA are available.

- Lectures and assignment requirements can be the same for traditional and Remote Laboratories.

- Differently-able students can be given access to experimental practices through Remote Laboratories when they might not be able to work with traditional equipment setups.

Secondary Question 4

What types of courses can utilize Remote Laboratories?

Any course that teaches material that could benefit from a practical example would be a candidate for Remote Laboratory experimentation. Those which already require students to perform experiments can allow remote users to participate. Even courses which currently do not include any experiments could benefit by using one for demonstration during a lecture.

Secondary Question 5

What are the non-university applications for Remote Laboratories?

A school district, state, or host university can create remote experiments that allow K-12 students to experience a laboratory experiment without causing significant monetary loss to their school. Companies can benefit by providing training to employees without buying multiple apparatus or paying transportation costs.

6.2   Future work

This thesis presents a foundation for developing Remote Laboratory experiments and provides the findings of surveys and laboratory repots by RL participants. Although the findings concur with previous studies that RLs can instruct experimental techniques remotely, there is still more work that must be done to prove that laboratory experiments can be preformed

remotely to achieve the same educational outcomes as traditional experiments. The following list is used to guide future actions to support this work.

- More remote experiments must be administered to confirm the effectiveness of RLs.
- Templates should become more clearly defined and presented as models for creating RLs.
- An analysis of the faculty bias and costs associated with RL implementation should be preformed.
- The requirements to make a RL program pass an accreditation board should be researched
- The characteristics of an effective human computer interface for RL experimentation and how to create one should be further researched.
- A broader look into the technical issues associated with RL, such as bandwidth limitations and port-forwarding options, should be made.

6.3   Closure

This thesis was intended to present an overview of the state-of-the-art and provide guidance for Remote Laboratory experimentation. The topics discussed here have been crafted to offer background information and circumstances for creating and implementing remote experiments, but should not be rigidly followed. Each institution and apparatus will have characteristics which will require flexibility with respect to the IT and educational requirements of a laboratory experiment.

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APPENDIX A: TRADITIONAL AND REMOTE LABORATORY SURVEY

<u>Pre-Survey</u>

Key

<u>Traditional Experiment</u> – A laboratory experiment where students work in groups to manipulate equipment to gain and process experimental data.

<u>Remote Experiment</u> – A laboratory experiment where students work in groups *from a remote location and use computer software robotics* to manipulate equipment to gain and process experimental data.

Please circle the answer that best fits your experience

How useful do you believe a <u>traditional experiment</u> will be with helping you understand experimental procedures?

Not useful	Less useful than a lecture	Slightly less useful than a lecture alone	Slightly more useful than a lecture alone	More useful than a lecture	Very useful

How useful do you believe a <u>traditional experiment</u> will be with helping you understand technical concepts?

Not useful	Less useful than a lecture	Slightly less useful than a lecture alone	Slightly more useful than a lecture alone	More useful than a lecture	Very useful

How useful do you believe a <u>remote experiment</u> will be with helping you understand experimental procedures?

Not useful	Less useful than a lecture	Slightly less useful than a lecture alone	Slightly more useful than a lecture alone	More useful than a lecture	Very useful

How useful do you believe a <u>remote experiment</u> will be with helping you understand technical concepts?

Not useful	Less useful than a lecture	Slightly less useful than a lecture alone	Slightly more useful than a lecture alone	More useful than a lecture	Very useful

Please note any preconceived ideas about remote experimentation:

_____

_____

_____

Post-Survey (page 1)

Key

Traditional Experiment – A laboratory experiment where students work in groups to manipulate equipment to gain and process experimental data.

Remote Experiment – A laboratory experiment where students work in groups *from a remote location and use computer software robotics* to manipulate equipment to gain and process experimental data.

Please circle the answer that best fits your experience

How useful do you believe a underline traditional experiment will be with helping you understand experimental procedures?

Not useful	Less useful than a lecture	Slightly less useful than a lecture alone	Slightly more useful than a lecture alone	More useful than a lecture	Very useful

How useful do you believe a traditional experiment will be with helping you understand technical concepts?

Not useful	Less useful than a lecture	Slightly less useful than a lecture alone	Slightly more useful than a lecture alone	More useful than a lecture	Very useful

How useful do you believe a remote experiment will be with helping you understand experimental procedures?

Not useful	Less useful than a lecture	Slightly less useful than a lecture alone	Slightly more useful than a lecture alone	More useful than a lecture	Very useful

How useful do you believe a remote experiment will be with helping you understand technical concepts?

Not useful	Less useful than a lecture	Slightly less useful than a lecture alone	Slightly more useful than a lecture alone	More useful than a lecture	Very useful

Please note any preconceived ideas about remote experimentation:

_____

_____

_____

_____

Please circle the answer that best fits your experience

How well could you understand the instructions?

| They gave too much information | More detail would have been helpful | They were adequate | There was not enough information |

How do you feel experience relates to other experiments you have done?

| This seemed like a video | There was not enough interaction | It felt similar, but less hands-on | There were some benefits and failures | It felt exactly the same | It felt more beneficial |

How would you rate the visual impact of the program?

| I could not understand the layout and the video was hard to see | I needed to concentrate more to understand what was happening | It was alright, but lacking something important | I got the same or better experience as if I was with the apparatus |

How would you rate the audio impact of the program?

| I could not understand what I was hearing | The sounds were too distinct from what I was seeing | I heard and saw the same actions | I heard more than with a traditional experiment |

How would you rate the kinesthetic, or physical interaction of the program?

| I sensed no correlation with a physical system | I understood it was a physical system, but it did not seem like I was interacting with it | I understood I had control over the system | I believe I had a better experience as if I were manipulating a physical system |

Please circle all that apply

How would you classify the user interface?

| Impossible to understand | Complicated yet functional | Too much visual stimulus | Concise and practical |

What did you think of the controllable functions?

| Too many options | Not enough options | Difficult to manipulate | Easy to work with |

What suggestions could you make to improve this experiment?

_____

_____

_____

_____

APPENDIX B: 3 AXIS GANTRY CONTROLS SYSTEM LABORATORY

MANUAL

6.4   Student Background Information

A proportional–integral–derivative controller (PID controller) is a generic controller widely used in industrial control systems. A PID controller attempts to correct the error between a measured process variable and a reference input by calculating and then outputting a corrective action that can adjust the process accordingly.

The PID controller involves three separate parameters: The Proportional, the Integral and Derivative values. The Proportional value determines the reaction to the current error, the Integral value determines the reaction based on the sum of recent errors, and the Derivative value determines the reaction based on the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via an actuator. By "tuning" the three constants in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the reference and the degree of system oscillation.

Some applications may require using only one or two modes to provide the appropriate system control. This is achieved by setting the gain of undesired control outputs to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are particularly common, since derivative action is very sensitive to measurement noise, and the absence of an integral value may prevent the system from reaching its target value due to the control action.
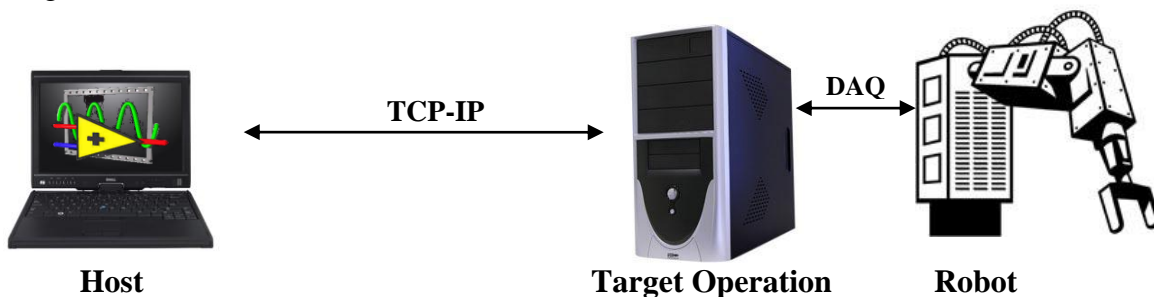
Host   **Target Operation**   **Robot**

Figure 25: Simplification of Robot Control Through an External Program

Robotic systems consist of a complex network of actuators and sensors. However, these components themselves are incredibly simple. In a general robotic system, each joint contains a drive and an encoder. The drive initiates motion of the joint and the encoder measures the displacement of the joint in order to determine the robots exact position in space. PID controllers are often used to close the loop around these drives via the encoder signal and ensure the robot travels to its commanded position while satisfying the requisite performance characteristics.

These joints are controlled concurrently to produce the desired end effector trajectory (the translation of the load). This motion is coordinated with a slave or target, which is a dedicated

computer, which receives the user's commands from a host computer and translates these instructions into control inputs to the drives of each joint. The host computer is the point of interaction for the user, and is at any given time in direct communication with the slave. For this laboratory you will be exploring a system similar to this. However the host system is located at a remote location. Thus, you will use Distance Learning tools to set up a remote terminal to the host computer so that you may in direct control of the robot.

6.5   Laboratory Instructions

To gain the best chance of maintaining a stable connection, the following instructions must be adhered. Notes for possible reasons for error are included with the pertinent steps.

6.5.1   Communications Protocol
This must be performed by the TA before the experiment is started

1. Open a dedicated port *if it is independent from other ports, there will be no conflicting data flow causing a connection interruption.*
   a. On the network supporting the robot (Host Network)
   b. On the computer supporting the robot (Host Computer)
      The dedicated port must be the same for the network and computer. A network administrator is usually required to handle this task.
2. Open firewall settings
   a. Allow the firewall to open communication in for the dedicated port
   b. Allow the use of Microsoft Remote Desktop
      Different operating systems have different ways to allow Remote Desktop Access. A network administrator will be able to quickly complete this task.
      MAC has a remote desktop function that has the potential to work, but is not seamlessly compatible with Windows systems.

6.5.2   Robotic Apparatus Preparation
This must be done on the local end by the TA before the experiment is started

1. Allow the host computer to run on a fresh boot up
2. Open Controls program
      Remote users can open the program, but it is best to be done by a host supervisor due to complications which may arise from the time delays.
3. Turn on the robot and leave in standby mode
      This is assuming it is functioning properly.
      Currently, a supervisor in the host location must do this step.
4. It is optional to test the functionality of the robot from the host location to ensure the apparatus can be controlled remotely with the current setup

6.5.3   Gaining Remote Access
1. Identify host computers IP Address, possibly from the course website
2. Open Remote Desktop on computer seeking to access robot (Remote Computer)
3. Enter Host Computer IP Address and dedicated port number in the format:
   "IP Address::port number" for example 12.34.456.89::1234
   This should turn the host computer monitor black and bring up a login screen on the remote computer. If there is no login information, it must be set up on the host computer, requiring the user to restart step 3.
   Once the remote computer has access, they will be able to control the robot as if they were on the host computer.
   There will be a variable time delay in control and perception of response subject to host and remote network traffic.

6.5.4   Experimental Procedures
1. Understanding the apparatus
   a. Click to the Trajectory Generation tab
   b. Set the X-axis to output a Sawtooth function and the Y-axis to output a Square wave function
   c. Set the X-amplitude to appx 15 cm and the Y-amplitude to appx 20 cm
   d. Set the X-frequency to appx 2.5Hz and the Y-frequency to appx 2 Hz
   e. The screen should appear similar to the following figure

Figure 26: Representation of initial experimental setup screen

   f. Turn on both axes
   g. Familiarize yourself with the other tabs
   h. Change the values in the Control Design tab and note any changes in the Trajectory Error tab
   i. Reset the figure in the End Effecter tab and verify that the head of the robot is synced with the repose indicated in the graph.

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i. It may be necessary to adjust the X and Y amplitudes and frequencies to be able to clearly notice the responses

ii. Use the video and sound of the robot to compare with the end effecter readings

j. Test the response time of the robot by turning one axis off and adjusting the other on or off.

i. Note the time required for the video to change using a stopwatch

ii. Note the time required for the end effecter to change

k. Turn both axes off

2. Error reduction in the X axis
    a. Set the X wave type to sine
    b. Set all other inputs to their middle value
    c. Turn on the X axis
    d. Use trial and error to reduce the error in the x axis as much as possible and note the values
    e. Use the question in the following figure to calculate the theoretical output
    f. Calculate the gains which theoretically result in the least error
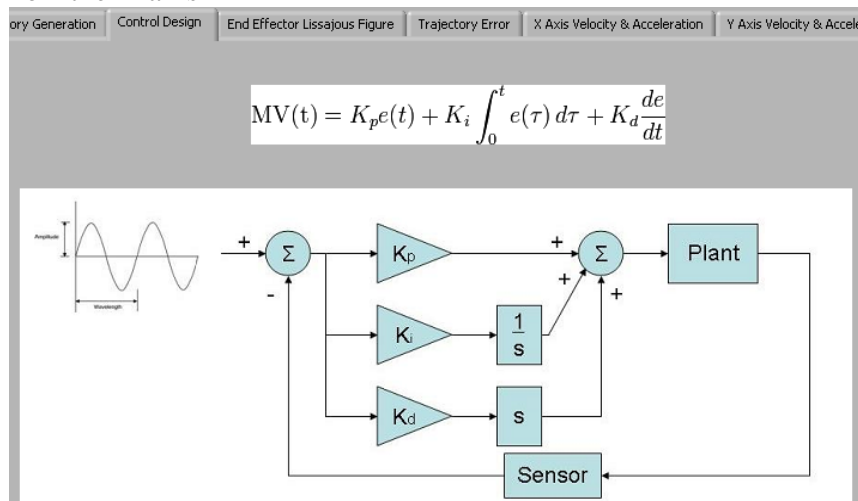   g. Set the gain to the calculated value
    h. Turn off the X axis

$$MV(t) = K_p e(t) + K_i \int_0^t e(\tau) \, d\tau + K_d \frac{de}{dt}$$

Figure 27: Equations and simplified response schematic

3. Error reduction in the Y axis
    a. Set the Y wave type to sine
    b. Set all other inputs to their middle value
    c. Turn on the Y axis
    d. Use trial and error to reduce the error in the Y axis as much as possible and note the values
    e. Calculate the theoretical output with these values
    f. Calculate the gains which theoretically result in the least error
    g. Set the gain to the calculated value
    h. Turn off the Y axis
    i. Note any results that differ from the previous experiment

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4. Error reduction in the both axes
    a. Set both wave type to sine
    b. Set all other inputs to their middle value
    c. Turn on the Y axis
    d. Use trial and error to reduce the errors as much as possible and note the values
    e. Calculate the theoretical output with these values
    f. Calculate the gains which theoretically result in the least error
    g. Set the gain to the calculated value
    h. Turn off both axes
    i. Note any results that differ from the previous two experiments
5. Types of damping
    a. Set the X axis to a square wave
    b. Set the X frequency to 0.1
    c. Set the X amplitude to 25
    d. Use trial and error by adjusting the gains to create a response that appears to be over damped, verify with calculations
    e. Calculate a gain combination that will result in an under damped response, verify with the error output
    f. Calculate a gain combination that will result in an critically damped response, verify with the error output
    g. Turn off both axis

6.5.5 Creativity Exercises
Student will have the option to choose one of the following exercises
1. Alternative methods
    • Repeat one of experiments 2-4 using a any combination of a square wave or sawtooth function
2. Visualization
    • Use any combination of the inputs including wave functions to create at least 5 interesting result in the end effecter response screen. An example is making a near perfect circle
    • Device a way to represent aliasing and describe why and how this could affect the results in this experiment, if at all
3. New design
    • Using your background of control system, create an outline for a new experiment using the available tools

6.6   Clean up Instructions
• Stop all motion on the robot
• Close all open programs
• Restart the computer. This will automatically relinquish control of the host computer

APPENDIX C: HEAT TRANSFER BY CONVECTION REMOTE LAB

INSTRUCTIONS

Remote Labs

- Remote connection requirements:
  - Internet access
  - TeamViewer Access - Computer ID: <u>SRL</u>
  - Armfield Extended Surface Heat Transfer Accessory HT15 running on "Remote" mode
1. Connect to remote computer through TeamViewer
2. Once connected, run the Heat Distribution software application for the "Armfield Software"
- If you need any Assistance, contact the TA <u>ONLY</u> through the Teamviewer program
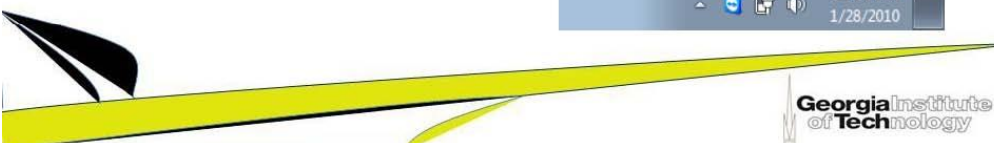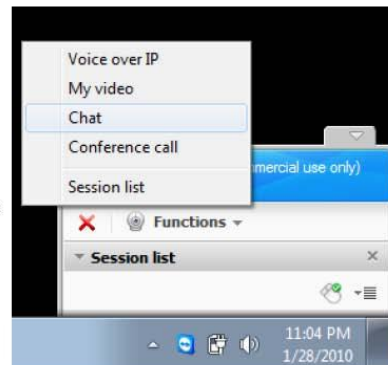
Remote Labs

- Teamviewer should already be running when you get to the lab
- To ask a question,
  → Bottom right of your screen
  → Click arrow above the time
  → Select "Functions"
  → Select "Chat"

Setting up the Equipment

- Follow the instructions starting on page A-1.
- Instead of adjusting the voltage knob, increase the "Voltage Control" (Figure 1) until the voltage readout is 20 V.
- There is no need to record data on the computer, only in your notebook
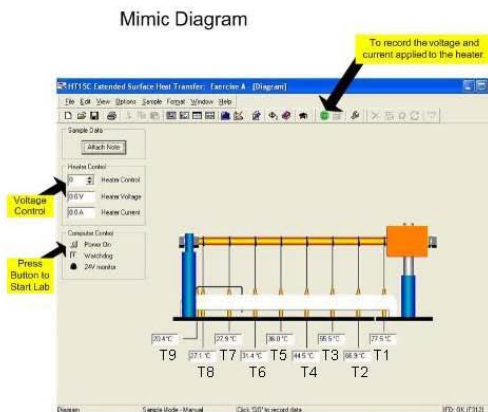- Feel free to explore the program to view additional information

Mimic Diagram

Figure 1 Mimic Screen Diagram

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Mimic Screen Diagram

1. Monitor temperature T1 regularly
2. When T1 reaches 80C, reduce the heater voltage to 16 Volts
3. When the temperature is stable for 2 minutes, record data
4. Reduce the voltage from high to low and repeat step 3
 •20V>16V>14V>12V>9V
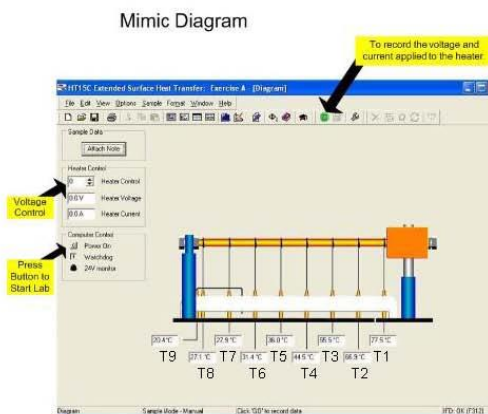**5.** Continue to 9V unless you have spend more than 1.5 hours in your lab (10:30 or 12:00)

Mimic Diagram

Figure 1 Mimic Screen Diagram
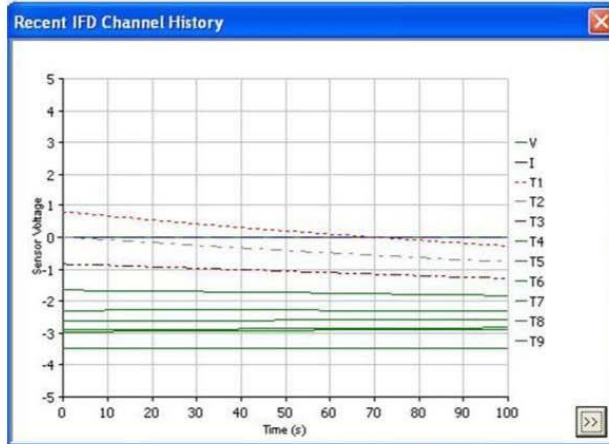
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Sensor Voltage vs Time

SRL

Graphs for reference only (not available for non-remote sections)

References

SRL

- Armfield Extended Surface Heat Transfer Accessory HT15 (Computer Compatible) Manual, Issue September 2004.

SRL

Extended Surface Heat Transfer
Remote Laboratory Instructions

By: David Osemwengie & Pierre H Thys
Edited by: Andrew Hyder

Georgia Institute of Technology

APPENDIX D: FLYWHEEL REMOTE LAB CODE

```java
import java.awt.event.*;
import java.io.*;
import java.awt.*;
import javax.swing.*;
import com.phidgets.*;
import com.phidgets.event.*;
import javax.swing.event.ChangeListener;
import javax.swing.event.*;


public class in2 extends JFrame {
    JButton setup=new JButton("Begin Process");
    JButton init= new JButton("Initialize DC Motor");
    JButton reset= new JButton("Reset");
    JButton Quanser=new JButton("Start Quanser OICii");
    JButton Brake= new JButton("Brake");
    JButton StopBrake= new JButton("Stop Brake");
    JSlider brake=new JSlider(JSlider.HORIZONTAL,0,2,0);
    JTextArea note= new JTextArea("BRAKE");
    JTextArea explain= new JTextArea("Begin Process, starts the VH multicam software.When
exited, Skype appears " + '\n' +
        "Start Quanser, opens the DC Motor software to control it" + '\n' +
        "Initialize DC Motor, Presses the User Switch " + '\n' +
        "Reset, Presses the Reset Button " + '\n' +
        "Brake Slider, slides the brake onto and off the DC Motor Wheel");

    ServoPhidget servo;

    public in2() {
        setup.setBackground(Color.YELLOW);
        init.setBackground(Color.YELLOW);
        reset.setBackground(Color.YELLOW);
        Quanser.setBackground(Color.YELLOW);
        brake.setBackground(Color.BLACK);
      note.setFont(new Font("sansserif",Font.BOLD,16));
        note.setBackground(Color.YELLOW);
        explain.setFont(new Font("sansserif", Font.PLAIN, 14));
        explain.setBackground(Color.BLACK);
        explain.setForeground(Color.YELLOW);
        setLayout(new GridLayout(5,1));
        JPanel screen= new JPanel();
        screen.add(setup);
        screen.add(Quanser);
        JPanel screen1= new JPanel();
```

```java
        screen1.add(init);
        screen1.add(reset);
        JPanel screen2= new JPanel();
        screen2.add(note);
        JPanel screen3= new JPanel();
        screen3.add(brake);
        this.add(screen);
        this.add(screen1);
        this.add(screen2);
        this.add(screen3);
        this.add(explain);
        setup.addMouseListener(new MouseAdapter(){
           public void mousePressed(MouseEvent e){

             try{
             Process r =Runtime.getRuntime().exec("C:\\Documents and Settings\\All
Users\\Desktop\\HmelyoffLabs\\VHToolkit\\VHMultiCam.exe");
             r.waitFor();

             Process s =Runtime.getRuntime().exec("C:\\Program
Files\\Skype\\Phone\\Skype.exe");
             s.waitFor();
             } catch(Exception err){
                err.printStackTrace();
             }
           }
        });
        Quanser.addMouseListener(new MouseAdapter(){
           public void mousePressed(MouseEvent e){
             try{
                Process t=Runtime.getRuntime().exec("C:\\Program
Files\\Quanser\\QICii\\qicii.exe");
             } catch(Exception err){
                err.printStackTrace();
             }

           }
        });
        init.addMouseListener(new MouseAdapter(){
           public void mousePressed(MouseEvent e){
             try{ ServoPhidget servo;

             System.out.println(Phidget.getLibraryVersion());


             servo = new ServoPhidget();
```

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```java
servo.addAttachListener(new AttachListener() {
  public void attached(AttachEvent ae) {
    System.out.println("attachment of " + ae);
  }
});
servo.addDetachListener(new DetachListener() {
  public void detached(DetachEvent ae) {
    System.out.println("detachment of " + ae);
  }
});
servo.addErrorListener(new ErrorListener() {
  public void error(ErrorEvent ee) {
    System.out.println("error event for " + ee);
  }
});
servo.addServoPositionChangeListener(new ServoPositionChangeListener() {
  public void servoPositionChanged(ServoPositionChangeEvent oe) {
    System.out.println(oe);
  }
});

servo.open(34950);
System.out.println("waiting for Servo attachment...");
servo.waitForAttachment();
System.out.println("Serial: " + servo.getSerialNumber());
System.out.println("Servos: " + servo.getMotorCount());
for (int i = 120; i < 180; i++) {

  servo.setPosition(0, i);
  Thread.sleep(10);
  //System.out.println("Position: " + servo.getPosition(0));

}
servo.setPosition(0,120);
System.out.println("Outputting events.  Input to stop.");
//System.in.read();
//servo.setPosition(0, 232);
System.out.print("closing...");
servo.close();
servo = null;
System.out.println(" ok");
} catch(Exception err){
  err.printStackTrace();
}
}
```

```java
      });
      reset.addMouseListener(new MouseAdapter(){
        public void mousePressed(MouseEvent e){
          try{ ServoPhidget servo;

          System.out.println(Phidget.getLibraryVersion());

          servo = new ServoPhidget();
          servo.addAttachListener(new AttachListener() {
            public void attached(AttachEvent ae) {
              System.out.println("attachment of " + ae);
            }
          });
          servo.addDetachListener(new DetachListener() {
            public void detached(DetachEvent ae) {
              System.out.println("detachment of " + ae);
            }
          });
          servo.addErrorListener(new ErrorListener() {
            public void error(ErrorEvent ee) {
              System.out.println("error event for " + ee);
            }
          });
          servo.addServoPositionChangeListener(new ServoPositionChangeListener() {
            public void servoPositionChanged(ServoPositionChangeEvent oe) {
              System.out.println(oe);
            }
          });
          servo.open(34950);
          //servo.openAny();
          System.out.println("waiting for Servo attachment...");
          servo.waitForAttachment();
          System.out.println("Serial: " + servo.getSerialNumber());
          System.out.println("Servos: " + servo.getMotorCount());

          for (int i = 120; i >84; i--) {

            servo.setPosition(0, i);
            Thread.sleep(10);
            //System.out.println("Position: " + servo.getPosition(0));
          }
          servo.setPosition(0,120);
          System.out.println("Outputting events.  Input to stop.");
          //System.in.read();
          //servo.setPosition(0, -23);
          System.out.print("closing...");
```

```java
      servo.close();
      servo = null;
      System.out.println(" ok");
      } catch(Exception err){
         err.printStackTrace();
      }
   }
});
brake.addChangeListener(new ChangeListener(){
   public void stateChanged(ChangeEvent e){
      try{ ServoPhidget servo;
      servo = new ServoPhidget();
      servo.addAttachListener(new AttachListener() {
         public void attached(AttachEvent ae) {
            System.out.println("attachment of " + ae);
         }
      });
      servo.addDetachListener(new DetachListener() {
         public void detached(DetachEvent ae) {
            System.out.println("detachment of " + ae);
         }
      });
      servo.addErrorListener(new ErrorListener() {
         public void error(ErrorEvent ee) {
            System.out.println("error event for " + ee);
         }
      });
      servo.addServoPositionChangeListener(new ServoPositionChangeListener() {
         public void servoPositionChanged(ServoPositionChangeEvent oe) {
            System.out.println(oe);
         }
      });
      //servo1.openAny();
      servo.open(42698);
      System.out.println("waiting for Servo attachment...");
      servo.waitForAttachment();
     // System.out.println("the position is "+ brake.getValue());
      if(brake.getValue()==0){
         servo.setPosition(0,150);
         Thread.sleep(10);
      }
      if(brake.getValue()==1){
         servo.setPosition(0,177);
         Thread.sleep(10);
      }
      if(brake.getValue()==2){
```

```java
            servo.setPosition(0,182);
            Thread.sleep(10);
          }
          servo.close();
          servo = null;
          } catch(Exception err){
            err.printStackTrace();
          }
        }
      });
    }

    /** Creates a new instance of instructions */

    public static void main(String[] args)throws Exception {
      in2 frame= new in2();
      frame.setTitle("REMOTE LABORATORY");
      frame.setSize(500,400);
      frame.setLocationRelativeTo(null);
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setVisible(true);
      //File Security=new File("C:\\Program Files\\Home Security
Camera\\HomeSecurityCamera.exe");

      //Process p=Runtime.getRuntime().exec("C:\\Program Files\\Home Security
Camera\\HomeSecurityCamera.exe");

      // p.waitFor();

      //Process r =Runtime.getRuntime().exec("C:\\Documents and Settings\\All
Users\\Desktop\\HmelyoffLabs\\VHToolkit\\VHMultiCam.exe");
      // r.waitFor();
      // System.out.println(pass);


  }

}
```