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Environmental Control for Persons with Disabilities

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WORCESTER POLYTECHNIC INSTITUTE

Environmental Control for Persons With Disabilities

An Interactive Qualifying Project Report submitted to the faculty of WORCESTER POLYTECHNIC INSTITUTE in partial fulfillment of the requirements for the Degree of Batchelor of Science

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Abstract

This project researched available environmental control units (ECUs) designed to electronically aid persons with disabilities in their daily lives. Working from literature, interviews, and hands-on experience with the technologies, we use a simple environmental control technology (X-10) to develop reconfigurable laboratory modules that can be used in ME3506 (Rehabilitation Engineering) to demonstrate different aspects of environmental control to WPI students and create tutorials to introduce other people, specifically health care professionals such as physical therapists, to environmental control technologies for use by persons with disabilities.

Acknowledgements

There are many persons we would like to thank because without their input this project would not have been possible. First we would like to thank Mr. Gary Wittmann, who invited us into his home and showed us his own environmental control system (X-10 based) which he has been running for many years. We would also like to thank Professors Demetry and Miller, who took time out of their busy schedules to discuss pedagogy and laboratory activity creation with us. As well as Laura Hanlan, Reference Librarian at WPI's Gordon Library, for helping us perform research using WPI's research resources. Lastly we would also like to thank our advisors for this project, Professors Hoffman and Ault, for all their guidance and patience throughout the duration of the project.

Authorship

Kevin Harrington

Kevin worked on the laboratory activities, both in the development of the activities and the creation of the supporting hardware. He contributed to the Discussion, Background, and Appendix sections of the report.

Timothy Loughlin

Timothy wrote most of the Background sections and all of the Results section. He also contributed greatly to the Appendices and Recommendations sections.

Bryan Mancuso

Bryan compiled the whole report together, as well as performing the editing duties for all of the content. He also wrote the Abstract, Introduction, and Methodology sections, as well as contributing to the Discussion, Recommendation, and Background sections.

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1 Introduction

Persons with disabilities have long suffered from limited mobility and ability to interact with their surroundings. In the last few decades, much advancement has been made in the way we are able to interact with our environments. Environmental control technologies have been invented that allow users to remotely control electronics using a multitude of data transmission mediums; such as infrared (IR), radio frequency (RF), ultrasonic, and traditional copper wiring. Environmental controls aim to give control and independence to the users of the technology. Therein is potential to give that independence and control back to persons with disabilities and therefore greatly improving their quality of life.

The scope of this project is to research and learn about environmental control technologies in general and choose one to develop introductory materials for persons unfamiliar with the technology. There are two separate groups of people we are providing information for; however each should be able to utilize the same general information presented in different mediums. First there are WPI students enrolled in the Rehabilitation Engineering class (ME3506). The Rehabilitation Engineering course:

> "exposes the students to the use of technology to design devices to ameliorate the handicaps of individuals with disabilities. This course focuses on the design process for assistive devices including defining the problem, setting design criteria, developing preliminary designs, selecting, analyzing and testing a final design. Human factors are integrated into all phases of the design process. Topics include: ergonomics, physical and cognitive parameters that effect the user interface, safety, economics, reliability and esthetics. Design and analysis of devices used for mobility and in daily activities in residential, educational and vocational settings. Laboratory sessions will be used to develop conceptual designs that solve real problems." (Worcester Polytechnic Institute)

For those students in the course, we have created a number of reconfigurable laboratory modules to achieve the goal of developing conceptual designs to solve the real problems of independence and control for persons with disabilities. These laboratory exercises have been developed with accompanying laboratory instruction materials and introductory materials for the class in preparation for the aforementioned exercises. The second set of people for which we are providing information are persons not affiliated with ME3506; specifically health care professionals, persons with disabilities and those that care for persons with disabilities. For these persons, the first laboratory exercise has been modified and should provide sufficient information to become acquainted with the technology and this guide should be written with this diverse audience in mind. It seems that much of the information we have gathered will be useful within the same context in both groups. However the students are intended to have a more hands-on learning experience with the technology, whereas we will not be able to provide the laboratory activities to the broader community to enrich them with the experience of setting up an environmental control solution. Our laboratory modules should also be written so that they can be easily adapted for use in seminars presented by a professional familiar with the technology

to this wider group of users. This way we are able to provide a greater understanding of how a network would look, behave, and introduce a deeper understanding of the underlying technologies.

1.1   Goals of the Project

Goal 1:

Our first main objective for this project is to develop an understanding of environmental control technology currently available to persons with disabilities. We will discover what can and cannot be done with environmental control technologies as well as what persons with disabilities stand to benefit from the use of environmental control technology. We will also learn what steps and considerations are necessary to set up and use an environmental control system in a home environment.

Goal 2:

Our second main objective is to use a simple environmental control technology (X-10) to develop reconfigurable laboratory modules that can be used in ME3506 (Rehabilitation Engineering). We aim to introduce the students to ECUs and demonstrate different aspects of environmental control and how these controls can be implemented in the home of a person with a disability. Students will also learn about and experiment with the features and limitations of the technology.

Goal 3:

Our third and final goal is to create a tutorial to introduce persons who are not WPI students, such as health care professionals, to environmental control technologies for use by people with disabilities. There are many health providers in the professional community that would benefit from the same type of introduction to environmental controls as the WPI Rehabilitation Engineering students. This tutorial would have to be tailored to people who may not have the same level of technological background as students.

2 Background

2.1 Environmental Control Technologies

There are many different Environmental Control Units (ECUs) and technologies that that are available for use in a home. These technologies each employ their own type of signal to transmit information to devices that are to be controlled. These technologies receive input commands from a user into a controller and perform the requested operation on the device being controlled.

X-10 technology is one type of environmental control technology. It has its own signal that is transmitted through a building's existing electrical wiring. The devices to be controlled, such as lighting and virtually every electrical appliance, can be operated using a controller and a module installed at the location of the device. These modules react to a command by turning the power to the device on or off. X-10 has interfaces that can receive radio frequency (RF) signals from wireless controllers that are then translated into X-10 signals and transmitted through the electrical wiring. This means that other technologies that can send an RF signal can potentially send an X-10 signal, allowing other ECUs to control X-10-enabled devices.

Insteon technology is another type of ECU, unlike X-10, Insteon uses RF to send its signals to the modules. The devices are controlled similarly to X-10, by installing Insteon modules between electrical outlets and the device's power plug. Insteon also has interfaces that receive RF and infrared (IR) signals that are then translated to Insteon RF signals that the modules can receive and decode.

There are many other types of environmental control technologies, including many specialized systems that are not designed to be versatile like X-10 and Insteon. These specialized systems include hospital beds and equipment, telephone devices, and other common household remotely controlled devices like televisions and garage door openers. These devices all differ in the way they receive signals. Hospital beds, for instance, can be controlled by an on-bed menu display or by simple control switches. To control the bed a user simply has to use the built-in menu display or the buttons on the controller. These simple controls make it possible for more versatile ECUs to control the bed if the ECU is able to send the same signal that the bed can receive and translate. Similarly, devices that can be controlled by some sort of electronic signal can be considered an environmental control technology. Remote door openers, automatic lights, and any other devices that can be controlled through some signal are considered an environmental control. The major differences between all these different devices are the language through which they are controlled and the input signals they require to be activated.

Generally, an ECU can interface between many different types of technologies. For instance, the Imperium 200H (Figure 1) can communicate between X-10 technology, Insteon technology, general IR devices, specialized hospital devices such as beds and nurse calls, telephones, and other similar equipment. This versatility of this ECU comes at a price, $4500, which is very expensive relative to other Environmental Control Technologies.
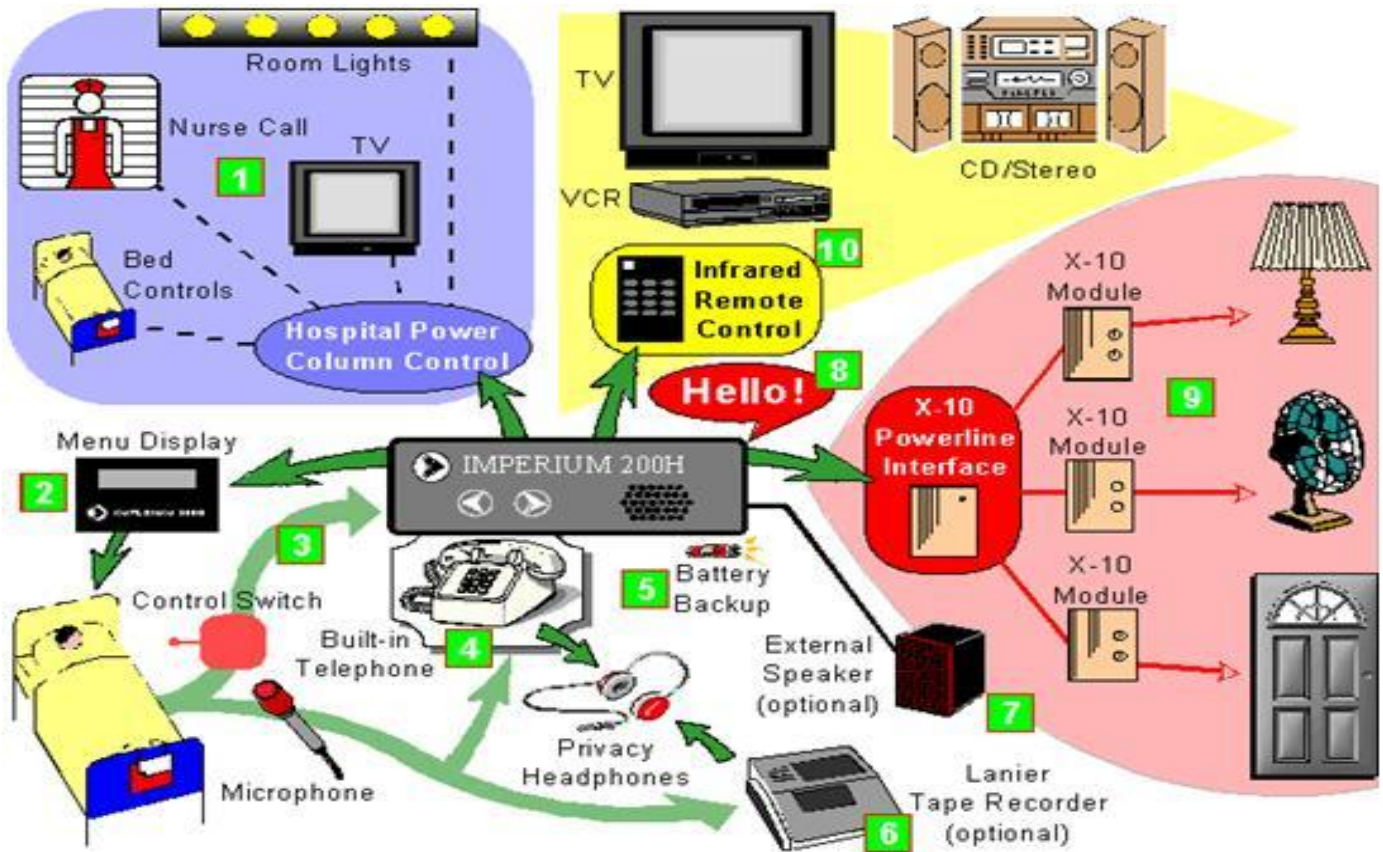
Figure 1: The Imperium 200H Environmental Control System.

Each individual technology uses a different signal "language" between the transmitting and receiving modules. Some technologies require the devices to have built-in receivers and some can control devices by installing interfaces between the power source and the device. What they have in common is that every environmental control technology is limited by its method of transmitting and receiving signals.

Almost all electrical appliances can be controlled by the environmental control technologies discussed. There are, however, limitations to the devices that can be controlled. Certain appliances require more power than the modules can handle passing through their internal circuitry, such as air conditioners and powerful electric motors. Also, when choosing a technology to control a hospital bed remotely, the controller being used must be able to send the signal that the hospital bed can receive and interpret. Conversely, environmental control technologies cannot control devices that aren't electronic. This means that environmental controls (EC) cannot be applied to situations that require direct physical interaction with the user, such as opening normal window blinds or straightening pictures. For EC to be applied to these situations there must be electric motors and a control interface installed so that the capability to interface with the blinds is present. Once that capability is present, it is nearly effortless to control a device remotely using technologies like X-10 and Insteon.

Environmental control can also help to control devices without the need for physical, bodily, interaction or by controlling them by some method other than how they were designed to be

controlled. This means that devices like telephones and computers can be used by people without full control of their arms and hands. They can be controlled with the user's voice, head-pointed devices, and switches that allow users to use other body parts such as their mouths. For instance, EC allows persons with quadriplegia to control computers, telephones, electronic devices, etc. with a sip-and-puff switch, tongue switch, or other kinds of specialized switches. Using such input methods, people can overcome physical limitations by exploiting the capabilities that the users still have to control devices that normally require capabilities that users have lost.

Environmental control technologies can help people who suffer from physical disabilities such as paraplegia, quadriplegia, Parkinson's disease, and arthritis. EC can also help people who suffer from mental disabilities such as autism and Down Syndrome. EC helps persons with disabilities to interact with devices in their environment, allowing them to be more independent. Environmental control technologies are not intended to relieve pain or heal or cure a disability. They are simply intended to give persons with disabilities more freedom and ability to interact with their environment. For this reason, EC cannot be applied to situations that don't involve interacting with objects in a person's environment such as walking, curing depression or bipolar disorder, or improving motor skills of persons with disabilities. EC is simply intended to give persons with disabilities other methods of interacting with their environment by bypassing their disabilities and focusing on their abilities.

2.2   Methods for Use by Persons with Disabilities

Environmental Control Units (ECUs), also known as Electronic Aids to Daily Living (EADL), are the equipment that persons with disabilities use to interact with and control their environments. ECUs can control a wide range of electronic devices including garage doors, thermostats, windows, doors, beds, "call nurse" buttons, telephones or audio recording devices, lights, televisions, and radios, just to name a few.

There are three main parts to environmental control systems: input devices (the user interface that accepts inputs from the user), the processor (the unit that sends signals to control the electronic devices), and outputs (the devices to be controlled). The input device is the part of the ECU that the user interacts with to effect a change. The signal from the input device travels to the processor which determines what action the user wanted to perform on the output devices and then sends the corresponding signal to that device. Other than regular TV remote control style input devices, there are alternative input devices that are called switches. These alternative input devices are used by persons with disabilities where the users are unable to use typical multi-button controllers. There are two types of switches, single switches and dual switches. A single switch is a switch that only has a single action or button. A dual switch has two input actions, or two buttons. For instance, in a sip-and-puff switch the user has two types (dual-switch) of inputs that can be chosen, sipping and puffing on a straw which could correlate to moving a menu up or down. A single switch, by contrast in the same menu example, like a button would only be able to advance a menu in one direction. A switch or controller can be used to either directly interact with an electronic device or it can be used to communicate with the processor, which will then communicate with the specified electronic device. Similarly, a switch can be installed on a device that will allow a user to turn it on or off with the installed single or dual switch. Switches for

persons with disabilities that do not allow them to use standard control units typically range in price from a $45 "Buddy Button" to devices that are priced close to $500, such as sip-and-puff switches.

The processor, also referred to as the ECU, is the device that gives the user options of what actions can be performed by using a switch. When using switches, the ECU will display a list of available options to the user usually through a menu-based display. One type of ECU is called a scanning ECU which automatically cycles through the available options in the menu. Scanning ECUs are typically used when the input device is a single switch because the user can only push a single button therefore the scanning ECU cycles through the options, giving the user enough time between options to select the command. There are also ECUs that work with dual switch inputs that do not scan but will cycle based on one of the 2 input methods of the switch. For example, consider a system that uses a single-switch input device working with the Mini-Relax ECU (Figure 2). The Mini-Relax ECU, used for controlling a television, has 6 options: On/Off, Channel Up, Channel Down, Volume Up, Volume Down, and X-10 (the

Figure 2: Mini-Relax with X-10 Environmental Control Unit, used to control televisions and X-10 modules.

X-10 option is a feature that was added to this ECU as an afterthought). The X-10 feature allows the device to act as a universal controller for X-10, similar to how it acts as a universal controller for TVs. The Mini-Relax cycles through the options by illuminating a LED to the left of the option on the ECU. When the desired option's LED is lit, the user will activate their switch and the Mini-Relax will send a signal to the corresponding device.

ECUs can also control many types of devices using many different signals. ECUs can control devices that use IR (Infrared), RF (radio frequency), X-10 (over electrical wiring), and Ultrasound signals. There are other devices that require their own unique types of signals, such as an electric beds, nurse calls, or touch-tone telephones. These devices tend to be designed specifically for a single task, and are not as versatile as other control technologies, for example, a hospital bed would be built with a controller integrated into the bed and is probably unable to control room lighting. In order for a generic ECU to control the bed, the bed must support universal, generic codes that may not be specifically labeled on an ECU.

There are also two families of ECUs, stand-alone and computer-based. A stand-alone ECU is one that has all it's programming and processing built-in so that it doesn't need a computer. The Mini-Relax (Figure 2) is an example of a stand-alone ECU because the input device attaches directly to the Mini-Relax and based on user input the Mini-Relax will send out an appropriate signal. The computer-based ECUs have software that typically allow the users more freedom. The freedom that computer-based ECUs grant is the ability to create complex functions that can be used to control multiple devices at the same time from the same window or to make macros that perform preset functions. Stand-alone ECUs range from a $275 Mini-Relax to a $4500 Imperium 200H (Figure 1). Computer-based ECUs are typically much less expensive on their own but require additional hardware to interface between the computer and ECU modules. Some examples of computer-based ECUs are ActiveHome and PowerHome.   Both of

these ECUs are software but require a USB computer interface module to transmit the X-10 signal into the electrical wiring to the network of devices being controlled. In order to get a single-switch system working with PowerHome, a user needs to buy a certain device such as the Ocelot ($200). The Ocelot is a controller that allows the computer to be connected a device called an "8 Input Low Current Relay Module" ($100) that has switches (single or dual) that can interface with the Ocelot and PowerHome. Stand-alone ECUs are considerably easier to set-up and do not need to rely on the computer they are running on to function, but they tend to be less cost-effective, If the user has a large network of different devices.

The output devices are the elements of the environment that the user wishes to control, such as televisions, radios, thermostats, etc. Some of these sorts of devices already have remote control functionality built into them, and they are able to decode commands the remote or other controls are sending them. If the device is controlled by IR such as a TV, the ECU can send an IR signal that will tell it which action to take. For environmental elements, such as fans, that were not designed to be controlled remotely, there are modules that act as "middle-man" devices that can control the power flow to the device. X-10 and Insteon technologies use the middle-man device approach to give the user control over their electrical appliances.

2.3   X-10 Technology

There are many different types of environmental control technologies available that we had to choose from for a technology to demonstrate to the students of ME3506. The one we ultimately settled on is X-10 technology.

While determining which technology to use, there were many factors to consider. The most important factor was simplicity. Simplicity is important because one of our goals is to teach the students of ME3506 an environmental control technology that can be learned in the form of a laboratory activity. This means that we have to teach them all they need to know in an amount of time that is appropriate for a lab, roughly one hour.

Another factor that we had to consider was cost. We had a limited budget for this project, so some of the more exotic solutions were not appropriate. Our budget was in the low hundreds of dollars. Our budget also played a key role in our decision because many of the available technologies cost a significant amount of money over our budget. For many technologies, the entry cost was in the thousands of dollars for all the necessary components that would be necessary to set up a demonstration site or laboratory activity.

We also considered the practicality of the technology. If we are to teach the students of ME3506 to use an environmental control technology that "ameliorates the handicaps of individuals" (WPI Course Catalog), we must consider a technology that is practical and can be adapted for use by persons with many different types of disabilities and can be applied in situations the students are familiar with.

With these three factors in mind, we decided to not to focus our research on environmental control technologies that are involved with telephones or hospital devices, but focus on technologies that are designed for use in the home. Although communication with family and aides is important to

persons with disabilities, we decided that telephone-related technologies were not appropriate for the laboratory environment, which was a major concern in this project. Technologies that interact with and provide service to hospital devices tend to be highly specialized and generally not interoperable with other environmental controls. These hospital devices, such as hospital beds and nursing call systems, can be very expensive also. The devices needed to control hospital devices usually start in the thousands of dollars and get more expensive very quickly. They are also very complex systems that require understanding of many different types of devices and concepts (such as electronic interface devices and some networking knowledge). Similarly, the cost and complexity of specialized devices exceeded our intentions for the lab. Specialized systems like these require many devices in order to perform even simple functions. They require expensive switches, ECUs, sensors, actuators, etc. This level of system complexity is also outside the scope of the project.

This brings us to X-10 technology as well as Insteon technology. Both of these technologies use similar technological concepts and are also very similar in complexity and cost. Both technologies are relativity cheap, with basic starter kits, comprised of appliance and lamp modules and controllers, starting at around $50. The technologies be taught or learned, and a system can be set up in under an hour. Lastly, both X-10 and Insteon are practical. They can be applied to everyday situations for both persons with and without disabilities. Both technologies interact with common appliances ad devices, such as televisions, radios, doors, windows, and lights.

This limited our selection of a system to use for the laboratory activities to X-10 and Insteon technologies. We chose X-10 technology over Insteon technology because X-10 has educational value that Insteon does not. X-10 is slightly more complicated than Insteon, requiring those who seek to understand how it works know simple electrical concepts, how houses are wired, and how electricity passes through wiring. It also has limits because of the electrical characteristics of house wiring. Insteon, on the other hand, is a bit simpler, not requiring understanding of electronics or any knowledge other than understanding that radio frequency technology (RF) exists. The slightly more complicated nature of X-10 over Insteon gave us the confidence that X-10 would offer a better educational experience to the students and they would learn a technology that is simple, cheap, and applicable to common situations, yet complicated enough that they could learn about house wiring and some basic electrical concepts. The basics of X-10 can be learned in an appropriate length of time for their laboratory activities and they would gain more from X-10 than they would from Insteon. Therefore, we chose X-10 technology as the environmental control technology that we would teach to the students of ME3506.

2.3.1 History of X-10 Technology

X-10 technology has been around since the 1970s. It was developed by a company named PICO Electronics while they were working on a way to control a record player remotely using a house's existing electrical lines (Simply Automate). They sought to use a building's existing electrical wiring to send control signals to their record players. Eventually, they reasoned that any appliance could be controlled using signals sent through AC wiring. It became known as X-10 technology because it was the 10th experiment by the company in trying to control devices remotely. With this new technology, they developed what is now known as the X-10 home automation technology.

2.3.2 How X-10 Technology is Used

After its initial application in record players, X-10 was implemented in different forms to allow more devices to be controlled remotely from within an environment. X-10 is capable of controlling all types of home electronics and electrical devices, allowing users varying levels of environmental control. This notion of environmental control empowers persons with disabilities by allowing them more freedom within their household. The technology can be used to open properly modified doors and windows, turn up or down a thermostat without a user having to get out of bed, or control many other devices that would otherwise present challenges for users with disabilities.

Another potential use for environmental control technology is in its comforting effects. There are computer programs that allow its users to set macros which allow scenes to be made and complex actions to be taken. A user can make a "dinner scene" by having a pre-programmed scene that correctly dims certain lights in the dining room as well as turning on the radio in order to make dinner more comfortable. Macros also allow security systems to become more useful. For instance, a macro can be programmed that signals all of the lights in the house to flash as well as for the security camera to turn on and record when a motion sensor detects motion after a designated hour.

2.3.3 How X-10 Technology Works

X-10 technology has been around since the 1970s but very little has changed from its original form. It still uses the same basic principle of sending a signal across a building's existing wiring to control appliances and home electronics, such as lights, throughout a home. The X-10 signals are sent at specific points on the AC waves (for technical specifications see Appendix C) and that signal produced by X-10 is designed so that it doesn't hinder any other device in the house. This is because these other devices are operating off of a different part of the AC wave than the X-10 signal. Therefore, X-10 is transmitted transparently and does not interfere with any of the power that is being transferred through the house's wiring.

The X-10 protocol is the way X-10 determines which devices receive which signal and how the devices know what specific signals mean. The X-10 protocol is a signal made up of a house code, a unit code, and a command code. Each device is identified by two criteria, first the device is assigned a house code and then a unit code. (How X10 Works) The X-10 protocol allows for 16 units to run under one house code, and for 16 house codes to co-exist at one time. The house code can be used to distinguish one house in a neighborhood from another so that they don't interfere with each other if more than one household is utilizing the technology. For instance, one house equipped with X-10 might use the house code A and another adjacent house might use house code B. In such a setup both homes can run X-10 devices without interfering with each other's systems or having the wrong device intercepting a command. Experience shows that house codes are used in a slightly different manner than their original intent. House codes are often used to group devices within one particular house because of the sixteen device limitation per house code. For example, one house can be using house code A to group all the lights in the house and house code B for each element in a home theater system. Such an arrangement allows for organization of like devices and ease of control over a house's X-10 installation. Each X-10 signal transmission is seen by every X-10 enabled device in the home, however only the device with the

matching house and unit code couple will act on the command. As an example, although a command for device A1 (house code A and unit code 1) is transmitted throughout the house, only the device set to A1 will decode this message. If the device is a light and the command code was to dim the light, only light A1 will be dimmed.

In order to send and receive signals, an X-10 network is comprised of three types of devices: the controller, transceiver, and modules (receivers).

Figure 3: Simple X-10 Controller (left) and Transceiver (right).

The controller (Figure 3 Left) is the main interface between the user and X-10. It operates in the same basic way as a TV or stereo remote control. The user interfaces with the controller to make a device take a certain action, such as turning a light on or off. Controllers typically have on and off buttons for most appliances as well as dimmer switches for lights (these buttons allow for lamps that weren't designed with a dimming function to be dimmed also). When the user chooses a device on the controller to perform a function, such as turn on, the controller utilizes a transmitter to send the signal throughout the household wiring. Most standard controllers have integrated transmitters and interface with the network of X-10 devices through any standard electrical outlet in the home. Some examples of these controllers are: credit-card controller, normally styled remote (like TV remote), and an interface monitor. Prices range from $20 to $6400. There is also a touch-tone phone controller which allows users to call into their home and control their devices remotely, which can be purchased for about $40.

The transmitter is the device that generates and sends the signal throughout the electrical wiring. Another device closely related to transmitters is called a transceiver which is a transmitter and a receiver in one. A transceiver (Figure 3 Right) receives signals from a controller which it then transmits throughout the house. The distinction between the two is that the transmitter is always connected to an outlet, however if that transmitter is also a transceiver, the controller need not be directly attached to the outlet. A transceiver allows the user to use a controller that is wireless utilizing radio frequency (RF), infrared (IR), ultrasonic, or virtually any other means of wireless communication. These controllers send their signals to the transceiver which then propagates that signal throughout the house. These are generally inexpensive, ranging from $24 to about $50.

A receiver (Figure 4) is the unit of the system that directly controls the appliance, lamp, or other device plugged into it after it receives the signals sent out by the transmitter (or transceiver). The receiver is also commonly referred to as a module, and we will continue to use that term throughout the rest of this report. Each module is assigned a coupled house code and unit code, such as A1 or B3. Each module in the network receives every X-10 signal sent throughout the house and if the signal matches

Figure 4: X-10 Appliance Module (Receiver).

the couple for the module, the module will perform its assigned command. There are two main types of modules, light modules and appliance modules. Light modules control devices that use resistive loads, almost exclusively lamps with incandescent bulbs, whereas an appliance module controls devices that use inductive loads, such as home theater systems, kitchen appliances, and fluorescent lights. A light module can be used to dim lights even if they don't have a dimming feature built into the lamp because of the resistive loading built into the module. If one were to connect an appliance such as a TV to a light module erroneously, any command to "dim" that TV would likely damage either the module, TV, or both. Some other examples of modules are: computer transceiver that works the same way as the telephone controller (lets users control their home by communicating with their computer), digital video cameras, and motion detectors. Prices of the cameras range from $120 to $800 and motion detectors cost about $50.

There are many reasons X-10 is a viable environmental control solution for most users. A major consideration is that X-10 is easy to install using the existing infrastructure of wiring in the house with little to no modification required for use. X-10 is a plug-and-play technology, meaning that a user need only to plug modules and controllers into an outlet and the system is ready to use. Since no modification to the house is needed, implementing a system is relatively inexpensive and requires little expertise. The most basic X-10 network is a simple controller/transmitter and a single module, these two can be purchased for about $10 each. Another benefit to using this technology is that it has had time to mature and there are a wide variety of products on the market which allow varying degrees of control and give users a plurality of solutions for most needs. Consumers can buy modules to effect lights and appliances, as well as many more advanced technologies such as thermostats, door openers, bed controllers, and even security devices like X-10-enabled cameras and motion sensors.

2.3.4 Limitations of the X-10 Solution

X-10 technology is a very simple means of controlling one's environment however it does have some limitations. The biggest problem X-10 users face is the degradation of the X-10 signal when passing through the building's circuitry. Because of the way the X-10 technology sends and receives signals, the system can be subverted by a phenomenon of electrical wiring and devices connected to it known as EMI (Electro-Magnetic Interference) filtration (Hambley, 2005). Inductance (a property of wire that stores magnetic potential as in electromagnets) combined with capacitance (a function of having capacitors in power supplies of electronics) creates the EMI filtration effect. The capacitors which can be found in many different electronic devices (i.e. televisions, computer monitors, microwaves, etc.) in the home are designed to filter imperfections in voltage out of the AC (Alternating Current) power source. The X-10 signal could be viewed as imperfections in the AC wave that the receiving modules can detect and interpret as a command. When there are too many capacitors connected to the electrical wiring (which naturally has inductance) the EMI filtration effect is strong enough to 'clean' the X-10 signal from the AC household signal at relatively short distances from the transmitting module (Hambley, Electronics, 2000).

The distance from a transmitter to receiver can also become problematic, because the signal strength decreases the further away from the transmitter a receiver. If the length of wiring from transmitter to the receiving module is too great, the module may not receive the command. There are other electrical hurdles to overcome, such as the US has a two-phase electrical system (i.e. voltage on one phase is -110V to 0V, and on the other 0V to +110V). A transmitter can only transmit its signal along one phase because the two phases are separated and isolated at the circuit breaker in the house. In order to get around the two-phase problem, home-owners must install an X-10 coupler to allow a signal to pass between phases. This one device does not pose a complex installation, but this limitation can cause confusion among X-10 users who may be unaware of such a condition existing in their own homes. The final problem with X-10 is that there is a time delay between when a command is sent and when a receiving module produces a perceptible result. This delay can range from one half of one second to one and a half seconds. This limitation exists because of how the X-10 signal gets sent across the AC wave (see Appendix C for the technical description). The time delay is apparent when compared to a standard light switch which produces a result almost instantaneously. Users may require a period adjustment to become comfortable with the delay.

2.4   Other Environmental Control Technologies

Insteon Technology is another home automation system similar in functionality to X-10. Insteon controls devices throughout a home by transmitting through a dual-mesh network. This dual-mesh network sends a signal both through the electrical wiring, like X-10, and through the air using Radio Frequency (RF) technology (SmartHome, 2006).

Insteon was designed to overcome most of the limitations of the X-10 technology. Insteon is peer-to-peer system which means that each module is capable of communicating with every other module in the network. This dual functionality of each module, as transmitter and receiver, allows each device to be a repeater to propagate a command signal through the house. This meshed network of transceiver modules allows this solution to be more robust and not as susceptible as the X-10 signal to weakening over distance or having different phases standing between the transmitter and the receiver. Receiving modules send receipts of confirmation back to the transmitters to ensure that a command has been received. If a transmitting module does not get a confirmation, it will resend the signal.

Insteon technology was also designed to reduce the delay between when a command has been sent, and when a device receives and acts on the command. The Insteon signal is transmitted over RF as well as electrical wiring so the signal does not depend solely on the AC wave for transmission. The delay that X-10 suffers from is effectively circumvented by the RF transmission so that Insteon commands appear more instantaneous (Instant-On= Insteon).

Insteon is also more convenient, as well as overcoming limitations of X-10. There are no dials or knobs to turn on an Insteon device, as are required to identify modules (by house code and unit code) in X-10 networks, each has its own unique ID. The dual-mesh networking of Insteon also makes it backwards compatible with X-10 technology, allowing for easy upgrades from X-10 modules in a house to comparable Insteon modules.

Where Insteon overcomes problems that X-10 has, it still has limitations of its own. One limitation of the Insteon solution is that signals are sent via RF and there are many consumer electronics that send signals using RF which can interfere with Insteon signal transmission. Along with competing with other RF devices, there are many other things that can confuse or block RF signals, like wire mesh, walls, and even electrical wiring in the walls. Many of the controllers, modules, and devices that are available with X-10 technology are also available with Insteon technology. Insteon is also priced rather similarly to X-10, starting at around $20 and up making it a very affordable and useful technology for home automation and environmental control.

2.5   Educational Philosophies

We began our research into curriculum development by first meeting with WPI Professor Chrys Demetry, Associate Professor of Mechanical Engineering and Director of the Center for Educational Development and Assessment (CEDA). Professor Demetry helped direct our research by giving us keywords and potential resources to help us hone in on sources that would help us design effective laboratory activities, a search that had until then only yielded results relating to curriculum development in general. When we had an opportunity to meet with Dr. Judith Miller, former WPI Professor and Associate Dean for Special Academic Initiatives at Clark University, she introduced us to Bloom's Taxonomy. This taxonomy was the basis for our evaluation of the laboratory activities we created, and also it served as a guide to help us determine what the students could be expected to know at the outset of the laboratory exercise.

2.5.1 Bloom's Taxonomy of Educational Objectives

There has been considerable research into the study of curriculum development, also known as pedagogy. Pedagogy outlines, for curriculum developers, good design practices for educational materials that result in effective activities for students who will then be able to demonstrate what they have learned.

There are three areas that pedagogy is centered on: the learning objectives, the process by which the students learn the objectives, and the way that the educators will evaluate the students' level of knowledge throughout the learning process. The main educational philosophy that we have employed is Bloom's Taxonomy. Bloom's Taxonomy consists of six levels of comprehension of material, with the first level being the most basic form of knowledge and progress to more complex levels of understanding.

The Levels of Bloom's Taxonomy:
1. **Knowledge**
2. **Comprehension**
3. **Application**
4. **Analysis**
5. **Synthesis**
6. **Evaluation**

At the first level, knowledge, a student would be able to memorize information, such as formulas and definitions. Examples of questions that demonstrate this level, and each subsequent level can be found in Appendix H.

At the second level students understand the material that was learned. This surpasses simple knowledge in that the student should understand the meaning of what was learned rather than just repeating something that has been committed to memory.

The third level expects a student to be able to apply any material that was learned in the first two levels to a new problem or situation. In addition to knowing and understanding, the student should be able to use their knowledge to solve problems.

The fourth level goes beyond problem solving to analysis. Analysis is being able to understand how concepts, formulas, or definitions fit together to work as a whole. At this point, a student should be able to analyze a given problem or system and determine how it functions or works.

The fifth level of synthesis is the design stage. Students are expected to be able to design and build something, using the skills from the lower levels of the taxonomy, to solve a problem or fit a designated situation.

The sixth and highest level, evaluation, requires that the student can analyze a design or system and be able to determine how well it would perform in the confines of a problem without having to interface with the system.

Each level of the taxonomy has general terms that can cue the level of the material. For instance, the first level of Knowledge generally uses the terms, "list, define, tell, describe" to form the questions. At the higher levels, that of Evaluation, terms such as, "assess, decide, rank, grade" are used to form the questions. Using the terms that relate to the given level, we can easily identify the levels that our laboratory exercises and corresponding questions fall into.

Using and applying Bloom's Taxonomy will result in successive skill building for the students. Bloom's Taxonomy is used by educators to design laboratory activities that reach certain levels of knowledge. As the educators design educational materials, they can refer to Bloom's Taxonomy to determine the level of comprehension students would be expected to have at the outset of an exercise, or to modify an exercise to produce a certain desired level of comprehension. In this way, the educators can know what they can expect from the students after the material has been designed. In other words, using Bloom's Taxonomy gives educators a way to know what level of knowledge the students should be able to demonstrate, therefore giving the educators a way to design the learning objectives and also the evaluation process (Seddon, 1978).

Bloom's Taxonomy is used widely across the field of education, in grades K-12 as well as higher education and college-level curriculums. ABET, the Accreditation Board for Engineering and Technology, of which WPI is a member, uses Bloom's Taxonomy as one of their criteria to accredit an institution's educational program (Accreditation Board of Engineering and Technology, 2006). Similarly, creators of

online assessment tests use Bloom's Taxonomy as a way to guide the development of assessment questions. For instance, when developing math-related questions, they determine the level of knowledge the question should reach and format the question accordingly. They use Bloom's Taxonomy as a way to gradually move students into more complex understanding of topics and concepts. The graduating level of the questions, according to Bloom's Taxonomy, allows the students to learn the basic concepts and then use their knowledge in many different and more complex situations. The use of the higher-level questions forces students to develop a better understanding of the material beyond that which can only be learned by memorizing formulas and solving simple problems (Vidakovic, Bevis, & Alexander, 2003). When teachers or professors gain control of the online assessment tests they can use Bloom's Taxonomy to measure the understanding that their students have of the material and alter the teaching and/or assessment according, giving the students a more comprehensive learning experience that precisely matches their learning rate.

2.5.2 Linear and Non-Linear Processes

One aspect of creating educational materials not covered by Bloom's Taxonomy is the process by which to teach the students the material. There are many different theories and means to transfer knowledge on different levels of comprehension ranging from a linear process to a more active, hands-on approach.

Linear processes are designed so that the students learn the material by following a fixed set of instructions in a given order. This introduces the students to the material in a controlled fashion that allows the educators a greater degree of control over what the students are learning from the material. Usually, linear processes reach low levels of Bloom's Taxonomy due to the fact that the higher levels deal with design and analysis that the students cannot learn from following specified instructions.

Non-linear processes are designed so that they usually have a cyclical or dialectical movement allowing the students to learn as they go and to develop their own ideas, principles, and theories based on the materials that are presented to them. These usually follow a pattern of design and building, going back and forth and cycling through, in order to reach an end product or higher level of comprehension that a linear process would not allow them. In other words, giving the students freedom to develop their own ideas while following given informational material allows the students to reach all levels of knowledge in Bloom's Taxonomy in an immersive, fun, and very effective way. Although these processes remove some control from the educators, the students gain a better understanding of the material and can reach a more significant level of understanding because they discover principles and laws of systems on their own.

3 Methodology

In order to achieve the goals of our project we needed to conduct research on environmental control technologies as well as learn about methods employed to develop effective laboratory exercises in an academic setting. Once we had a base of technical information for a simple environmental control technology (X-10), we developed concepts for laboratory activities and exercises that could be utilized in the Rehabilitation Engineering class, ME3506. These concepts were then developed into more comprehensive exercises that incorporated the methods and techniques we had learned while researching pedagogy in a laboratory environment. With volunteer WPI students, we assessed the effectiveness of the exercises in order to ensure they could be used with little to no modification in the Rehabilitation Engineering class. Finally, one requirement we set for the laboratory exercises, is that the introductory material is both relevant to the classroom exercises and can also serve as an introduction to the technology for persons in a professional field, such as occupational or physical therapy, independent of the exercises themselves. In this section we will discuss the steps outlined above.

3.1   Research

Before we could achieve our main goals of creating laboratory exercises for use in the Rehabilitation Engineering Class (ME3506) and an introduction for persons who are not in ME3506, we needed to research available low-cost environmental control technologies that could be used for persons with disabilities. In the course of our research in print articles, online resources, and retailers; we came to the conclusion that X-10 technology was the ideal technology for use in our laboratory exercises. We decided on X-10 because it was a mature technology, first debuted in the 1970s, that was low-cost and has a very large range of available products. We also visited and interviewed an X-10 user, Gary Wittmann, who had an existing system set up in his house and he was kind enough to answer questions and demonstrate how he uses the technology, a full report can be found in Appendix A. Once we had a comprehensive history of the technology and understanding of how it works we changed focus to researching how to make an effective laboratory exercise. Our investigation into pedagogy was given focus after a meeting with a Clark University professor, Dr. Judith Miller, who introduced us to Bloom's Taxonomy. Bloom's Taxonomy is a teaching scale that allows us to assess how much knowledge and comprehension of a subject a student is asked to perform or is able to demonstrate. A full account of that interview with Professor Miller can also be found in Appendix A. Once we had researched X-10 technology and pedagogy, we had to combine that knowledge to create laboratory exercises to serve as vehicles to teach and inform students of ME3506.

3.2   Laboratory Exercise Creation

The laboratory exercises are to be included in the Junior-level Mechanical Engineering class, ME3506, comprised of mostly Mechanical and Biomedical Engineering majors. Rehabilitation Engineering laboratories should be of an appropriate complexity so they are neither trivial nor unreasonably difficult. The activities should showcase the abilities and versatility of the technology, as well as require the students to think critically about how to set up a system. After we had a solid understanding of the history of X-10 technology and how it works, we searched for available modules

and Electronic Aids to Daily Living (EADLs) that were compatible with X-10 and compiled a list. Some examples of modules we found, aside from the basic appliance, lamp, and controller modules, are: sundown controllers (sends a signal when the sun sets, similar to a motion sensor), panic button pendants for the elderly or disabled, and home security systems with motion sensors, sirens, cameras, etc. (for a complete listing, please see Appendix D). From this list, we brainstormed concepts for exercises that could be developed to demonstrate different functional characteristics of the technology, as well as creating compelling and engaging activities that would stimulate the interest of students performing the activities. From those concepts we developed and outlined the process of five into activities: Understanding X-10 and How it Works, Using Macros to Integrate Sensors and Actuators, Benefits and Limitations With X-10 Enabled Cameras, Specialized Input Controls for Persons With Disabilities, and A Comparison of X-10 and Insteon Technologies. In order to make the labs more efficient and modular, we chose to create an introductory handout to X-10 technology that would be common and relevant to each activity. The introduction provides a basic overview of the X-10 technology which should help the students understand and comprehend how X-10 technology works, rather than just follow a static set of instructions. Once we had the introduction complete, we added instructions relevant to each activity that showed how each module (or software) could be configured as required for each activity. After those instructions were added, we assessed the activity per Bloom's Taxonomy to determine how effective each of the five would be as an aid to learning for the students. Using that information we were able to modify the goals of an activity to make it easier to understand and complete, or be more demanding and require application of learned concepts highlighted in the introduction. We decided to add pre-labs to each activity, which guided the students through configuring a system, so they could see how it all went together. Once they had that background in place, we assigned a problem (exercise) that would test their understanding of the technology and their ability to tailor a system to solve the problem. We then stepped through the entire activity, writing directions that could be followed in a logical progression from pre-lab leading up to the exercise, so that when the labs were tested with volunteers, there would be minimal need for us to intervene and explain absent or unclear instructions. While modifying the activities so they were ready to be tested, we determined that we were unable to complete two of the activities because we did not have the required modules or hardware. These partially formed activities (Limitations With X-10 Enabled Cameras and Specialized Input Controls for Persons With Disabilities) will be completed as much as possible and available to the professors to develop further if they choose to purchase the required materials to perform the activities. The other three laboratory exercises (Understanding X-10 and How it Works, Using Macros to Integrate Sensors and Actuators, and A Comparison of X-10 and Insteon Technologies) were consolidated into two activities because we felt that the combined activities were too short on their own and a stronger product could be delivered if they became a single laboratory exercise. Once we had these two draft activities (Using Macros to Integrate Sensors and Actuators and Understanding X-10 Signal Transmission), we began the process of testing the activities and assessing their performance.

3.3   Laboratory Exercise Testing and Assessment

While creating laboratory activities for use by students in the class, it was integral to both test the exercise to ensure that it is appropriate for that target audience and assess its effectiveness in

teaching material to them. We first found volunteers from the WPI student body to be the subjects of our testing. Each volunteer had to be a current student at WPI, have attended school for no less than 2 semesters, and have had no prior experience with X-10 technology. We tested the activities in a laboratory setting in an available on-campus location, primarily in the Rehabilitation Engineering Laboratory in Higgins Labs. The volunteers were given paper copies of the activities which included pre-labs, the exercise, and introductory material necessary to understand how the technology they were to use works. They were then asked to read through the overview of X-10 technology and as far into the material as they felt comfortable reading ahead. We allowed the volunteers to work uninterrupted through the activity unless they had questions related to shortcomings in the material provided to them. Once they had completed reading the introduction, and performing the pre-lab and exercise materials to their satisfaction as well as our own; we interviewed them to assess both their performance and understanding of the activities as well as the quality of the material they had used to guide them through the activities. We did not ask a formal report of them, as we would if it were used in the context of a class, but we did ask questions to test their comprehension of the information provided (facts) and more abstract concepts that required the understanding of how the technology works. The reports that we created about the testing of these activities can be found in Appendix B. These reports helped us locate areas for improvement to make the final product as effective as possible.

3.4   Standalone Introduction to X-10 Technology

The third goal of our project was to create a document that could serve as an introduction to simple environmental control technologies for persons who were not WPI students and more likely to be in a professional field, such as occupational or physical therapy. These persons are not assumed to be technologically or computer savvy and would need a more basic overview that did not go into unnecessary detail. Once we had completed the creation and testing of the first laboratory exercise, we then re-evaluated the document and rewrote some of the content to make it more appropriate for users who were not necessarily students of the ME3506 class. We sought to make the first laboratory activity as general as possible so that it would not need to have any major changes to serve its secondary purpose within this project. Once references to material that did not apply, such as turning work in to instructors, had been removed, we then reviewed the document to ensure that it was completely understandable. This document can be found in Appendix E.

4 Results

After the laboratory exercises were created and tweaked we began testing them with volunteer WPI students to verify their effectiveness. There are many aspects of the labs that we had to test. Mainly, we had to make sure that the information and instruction materials provided to the students were sufficient to correctly complete the requirements of the laboratory exercise. We also had to ensure that the lab material was explained in an understandable way. This second aspect of the testing was necessary because it is possible for the students complete the labs correctly without understanding the material. We had to make sure that the activities required a certain level of comprehension to be completed. One of the primary goals of the activities is that the students could complete them with a general understanding of the system.

There are two main laboratory activities that we have tested: Lab 1 and Lab 2. Lab 1 had two separate tests dubbed: Alpha 1 and Alpha 2.

4.1 Overview of the Laboratory Activities

Both Lab 1 and Lab 2 begin with similar pre-lab activities consisting of an introduction to X-10 Technology and instructions on how to set up a basic X-10 system. These pre-lab activities are intended to introduce the students to the technology so that they will be able to complete the objectives of the laboratory activities. Lab 1 and Lab 2 differ in material beyond the first two pre-lab sections. Both Lab 1 and Lab 2 are structured to teach the students using both the general material in the pre-lab sections and the more targeted material that follows. Once the students have completed that introductory material, they are given problems and questions that test their understanding of the material.

The X-10 introduction section explains how X-10 works in the home, the X-10 addressing protocol, the three main components of the system and their functions, and what X-10 can be used for. This section explains the general concepts of X-10 so that they may understand the lab material.

The pre-lab section designed to teach how to set up a basic X-10 system, is intended to show students how to actually use the X-10 devices for environmental control. They will be taught how to control a light and a TV (or computer monitor) using basic X-10 modules and controls. This section explains how to identify the devices, how to set the devices to certain addresses (house code and unit code) so that they can receive their corresponding signals, and how to install the system in a house so that the user can control devices in their environment. This section also has step-by-step instructions for the students to follow so that they can get hands-on experience in setting up a basic X-10 system.

4.1.1 Lab 1

The objective of Lab 1 is to teach students how to set up an X-10 system that uses macros created with ActiveHome Pro and are triggered by a motion-detecting sensor.

Lab 1 has a section teaching the students how to create macros using ActiveHome Pro. The students are taught how to set up X-10 devices so that they can be used with macros in ActiveHome Pro,

how to install and use the USB computer interface device, and how to create rooms and modules in ActiveHome Pro (digital representations of physical X-10 devices). The students are then taught how to create macros with the ActiveHome Pro software. The macros created by the students in the pre-lab sections are simple macros that control both the lamp and the TV and are triggered by a user-generated signal from an X-10 controller. The pre-lab sections are intended to teach the students how to use their knowledge of setting up basic X-10 systems and applying it a bit further to create a slightly more complex system.

The next pre-lab section teaches the students how to set a motion sensor so that it can be used to trigger an X-10 module. Then, the students are given the lab requirement, which is to set up a pre-defined system and macro that uses the motion sensor as the trigger. The macro they are required to create must activate devices with specific addresses in a particular order that gets triggered by the motion sensor. Knowledge and understanding of the material will allow them to accurately set up the devices and create the macro to the specifications.

4.1.2 Lab 2

There are two objectives for Lab 2, one is to teach students how X-10 signals get transmitted and the other focuses on how the X-10 signals can become degraded. The laboratory activity has therefore been broken into two parts for the students to complete.

The first part of Lab 2 is directed at teaching students how the X-10 signal gets transmitted along the AC (Alternating Current) sine wave. To teach the students signal transmission, we have created some synthetic sine waves that show the "power spikes" that make up the X-10 signal. These waveform images are graphical representations of the actual sinusoidal alternating-current waves. The students are taught how to interpret the waveforms to find the locations of the X-10 spikes in the waves that represent the X-10 signals. They are then taught how to decode the spikes to determine which X-10 command is being sent on the waveform.

The second part teaches students about how the X-10 signal gets degraded. To perform the second part of Lab 2, we have built a wiring rig that simulates a circuit and conditions one would find in an average house. We have built the wiring rig rather than using an actual wiring system because the degradation we wanted to teach the students occurs as a result of the length of wires between X-10 modules and the transmitters as well as the effects of noise filtration on the system. The wiring-rig allowed us to isolate the electrical system to be able to control the conditions in the circuit. This control allows us to expect certain results that the students will come up with, instead of allowing for uncontrollable conditions and interference that we might experience if using the electrical circuit of an on-campus building.

The wiring rig is a board that has 8 electrical outlets connected in parallel; similar to how a house is wired. The electricity that comes into the wiring-rig's system is filtered using an isolator and an Electro-Magnetic Interference (EMI) filter. There is 25 feet of wire between each outlet.

The second part of the lab first informs the students of some electrical concepts that effect the X-10 signal transmission. We have informed them of the effects of EMI filters that are a product of

inductance and capacitance introduced into a circuit. Both inductance and capacitance are found in buildings and cause X-10 signal degradation in real-world conditions.

There are two main lessons the students will learn in the second part of the lab. The first lesson exemplifies the effect of EMI filters in the system. To show this, the students are instructed to install the transmitter into front of the system and a lamp module close to the transmitter. Then, the students are asked to move the lamp module to outlets that are increasingly further away from the transmitter. The students first do this without a capacitance introduced into the system (the system inherently has inductance due to the amount of wire used on the rig) to show that the system functions without any signal degradation. The students then introduce a capacitor into one of the outlets which creates the conditions necessary to create an EMI filter. They are then instructed to test the modules in each outlet again, this time to find out that the further from the transmitter the module is, the more likely the signal will not be received.

The second lesson that the students should learn from Part 2 of this laboratory activity is that having more X-10 transmitters on a line also affects the signal strength. They are instructed to plug in two transmitters to the line at specified locations on the wiring rig to show that the signal actually gets degraded due to the added capacitance having extra transmitters introduce into the circuit.

4.2   Lab 1: Alpha 1

The first Alpha test of Lab 1 was a failure, but also a valuable learning experience for us. When the volunteer WPI students were ready to begin the laboratory activity, they were given a paper copy of the lab materials. All of the X-10 modules need to complete the exercise as well as a computer with ActiveHome Pro installed on it were on a table in front of the volunteers. When given the material, the students were instructed to go through the handout as they would perform a laboratory activity in one of their classes. The students saw fit to skim through the introduction section, the section on setting up a simple X-10 system, and they started at the "problem" section that was to test their understanding of the previous sections by asking the students to solve the problem using the modules and software provided to them. Skipping ahead caused the students to miss some crucial non-instructional information in the handout and therefore their understanding of the concepts the activity was designed to teach was lacking. Because they had not read through the material, the activity became an exercise in following directions, rather than a test of understanding.

As the volunteers were working through the lab instructions we observed and noted the steps they took. The volunteers did not have many comments about the material other than simple grammatical errors and there was no necessary information absent. The volunteers had gone through most of the first pre-laboratory activity's instructions and had successfully set up the X-10 system that we had intended them to set up. There were some minor problems they encountered when setting the system up. The volunteers had not plugged in any of the devices (lamps, etc.) to the modules until they had noticed that they were unable to control them. The second problem came later when the volunteers had reached the second pre-lab outlining how to set up a macro. The students had correctly programmed the macro, however they did not understand that the modules in ActiveHome Pro had to

correspond directly to modules in the system. The volunteers had the wrong house and unit codes on the physical modules, so ActiveHome Pro was unable to communicate with the modules.

The major problems with Alpha 1 were in the testing of the system the volunteers had created. When attempting to test their system of modules and macros, the students ran into several problems. Although the macro was created correctly (we compared their macro to the test macro we created while testing the exercise), the macro did not behave as it was supposed to. The light attached to the lamp module flickered when it shouldn't have, the monitor turned on when it shouldn't have, and the entire macro was looping instead of running once. The macro restarted approximately every 30 seconds even though it was supposed to take 90 seconds to run. Then the USB interface device failed, reporting a communication error between itself and ActiveHome Pro, which in turn caused ActiveHome Pro to also freeze and crash.

We could not fix these problems immediately and aborted the testing. The activity was run for a total of 25 minutes before we determined it needed to be aborted. Due to the failure at the end of the second pre-lab, the volunteers never reached the problem solving exercise. Since we were unable to give the volunteers the opportunity to test and expand their understanding of X-10, we opted not to do a post-lab question session to evaluate their knowledge and understanding.

We had gathered a lot of feedback about the quality of the lab material, so we augmented the instructions accordingly to get them to a more completed stage. After the material was fixed and we stepped through the instructions again we began a second test of Lab 1, Alpha 2.

4.3   Lab 1: Alpha 2

Alpha 2 was a significantly more successful trial. The format we chose for this test was to allow the volunteers to work through the material and leave our questions for later. This format seemed to be more appropriate and allowed us to gauge how well the material worked, as well as allowing the volunteers freedom to complete the lab. Contrary to Alpha 1, we instructed the volunteers to read through the material before they attempted any of the pre-lab activities. We hoped that encouraging them to read all the introductory materials would alleviate some of the problems encountered in Alpha 1. The volunteers asserted that they would have read through all of the material before attempting to perform the activity regardless of our encouragement, unlike the previous group of volunteers.

The two new volunteers worked through each of the pre-labs slowly and carefully. They read through all the instructions before attempting to perform any work, and sometimes even rereading it (not due to our wishes but because of their own desire to). After each of the sections we questioned them informally about the quality and understandability of the writing and directions. Other than some minor grammatical errors the volunteers commented that the sections were fully understandable.

We observed the volunteers working through course of the activity. We noticed that they setup the entire system flawlessly. They discussed the problems they were experiencing among themselves and they successfully addressed their problems. They were able to identify all the modules, set up the system, create macros, and program the motion sensor. At the end of the activity, the volunteers were proficient in setting up the system and fulfilling the requirements for the entire lab. This gave us

confidence that the material was designed well enough that the activity could be used in a class setting barring any problems with the technology.

The second part of the evaluation of our laboratory activities was testing the knowledge and understanding of the volunteers. After the lab was completed, we gave the volunteers a series of questions to answer to test their understanding of the introductory material. The volunteers answered most of the questioned correctly, except for those questions that they did not fully understand. The questions that needed clarification were reevaluated and changed appropriately (for a full list of question and answers, please reference Appendix D).

There were some serious complications in this test, as in Alpha 1. For the location of the testing, we chose to utilize the Rehabilitation Laboratory in Higgins Labs at WPI. We chose this location because it is the location where the activities will be performed in ME3506. The problem faced is that the lab's wiring contains considerable noise (interference) filtration, from the many mechanical devices in the building that are plugged into the electrical wiring. The filtration caused problems when testing the macros and the system setup. The modules didn't reliably receive signals being sent to them and therefore we could not empirically determine whether the volunteers' modules and macros worked properly. We compared them to our own system and macro that we made in a controlled situation prior to the test. We confirmed that their system and macro were setup correctly and identical to ours.

We have taken some steps to correct the noise filtration problem found in the Rehab Lab. We have built a wiring rig for Lab 2 which isolates the X-10 signals and prevents X-10 noise from leaving the system.

Lastly, we had another problem with the USB interface device that was outside of our control. There was a communication failure between ActiveHome Pro and the USB interface. We believe that the failure was due to empty or low batteries in the interface but we have not ruled out that the device itself is defective.

Overall, Alpha 2 was considered successful, despite the two problems we encountered. It took our volunteers about 55 minutes to work through the activity and for us to troubleshoot the few problems they were having. Our success was evident in volunteers' performance of the activity, validating the quality of the lab material. Alpha 2 gave us the confidence that our material was written well enough to be used as a laboratory for ME3506. The volunteers understood the material, set up the system, created the macros correctly, and answered the questions to our satisfaction. This tells us that the material is understandable and teaches the students the concepts intended to be covered by the activity.

4.4   Lab 2: Alpha 1

The first alpha test for Lab 2 was a partial success. The format we chose for testing was to closely observe the two new volunteers as they read through the material and performed the lab. We figured that the material is intellectually demanding and so we decided to question the volunteers frequently. This frequent questioning allowed us to make sure that each section effectively introduced the students to the electrical engineering topics presented.

As the volunteers worked through the material we found that they soon became confused. They told us that they were unsure of many of the electrical engineering topics that were raised by our material. They did not understand why we were teaching them about ElectroMagnetic Interference (EMI) filters, capacitors, and inductors. They mentioned to us that there was no information explaining what the objective of the lab was, to show the students that EMI filters degrade the X-10 signal and therefore the information we gave explaining how the signal was being degraded was confusing.

It was determined that we had to explain the objectives of the laboratory activity more effectively, as well as give them further explanation of the electrical concepts presented. This told us that the lab material needed to be more comprehensive and explained in a more general way to ensure that the concepts we sought to cover were understood. We had to explain to the volunteers why they were learning about EMI filters and how they relate to signal degradation.

Once they had learned the basic concepts and reasons for the laboratory exercises they moved on and started performing the lab. They did not find any problem with the instructions for the lab. They performed the lab without error, getting the results we had expected. We encouraged the volunteers to stray from the instructions and try out some of their own configurations. They found some inconsistencies with the positioning of the elements in the circuit that none of us had expected to see. The configurations they came up with uncovered some flaws that were inherent in the wiring rig that are not in a household's wiring. For instance, due to some complicated electrical engineering principles that we do not understand, the wiring rig does not necessarily behave in the same manner when the position of the X-10 receiver module and controller are swapped. We did not expect it to have same characteristics as that of household electrical wiring, but it was expected to be a reasonable facsimile. This has no effect on students' ability to complete the lab and build an understanding of the signal transmission and degradation information that they were intended to obtain. These findings are simply anomalies in the testing rig circuit we had designed rather than problems with the laboratory exercise itself. Therefore, these anomalies do not impede on the successful completion of the lab but they may confuse the students who find them. Therefore, we have taken steps to revise the instructions to prevent students from encountering confusing situations with the configuration of the testing rig.

The students then answered the two questions that followed the lab. They answered the questions to our satisfaction and that conveyed to us that they understood the concepts that were presented to them. They understood how to apply the concepts to real-world situations which showed that the second part of the lab was successful!

Note that there are two parts to Lab 2, understanding signal transmission and understanding signal degradation. The first part, was not functioning correctly due to hardware failure before the Alpha test took place. We were therefore not capable of testing the transmission part of the lab.

The Alpha test of Lab 2 proved to us that the wiring-rig worked as designed and we hold confidence that it will be an effective tool for explaining X-10 signal degradation concepts. However, it revealed some differences in the simulated environment compared to the real-world situations that may confuse the students. It took the students a total of 45 minutes to read through the material and to

perform the activities. We did spend extra time on top of that explaining in detail some of the electrical concepts at work in the lab, which were then deemed too in-depth for the laboratory materials, or we noted them for inclusion in the materials. We also stopped them a few times to experiment with some of the anomalies of the system, different configurations of the elements that produced unexpected results.

4.5   Introduction to X-10 Technology for PTs and OTs

In order to test the effectiveness of the X-10 Introduction for professionals in fields such as Physical Therapy (PT) and Occupational Therapy (OT), a "roommate test" for the PT/OT material was conducted. The volunteer for this test was not a student at WPI, and had no prior experience with environmental control technologies. The test was performed to determine the effectiveness and clarity of the material we developed for Physical Therapists (PTs) and Occupational Therapists (OTs) to use to familiarize themselves with X-10 Technology. We were mainly concerned with how well the material explained the concepts of X-10 and whether or not the material could be used by a PT or OT to set up a system for one of their clients.

We asked our volunteer questions to test her understanding of the material, and we received feedback in the form of comments she had while reading through the material. We questioned her on her knowledge of what each component of the system is, what function they perform, what macros are useful for, what a basic house-code unit code address is, and how motion sensors initiate actions. The volunteer answered all of these verbal questions correctly with only information gathered from the reading.

This test for the PT/OT material gave us confidence that a person with little experience with environment control technologies, or even technical knowledge in general, could read the material and gain a basic understand of X-10 systems and how to set up a basic system. The volunteer gave us some notes on where grammar and informational material could be clarified and that feedback was considered when revising the materials.

5 Discussion

At the beginning of this project we had little understanding of what environmental control technology was available for home use or for persons with disabilities. We also were not aware of the level of planning and design goes into developing laboratory activities. We have researched the various different types of environmental controls that are on the market today. Our initial research revealed that one environmental control technology that was significantly more prevalent than the other available technologies. X-10 Technology is the foundation for a significant portion of commercially available environmental control systems. Not only is there a large user base and plethora of available modules, but it is also a relatively inexpensive and simple technology to implement. These factors contributed in a large way to our decision to use X-10 as our environmental control system for the Rehabilitation Engineering laboratory exercises.

The first step we took was to research different ways that persons with disabilities use environmental control technologies already available to them. This is a very broad topic so we focused on the technologies that aren't already installed in the average home, for instance ignoring the simple thermostat and light switch which could be considered environmental control technologies if one were to define the term loosely. We also focused our research on different Electronic Control Units, or ECUs, and we found a wide variety of high-priced, specialized units specifically designed for persons with disabilities and also a few low-cost universal systems, such as X-10 and Insteon. We quickly realized that the better choice between the two types of systems from which to develop laboratory activities would be the lower-cost universal systems (X-10 and Insteon) due to the relatively small entry cost and the fact that they are very versatile systems that can control many different types of devices and appliances. Any of the specialty ECUs would have to be attached to a base X-10 system to control some devices anyways.

Once we decided to focus on X-10 and its RF counterpart, Insteon we researched what types of inputs and actuators were available in retail stores and catalogs. We found a variety of input devices and actuators that can decode X-10 signals. The inputs went from simple wired switch boxes to RF/IR transceivers to computer controllers. On the other side we found lamp and appliance modules for turning on and off any sort of appliance that plugs into an outlet. We also found X-10 controlled pan/tilt bases for camera systems. From these devices we found that the most useful devices to teach to students who might be implementing these systems were the basic light and appliance units along with the simple actuators and the camera units.

The next step was to develop labs that will perform as a learning platform for students to understand how this technology works and how to use it. In order to do this, we need to know what makes a good lab and learn about how people learn. We talked with WPI Professor Chrys Demetry and Clark University Professor Judith Miller who told us about Blooms Taxonomy, the different levels of learning. We aimed each of the labs at a specific level of comprehension, with the final lab being an evaluation of the X-10 system.

Initially we developed 5 labs, one laboratory activity dealing with X-10 signal transmission, one activity introducing macros for lights and appliances, one lab teaching the students how to use the pan tilt bases with the cameras, one lab comparing Insteon and wired X-10 systems, and one lab studying the signal degradation of wired X-10 systems. Upon fleshing out these labs we realized that using Insteon and the camera systems would be costly and we eliminated them from our development. We realized that the first lab was far too short and decided to combine it with another. Thus we were left with 2 full labs. There was one lab analyzing the signal itself by studying the waveform and observing and understanding how the interference happens and what factors to look at if a system stops working or fails to work. The second lab gives the students a chance to write a small program and have it execute to accomplish a task using the X-10 actuators.

As we were developing the laboratory exercises, we utilized Bloom's Taxonomy as a guide for the creation of the learning objectives of the exercise. The goal of the first laboratory activity is to introduce the students to X-10 technology and to setting up a basic X-10 system. User-friendliness is one of the features of the X-10 system, and because the system is easily understood we did not expect this laboratory exercise to garner understanding in the higher levels of Bloom's Taxonomy. In assessing the first laboratory exercise, we determined that the students reach the Application level (level 3) of Bloom's Taxonomy. We have included some Analysis-level (level 4) questions at the end of the laboratory exercise that will help the students critically think and apply what they learned while performing the activity.

The second laboratory exercise reaches higher levels of Bloom's Taxonomy. We designed the second exercise to reach the Synthesis level (level 5) of the Taxonomy. Using what they had learned in the activity, the students are asked make inferences about what may cause X-10 signal degradation in a home environment. Therefore we introduced them to some factors that have been attributed to the degrading of the signal. These concepts, mixed with some basic information about how electrical circuits work, will be evaluated by the students. They should be able to apply these concepts to fix problems in an X-10 system and to create better networks the first time to avoid problems and optimize performance. Our questions have been designed to test the students' ability to apply their knowledge to new situations to create a better operating environment for X-10 systems.

We would suggest that any further development of labs would reach the highest level of Bloom's Taxonomy, Evaluation. The students should be involved with hands-on experience with an X-10 system and be able to evaluate the situation to find problems, as well discover ways to improve the functionality of the system. We had considered giving the students the blueprint of a house to assess the wiring setup of the house, the appliances plugged into each circuit, and the placement of the X-10 devices. The students should be able to determine how well the system would work based on the knowledge they have learned and be able to locate areas for improvement. We ultimately decided that such an assignment would be too time consuming and advanced for the scope of this project.

Furthermore, we had also considered assigning the students different disabilities to research and determine the needs of persons with those disabilities. The students would then have to evaluate a given system to determine if the needs of the persons with the disabilities they were assigned were met

and whether or not there was something that could be changed to meet the needs better. The students would have to evaluate the household diagram and determine possibilities given the environment of the person with disabilities. This project would have involved much more work and would probably constitute an entire class, rather than a small subset of one (as are the laboratory activities we created for Rehabilitation Engineering). We also thought that such an assessment would be largely subjective, as the students could come up with different systems in order to meet the needs and so the assessment of their knowledge would be hard to determine.

The first set of hardware that was purchased came with an X-10 computer control module with a serial port interface and a copy of ActiveHome. The software had been written for Windows 3.1 and had problems with our more contemporary computers and operating systems. Simple tasks such as turning on lights and off again managed to cause the software to crash along with sporadic instances when the wrong signal was sent out. The interface was difficult to understand and we were unable to ever successfully get a macro program to work more than once. Because of these difficulties we made the decision that an updated software package and a more modern computer interface module, one supporting USB, would be preferable for the purposes of this project. When we got it we found the software to work much more reliably and we estimate that it is much easier for an average computer user to learn how to use the updated software. During the testing period we had no problems with either the software or the USB control module.

In developing the signal degradation lab we found that the system often encountered enough interference to cause it to cease transmission, frequently causing frustration. We could not determine what exactly was causing the interference. After a long conversation with a professor with expertise in signals and a lot of experimentation, we determined the cause of the interference to be related to the inductance of the power lines and the capacitance of component devices plugged into the circuit the modules were on. With the cause to the interference understood and isolated from our testing rig, the same effect could be produced under controlled environments, and thus is part of the latest revision of the lab.

The development of the laboratory activity about macros went smoothly until it was actually tested by our volunteer testers. We started to get erratic behavior from the USB computer control interface. Afraid we were having similar problems to the first computer controller, we ran extensive testing. We found that the computer module is extremely sensitive to low battery voltages and has problems when being used with rechargeable batteries as they tend to drop voltage more quickly than alkaline batteries. Once fresh new alkaline batteries were placed in the control unit it once again began to function as well as it had at the beginning of the laboratory exercise development.

With the laboratory activities being tested and tweaked, we switched focus to developing introductory material on X-10 technology to be used by physical and occupational therapists so that they can benefit from the research we have done on X-10 technologies and ECUs in general.

6 Recommendations

6.1 Recommendations for the Laboratory Activities

When developing the laboratory activities we encountered some problems. In order to fully develop the labs so that they were ready for use in a classroom setting, we had to tweak the activities using empirical data we had gathered from following our own instructions. For half of the activities we had created, we did not have the hardware required to test them, and did not have the budget to purchase them either. We have, to the best of our ability, developed the laboratory activities so that they can, at the professors' discretion, be completed at a later time when the corresponding hardware has been purchased. We felt that the two labs that had been developed and tested using the modules we had purchased as a part of the project, were ready to be used in the Rehabilitation Engineering class and sufficiently met the requirements for this project.

With a larger budget to create laboratory activities with, one can create a much more relevant and immersive laboratory experience for the students of Rehabilitation Engineering. We envision an activity where the students have available to them, specialized (expensive) control interfaces used by persons with disabilities. These input devices, such as sip-and-puff switches, tongue switches, and head pointers, would serve the dual purpose of introducing the students to these user interfaces that have been specially designed for use by persons with disabilities, and they can also help the students empathize with persons with disabilities. This empathizing allows them to have a greater understanding and respect for what limitations persons with disabilities have to overcome. Unfortunately the entry cost of the specialized input system was prohibitively expensive for us to pursue in this project.

6.2 Recommendations for the Introduction for PTs and OTs

For the introductory materials for professionals, such as Physical Therapists (PTs) and Occupational Therapists (OTs), we estimate that most people, regardless of technical inclination, should be able to grasp an idea of how X-10 technology works and what needs to be done to set up a system. With this information, PTs and OTs could probably fashion a basic X-10-enabled environment for a user who had limited mobility or ability to interact with their environment. Persons with disabilities, who have adapted to using computers, can definitely use an X-10 solution through ActiveHome or similar software suites. Those who are able to use a standard TV remote should be able to control all X-10 enabled devices that could be installed in their environment.

6.3 Recommendation for Other Exploration or Projects

In the course of our research, we came across a study in the Archives of Physical Medicine and Rehabilitation journal which polled 29 quadriplegic patients asking about the perceived usefulness of Environmental Control Technologies. Ranked highest was the ability to communicate through the telephone, intercom, or beeper. (McDonald, Boyle, & Schumann, 1989) These persons with high-level spinal cord injuries felt more comfortable for longer periods without a caregiver, however they needed a means of getting in touch with such a person if the need arose. Due to the apparent demand for control over telephones or other communication devices, it would behoove anyone seeking to improve the

quality of life for persons with disabilities to explore in detail the technologies available that enable users such functionality. Again, due to cost constraints, such technologies could not be purchased by our project group, and we foresaw complications arising in a laboratory environment with acquiring phone equipment for use in these activities.

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Appendix A: Interview Reports

Gary Wittmann

On Sunday, September 24, 2006 we met with Gary Wittmann at his house in Westborough, MA. Upon arrival, Mr. Wittmann kindly introduced himself and his wife to us. We were even given delicious homemade cookies that his wife had baked for us. Then we got down to business.

Mr. Wittmann first gave us his background with X-10 technology. He told us that he had been involved with X-10 for over 20 years and had seen many of the modules that were developed for it. X-10 was introduced in 1977, so Mr. Wittmann's experience with X-10 made him a very reliable and credible source. His credibility could also be seen with the X-10 set-up he had installed in his own home.

Mr. Wittmann showed us some of the modules he had set-up throughout his house. He showed us the controller he used for most of the modules as well as demonstrating his equipment. He showed us how he turns lights on, off, and dims lights that normally don't have dimming capability. In his kitchen, he explained how he used a computer program to set schedules for his coffeepot and both inside and outside lights. He showed us the receiver that was mounted in the wall to receive the controller's signals. He showed us the actual X-10 modules that the appliances were plugged into in order to receive X-10 signals. At this point, he explained the general idea behind X-10 technology.

Holding an X-10 appliance module in his hand, he showed us the dials that represented house code and unit codes. He explained to us the difference between house codes and unit codes and how house codes can be used to organize appliances within a house (and also to control a neighbor's appliances on the same house code).

Mr. Wittmann then introduced us to ActiveHome, the computer program he used to set schedules for some of his appliances. He opened up the program and ran it. He briefly explained the layout and how it was a pretty simple program to use. He showed us how ActiveHome's interface is similar to that of a physical controller. It lays out the modules that are controlled by ActiveHome and shows which action that can be performed for a module, such as turning a light on or off and dimming. He explained that the computer installs the programmed schedules directly into the transceiver by a cable that runs from a computer port to the transceiver port. We learned that the transceiver stores the code once. This allows the transceiver to still issue the scheduled commands even if the computer is off or disconnected from the transceiver.

Mr. Wittmann had a box of X-10 components set-out on his table. Rummaging through the box, he showed us some of the oldest and newest X-10 modules and controllers he owns. He showed us the old way of creating schedules for modules by setting a module that looked like an old digital alarm clock.

Then Mr. Wittmann showed us the audio/video capabilities of X-10. He had an X-10 camera that transmitted the information via RF to a receiver that could plug into a computer or TV. We all walked outside with Mr. Wittmann after he had connected the transmitter to his cable box and he showed us

how he used his portable TV to connect to the RF receiver so that he and his wife could get cable television in a tent in their yard. Along these lines, he connected the receiver to his portable TV, positioned the camera towards all of us, and simply plugged the camera in. The set-up of the camera and receiver took about 30 seconds but when he plugged in the camera, the video was instantly displayed on the portable TV.

Mr. Wittmann explained some potential uses for the camera. He mentioned using it for security, like he had done for his daughter. He also showed us his pan/tilt base that he had for his camera that made security even more reasonable. He even showed us a motion detection module that could help with security. Mr. Wittmann explained how a security system could be installed with X-10 by setting up the camera and receiver as well as programming lights to turn on when a motion detector was tripped. X-10 also allows the pan/tilt to be programmed so that the camera will sweep and scan preset areas that the user wants it to as well as focusing on doors or windows (or any other location) in the sweep or scan.

In terms of security, he explained how there are modules that receive telephone calls that can then be used to control the X-10 modules in the house. This makes it possible for users to control their house by a phone from anywhere in the world! He also explained how the house could be, more contemporarily, controlled via the internet. With these capabilities, users can watch over their house even when they aren't in the area.

He then told us about the range limits. We were informed that the range of RF is quite limited and can be reduced even more by interference from object and other signals. This may interfere with RF remotes or any module that uses RF (such as the security camera). Mr. Wittmann also mentioned that depending on the length of the circuit that the module is on, it may be hard for the signal to reach it. He told us that the two-phase issue that we were concerned about doesn't particularly apply. He said that X-10 uses the neutral and so the phases don't interfere.

Mr. Wittmann has given us a great deal of information that we can use for our project. He also opened our eyes to some more interesting technology with X-10 and gave us some ideas on how to use it.

Professor Chrys Demetry

On Wednesday, October 4, 2006 we met with Chrys Demetry at her Office in Washburn Shops. We were hoping to gather some information and resources on how to effectively develop instructional materials. She had just taken a position in CEDA (Center for Educational Development and Assessment).

The first important suggestion she was able to offer us was that students, especially in a technical or design lab, respond well to the lab being structured as a game or puzzle to a final end. The possibility of multiple solutions also fitted into the idea of the lab being structured as a puzzle. Another aspect of a design with multiple solutions would be to have students examine the idea of optimization in their designs. A lab with such goals should have feedback mechanisms built in, indications of success or optimization in a design.

One thing she suggested is that when we are looking for resources to help us in our quest for pedagogy, to note that we are not designing a scientific-type lab, our lab will probably be tailored differently with different emphases. The difficulty there being that most books and resources are intended to aid in the creation of the scientific-type labs. This is not to say that those are the only available resources, but we should be aware of the difference and choose our search terms carefully.

We asked Professor Demetry if she could point us in the direction of one or more specific resources we should look at. She did not have any suggestions other than a book titled (or so she thinks) "Learning by Design," which had been recommended to her, but she had not had time to read. She also mentioned that we should not zone in on any one resource, but to use several so as to not miss anything.

Before we left, she wanted us to know that strategies in teaching are as important as the material covered. Collaborative learning (peer to peer) should be a big part of our lab, and it is a common practice in education these days primarily in larger lab classes. She also told us that the research desk in the library would be the next place to go after talking to her, to find some actual resources we can read and to have any of the staff there (not necessarily Christine Drew) help us in this next step.

Professor Judith Miller

On Monday, November 21, 2006, we met with Professor Judith Miller from Clark University. She decided to meet with us on the WPI campus in a conference room in Higgins Laboratories.

We started the interview by giving Professor Miller a background in our IQP project. We explained what our goals were and also what we were working with. We gave her a general idea about X-10 technology so that she could better understand the laboratory objectives that we had designed. Then, we gave her a copy of the laboratory objectives that we have designed up to this point and we then discussed these for the rest of the interview.

She gave us some general background on teaching and how to understand the process of teaching. She introduced us to "Bloom's Taxonomy" which is a 6 point teaching scale. Each point represents a level of comprehension or understanding of a topic a student is able to demonstrate. For instance, the first level's objective is to teach the students knowledge through formulas and memorization. Conversely the sixth and highest level, evaluation, has the objective to get the students to be able to tell how well something will perform a task it had been designed to accomplish. Evaluation uses all the other levels to build up from, that is, it uses knowledge taught in the first level, student's comprehension in the second, and so on.

Professor Miller explained to us the potential use of Bloom's Taxonomy. When designing the laboratory exercises, she said, use the scale as a way to determine the level at which we are trying to teach the students. In other words, we are to ask ourselves, "What level in Bloom's Taxonomy does this laboratory exercise try to reach?" This way, we then know how to formulate the objectives and we have an understanding of the level that the students will know the material. We can then develop accurate evaluations based on their level of knowledge. She also commented that our laboratory activities

followed the scale closely, progressing up the scale as the laboratory activities went on, that is, getting to a deeper understanding of the objectives of each activity.

In terms of evaluating the students' level of understanding, she also told us to formulate our objectives in terms of what the students will do with their understanding. For instance, will they be able to solve a pen and paper problem? How about building a system? Using this method, she explained how we should change our objectives from the form of, "The students will understand….." to something such as, "The students will be able to…"

She gave us some advice in designing our laboratory exercises and means of evaluating the students also. We have written some laboratory exercises that have subjective evaluations. She suggested that we might do simulations in order to evaluate the subjective laboratory exercises. For instance, she said that we might try using gloves, straight-jackets, wheelchairs, or handcuffs to simulate some disability. Then, having those people (probably from other classes, or majors like Biology) try to use the X-10 system that the students designed and have them assess whether or not the system gave them the ability to control their environment as required. This would be a less subjective way to evaluate a laboratory exercise. The evaluation would then be based on its effectiveness and not any TA's or Professor's subjective review of the design.

Another process she suggested to us was to get the students to discover principles or limitations of the system on their own. She used the example of having the students find the limitations of X-10 on their own, that is, to figure out that the phases in a house matter.

We also explained one way we were going to teach the students of the limitations was by setting up our own system of wiring and circuits of desired wire length and having them do their tests on that. She enjoyed that idea and said it was more "feasible" to teach them the limitations that way.

Professor Miller also gave some guidelines to follow when designing the laboratory activities (or redesigning them). Here is the outline she gave:

- Objectives- tells the students what they will be able to do after the laboratory activity
- Process- this is where the students practice some activity and then get feedback from the TA's or Professor.
- Evaluation- ask the students to perform the objectives

Professor Miller also mentioned that the Process and Evaluation may be grouped together so that as the students are performing the activities they are also being graded and evaluated.

Lastly, Professor Miller warned us to be aware of the influences of logistical factors such as the hours the lab is open, places, needed people (such as TA's and Lab Assistants), cost of modules, and group size. She said a group size of 10 students is almost pointless and that the ideal group size is around 2 or 3.

Overall, Professor Miller helped us understand much more about the design of laboratory activities than we had known prior to the meeting. She offered new perspectives to the problem of designing the exercises. We can use Bloom's Taxonomy to help us as well as all the suggestions she made throughout the interview.

Appendix B: Alpha Test Reports

Lab 1: Alpha Test 1

The Alpha 1 test was a test of the lab Lab 1. This test was conducted on Wednesday, January 25, 2007. It was conducted in the "Power Lab" in the basement of Atwater Kent.

For Alpha 1 test we found two volunteers, an IMGD major and a CS/IMGD major. Neither of the volunteers was familiar with X-10 technology, nor have they previously heard of it.

The Procedure:

The testing procedure was supposed to follow a material-questioning cycle, meaning, we were supposed to give them a portion of the lab and then test their knowledge of that portion of the lab. What actually happened was quite different. After briefly reading through the introduction section, they skipped down to "Setting up a macro" section. They skipped the end of the introduction section as well as the section on setting up a basic X-10 system. Right away, we were already at a loss as to test their knowledge of the system based on our handouts. We then decided to test them at the end of the lab session by having them answer questions on the form we had for them.

The Results:

We handed out the lab materials at 6:18 P.M. and the volunteers actually started working through the lab at 6:23PM. We decided not to force them into reading through the introduction section and system section thoroughly as to simulate what students would actually do given the lab in hand with no lab instructor over their shoulders. (Note: they told us that they wanted to just jump right into the procedure and skip the background section as that is what they would normally do)

Going through the lab material, starting at the macro section, the volunteers setup the system rather well. When an instruction named a given device they were keen to choose the right one from the equipment they had in front of them. In fact, we had accidentally given them two transceiver modules, one for the ActiveHome Pro interface and one for the credit-card controller, and yet they still followed the lab correctly by using the USB interface.

After some time, the volunteers found some errors in the lab. Some instructions were not applicable (such as setting the transceiver to house code A when, in fact, the transceiver doesn't have dials to set a house or unit code). They also found some grammar errors.

The most important observation we made was that they didn't plug in any of the modules or the interface into the outlets until they had realized on their own that they had to do so. They also didn't plug in the lamp and monitor into the modules. This was due to some simple instructions that were missing in the lab. Most importantly, this was due to them skipping the first few sections.

The volunteers correctly setup the macro without help from us. We did need to interfere once because the synchronization of the physical modules with the macro modules was out of line (i.e. the lamp was set to A2 physically, but to A3 in the macro yet they are supposed to be the same).

After the macro was created and the modules were correctly setup the volunteers set out to begin testing the macro. We noticed that the volunteers testing the macro did not understand what the macro was going to do and so on their attempt at executing the macro they were surprised when the light turned on and took some time to dim. Due to this misunderstanding of the system (and delay time of X-10 signals) they began sending other signals to the system by pressing many buttons on the controller. We believe this, and some other things, led to the crash of the system.

The testing of the macro failed for the volunteers. It failed because the macro did not function as was designed, that is, it didn't wait 5 seconds after the light was dimmed to turn on the TV. In fact, it was completely broken in that every 10 seconds or so the light would turn to full power and start the whole macro over again (which should NOT occur under any circumstance). Then the ActiveHome Pro software crashed and the laboratory exercise had to be terminated.

When the entire system crashed the students hadn't gone through the entire lab. They hadn't reached the motion sensor section as well as the main section of the lab. They didn't attempt to create the required macro for the completion of the lab because of the failure of the system (mainly ActiveHome Pro and the USB interface). We had decided at that point that the lab failed and that following the lab with the questions would not help us, as they did not complete the lab.

Conclusions Drawn:

The failure of Alpha 1 led us to go through the entire lab again to make fix the mistakes the volunteers helped us to find. Some of the main issues that we found and corrected were:

- The interface continued to crash even after the entire system was reset. We found that this is due to empty or near-empty batteries. Once the batteries were replaced, the interface worked as expected. This also leads us to believe that the interface device has a defect because it is supposed to be able to run without batteries yet it needs batteries for the computer to recognize it and install its drivers. From this, we added instructions for the volunteers to install batteries and remove the batteries (we also think the interface quickly drains batteries if they are left in).
- We realized that the macro recycling itself after some time was probably due to other macros that were stored on the interface device. From this, we added instructions to the lab to clear the interface of all macros currently installed before they begin making their macros.
- The main problem was that the volunteers skipped the first couple of sections. We decided to place more dependencies throughout the lab, that is, each section builds upon the previous section so that the students cannot continue the lab without first completing the previous sections. This is to ensure the students gain all the information that the lab is intended to teach.
- We also assembled the different sections of the lab into one continuous handout (previously it was sectioned into different handouts that were all given to the students). This will also help keep students from skipping ahead and missing information.
- We fixed all the inconsistencies and incorrect lab instructions and procedures that were found from the volunteers. These include setting the interface to house code A (which is impossible),

correct synchronization of the physical modules address (house and unit code combination) with the macro module's address, and clearer instructions to plug the devices into outlets and the TV and lamp into the modules.

- We also added in and fixed some sections to inform the students of the X-10 delay (time between button press and response of the system) so that they don't confuse their system and macros.
- Lastly, we added in a section to clear the interface and ActiveHome Pro of all macros that were created. This ensures that no group of students can cheat and copy another group's work (intentionally or unintentionally).

After these changes, we then ran through the lab ourselves and made sure that the new lab instructions didn't cause the same crash as last time. This second test run of the system was successful, giving us confidence that we are ready for another Alpha test that can be run completely through correctly.

Lab 1: Alpha Test 2

"Alpha 2" was the second test of Lab 1 conducted on Thursday, February 8, 2007 in Higgins Laboratories Rehabilitation Laboratory. Both of the volunteers were Mechanical Engineer majors with no prior experience with X-10 technology.

The Procedure:

The testing procedure was to have the volunteers follow our lab instructions while we observed. Then, after the lab was done, we interviewed them to test their understanding of all the material covered in the laboratory exercise.

The Results:

The instruction packets were handed out at 5:10 P.M. The volunteers sat down and read through the entire introduction section. When they were finished, we asked them some informal questions about the quality and understandability of the introduction material. They answered that the section was quite understandable.

Then the volunteers proceeded onto the next section, the first pre-lab designed to introduce them to setting up a basic X-10 system. They decided to read through the whole section first and then go back and perform the necessary activities to complete the pre-lab. They easily identified all the X-10 modules and set up the system correctly.

The volunteers were also able to set up the final, required, macro that encapsulates all the material they learned throughout the lab. They understood how to set the modules, install the batteries to the interface, connect the interface, use ActiveHome Pro, setup the motion sensor, and make their own macros.

Overall, Alpha 2 testing was a success in terms of the volunteers correctly setting up the system and macros. There were some minor grammatical errors within our lab procedures that the volunteers found that have been corrected. However, there were major technical problems that were outside of

our control. The X-10 modules didn't seem to work in the Rehabilitation Laboratory. The modules only rarely received the signals from the controller and those signals were inconsistent at best. The modules would not regularly receive ON or OFF commands when we elicited them and there was no reason we could find to explain why the signals did work some of the time. We then tried other outlets in different parts of the lab but with no success. The other hardware failure we had was with the USB interface. At first, it had an error communicating with the computer and once we had established that connection, data would not transfer from the computer to the module. This problem made did not allow the volunteers to download their macros to the interface or run them directly from ActiveHome.

These problems are outside of our control. It seems that the Rehabilitation Laboratory is incompatible with X-10 technology, most likely due to the noise in the electrical wiring. The circuitry seems to be fine as the devices received a signal and worked sometimes, indicating that the noise on the line changed with time. We have looked into ways to make the line less noisy and less hostile to X-10. One solution we have found is to perform the laboratory exercise on a surge-protected circuit which will block all the outside noise from the building's wiring. http://kbase.x10.com/wiki/Identifying_and_Troubleshooting_Powerline_Noise_and_Control_Problems

Also, the USB interface is very inconsistent in its functioning and we are unsure of how to resolve this problem.

The lab was finished at 6:30 P.M., making the entire lab session and hour and twenty minutes long. The lab took longer than we expect the final product to take because the volunteers first read the introductory materials after they had arrived, and the time taken to debug the modules and the problem sending commands.

Lab 2: Alpha Test 1

Lab 2 Alpha was the first test of Lab 2 conducted on Thursday, March 1, 2007 in the basement of Atwater Kent. This lab test was performed by two volunteers, an IMGD major and an ME major. The IMGD volunteer had only prior high-school knowledge of electrical engineering concepts. The ME major volunteer had some basic knowledge of electrical engineering concepts.

Procedure:

Due to the knowledge of electrical engineering concepts, the testing procedure was to have the volunteers read through the material. After each paragraph of reading, we asked them to pause reading and answer some simple questions ensure that they understood the concepts being presented in the text.

Results:

Lab 2 Alpha began at 3:10 P.M. The volunteers were introduced to the wiring-rig and given the material. They instantly began reading the material.

The first part of the lab was to decode the signal in a waveform image. Prior to the lab, some hardware needed to capture the waveform in LabVIEW had failed, resulting in the inability for the volunteers to do the first, lesser part of the lab. We decided to have them move on to the second part of the lab which was more directed at using the wiring rig. We decided to move on because we had to be sure that the wiring rig worked correctly.

The volunteers found many problems with the lab material. Mostly though, the volunteers found that the material didn't explain the problem in whole, that is, it didn't explain that this second part of the lab was aimed to demonstrate the effects of ElectroMagnetic Interference (EMI, noise) filtration on an X-10 system (X-10 is treated as electromagnetic noise in this context).

Furthermore, they didn't understand the concept of how an EMI filter is created and how it filters out noise. They didn't understand that when there is significant inductance and capacitance in a circuit that an EMI filter will naturally be created that will filter out noise on the wiring.

We had to then explain how inductance and capacitance worked together to filter out the X-10 signal and how the EMI filter worked on the line.

The volunteers had also mentioned that the complexity of the formulas involved in the initial conception of the lab and subsequent explanations we had given them were way too advanced, and required a background in ECE3601 or greater to understand. In the lab report, we had included some formulas that further explained the way the signal was being diminished from the EMI filter, however we decided that the exclusion of this information was more beneficial to the understanding of how X-10 works, rather than to overload the students with, unnecessary information.

After the volunteers had a better understanding of the basic electrical concepts, they moved on to performing the actual lab. They didn't experience any problems with the material. The lab directions worked perfectly, they were easily followed and the wiring-rig (circuit diagram presented in Appendix G) performed as expected. However, the volunteers had found some configurations of the placement of the capacitor, controller, and module that made the system behave differently than we had conceived. For instance, the volunteers had found two configurations whose results contradicted each other. In the first configuration: the controller and module were at opposite ends of the rig (controller in outlet 1 and module in outlet 8). When, in configuration two, when the positions were reversed and the results were the opposite from the first configuration. In the first configuration, the lamp module was not being activated by commands from the controller, however when reversed signal it did work! Theoretically there should have been no change. We were unable to determine the precise cause of this anomaly in a reasonable amount of time, so we made changes to the directions that force the students to leave the wired controller in outlet 1, so that the results of their experiments will be more predictable.

Lastly, the students got to the final paragraph, about trying to send signals from two different transmitters simultaneously. As the students performed this section of the lab, they didn't get the results we had expected. The signal was sent and received with no problems. Therefore, it had failed to prove the point that two transmitters on the same circuit had an effect on the signal reception. The section has been re-written to a slightly different goal that is reproducible and challenges the students

to think more critically about what are possible sources of capacitance that are introduced into the system.

Overall, the testing of Lab 2 proved that the wiring-rig worked as designed. It also showed the aspects of the material that needed some more work. Finally, we didn't get to test the first part of the lab, the signal decoding, so we are unsure of its effectiveness.

Based on the results of this testing we decided to change the lab material in the following manner:

- We added sections to explain the context of the problem and the reasons we explained topics such as EMI filtration and capacitance. In particular, we explained that the second part of the lab was directed at teaching the students about the creation of EMI filtration using everyday appliances such as TVs and monitors that can lead to degradation of the X-10 signal.
- We changed the final section of the second part of the lab because of the problems we had encountered. The final paragraph was to show the students that having many transmitters in a circuit actually makes the signal weaker because the transmitters have capacitors in them. Therefore, we changed the final paragraph to reflect this explanation of why multiple transmitters in a circuit is detrimental to signal transmission.
- We created synthetic waveform files for use in the first part of the lab, due to the problems we were having capturing the files in LabVIEW.

Answers to questions asked of the volunteers:

1. What might be factors in the premature degradation of the signal?
   a. The signal is degraded from the EMIs created when a capacitor is plugged into the circuit. The combination of the inductors and capacitors on the line create the EMI and therefore the signal is degraded and might not be received if the module is too "far" from the transmitter.
2. Knowing what causes the signal to degrade, what should you do if you find that an X-10 signal is not being received by modules?
   a. We would check the circuit to see if there were any devices in the circuit that have a large power supply. If this is the case, I would remove the device from the circuit and try it again.

Appendix C: Technical Specifications of X-10 Technology

X-10 Functionality

In this appendix we are going to explain how the X-10 system works. The basic idea comes from the way power is transmitted in house wiring. All outlets receive alternating current which means the voltage goes from 120v to -120v and back 60 times every second. The voltage flowing across the two wires can be modeled by a sine wave with voltage on the y-axis and time on the x-axis. To go from positive to negative and back to positive is one cycle. During a cycle the voltage crosses over the zero line twice. And this point, and during a small period of time before and after the crossing of the zero line, the voltage on the line is so small that a 5V signal voltage at 120kHz can be applied and detected. It is this principal that the X-10 systems use to transmit data using the household wiring.

X-10 Language

The X-10 devices use a highly redundant binary system to transmit data. Each cycle has 2 zero crossings and can either have a +5 voltage or no voltage. The X-10 system reads this as +5 is ONE and nothing is ZERO in binary language. It uses a special code of 1110 to create the start of a message (Montoya). This is special because all the data information is transmitted one bit per cycle by using the system of True and complement redundancy. This means that the first crossing has the information you are trying to send and the second has the opposite signal. So if you are trying to send ONE the cycle will look like 10 and if you are trying to send ZERO it looks like 01. The only code that does not follow this pattern is the start code. It is special because of the true/complement system you can never have 3 ones in a row. It takes 2 cycles for the start code, 4 cycles for the house code and 5 cycles for the function code. For a breakdown of which binary codes correspond to which house and function codes, see the table on the next page.

House Codes	H1	H2	H4	H8	Key Codes	D1	D2	D4	D8	D16
A	0	1	1	0	1	0	1	1	0	0
B	1	1	1	0	2	1	1	1	0	0
C	0	0	1	0	3	0	0	1	0	0
D	1	0	1	0	4	1	0	1	0	0
E	0	0	0	1	5	0	0	0	1	0
F	1	0	0	1	6	1	0	0	1	0
G	0	1	0	1	7	0	1	0	1	0
H	1	1	0	1	8	1	1	0	1	0
I	0	1	1	1	9	0	1	1	1	0
J	1	1	1	1	10	1	1	1	1	0
K	0	0	1	1	11	0	0	1	1	0
L	1	0	1	1	12	1	0	1	1	0
M	0	0	0	0	13	0	0	0	0	0
N	1	0	0	0	14	1	0	0	0	0
O	0	1	0	0	15	0	1	0	0	0
P	1	1	0	0	16	1	1	0	0	0
					All Units Off	0	0	0	0	1
					All Lights On	0	0	0	1	1
					On	0	0	1	0	1
					Off	0	0	1	1	1
					Dim	0	1	0	0	1
					Bright	0	1	0	1	1
					All Lights Off	0	1	1	0	1
					Extended Code	0	1	1	1	1
					Hail Request [1]	1	0	0	0	1
					Hail Acknowl.	1	0	0	0	1
					Pre-set Dim [2]	1	0	0	1	1
					Extended Data [3]	1	1	0	0	1
					Status = On	1	1	0	1	1
					Status = Off	1	1	1	0	1
					Status Request	1	1	1	1	1

Table 1: X-10 Binary Codes also referred to as the X-10 language.

Appendix D: Available Modules

- Lamp module (multiple varieties)
- Screw-In lamp module
- Appliance Module
- Universal module
- Chime module
- Dimmer (wall) Switch
- Light (wall) Switch
- Appliance (wall) Switch
- Split wall receptacle (outlet)
- Heavy-Duty Wall Receptacle (220)
- RF receiver (connects to computer)
- RF to X10 Transceiver
- In-Line receiver Modules (for recessed lighting)
- Wireless Wall Switch (taped)
- Electronic Timer Switches
- X10 Noise Block Module
- Desktop Controllers
- Timer Controlers (Looks like Alarm Clock)
- Sundowner Controller
- Wall Mounted Programmable Transmitter
- Telephone Responder (remote controlling via Touch-Tone phone)
- Keychain Wireless Remote
- Handheld wireless remote
- Universal Remotes (works with TVs, etc)
- RF Repeater
- Relay Controller (many varieties)
- Sprinkler System Controller
- PowerFlash module (sends x10 signal in response to a motion detector, photocell, etc)
- Macro Module
- Pool & Spa Controller
- Motion Sensor
- Smart Floodlights
- Noise Filter (for TVs)
- Coupler/Repeater (amplifies signal from 100mV to more than 5V)
- Signal Bridge
- Personal Assistence Alarm (panic pendant button)
- Preassembled Security Kits
  - Motion sensors
  - Smoke detectors
  - Keychain controllers
  - Main control units
  - Sound detectors

- Door/window detectors
- Lamp module
- Siren module
- X10 Signal Meter
- Powerline Signal Analyzer
- Camera Systems

Appendix E: Introduction of X-10 Technology for PTs/OTs

Tutorial: Setting Up an X-10 System with Macros

To perform this tutorial correctly, you should have the following equipment:

- A Computer running ActiveHome Pro with the Smart Macros Plug-in
- One X-10 Lamp Module
- One 3-Pin X-10 Appliance Module
- One Standard Screwdriver
- A Lamp
- A Television
- The X-10 Credit Card Controller
- One X-10 Transceiver
- One X-10 Computer Interface Module
- Four AAA batteries

X-10 devices can be purchased from local electronics shops or on the internet at sites like www.x10.com.

Introduction to X-10 Technology

X-10 technology is an environmental control technology first developed in the 1970s and little has changed since. It uses a building's existing electrical wiring to send signals to control appliances and home electronics, such as lights and heaters. The way that standard home electronics and appliances can be controlled is by putting a 'module' between the power outlet, and the device's power cord. This arrangement allows the module to control the power flow to the device and thusly can control whether or not the device is on.

The X-10 protocol is the way X-10-enabled devices (home appliances or lights) determine which signals to receive, and what action to take once a signal sent to them has been received. The X-10 protocol is a signal made up of a house code, a unit code, and a command code. Each X-10 module is identified by two criteria: first the device is assigned a house code and then a unit code. These identifiers are manually set, and can be changed at any time. The command code is the part of the signal that tells the device what action to perform once the signal has been received. Every X-10 module

within range of the signal (it is possible to be too far away from the source of the signal) receives every command sent. Only devices whose house code and unit code match that in the X-10 signal perform the action.   Because every device receives the signal, it is possible to assign multiple lamp modules or appliance modules the same house and unit codes so that multiple devices perform the same action. For example, it is possible to assign every light in a given room the same house and unit code, so that when send the "on" command, all lights in the room will turn on.

The X-10 Protocol allows for 16 X-10-enabled devices to run on each of 16 house codes (A through P), this property limits any one area to 256 different devices.   The house code can be used to distinguish one house in a neighborhood from another so that they don't interfere with each other, if more than one household is utilizing the technology. For instance, one house equipped with X-10 might use the house code A and another adjacent house might use house code B. In such a setup both homes can run X-10 devices without interfering with each other's systems or having the wrong device intercepting a command. Experience shows that house codes are used in a slightly different manner than their original intent. House codes are often used to group devices within one particular house because of the sixteen device limitation per house code. For example, one house can be using house code A to group all the lights in the house, and house code B for each element in a home theater system. Such an arrangement allows for organization of like devices and ease of control over a house's X-10 installation.

In order to send and receive signals, an X-10 network is comprised of three types of devices: the controller, the transceiver, and the modules (receivers).

The controller (Figure 1) is the main interface between the user and the X-10 system.   It operates in the same basic way as a TV or radio remote control. The user interfaces with the controller to make a device perform a certain action, such as turning a light on or off. Controllers will typically have "on" and "off" buttons for each module, as well as dim (and brighten) buttons for use with lamp modules (these buttons allow for lamps that weren't designed with a dimming function to be dimmed also). The controller utilizes a transmitter to send the signal throughout the house. When the user pushes a button on the controller, it will send a corresponding signal through the house for the X-10 devices to receive.

Figure 5: X-10 Controller (Left) and X-10 Transceiver (Right).

Figure 6: Appliance Module

A module is the unit in the system that directly controls the appliance, lamp, or other device plugged into it. The module is also commonly referred to as a receiver because it receives the signals sent out by the transmitter (or transceiver). Each module is assigned a coupled house code and unit code, for example, A1 and B3 are couples, with the letter being the house code and the number being the unit code. The appliance module in Figure 2 has two dials: the house code dial and the unit code dial. To assign the module its house code and unit code couple, the user turns the dial to point to the desired house code and unit code.

There are two types of modules: lamp modules and appliance modules. Lamp modules control devices that use resistive loads (almost exclusively lamps), whereas an appliance module controls devices that use inductive loads, such as home theater systems or kitchen appliances. The resistive loading built into the lamp modules allow them to control the amount of power that goes into the lamp connected to the module and consequently is able to dim lights even if the lamp was not designed with a dimming feature. If one were to connect an appliance, such as a TV, into a lamp module erroneously, any command to "dim" that TV could damage either the module, TV, or both.

Putting X-10 to use:

Setting up X-10 system is easy and anyone can do it. In this tutorial, you will learn how to configure modules to the desired house and unit codes, and how to use the controller properly.

To perform this tutorial, you will need to have a lamp, a lamp module, a credit-card controller, and a transceiver (if you are unfamiliar with the modules, please see the pictures at the end of this document for a visual reference).

The wireless controller sends signals, using RF (radio frequency), to the transceiver which then interprets that RF signal and translates it into the X-10 code. The X-10 code is comprised of the house code, the unit code, and the command (like ON or OFF). The transceiver then sends that X-10 signal through the building's electrical

Figure 7: Lamp Module

Figure 8: X-10 USB Computer Interface Module

We will now go through the steps necessary to set up a basic X-10 system. First, identify the transceiver (Figure 1) and plug it into a vacant electrical outlet in the room you wish to control the system from. Then set the house code to A (by turning the dial with a screwdriver) and make sure that the "unit range" is set to 1 (the slide-switch under the house code dial should be pushed to the left) and not to 9 (slider to the right).

Now make sure the lamp's built-in power switch in the ON position. If the lamp's switch is not in the ON position, the lamp will not turn on when using the X-10 module regardless of whether the module is allowing power to the lamp or not.

The next step is to plug the lamp module (Figure 3) into an outlet close to where the lamp is to be, and then plug the lamp into the module. Set the dials on the lamp module to house code A and unit code 2. Now, that lamp has couple (also called the address) A2. You are now ready to remotely control that lamp!

If the lamp is on, push the A2 OFF button on the credit card controller to turn it off. If the lamp is OFF, push the A2 ON button to turn it on. There is a short delay between when you push the button and when the lamp responds. This delay is normal and is an artifact of the way the signals are transmitted over the electrical wiring, please do not perform more than one command at once, otherwise the multiple signals may interfere with each other like multiple simultaneous keystrokes on a typewriter. Once you have a feel for turning the lamp on and off, turn the lamp on again and then try using the dim and brighten buttons. You have now set up a simple X-10 system and are ready to start doing more advanced work with X-10..

Note: there are only 4 buttons on the credit card controller. This is because the controller is pre-programmed to only control 4 modules: A1, A2, A3, and A4. Any other addresses that you want to send to cannot be sent with this controller. You will need a more versatile controller, which will allow for greater freedom in the number of devices you control.

Setting up a macro using ActiveHome Pro

ActiveHome Pro is a computer program that is used in conjunction with X-10 systems. ActiveHome Pro allows you to use a computer as an X-10 controller as well as perform many more advanced functions. ActiveHome Pro requires a computer interface module (Figure 4) that allows the computer to send the X-10 signal onto the electrical wiring. ActiveHome Pro uses macros to control multiple X-10 devices simultaneously, with a single button press. Macros can also be used to create 'scenes' easily. For instance, if we wanted to adjust our lighting and sound in a living room so that it is optimal for watching movies, we could use a macro to turn off all the lights in the living room to a certain brightness, turn on the TV, turn on the DVD player, turn on a surround-sound system, and to dim the lights in the other rooms.

Macros can also be used for more complex tasks. For example, we could use macros to set up a security system by programming the macro to turn on the lights in a house when a motion sensor is tripped outside, which would then activate an X-10 camera to follow the potential intruder at the location of the motion sensor activation.

We will be using ActiveHome Pro to create some simple macros that might be used in an average household. The macros we will create will control both a lamp and a TV with the single press of a button.

First, you should have a lamp module, lamp, and transceiver set up as you had in the previous part of the tutorial. In addition those elements, you will need: an appliance module, a TV, four AAA batteries, and an X-10 USB computer interface module.

First, set the appliance module to A3 and ensure the lamp module is still set to A2. Plug the appliance module into an outlet and the TV into the appliance module. Now, take the computer interface module and remove the front plate to expose the battery compartment. Install the 4 AAA batteries into the module and replace the cover. Next you will have to plug the USB cable into the module into the computer using the USB cable that was provided with the module. If both the computer and your speakers are on, you should hear a chime, if your computer is not on, you should do that now. The chime is to signal that the device was recognized by computer automatically. If you did not hear a chime, the batteries' voltage may be too low need install new batteries. Lastly, plug in the USB interface into an empty outlet.

Note: It is recommended that you always use new batteries of the same brand in the computer module, and you should never mix rechargeable batteries with alkaline (standard) batteries.

Now you will need to open the ActiveHome Pro software on your computer. There may be an icon on your desktop for it, otherwise you can find it in the "all programs" section of your Start Menu. If ActiveHome Pro opens any pop-up windows while starting, simply exit out of them by clicking the appropriate buttons on the windows.
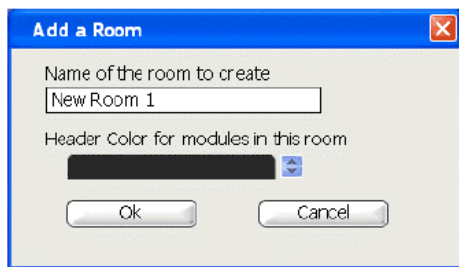
Once ActiveHome Pro has been opened you will need to locate a bar labeled "Rooms" (with a "+" next to it). Click the "+" symbol to begin creating a new room. A room is a grouping of X-10 modules, usually representing a room in a home. Feel free to name the room anything you like, descriptive names such as "living room" or "bedroom" tend to be the most convenient.

Figure 9: "Add a Room" Dialog Box

Next you will need to add some modules to your room. For every module in the real world you have, one will have to be added to ActiveHome Pro. We need to add two modules now, a lamp module and an appliance module. Be sure that the room you have just created is the room that is selected. To select a room that isn't currently selected, click on the desired one from the list of rooms on the left. The

page you see should be empty (no modules). Now we will add a lamp module. On the left, under the "Rooms" menu bar, there should be a bar labeled "Modules.". Click the item labeled "Lamps" and from the menu with the list of possible modules, select the one that says "Lamp Module" by clicking and dragging the icon into the empty space above the menu. You should see a new icon in your room that represents the lamp module you have in your 'real' room, it should look like the one in Figure 6.
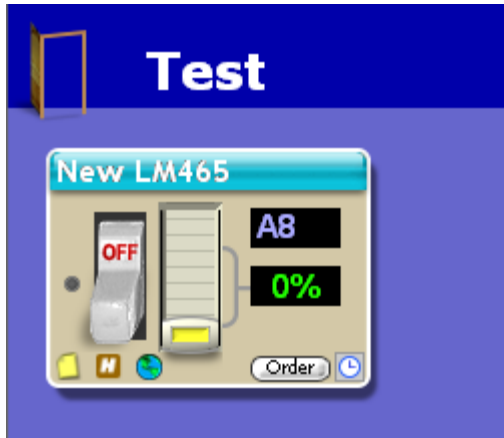

Figure 10: Lamp Module in ActiveHome Pro

You must set the house and unit code on the module to A2 to reflect the module you have connected to your lamp. In the figure to the left, the house code of the module is A and the unit code is 8. The "0%" in the figure is the brightness level for the lamp, 100% means it is on with full brightness; 0% means it is off (at 0% the light switch is also in the "off" position).

Now you will need to add the other module. This time, add an appliance module with the type being "Appliance Module (3-pin)". You should notice that this module in ActiveHome Pro has only the identity of the module and the on/off switch in the icon. Set both the module in ActiveHome and the Appliance module (the real one) to A3.

Figure 11: Macro Designer Window

We will now create a macro. There is another menu bar on the left side of the program that is labeled "Macros" with another "+" symbol next to it. Click the "+" and a dialog box should open up, labeled "Smart Macros Creator" with a few options. Select the "Simple Interface" radio button and click "next". The Macro Designer (Figure 7) should come into view. At the top of the Macro Designer, there is a name and a trigger. Name the macro something that is memorable to you (the name is arbitrary) and set the trigger to A1. The purpose of the trigger is the button on an X-10 controller that activates the macro. Also, be sure that the module operates in the room that you set up in the beginning by selecting it in the drop-down menu labeled "Macro operates in".
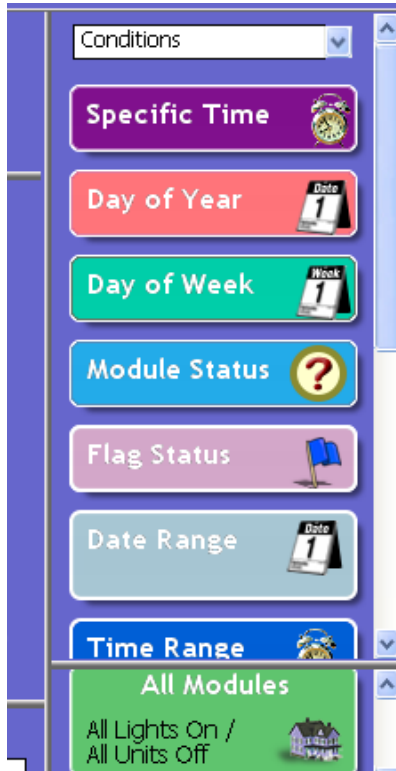
Figure 12: Macro Creation Toolbar

There should now be a section in the middle of your screen that says: "Drag Modules Here." On the right side of the screen there should be some icons (Figure 8). There is also a drop-down menu that says "Conditions". Click on the drop-down menu and select your room from that menu. This will bring up all the modules that you have put into that room. Drag both modules into the macro (make sure that the lamp module is above the appliance module in the list). You should see that they turn on when the macro is triggered (the setting next to the devices code combination is set to "ON". To make them shut off when the macro is triggered, set these to "OFF" instead)

You now see that you have a brightness options for the lamp module, the yellow slider in the middle of the lamp module icon is the level of brightness the lamp module will be set to when the macro is triggered. Set the brightness to somewhere around 50% for this macro.

Figure 14: Lamp Module with Brightness-Control Slider

Lastly, you are to put in a delay command so that there is a delay between the light turning on and the appliance turning on. To do this, click and drag the "Delay" icon between the two modules in the macro. Set the delay to 5 seconds (00:00:05) by clicking on the text box inside the delay command. As would be expected, this sets a five second delay between the light turning on and the appliance turning on.

Figure 13: Delay Icon

At the bottom of the screen you should also see two more radio buttons labeled "Store in Interface" and "Run from PC". Check the box that says "Store in Interface". This option allows you to run macros stored on the computer interface module without the need for the computer to be on or connected to the interface. Once you have finished setting up your macro, go to the Tools menu and select Clear Interface Memory. This step will make sure that your macros don't get interrupted by other macros that are already installed in the interface device. Next, download your macro to the Computer interface module by going back to the Tools manu and select the Download

Timers and Macros option. You will need to click "YES" in the confirmation dialog box that pops up. Then you must wait while the macro is downloading until another confirmation dialog box pops up telling you the download has finished, select "OK". Now you can test your macro. First test it with the credit card remote control. Push the A1 button, the Lamp should turn on to 50% brightness followed five seconds later by the TV turning on. Note that a delay exists for macros in the same way as for the modules by themselves. Again, please be patient and do not try to send the command before the first one has had a chance. You do not want to confuse the macro or any of the modules as this may end up confusing you! If your macro runs as you had designed it, then you have successfully created your macro.

Appendix F: Laboratory Activities

1. Using Macros to Integrate Sensors and Actuators

Objective:

In this lab you will be able to create macros that control lamp and appliance modules according to the input of a motion detecting sensor.

Abstract:

In this laboratory you will have a chance to work with ActiveHome. You will be creating macros to control multiple actuators with a single sensor input. You will have to create a program using ActiveHome Pro that will integrate several simple devices to perform a complicated task.

This lab will be performed in groups of 2 – 3 students. Therefore, split into groups of 2-3. This lab will be due on _____. Be sure to plan ahead and set aside some time for the group to get together and do the lab.

Equipment:

Each group will be given one motion detector, ActiveHome Pro, one lamp module, one appliance module, a very small Phillips screwdriver, a medium regular screwdriver, a light, a TV, credit card controller, transceiver, and the computer interface box.

Introduction to X-10 Technology

X-10 technology has been around since the 1970s but very little has changed from its original form. It still uses the same basic theory of sending a signal across a home's existing AC wiring to control appliances and home electronics, such as lights, throughout a home.

The X-10 protocol is the way X-10 determines which devices (home appliances or lights) receive which signal and how the devices know what the signals mean. The X-10 protocol is a signal made up of a house code, a unit code, and a command code. Each device is identified by two criteria: first the device is assigned a house code and then a unit code.

The X-10 Protocol allows for 16 units to run under one house code (A through P) and there can be 16 (1 through 16) units for each house code. The house code can be used to distinguish one house in a neighborhood from another, if more than one household is utilizing the technology, so that they don't interfere with each other. For instance, one house equipped with X-10 might use the house code A and another adjacent house might use house code B. In such a setup both homes can run X-10 devices without interfering with each other's systems or having the wrong device intercepting a command. Experience shows that house codes are used in a slightly different manner than their original intent. House codes are often used to group devices within one particular house because of the sixteen device limitation per house code. For example, one house can be using house code A to group all the lights in the house and house code B for each element in a home theater system. Such an arrangement allows for organization of like devices and ease of control over a house's X-10 installation. Each X-10 signal

transmission is seen by every X-10 enabled device in the home, however only the device with the matching house and unit code couple will act on the command. As an example, a command for device A1 (house code A and unit code 1) is transmitted around the house, only the device set to A1 will decode this message. If the device is a light and the command code was to dim the light, only light A1 will be dimmed.

In order to send and receive signals, an X-10 network is comprised of three types of devices namely, the controller, transceiver, and modules (receivers).

The controller is the main interface between the user and X-10. It operates in the same basic way as a TV or radio remote control. The user uses controller to make a device take a certain action, such as turning a light on or off. Controllers typically have on and off buttons for most appliances as well as dim (and brighten) buttons for lights (these buttons allow for lamps that weren't designed with a dimming function to be dimmed also). The controller utilizes a transmitter to send the signal throughout the house. When the user pushes a button on the controller, it will send a corresponding signal through the house for the devices to receive.

X-10 Controller (left) and Transceiver (right)

A module is the unit in the system that directly controls the appliance, lamp, or other device plugged into it. The module is also commonly referred to as a receiver because it receives the signals sent out by the transmitter (or transceiver). Each module is assigned a coupled house code and unit code, such as A1 or B3.

This appliance module has 2 dials, the house code dial and the unit code dial. To give this device its unique house code and unit code couple, the user could turn the dial to point to the desired house code and unit code.

Each module in the network receives every X-10 signal sent throughout the house and if the signal matches the couple for the module, the module will perform its assigned command. There are two types of modules, light modules and appliance modules. Light modules control devices that use resistive loads,

X-10 Appliance Module   almost exclusively lamps, whereas an appliance module controls devices that use inductive loads, such as home theater systems or kitchen appliances. A light module can be used to dim lights even if they don't have a dimming feature built into the lamp because of the resistive loading built into the module. If one were to connect an appliance such as a TV into a light module erroneously, any command to "dim" that TV would likely damage either the module, TV, or both.

Pre-lab Exercises:

In order for you to complete the above objective, there are 2 pre-labs that you must complete (setting up a basic X-10 system and introduction to creating macros). Be sure that you can go through the pre-labs and that you understand them well.

Setting up a basic X-10 system

In this pre-lab, there are some exercises to perform that will allow you to become familiar with how to set up an X-10 system using a controller and some modules.

First, you should have in front of you a lamp, a lamp module, a small black credit-card controller, and the transceiver (module with the antenna).

You will be pushing the buttons on the controller to turn on, off, or dim the light. The controller then sends a signal to the transceiver through RF (radio frequency) which then interprets that signal and extracts the house code, the unit code, and the command (like ON or OFF) to send out. Then, the transceiver sends that extracted signal through the house's wiring so that the devices can take action! Interesting isn't it?

Not only is it interesting, it's easy to set up. Take the transceiver and plug it into an outlet in the room you are in. Set the house code to A (by turning the dial with a screwdriver). Make sure that the unit range is set to 1 (the slide-switch under the house-code dial should be pushed to the left) and NOT 9! This sets the range from 1-8 and not 9-16. (If you want, after you have setup the system completely, go back and change these around to see what happens).

We first have to make sure the lamp's built-in switch is turned to ON, otherwise, it will not turn on when the lamp module allows it power. To do this, take the lamp and plug it directly into an outlet. Make sure it is on; if it is not on, turn it on, then unplug the lamp WHILE IT IS STILL ON! Now take the lamp module and plug it into the outlet you plugged the lamp into. Then, plug the lamp into the bottom of the module. Set the dials to house code to A and unit code to 1. Now, that lamp has the couple (also called the address) A1. You are now ready to remotely control that lamp!

If the lamp is ON, push the A1 OFF button on the credit card controller to turn it off. If the lamp is OFF, push the A1 ON button. A few seconds after you push the button, the lamp should take action. Turn the lamp ON again and then investigate the dim and bright buttons to get a feel for what happens. Note that there is a delay from pushing the button to when the device actually responds. This is quite normal and any other button press should not be attempted as this might interfere with your previous signal. Be patient and wait for the signals to be processed.

You have now set up a simple X-10 system. In order to further understand what is going on, you should try to control the lamp when its couple is set to A2, or A3 or even B1.

Note that there are only 4 buttons on the credit card controller. This is because the controller is pre-programmed to only control 4 modules, that is, A1, A2, A3, and A4. Any other address that you want

to send CANNOT be sent with this controller. You need a more powerful controller, such as the programmable controller. Now you are ready to start doing more advanced work with X-10.

Setting up a macro using ActiveHome Pro

This pre-lab will introduce you to creating very simple macros using simple devices.

Be sure to know how to setup an X-10 system of modules that function from a controller. We will not be discussing how to set modules to proper house and unit codes or controlling them. You should have learned this in the previous pre-lab.

General Information:

A macro is a way to control multiple X-10 devices at once, with a single button press. Macros are used to create scenes with a single button press. For instance, if we wanted to adjust our lighting and sound in a living room so that it is optimal for watching movies, we could use a macro to dim all the lights in the living room to a certain brightness, turn on the TV, turn on the DVD player, turn on a surround-sound system, and to shut off the lights in the other rooms.

Macros are also used for more complex situations. We could use macros to setup a security system, for instance, by creating a macro that turns on the lights in a house when a motion sensor is tripped, which will then turn on an X-10 camera to follow the motion of an intruder.

In this pre-lab, you will be setting up a simple X-10 macro that will turn on and dim a light to 50% when the TV is turned on.

Procedure:

From the previous pre-lab, you should have a lamp module set to A1 (this will be changed) with a lamp plugged into it. You should also have the transceiver plugged in and set to house code A.

You should also have in front of you the appliance module, a TV, 4 triple A batteries, and a computer USB interface module.

First, set the appliance module to A3 and set the lamp module to A2. Plug the appliance module into an outlet and plug the TV into the appliance module.

Now take the computer interface module (it has a USB connection that connects to the computer) and take off the front plate to expose the battery location. Install the 4 batteries and replace the front cover. Plug one end of USB cable into the USB module and plug the other end into the computer. You should hear a chime. This is to signal that the device was installed on the computer automatically (if you don't hear it, unplug it and try it again. If this doesn't work the batteries may be dead and you may need to contact the professor to get new batteries.) Plug in the USB interface into an outlet.

On the assigned computer there is a program installed called ActiveHome Pro. There should be a shortcut on the desktop. Open ActiveHome Pro. If there are any pop-up windows, simply exit out of them by clicking the "OK" or "CLOSE" buttons.

When you first open ActiveHome Pro you will see a bar that is labeled "Rooms" (with a "+" next to it). Click the "+" sign to create a new room. A room represents a room in a home that is made up of devices such as lamps and appliances. Name your room with the last name of one of your teammates.
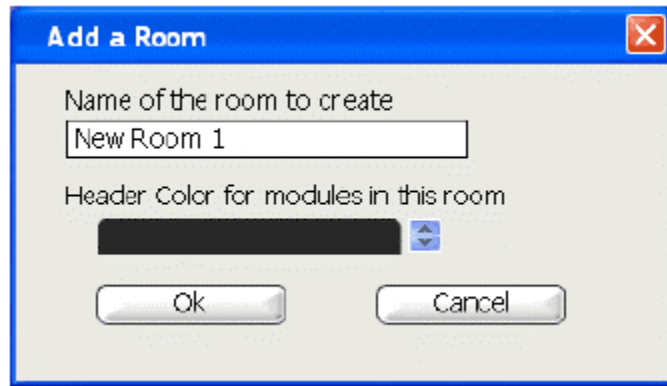
Next you will need to add some modules to your room. A module in ActiveHome Pro represents the real, physical, lamp or appliance modules. The modules we are working with here are a lamp module and an appliance module. Be sure that the room you just created is the room that is selected. To select a room if it isn't selected, click on it from the list of rooms on the left. The page you see should be empty. First, we will add a lamp module. On the left, under the "Rooms" menu bar, there should be a bar labeled "Modules". Click the item labeled "Lamps". From there, you should see a new menu with a list of the possible modules that you can choose from. Choose the one that says "Lamp Module" by clicking and dragging the icon into the empty space above the menu. You should see a new icon in your room that represents the light.
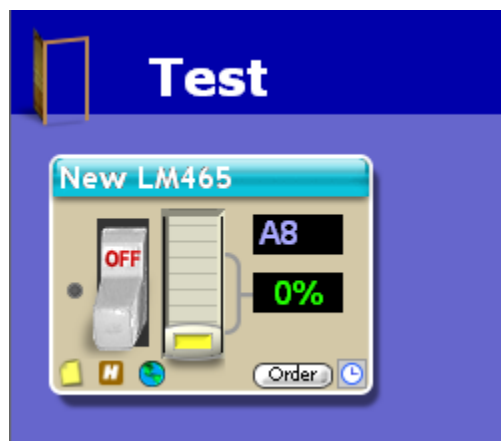
The "A8" (or some other address) in the picture is the house and unit code combination for this particular module in the room. The "0%" is the brightness level for the lamp. 100% means it is on full brightness; 0% means it is off (along with the light switch that is labeled "off").

Now, add another module. This time, add an appliance module with the type "Appliance Module (3-pin)". You should see that this has only the code combination and a graphical light switch (it cannot be dimmed).

Make the lamp module have the code "A2" and the appliance "A3" by clicking on the textbox area of each module's icon and entering those codes.

We shall now create a macro. There is another menu bar on the left side of the program that is labeled "Macros" with another "+" next to it. Click the "+". A dialog box should open up, labeled "Smart Macros Creator", with a few decisions to make. Select the "Simple Interface" radio button and click "next". The Macro Designer should come into view. At the top of the Macro Designer, there is a name and a trigger. Name the macro something that is memorable to you. Set the trigger to A1. The trigger means that when the device is turned on, the macro will be put into action. Also be sure that the module operates in the room that you set up in the beginning by selecting it in the drop-down menu labeled "Macro Resides in".

Now you should see a something that says "Drag Modules Here" in the middle of the screen. This is what we shall do. On the right side of the screen there should be some icons.
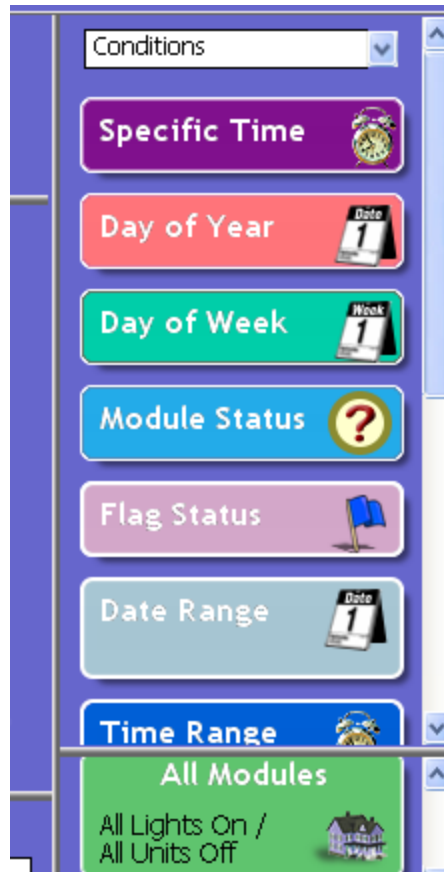
There is also a drop-down menu that says "Conditions". Click on the drop-down menu and select your room from that menu. This will bring up all the modules that you have put into that room. Drag both modules into the macro (make sure that the lamp ends up on TOP of the appliance module in the list). You should see that they turn on when the macro is triggered (the setting next to the devices code combination is set to "ON". To make them shut off when the macro is triggered, set these to "OFF" instead)

You will see you have dim options for the lamp modules (the yellow slider is the level of dim that the lamp is set to when the macro is triggered). Set the dim to somewhere around 50%. Lastly, you are to put in a delay command so that there is a delay between the light turning on and the lamp turning on. To do this, drag the "Delay" icon and put it in between the 2 devices in the macro.

Set the delay to 5 seconds (00:00:05) by clicking on the text box inside the delay command. This will make it so that there is a 5 second delay between the light turning on and the appliance turning on.

At the bottom of the screen you should also see two more radio buttons labeled "Store in Interface" and "Run from PC". Check the box that says "Store in Interface". This will make it so that the macro you create will be stored inside the computer interface device so that it can be run without being connected to the PC. When you get the macro fully setup, first go to Tools->Clear Interface Memory. This will make sure that your macros don't get interrupted by other macros that are already installed in the interface device. Next, download your macro to the Computer interface module by going to Tools>Download Timers and Macros. It will then have a confirmation dialog box. Cick "YES". Then wait until another confirmation dialog box pops up telling you the download has finished. Select "OK". Now you can test your macro. First test it with the credit card remote control. Hit the A1 button. Lamp should turn on to 50% brightness, then, 5 seconds later, the TV should turn on. Note that there is a delay for macros also, that is, there is a delay between the time you push the button and the time the macro responds, so be patient and don't push many buttons at once. There is also a delay from the time the macro is executed to the time the light is dimmed. Be patient here too. You do not want to confuse the macro or devices as this will confuse you! If your macro runs then you successfully created the macro. Now you must save the macro. Go to the file menu and select "Save-As". This file can be reopened from any ActiveHome Pro equipped computer (aka, the professors can open your macro and make sure you made it correctly). Note that you will not be doing anything with THIS file. This is still the pre-lab. You will be saving your macro from the actual lab to prove you have created the macro successfully.

Also note that macros can be very complicated. For instance, a macro can be setup that uses a motion sensor so that when the sensor is tripped, the lights turn on in the house for some number of seconds and shuts them off again.

Lab Material

You should now have an understanding of how to setup a basic X-10 system with a simple ActiveHome Pro macro. You will now be applying that knowledge to create a macro that is a bit more complex.

For the actual lab, you will be using all the same modules except for an additional motion sensor module.

To setup the motion sensor you must set the house code and unit code as you do with all modules. The house and unit code you set will be the house and unit code of the device that will be turned on when the sensor is tripped with motion.

A) To do this you will first take off the battery cover in the front of the module by removing the black screw. Notice there is two buttons.

B) Press and hold the unit/off button for 3 seconds and observe the number of times the LED flashes. This displays the unit code that is set; 1 flash is unit 1 and 2 flashes are unit 2 and so on.

C) Next press and hold the house/on button for 3 seconds and observe the number of flashes. This displayed the house code that is set; 1 flash is A and 2 is B and so on.

D) To set the codes, press and hold both buttons for 3 seconds. After the LED reports the current setting release the button then quickly press the button the corresponding number of times as the code you wish to set. The LED will light up for about one second to indicate it has changed the code.

E) Now got back and re-do steps B and C to confirm the code has been set.

Lab Instructions

This lab will not be using the system or macros setup in the pre-labs. You can disregard them. They were simply meant to teach you how to set everything up. Now you have to create one on your own setting up your own modules, creating your own macros, and knowing how to successfully use delays.

As a group you must create a macro with the following specifications:

- The motion sensor should be set to B3, the lamp module to B5, and the appliance module to B12. When the sensor is tripped, the lamp and TV should come on. The lamp will stay on for 30 seconds, after which point the lamp dims to 30% brightness. After another minute, both devices turn off (so after a minute and a half the whole macro should be completed and all devices should be off again).

- You should test your macro by walking in front of the motion sensor while also making sure that you save the macro to the computer interface device and disconnect the computer.

Once you have a macro that functions according to the specifications above, save the macro file and hand it in.

Almost done. You should now delete all your macros and room (do not delete your saved macro file. You will pass this in.) To delete your macros, click on the "Macros" button on the left hand side. This will bring up all the macros that have been created. You should clear out all the macros that have been created by clicking each macro icon and dragging it into the recycling bin at the bottom left hand side of the screen. Then, you should delete all the rooms you created also. Click on the "Rooms" button from the left hand side of the screen. Drag each of the rooms into the recycling bin. After you are done, right click on the recycling bin and select "Empty Deleted Modules".

The last step is to remove the batteries from the USB computer interface as it tends to drain the batteries rather fast. Now you are done. Hand in the macro.

Images of materials:

Motion Sensor

Lamp Module

USB Computer Interface Module

Appliance Module

2. An Evaluation of X-10 Signal Transmission

Objective:

In this lab you will be able to explain X-10 signal transmission and how X-10 sends command from the control boxes to actuator modules. You will be able to explain the limitations of the system and reasons for the signal being degraded in a simulated real world situation compared to its theoretical capabilities.

This laboratory activity will be performed in groups of 2 or 3 students and will be due on _____. Be sure to plan ahead and set aside some time for the group to get together and perform this activity.

Required Equipment:

- Signal Degradation Test Rig
- Lamp
- Capacitor + Plug
    - WARNING: The capacitor takes several seconds to "bleed off" its charge after you remove it from an outlet. Please, for your safety, DO NOT at any time touch the prongs on the plug with any part of your body.
- Television
- Credit Card Controller and Transceiver
- X-10 Controller
- 2 Lamp Module
- Lamp
- Screwdriver
- Waveform Screen Captures
- X-10 Signal Decoding Table

Introduction to X-10 Technology:

X-10 technology has been around since the 1970s but very little has changed from its original form. It still uses the same basic theory of sending a signal across a home's existing AC wiring to control appliances and home electronics, such as lights, throughout a home.

The X-10 protocol is the way X-10 determines which devices (home appliances or lights) receive which signal and how the devices know what the signals mean. The X-10 protocol is a signal made up of a house code, a unit code, and a command code. Each device is identified by two criteria: first the device is assigned a house code and then a unit code.

The X-10 Protocol allows for 16 units to run under one house code (A through P) and there can be 16 (1 through 16) units for each house code. The house code can be used to distinguish one house in a neighborhood from another, if more than one household is utilizing the technology, so that they don't interfere with each other. For instance, one house equipped with X-10 might use the house code A and another adjacent house might use house code B. In such a setup both homes can run X-10 devices without interfering with each other's systems or having the wrong device intercepting a command. Experience shows that house codes are used in a slightly different manner than their original intent. House codes are often used to group devices within one particular house because of the sixteen device limitation per house code. For example, one house can be using house code A to group all the lights in the house and house code B for each element in a home theater system. Such an arrangement allows for organization of like devices and ease of control over a house's X-10 installation. Each X-10 signal transmission is seen by every X-10 enabled device in the home, however only the device with the matching house and unit code couple will act on the command. As an example, a command for device A1 (house code A and unit code 1) is transmitted around the house, only the device set to A1 will decode this message. If the device is a light and the command code was to dim the light, only light A1 will be dimmed.

In order to send and receive signals, an X-10 network is comprised of three types of devices namely, the controller, transceiver, and modules (receivers).

X-10 Controller (left) and Transciever (right)

The controller is the main interface between the user and X-10. It operates in the same basic way as a TV or radio remote control. The user uses controller to make a device take a certain action, such as turning a light on or off. Controllers typically have on and off buttons for most appliances as well as dim (and brighten) buttons for lights (these buttons allow for lamps that weren't designed with a dimming function to be dimmed also). The controller utilizes a transmitter to send the signal throughout the house. When the user pushes a button on the controller, it will send a corresponding signal through the house for the devices to receive.

X-10 Appliance Module

A module is the unit in the system that directly controls the appliance, lamp, or other device plugged into it. The module is also commonly referred to as a receiver because it receives the signals sent out by the transmitter (or transceiver). Each module is assigned a coupled house code and unit code, such as A1 or B3.

This appliance module has 2 dials, the house code dial and the unit code dial. To give this device its unique house code and unit code couple, the user could turn the dial to point to the desired house code and unit code.

Each module in the network receives every X-10 signal sent throughout the house and if the signal matches the couple for the module, the module will perform its assigned command. There are two types of modules, light modules and appliance modules. Light modules control devices that use resistive loads, almost exclusively lamps, whereas an appliance module controls devices that use inductive loads, such as home theater systems or kitchen appliances. A light module can be used to dim lights even if they don't have a dimming feature built into the lamp because of the resistive loading built into the module. If one were to connect an appliance such as a TV into a light module erroneously, any command to "dim" that TV would likely damage either the module, TV, or both.

Pre-Lab Activity:

Setting Up a Basic X-10 System:

In this pre-lab, there are some exercises to perform that will allow you to become familiar with how to set up an X-10 system using a controller and some modules.

First, you should have in front of you a lamp, a lamp module, a small black credit-card controller, and the transceiver (module with the antenna).

You will be pushing the buttons on the controller to turn on, off, or dim the light. The controller then sends a signal to the transceiver through RF (radio frequency) which then interprets that signal and extracts the house code, the unit code, and the command (like ON or OFF) to send out. Then, the transceiver sends that extracted signal through the house's wiring so that the devices can take action! Interesting isn't it?

Not only is it interesting, it's easy to set up. Take the transceiver and plug it into an outlet in the room you are in. Set the house code to A (by turning the dial with a screwdriver). Make sure that the unit range is set to 1 (the slide-switch under the house-code dial should be pushed to the left) and NOT 9! This sets the range from 1-8 and not 9-16. (If you want, after you have setup the system completely, go back and change these around to see what happens).

We first have to make sure the lamp's built-in switch is turned to ON, otherwise, it will not turn on when the lamp module allows it power. To do this, take the lamp and plug it directly into an outlet. Make sure it is on; if it is not on, turn it on, then unplug the lamp WHILE IT IS STILL ON! Now take the lamp module and plug it into the outlet you plugged the lamp into. Then, plug the lamp into the bottom of the module. Set the dials to house code to A and unit code to 1. Now, that lamp has the couple (also called the address) A1. You are now ready to remotely control that lamp!

If the lamp is ON, push the A1 OFF button on the credit card controller to turn it off. If the lamp is OFF, push the A1 ON button. A few seconds after you push the button, the lamp should take action. Turn the lamp ON again and then investigate the dim and bright buttons to get a feel for what happens. Note that there is a delay from pushing the button to when the device actually responds. This is quite normal and any other button press should not be attempted as this might interfere with your previous signal. Be patient and wait for the signals to be processed.

You have now set up a simple X-10 system. In order to further understand what is going on, you should try to control the lamp when its couple is set to A2, or A3 or even B1.

Note that there are only 4 buttons on the credit card controller. This is because the controller is pre-programmed to only control 4 modules, that is, A1, A2, A3, and A4. Any other address that you want to send CANNOT be sent with this controller. You need a more powerful controller, such as the programmable controller. Now you are ready to start doing more advanced work with X-10.

Part I

Abstract:

In the first part of this laboratory exercise you will be taking a close look at the X-10 signal transmission. You have been provided four synthetic waveform images with spikes representing X-10 signals. You will be first asked to understand how the signal is transmitted on an AC sine wave. You will use those waveforms to decode the X-10 signal that the series of spikes represents.

Procedure:

First you need to look at the provided document with the waveforms and X-10 signals on it. You will find the 60 Hz sine wave (each sine function represented equals 1/60 of a second) with the peak amplitudes being +170V and -170V. The area of the graphs you are interested in is the area near the 0V crossing on the sine wave. In this area around each zero crossing (where the amplitude of the wave equals 0V) you will either see a spike of +5V on top of the sine wave, or you will not see any distortion of the sine wave. The +5V spike has been exaggerated in the synthetic waveforms so that they can be more easily detected. Examine the image and record whether or not spikes are present at each zero crossing throughout the entire wave. This recording should be written as binary with a '1' representing the presence of a spike, and a '0' representing the absence of one. (example 111001011010)

You should now have enough data to determine what signal was being sent by the X-10 controller in each of the representations. Please see the chart attached to this document to decode the binary you recorded. The "start code" is 3 spikes in a row followed by no spike at the next crossing. There is a second, "redundant parity bit," that follows each bit of information. This means that if your code is 1 (where 1 is a spike and 0 is no spike) the following crossing will be 0 and if your code is 0 the following crossing is 1. This is why 1 bit of information takes a whole cycle, despite the fact that there are two zero crossings in one cycle (+170V to 0V to -170V and -170V to 0V to +170V). Find the start code and decode the signal that follows it. You must first determine the House Code (A-P), Unit Code (1-16) and Function Code (the command: on, off, etc) that was transmitted based on the data you collected from reading the waveforms. Record these results in your notes.

Part II

Abstract:

In the second part of the laboratory exercise, you will experiment with X-10 modules and controllers in a simulated home environment to explore limitations of the system.

Procedure:

A test rig with 8 numbered outlets and a lamp has been provided for use with the X-10 units. There are 25 foot wire loops between each outlet on the test rig and each outlet is connected in parallel to the length of wire, similar to household electrical wiring. Under certain conditions, household wiring becomes an ElectroMagnetic Interference (EMI) filter which can be strong enough to filter out X-10 signals, because X-10 signals are essentially electromagnetic interference. The EMI filter is a function of capacitance (from capacitors present in power supplies of most electronics, the capacitor is a device that stores electrical power) and inductance (a property of electrical wiring, exacerbated by coiling wires). We have created the test rig using a commercial EMI filter at one end (the black box next to outlet 1) to prevent outside interference and to contain all our signals within the test rig. The X-10 signal is essentially electromagnetic interference sent along electrical wiring, which is interpreted by X-10-enabled modules connected to the wiring. The coils of wire on the test rig, along with inductors (black-taped rings between outlets 1 and 2 and outlets 3 and 4), introduce inductance into our simulated circuit. This inductance by itself will not interfere with X-10 signal transmission. Once a capacitance is introduced (simulated by the small capacitor at the end of a plug provided to you), an EMI filter has effectively been created and the X-10 signal is being actively filtered. This may have effect where any commands sent from the controller may not be received by the receiving module. In a real environment, the summed capacitance of the appliances of the building is much greater than the small capacitor that is being used in this exercise, and also the inductance between outlets in the same building would also be much less than the inductance we have introduced on the test board. This design was intentional and a capacitor that could store equivalent amounts of electrical power to what would be found in a home would be extremely dangerous, and probably deadly if the capacitor was to discharge on someone's body. For illustration purposes, the following equation has been provided to explain the reason such a substitution can be made:

$$EMI = x(Inductance) \times y(Capacitance) = y(Inductance) \times x(Capacitance)$$

(Home)   (Test Rig)

Where $x \ll y$

[Note: This is not the real equation for EMI, it is just an illustration to show a ratio between the inductance and capacitance has been maintained which still allows for the EMI filter effect to exist.]

Now you will test signal transmission on the board, with and without our simulated EMI filtration condition.

1. You will first need to plug the wired X-10 controller into the first outlet (1).
2. Now plug in one of the lamp modules with the lamp connected to it into the next outlet (2) and set the House Code of the module to A and the Unit Code to 1.
3. Test that you have control of the lamp and that your module settings are correct by turning the lamp on and off with the X-10 controller.

4. Now move the lamp module from outlet to outlet across the length of the test rig and test your control at each outlet. The light should have worked in every outlet along the test rig.

Now you will observe the effect of capacitance introduced into the circuit similar to what would be generated by televisions and computer power supplies connected to the building's electrical system. This capacitance completes the conditions necessary to turn the circuit into an EMI filter, this filter should degrade the signal quickly between outlets. Keep in mind that the EMI filter needs both inductance and capacitance to have a filtering effect on the signal and that the inductance is caused by the coiled wire. This means that the more coiled wire there is between the controller and the module, the more powerful the EMI filtering effect will be on the X-10 signal going to that module.

1. Plug the lamp and lamp module into the last outlet (8) and set it to A1.
2. Now plug the capacitor into any outlet (2-7) between the controller (outlet 1) and the lamp module. Note whether or not you still have control of the lamp.
3. Now move the lamp closer to the controller, one outlet at a time, testing at each outlet, until you regain control of the lamp. Make note of which outlet the capacitor is plugged into and which outlet the lamp begins to work at.
4. Feel free to test installing the capacitor in different outlets between 2-7, while leaving the controller in outlet 1, and see if the location of the capacitor makes a difference to signal transmission.

Finally you will see what happens when multiple transmitters are connected on a single circuit.

1. Plug the wired controller into outlet 1 and the transceiver into outlet 6. Remove the capacitor if it is still plugged in. Make sure both the controller and the transceiver are set to House Code A.
2. Plug one lamp and module into outlet 8 and plug the second lamp and module into outlet 4. Set both lamp modules to A2.
3. Use the wired controller to turn on the lamp modules (A2). Record the results.
4. Use the credit card controller to turn on the lamp modules (A2). Record the results.
5. Answer Question 3, based on those results.

Post Laboratory Exercises:
For the write up on this lab you will need to produce the correct House and Function code that is represented by the waveform that you analyzed in Part 1 of this activity. You will also need to produce an account of your experiences and results from working with the second part of this laboratory exercise.

Questions:
1. What are some factors in the premature degradation of the signal? What can you tell from the recorded waveform that hints at why the signal degrades?

2. Now that you have learned one major cause of X-10 signal degradation (the EMI filtration effect), what is one possible solution for improving the probability that the X-10 signal will be received by the modules?
3. Why do you think the two different controllers and modules behaved as they did in your experiment? Please utilize information found in this laboratory activity to support your explanation.
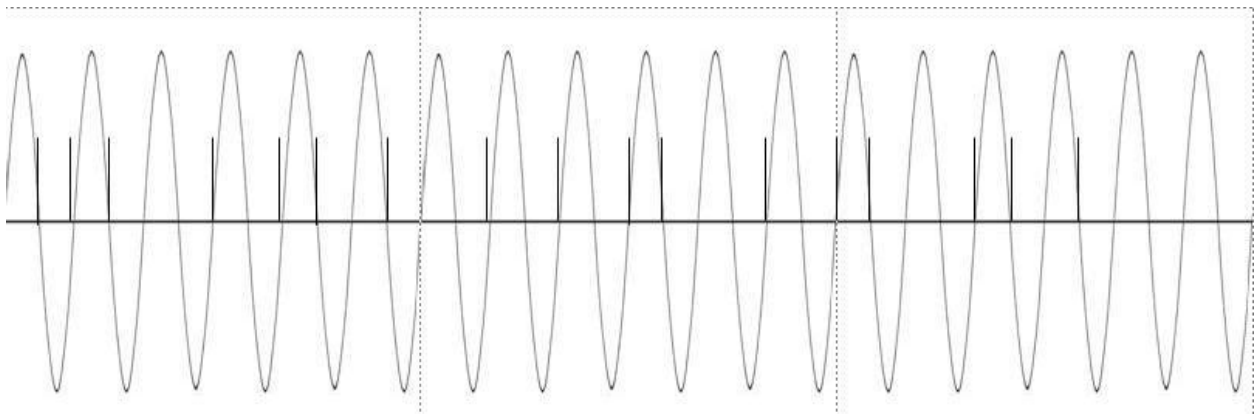
Synthetic X-10 Signals

Using the X-10 Binary Signal Key you have been provided; decode the four signals that have been transmitted on the AC (Alternating Current) sine wave. The bold horizontal crossing is the zero-amplitude point on the wave.
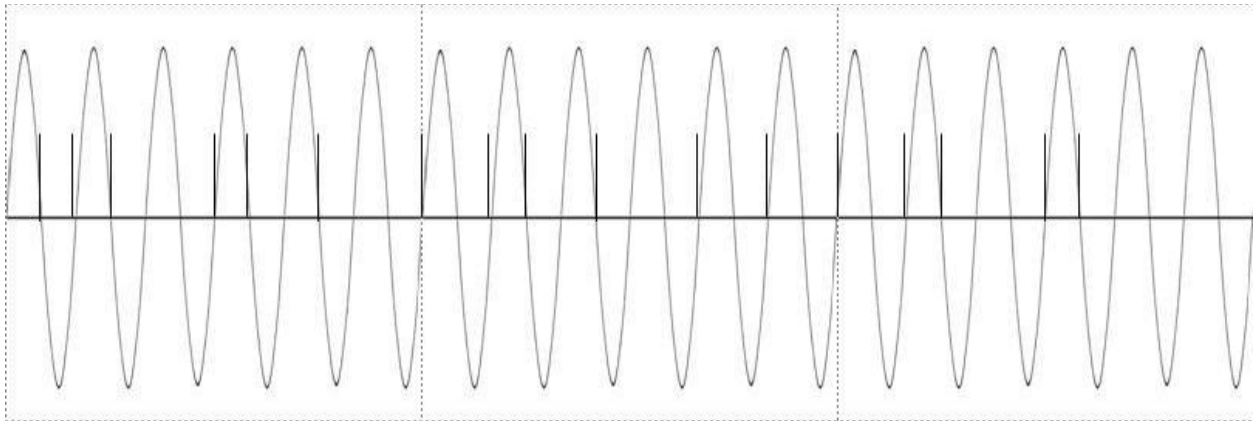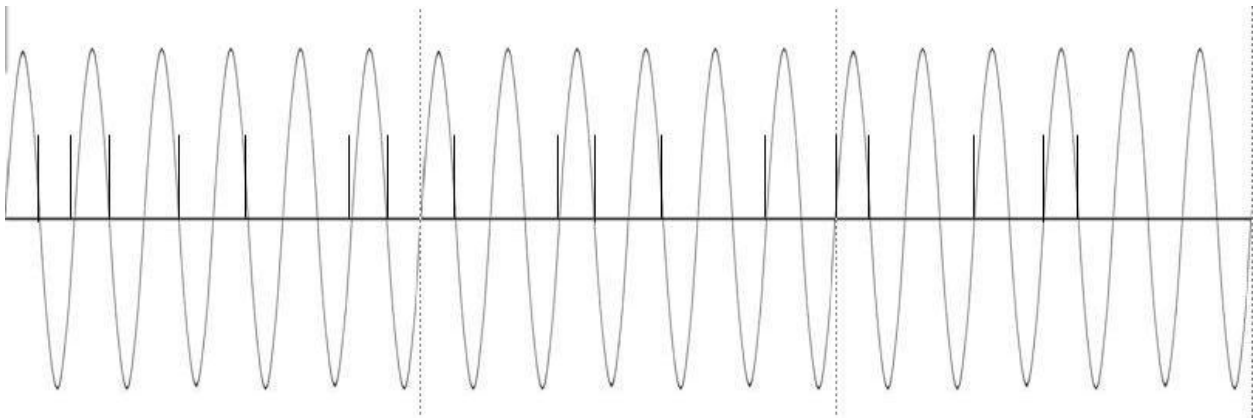
Signal 1
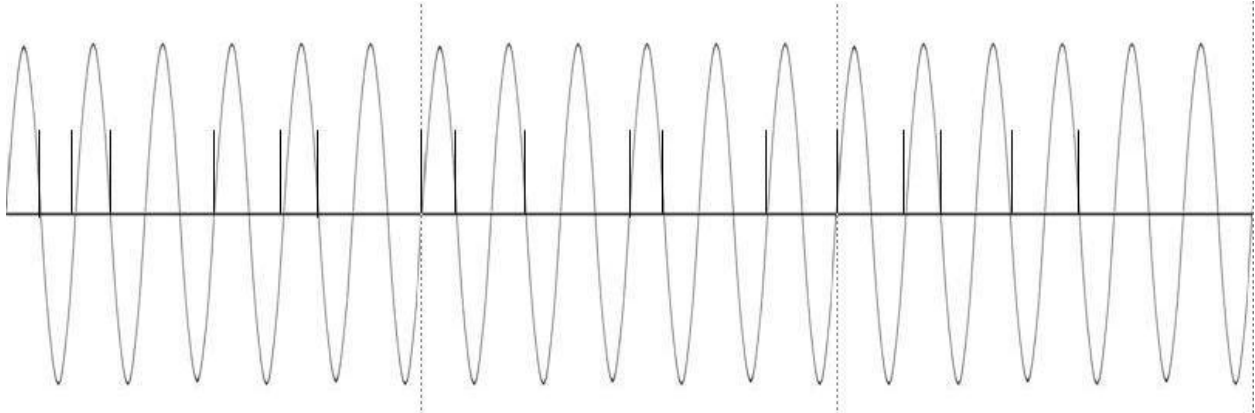
Signal 2

Signal 3

Signal 4

House Codes	H1	H2	H4	H8	Key Codes	D1	D2	D4	D8	D16
A	0	1	1	0	1	0	1	1	0	0
B	1	1	1	0	2	1	1	1	0	0
C	0	0	1	0	3	0	0	1	0	0
D	1	0	1	0	4	1	0	1	0	0
E	0	0	0	1	5	0	0	0	1	0
F	1	0	0	1	6	1	0	0	1	0
G	0	1	0	1	7	0	1	0	1	0
H	1	1	0	1	8	1	1	0	1	0
I	0	1	1	1	9	0	1	1	1	0
J	1	1	1	1	10	1	1	1	1	0
K	0	0	1	1	11	0	0	1	1	0
L	1	0	1	1	12	1	0	1	1	0
M	0	0	0	0	13	0	0	0	0	0
N	1	0	0	0	14	1	0	0	0	0
O	0	1	0	0	15	0	1	0	0	0
P	1	1	0	0	16	1	1	0	0	0
					All Units Off	0	0	0	0	1
					All Lights On	0	0	0	1	1
					On	0	0	1	0	1
					Off	0	0	1	1	1
					Dim	0	1	0	0	1
					Bright	0	1	0	1	1
					All Lights Off	0	1	1	0	1
					Extended Code	0	1	1	1	1
					Hail Request [1]	1	0	0	0	1
					Hail Acknowl.	1	0	0	0	1
					Pre-set Dim [2]	1	0	0	1	1
					Extended Data [3]	1	1	0	0	1
					Status = On	1	1	0	1	1
					Status = Off	1	1	1	0	1
					Status Request	1	1	1	1	1

X-10 House and Function Code Chart
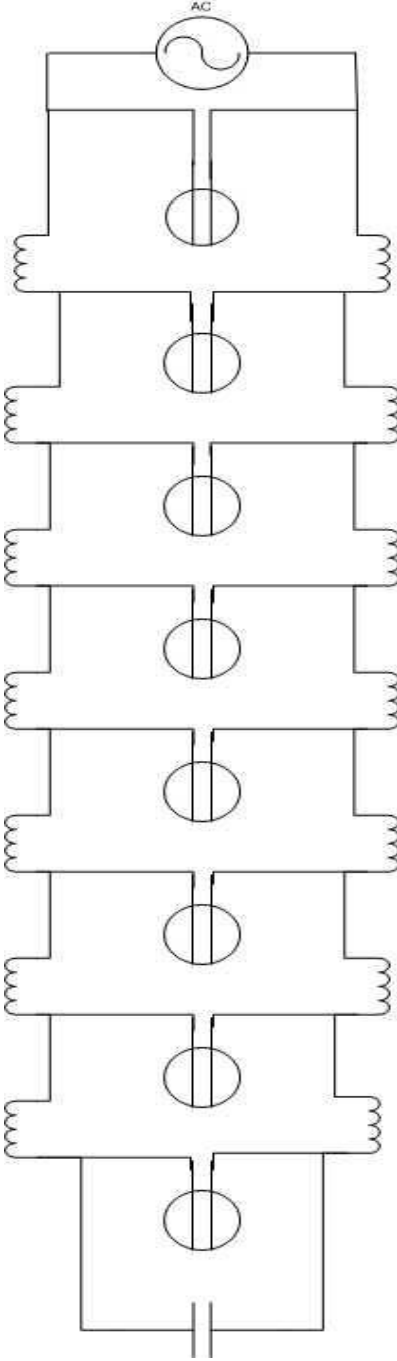
Appendix G: Circuit Diagram for Wiring Test Rig

Figure 15: Wiring Rig for use in Laboratory Exercise 2.

Appendix H: Sample Questions Illustrating Bloom's Taxonomy

Level 1: Knowledge
Which one of the following persons is the author of "Das Kapital"?
1. Mannheim
2. Marx
3. Weber
4. Engels
5. Michels

Level 2: Comprehension
Which one of the following describes what takes place in the so-called PREPARATION stage of the creative process, as applied to the solution of a particular problem?
1. The problem is identified and defined.
2. All available information about the problem is collected.
3. An attempt is made to see if the proposed solution to the problem is acceptable.
4. The person goes through some experience leading to a general idea of how the problem can be solved.
5. The person sets the problem aside, and gets involved with some other unrelated activity.

Level 3: Application
Which one of the following values approximates best to the volume of a sphere with radius 5m?
a. 2000m³
b. 1000m³
c. 500m³
d. 250m³
e. 125m³

Level 4: Analysis
"The story is told of the famous German Organic Chemist Auguste Kékulé who was struggling with the problem of how the six carbon atoms of benzene were linked together. He was getting nowhere with the problem, and one day fell asleep in front of the fireplace while he was pondering on it. He dreamt of molecules twisting and turning around like snakes. Suddenly, one of the snakes swallowed its own tail and rolled around like a hoop. Kékulé woke up with a start, and realized that his problem could be solved if the six carbon atoms of benzene were attached to each other to form a ring. work showed that this was entirely correct."

The above passage illustrates a particular phase of the creative process. Which one is it?
1. preparation
2. incubation
3. orientation
4. illumination
5. verification

Level 5: Synthesis

"Write a well organized theme, gives a well organized speech writes a creative short story (or poem or music), propose a plan for an experiment, integrate learning from different areas into a plan for solving a problem, formulates a new scheme for classifying objects (or events, or ideas)."

Level 6: Evaluation

Judge the sentence in italics according to the criteria given below:

"The United States took part in the Gulf War against Iraq BECAUSE of the lack of civil liberties imposed on the Kurds by Saddam Hussein's regime."

> a. The assertion and the reason are both correct, and the reason is valid.
> b. The assertion and the reason are both correct, but the reason is invalid.
> c. The assertion is correct but the reason is incorrect.
> d. The assertion is incorrect but the reason is correct.
> e. Both the assertion and the reason are incorrect.

All examples are courtesy of the University of Cape Town's page on Designing and Managing Multiple Choice Questions. (Carneson, Delpierre, & Masters, 1996)