AC 2012-4759: IMPLEMENTING A REAL-TIME WATER AND WEATHER QUALITY MONITORING SYSTEM WITH APPLICATIONS IN SUSTAINABILITY EDUCATION

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Implementation of a Real-Time Water Quality Monitoring Lab
with Applications in Sustainability Education

Abstract

The implementation of a real-time water monitoring system developed to enhance water sustainability education is discussed. This system, called LabVIEW Enabled Watershed Assessment System (LEWAS), is a logical extension of prior data acquisition modules that have been successfully implemented using LabVIEW in the first freshman engineering course at Virginia Tech. The system will measure water quality and quantity data including flow rate, pH, dissolved Oxygen, conductivity and temperature – as indicators of stream health - for an on-campus impaired stream in real-time. In addition, weather parameters (temperature, barometric pressure, relative humidity and precipitation) are measured at the site of the lab located on the stream.

LEWAS is solar powered and uses the campus wireless network through a high-gain antenna to transmit data to remote clients in real-time. Remote users can change the sampling intervals and modify the LabVIEW programs that run on the system to analyze the data with proper access privileges.

Pilot applications of LEWAS have been conducted in the freshman engineering course. Students have expressed positive attitudes towards the applicability and usefulness of LabVIEW in the context of environmental monitoring and the impact of real-time monitoring on increasing their environmental awareness. The authors plan to extend the use of this cost-effective yet highly accessible system to higher level civil and environmental engineering courses to provide an authentic context for problem solving involving environmental parameters of an impaired stream.

Introduction

The LabVIEW programming language has been introduced to the freshman engineering course at Virginia Tech since Fall 2007 as a successor to earlier modular and object oriented alternatives. LabVIEW follows a dataflow programming paradigm and is known for its strength in acquiring, processing, and presenting data from engineering applications that involve measurement instruments/sensors. In addition, LabVIEW provides extensive support for connecting instrumentation hardware, a feature used in developing LabVIEW based data acquisition activities in the course. For example, students used temperature data acquired through LabVIEW from a cooling probe to validate Newton’s second law of cooling. Since one of the learning objectives of the course is awareness of contemporary global issues including energy and environmental sustainability, the next step was to extend data acquisition using LabVIEW to remotely monitor environmental parameters from an impaired on-campus stream to enhance the sustainability component of the course and increase students’ awareness on environmental
sustainability. LEWAS has been designed to accomplish this task by measuring water quality and weather data from the site of an on-campus impaired stream and by providing end users with measured data in real-time in the form of a web-based interface.

The main objective of LEWAS is to increase student awareness on environmental and energy sustainability. Real-time remote monitoring of water parameters of an impaired stream serves this objective for three reasons [1]: First, it makes students aware of what is happening or will happen in their own campus if watershed development activities are not planned and executed in an environmentally friendly manner. Second, it enables stakeholders to assess the efficiency of remedial actions or regulation compliance. Third, it enables students to know the real world application of the LabVIEW programming language. Furthermore, implementing real-time collection of water data has a number of advantages over traditional sampling in the field [2] and real-time monitoring technology is becoming increasingly important for evaluating water quality [3].

In the following sections, first, the freshman engineering course and related programming initiatives that led to the adoption of LabVIEW in the course will be discussed. Next, the gradual introduction of data acquisition and LEWAS as an environmental data acquisition system relying on LabVIEW - since its early developmental stages-in the course, will be discussed. Next, challenges associated with developing an outdoor lab for environmental monitoring will be listed. In the following section, the design of LEWAS to overcome these challenges will be reviewed. In the following section, ongoing challenges associated with implementing LEWAS will be listed. Finally attitudinal data collected from students on LEWAS in the freshman engineering course will be reflected upon and its educational applications in energy and environmental sustainability will be discussed.

Educational Context of LEWAS and Prior Programming Initiatives

A few years before implementation of LEWAS, a number of program-wide hands-on activities were developed and implemented in the freshman engineering program of Virginia Tech as a result of an NSF funded curriculum reform and engineering education research grant, Departmental Level Reform (DLR), awarded to a group of engineering and education faculty in the university [4, 5, 6]. The first course in the program, Engineering Exploration (ENGE 1024), is the most affected course by the DLR project. This course primarily focuses on hands-on design, problem solving, professional ethics and skills, contemporary issues like sustainability, globalization, nanotechnology, and critical thinking skills [7]. This course is taken by approximately 1700 freshmen every year. The course delivery format includes one 50-minute lecture followed by one 110-minute hands-on workshop every week.

One of the learning objectives of this course is gaining the ability to develop and implement algorithms and demonstrate understanding of basic programming concepts. The instructors used FORTRAN in late 90s which was replaced by MATLAB in 2000. Beginning in Fall ’04,
MATLAB was replaced by Alice programming language. Alice is an object-oriented programming language where objects are represented graphically in a 3D environment and the program generates corresponding JAVA syntax when objects are instantiated or modified. Students can enable interaction between these objects and acquire/change their properties by applying “methods” or “functions”. Based on assessment data collected on Alice instruction, it was determined that engineering freshmen, particularly those with prior programming experiments (about 50 % of freshmen in the program), did not appreciate the drag and drop programming approach adopted in Alice for learning fundamentals of object-oriented programming. Furthermore, students did not perceive direct engineering applications of Alice in future engineering courses. Hence, beginning in Spring ’07, Alice was replaced by LabVIEW in ENGE 1024 with approximately 180 students. The dataflow programming paradigm supported by LabVIEW is suitable for many engineering applications and can be extended for collection, processing and communication of environmental data which in turn can be used to teach sustainability concepts [8].

**LabVIEW Programming**

LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) [9] is a visual programming language from the National Instruments based on the dataflow programming paradigm. Unlike control flow based sequential programming languages such as C/C++ and JAVA which the sequential order of program elements determines execution order, in a dataflow paradigm, the execution of the program and the order of operations is determined by the flow of data through programming blocks: each block executes only when it receives all its inputs. The dataflow programming paradigm lends itself well to engineering applications specially those involving data collection as repeating computational procedures are performed over the stream of collected data as opposed to changing the control flow of the program based on certain inputs as it is done in sequential text-based programming languages . LabVIEW has been used in engineering courses for covering fundamental programming concepts [8]. In Fall ‘07 LabVIEW was introduced in the entire freshman engineering class (EngE1024). A gradual integration approach was adopted for bringing LabVIEW programming experiences into EngE1024 [10]. Using this approach, first basic concepts including data types, inputs and outputs (called controls and indicators, respectively in LabVIEW) were presented in fall 2007 followed with programming structures (repetition and decision). Starting fall 2008 data acquisition using LabVIEW, a major strength of the programming language, was introduced to the course.

**Data Acquisition Activities Using LabVIEW**

Since Fall ’08, data acquisition (DAQ) using LabVIEW has been introduced in ENGE 1024. An example of a data acquisition activity, developed in Fall ’09, was to empirically validate Newton’s law of cooling. Newton's Law of Cooling states that the rate of change of the temperature of an object is proportional to the difference between its own temperature and the ambient temperature. This statement can be formulated into a differential equation whose
solution is displayed in Figure 2. For this purpose, we chose the following setup (Fig. 1): a temperature measuring probe, SensorDAQ data acquisition module, USB cable to send the digitized values to a computer running LabVIEW, and a LabVIEW Virtual Instrument (VI) to plot it. When the heated probe shown in Fig. 1 cools down in water, the change in temperature causes the electrical resistance of the thermistor (temperature sensitive resistor) inside the probe to change. This change in resistance results in change in voltage. The process of data acquisition which takes place in the SensorDAQ module consists of filtering the analog voltage signal from noise, amplifying it, sampling it at short intervals and quantizing these samples in the form of binary numbers sent to LabVIEW via the digital signal on the USB cable. Students were provided with VI that extracted and plotted the temperature data. The shaded area in Fig. 2 demonstrates temperature of the probe dropping when it was submerged in water after being heated up.

Students in ENGE 1024 are introduced with basic types of empirical functions (linear, power and exponential) and using linear regression to derive a function equation based on collected data points. They were asked to derive the equation for the function that relates temperature to time based on empirical data plotted by LabVIEW (shaded area in Fig. 2.). After they derived the equation, they were asked to compare it with equation predicted by Newton’s law of cooling. This comparison validated the law and also demonstrated the application of data acquisition in LabVIEW.

Using LabVIEW dataflow from sensor to final plot with the setting described above for data acquisition enabled students to understand how real-time data is acquired from physical phenomena using the software. In the next section, we will demonstrate how data acquisition in the course was extended to real-time water quality monitoring using the early (indoor) version of LEWAS.

Fig. 1. Data acquisition setup for validating Newton’s Law of Cooling
In Fall ’09 an in-class demonstration of remote acquisition of water quality data was added to the course to extend data acquisition beyond physical variables such as temperature and to include environmental variables such as dissolved oxygen from an on-campus creek. The setup used for this activity was phase 1 of LEWAS, described later in this paper. In this setup, water quality data is acquired from a water sample using a multi-probe water quality sonde and was made available to students as a URL link (Fig. 3) through LabVIEW Webpublishing tool. Details of the associated LabVIEW VI and setup to acquire data can be found in [2]. In the Spring 2011 offering of the course, the water quality sonde was taken to the installation site and was connected to a laptop with enhanced wireless capabilities loaded with LabVIEW. Therefore students were provided with data from the field through the campus wireless network, not from a sample in the lab. In the final setup, data from LEWAS lab which is under installation on the site of an impaired stream that flows through its home institution will provide weather and water quality data to remote users on a permanent basis in real time.

Fig. 2. Newton’s Law of Cooling and plot drawn by LabVIEW.

Extending Data Acquisition to Water Quality Monitoring

\[ T(t) = T_a + (T_0 - T_a) e^{-k(t-t_0)} \]

- \( T_a \): ambient temperature
- \( T_0 \): initial temperature
- \( t_0 \): cooling start time
- \( k \): decay constant

Fig. 3. URL made available to students in ENGE 1024 to access water quality parameters of water sample from indoor lab.
Application of LabVIEW in Programming Remote Labs

The setup for collecting data at one location and transmitting it to another to provide a lab experience for students is called a remote lab. Remote labs as a complement to traditional (proximal) labs are used in education in different fields and provide around the clock accessibility to their users [11]. From this perspective, LEWAS can be considered a remote lab that is programmed with LabVIEW, providing users access to environmental parameters through a web browser. Before addressing the design and implementation of LEWAS, a number of remote labs powered by LabVIEW will be reviewed to further justify the reason of using the software to program LEWAS.

An important consideration in the design of remote labs is the reliability of their operation. Grober et al. [11] point out only ten out of seventy remote labs that they surveyed globally in 2004 worked flawlessly (without broken links or out of order experiments). Burd et al. [12] noted that remote labs pose significant challenges in configuration, operation, and administration. Operating and configuring a remote lab is tightly dependent upon the programming language used to enable access to the lab, data collection and storage. Ertugrul [13] noted that in the context of virtual (relying on simulations) and remote labs, a programming language that addresses the problem of hardware limitations, short and long-term incompatibility issues should fulfill a number of characteristics including modularity, multi-platform portability, compatibility with existing code, compatibility with hardware, extendability of libraries, availability of add-on packages, and access to an intuitive Graphical User Interface (GUI). The author claims that LabVIEW fulfills all these characteristics and validates this claim by providing a survey result of LabVIEW-based virtual instrumentation applications that are implemented in engineering education.

LabVIEW has been used in Data Acquisition (DAQ) in developing systems in which data is acquired for the phenomena under study in one location and stored and analyzed in another location. In [14] a setup is implemented where a local PC controls a DAQ card on a remote PC to acquire data and subsequently transfers the data between the PCs using the standard telephone line. In [15] different available Web/Internet technologies that can be used in conjunction with LabVIEW to control/monitor experiments are compared. The system described by [16] enables students to perform experiments over the Internet by connecting to PCs running LabVIEW using a browser based user interface. These PCs are connected to pre-built circuits that constitute the test circuits for the distance experiments.

Among the several LabVIEW systems reviewed by Ertugrul [13] in different engineering fields, only one application in environmental engineering has been cited by the author. In this case, the lab software was based on LabVIEW with the intention to enable users to learn it in minimal time by providing a consistent interface design. This goal was reported to be achieved. A recent implementation of this remote lab can be found at [17]. The Environmental Teaching Lab in [17] utilizes pH, dissolved oxygen, temperature, and pressure sensors with remote monitoring capabilities. The users in the indoor lab conduct bench scale experiments and analysis of environmental samples and processes. In the broader context of remote labs, environmental monitoring can be best achieved when the environmental parameters are measured “in-situ”, in the field, instead of measurement based on samples in the lab. In the next section, challenges associated with an outdoor setup for implementing an environmental
monitoring remote lab, LEWAS, will be listed followed by sections devoted to the design and implementation of LEWAS to address those challenges.

**LEWAS as a Remote Lab in the Field**

LEWAS accomplishes “in-situ” measurement by measuring water and weather parameters from a site located Stroubles Creek, an impaired stream located on the campus of Virginia Tech. LEWAS differs from the typical LabVIEW based systems reviewed earlier in the fact that real time data is acquired from physical phenomena remotely from the field as opposed to the location of an indoor lab. As a result, the system is designed to enable a robust platform to run LabVIEW and provide reliable wireless communication to the end user. In addition, LEWAS as a remote lab is powered by a source of renewable energy available outdoors, solar energy.

An interesting distinction that arises for an environmental remote lab such as LEWAS which is situated in the field, especially from an educational perspective, is that users not only have access from any place, any time, they can “sense” the phenomenon physically as well as electronically (through data acquisition). For example, they can use their portable computer to access real-time reading on temperature and flow while visiting the data collection site to “feel” and “sense” the water temperature and flow.

Compared to commercially available setups that measure similar water quality parameters and provide remote access, LEWAS provides LabVIEW based programmability to the user and enables simultaneous remote access and operation as shown in Table I. In Table I, a number of

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<table>
<thead>
<tr>
<th>System</th>
<th>Can it be programmed?</th>
<th>Data collection method</th>
<th>Multiple remote access enabled?</th>
<th>LabVIEW used for data collection?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riverwatch Field Station [18]</td>
<td>No</td>
<td>GSM/Satellite/Ethernet</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>YSI 6200 [19]</td>
<td>No</td>
<td>Radio/Cellular/Modem</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>YSI EcoNet [20]</td>
<td>No</td>
<td>Cellular/Modem/Satellite/Wireless Ethernet</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Campbell Scientific DCP 200 [21]</td>
<td>No</td>
<td>Satellite</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>LEWAS</td>
<td>Yes</td>
<td>Wireless Ethernet</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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**TABLE I**

**LEWAS COMPARED AGAINST OTHER REAL-TIME REMOTE MONITORING SYSTEMS**
commercially available real-time remote monitoring systems are listed. Although some of the systems in Table I offer remote access to multiple users at the same time, only LEWAS provides programmability in addition to this feature. Programmability and multiple user access make LEWAS an ideal candidate in an educational setup. The technical implementation of LEWAS provides a realistic, scalable, and cost-effective approach, discussed in the next section.

**LEWAS Design Objectives**

The selected deployment site for LEWAS is an on-campus impaired stream. Due to this outdoor location, LEWAS should rely on solar power to acquire, store and communicate environmental data. In addition a reliable wireless communication system should be designed to enable simultaneous access for hundreds of users. Also, providing remote users with data from environmental sensors in the field requires designing a robust computation platform and programming it for processing data.

LEWAS has been designed to fulfill the following technical design objectives: programmability, accessibility, utilization of renewable energy, and providing a unified programming interface. The programmability objective is fulfilled when the real-time monitoring system has the ability to be programmed remotely to change the way it collects, processes, stores or communicates stored data. The accessibility objective is fulfilled when users can access to the system from any location with an Internet connection at any time. The utilization of renewable energy objective is fulfilled by powering the system with solar energy. Finally, the providing a unified programming interface objective is fulfilled when users have the ability to program data collection by different environmental monitoring devices through a single programming interface. In the following section, the phase-wise design of the system and the technical design objectives fulfilled in each phase is discussed (Table II).

<table>
<thead>
<tr>
<th>Technical design objectives for this phase</th>
<th>Programmability</th>
<th>Programmability, Accessibility</th>
<th>Programmability, Accessibility, Reliance on Renewable Energy, Unified Programming Interface</th>
</tr>
</thead>
</table>
Implementing Design Objectives

LEWAS has been designed and implemented in three phases to enable a gradual implementation from an indoor electrical grid-powered setup with wired communication to an outdoor configuration which is solar powered and wirelessly connected. Implementation details for each phase can be found in [10]. In the following, the first two phases are reviewed briefly and the third phase (outdoor deployment) is discussed in detail. A separate section following this section has been devoted to the implementation of “providing a unified programming interface design objective”

In the first phase, which is already implemented, water quality data is collected using a water quality multi-probe sonde and sent to a server (notebook computer) loaded with LabVIEW. The data is shared with remote clients via Wireless LAN in the same subnet. Clients have ability to control the server LabVIEW program, Virtual Instrument (VI), remotely and receive measurement data. Implementation of this phase addressed the programmability objective described above [2]

During the second phase, which is also implemented, the server computer is upgraded to an industrial computer (compactRIO) which is programmed to run remotely and without user intervention with less power consumption and more reliability compared to a personal computer. It is equipped with modules for data storage and wireless communications. The system is operated in an indoor lab setting. The embedded computer is powered from a wall outlet and is connected to the campus Ethernet (LAN). This phase mainly addressed the accessibility objective for accessing the system in an indoor development environment.

In the third phase, currently under development, the system is deployed to the field by establishing an outdoor lab. The selected deployment site is located on an impaired stream (Stroubles Creek) on campus. Table II summarizes the technical design objectives fulfilled in each of the three phases.

The selection of the outdoor site of LEWAS was made based on two factors: The site should be located on an impaired stream that passes through campus, and, there should be a way to connect to the campus wireless network from the installation site.

Stroubles Creek that passes through campus is classified as an impaired stream since it is unable to support its designated use in the area that it flows which includes the campus of Virginia Tech. Detailed information regarding the factors contributing to the impairment of the

| How this phase fulfills the objectives | Tablet PC as server, remote access from same wireless subnet of the server | Embedded computer as server (for increased reliability and reduced power consumption), access to indoor lab from any location at anytime | Solar powered deployment in the field, access through campus wireless Internet network |
The site’s potential to be connected to the campus wireless network was assessed through a wireless site survey to identify the nearest university building with the strongest signal. A wireless link was designed using a directional antenna to enable connection to an access point installed on the outside of that building (Hahn Hall). The location of the selected site on campus is shown in Fig. 4 and a picture of the installation site is shown in Fig. 5.

An outdoor location requires the system to be powered by a sustainable source of energy. A solar powered and battery backed electrical power supply system and a high gain wireless antenna and I/O module are added to the system to enable communication with the campus wireless Internet network. Due to weak wireless signal at the site, connection to the campus wireless network is established by utilizing a high gain (14dB) directional antenna and a wireless bridge. Also, in the third phase, a weather station is added to the system to monitor wind speed, precipitation, barometric pressure, and humidity and a flow meter is added to monitor water flow in the stream. In this phase all the remaining technical objectives will be fulfilled since the system will be powered by solar cells and users will be able to interact with the system through the campus wireless network.

The average power consumption of the controller (NI cRIO-9072 ) and the connected modules (NI 9802, NI 9870) and the wireless router, the main power consumers of the system as they consume considerably more power compared to the environmental sensors, is estimated to be around 20 W. The backup batteries have enough energy storage capacity (2.2 Mj) to sustain the operation of the system operation during night or cloudy overcast days. The battery will be recharged during availability of solar power which has a peak power generation of 80 W. In the unlikely event of power failure the collected data are safe since they are stored on non-volatile memory (SD card) of the NI-9802 I/O module. Furthermore, a remote user can increase the period of data collection or issue commands through the LabVIEW interface to stop sensors from collecting data and turn off CompactRIO plug-in modules to conserve power if there is a need to do so.
Implementing a Unified Programming Interface

As explained earlier, all weather and water sensors are connected to the compactRio embedded computer through an RS-232 serial connection. Adopting a uniform communication protocol (RS-232) from the hardware side demands a uniform software implementation for all

Fig. 4. Installation site of LEWAS, denoted with a star, on the campus of Virginia Tech. Image from Town of Blacksburg WebGIS.

Fig. 5. Installation site of LEWAS, Webb branch of Stroubles Creek.
environmental sensors which in turn streamlines collection, processing and storage of data. However, each environmental sensor uses its own proprietary software for RS-232 (serial) communication. In order to enable a uniform approach to data collection, the serial communication commands for each instrument was reconstructed in the LabVIEW environment. Details for extracting environmental data from the data sent through a serial connection using LabVIEW can be found in [2] for the water-quality Sonde, in [23] for the weather station, and in [24] for the flow meter. In each case, the main challenge was to find out how each sensor sends and receives information through its proprietary software and code that information into a LabVIEW VI. Fig 6. Displays the Block Diagram for the section of the VI that is tasked with extracting water quality parameters. The name of each parameter is shown where the extraction takes place.

![Block Diagram of VI](image)

Fig. 6. Screenshot of a VI for extracting water quality parameters.

The next step was to integrate the VIs written for each sensor. The final software product is a unified VI [25] which was developed by encapsulating the VIs written to access each of the three devices (water-quality sonde, weather station and flow meter) described earlier, into one VI using a single tabbed interface. This setup enables remote users to access all devices by loading a single URL which is generated by the LabVIEW Webpublishing tool (Fig. 7.). Creating a single VI enables using LabVIEW Webpublishing tool – used for publishing the VI on the Internet-
make the same interface for viewing environmental parameters and changing their sampling time available to the remote users as it is available to proximal users - in a Web-browser window - which contributes to making the remote lab experience feel more real and scalable to multiple users at the same time. Although multiple users can view the link at the same time, only one can control the instruments remotely (for example to change the sampling time). In Fig. 7, the user has been granted control after requesting it from the server hence the message “Control granted.”

**Functional Operation of LEWAS**

Fig. 8 shows the operational diagram of LEWAS lab. As depicted in this figure, first, each environmental parameter is converted to a digital representation of 0’s and 1’s through data acquisition that takes place inside each instrument and then sent to the embedded computer through an industry standard for serial computer data communications (RS-232). The details of acquiring data from the water quality sonde and RS-232 transmission can be found in [2]. Water
quality sensors in the Sonde measure pH, dissolved oxygen, temperature and conductivity, the flow meter measures water flow and velocity and the weather station measures air temperature, barometric pressure, precipitation, wind, relative humidity. The output of these three devices is sent via RS-232 serial links to the National Instruments’ NI 9870 Serial input module, a plug-in module for CompactRio 9072 controller. CompactRio is an embedded computer runs the real-time version of LabVIEW for reliable and deterministic operation. Another plug-in module, NI 9802, functions as secure removable storage for the collected data and is equipped with two slots for non-volatile memory (SD card). A wireless bridge (Cisco WET 200) enables the CompactRio to establish a wireless connection to the campus wireless network. The wireless bridge antenna input is connected to a 14dB directional antenna (Netgear ANT2405) which provides a point-to-point connection to an access point installed on top of the nearest building on campus.

**Current Implementation Status**

An indoor development lab has been set up for programming the compactRio controller and to functionally verify the operation of system in the processing, storage and communication areas. The main difference between in-lab and field operation is that in the indoor LEWAS lab, the system is powered from the wall outlet and measures the water quality parameters of a water sample and indoor weather quality whereas in field deployment mode, the system is powered by solar panels with batteries as back-up and measurement is performed on water flowing in a stream (Stroubles Creek).

The outdoor installation is ongoing. So far the instrument box (housing computation and communication elements), fixtures for water quality sonde and flow meter, and solar panels have
been installed. The conduit for connecting the instruments to the instrument box have been installed and wirings between the instrument box on one hand and directional antenna, solar panels and weather transmitter on the other hand have been completed. Fig. 9 shows the current installation status of the lab. In addition to installing remaining components, programming the embedded computer and completing the communication system is ongoing and is expected to be competed in Summer 2012.

Logistical and Implementation Challenges

The main challenge after the completion of the design of the lab [10] and before installation was procurement. Ordering the right parts that would not only perform per the lab design but also enable integration with other components and also accommodate future expansion and scalability of the lab was critical. This step was completed successfully with very few returns and redesigns.

In the course of development and implementation of the lab, a number of logistic and implementation challenges aroused. All of these challenges were eventually overcome, sometimes with the assistance of contractors and technical institutions affiliated with the university such as Virginia Tech Electrical Services (VTES), Facilities Services (Building Services and Grounds), and Campus Renovation Services. Also a number of regulatory/oversight
bodies such as Public Safety, Office of the University Architect, and Environmental, Health and Safety Services were contacted by inviting a representative of these offices to visit the installation site and providing them with additional information and documents to gain their approval.

**Introducing LEWAS to the Classroom**

As discussed earlier, LabVIEW has been gradually introduced in ENGE 1024 and as successive phases of LEWAS have been designed and developed (currently deployment of phase 3 is underway), beginning Fall ’09, students have been provided access to LEWAS. They were able to view an interface similar to Fig. 3. This allowed them to observe water quality parameters of a water sample located in an indoor development lab (phase 2, described in the design section). Fig. 10, 11, and 12 show how they perceived usefulness of LabVIEW, motivation to acquire higher level programming knowledge, and the role of LEWAS on changing their environmental awareness respectively, based on exit surveys collected online at the end of each semester.

In Spring 2011, as a test for deployment of LEWAS phase 3, the water quality sonde was taken to the installation site and was connected to a laptop with enhanced wireless capabilities loaded with LabVIEW (Fig. 9). As a result, unlike prior semesters where students viewed environmental data of a sample in the indoor setup (phase 2), students had access to four water quality parameters (pH, dissolved oxygen, temperature and specific conductivity) through a URL similar to Fig. 3, displayed by their instructor. As it can be observed in Fig. 11, 12, and 13, streaming data from the field as opposed to a water sample from an indoor lab setup, improved student perceptions in Spring 2011. Also, based on other questions in the exit survey, student attitudinal responses indicated positive attitudes towards the applicability of a dataflow programming language (LabVIEW) in the context of environmental monitoring. The majority of students agreed with the statement that access to real-time environmental data can enhance their awareness and curiosity about environmental issues such as the state of an impaired stream that runs through campus.
Questions in Fig. 13 were included in the Spring 2011 exit survey of the course which is a smaller offering (~180 students) compared to the Fall semester. Based on student responses, most students believed that remote access to real-time data makes environmental monitoring easier compared to collecting water samples at the site and measuring its parameters. Furthermore, a strong majority of students agreed with the statement that real-time water quality monitoring is useful for environmental sustainability and that they are interested in it.

Students enrolled in the in the spring 2012 of the freshman engineering course will complete a questionnaire that surveys them on their interest in environmental monitoring and motivation to learn about environmental sustainability both before and after they use the lab. The results of the survey will be collected and analyzed.
The demo of LabVIEW based Water Quality Monitoring System motivated me to acquire higher-level programming knowledge to develop applications related to environmental sustainability.

Access to real-time environmental data can enhance my awareness and curiosity about environmental issues such as the state of an impaired stream that runs through campus.
It was interesting to see the value of water quality parameters (temperature, dissolved oxygen, specific conductivity and pH) as they were being measured in Stroubles Creek in real-time.

Remote access to real-time water quality data makes environmental monitoring easier compared to going to the stream, collecting water samples and measuring their parameters.

Real-time water quality monitoring is useful for environmental sustainability.

Fig.13. Students’ perceptions on their interest, ease of monitoring, and usefulness of LEWAS when given access to real-time data from Stroubles Creek.
Potential Applications of LEWAS Beyond Freshman Engineering

There are a number of potential applications beyond increasing students’ environmental awareness in the freshman engineering course (ENGE 1024) at Virginia Tech. First, it can be used in higher level civil and environmental engineering courses to explore spatial and temporal relationships between different environmental parameters in the home institution or other institutions. Since LEWAS relies on a web-based interface, it can be accessed anywhere with Internet access. For example the relationship between dissolved oxygen on one hand and temperature, conductivity and pH on the other hand can be investigated using a multivariate regression equation. Second, it can be integrated into electrical and computer engineering programs to teach energy sustainability. As the LEWAS system converts solar energy to electrical energy for acquiring, processing, storing, and communicating environmental data, the rate that electrical energy is provided by the solar panel, stored in the battery, and consumed by the embedded computer and environmental sensors can be monitored and transmitted to the remote user in real time. For example, students can observe that in a cloudy day, the rate that the battery provides electrical energy for the system is much greater than the rate that the solar panel provides electrical energy for the battery. As another example, students can find out the time of the day that energy provided by the solar panel is maximized. Third, since LEWAS is deployed on the site of an impaired stream and can provide in-situ measurements, temporal variations of parameters can be compared against variations of similar water parameters collected in regional and national databases from downstream data collection sites over the same period of time which in turn, results in better transferability of predictions and interpretations over environmental data.

Conclusion

LEWAS, a real-time environmental monitoring remote lab, has been designed for deployment on an on-campus impaired stream. The selection of the deployment site was based on using a creek known and accessible to students which also has environmental problems. The specific installation location on the creek was selected to take advantage of the campus wireless network. LEWAS relies on solar power to acquire, store and communicate environmental data and on LabVIEW dataflow programming to acquire and transmit information. Due to this setup, LEWAS has been successful in showing how LabVIEW, the programming language taught in ENGE 1024, can be applied in real-world contexts.

Collected student responses indicate positive perceptions on the role of lab to make environmental monitoring easier and its success in enhancing curiosity and awareness on environmental issues such as the state of an impaired campus stream.

Educational applications of LEWAS can extend beyond the home institution, as everyone on the Internet can be provided with access to the lab. These applications include monitoring conversion of solar energy to electrical energy, using the collected parameters to investigate relations between them in higher level civil and environmental engineering courses, and providing a working example of data acquisition and communication that can be monitored remotely for introductory electrical and computer engineering courses.
References


