Insights and Challenges in Developing a Remote Real-Time Watershed Monitoring Lab

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Abstract: The LabVIEW Enabled Watershed Assessment System (LEWAS) is a remote real-time watershed monitoring lab in Stroubles Creek on Virginia Tech campus. The lab is comprised of an interdisciplinary group of researchers focused on developing an automated watershed monitoring lab with real-time data accessible to a wide range of users on an easy to use platform. Watershed monitoring hardware, including a water quality multiprobe, acoustic doppler flow meter, weather station, outdoor camera, and tipping bucket rain gage, are integrated together using LabVIEW software to provide continuous real-time watershed data. There have been many unique challenges in developing and implementing the remote real time watershed monitoring lab. These challenges include developing routine calibration and maintenance procedures and collecting accurate precipitation and flow data. Collecting accurate and reliable data has required developing calibration and maintenance procedures which prevent errors in data collection and ensure equipment upkeep. To maintain accurate precipitation data, a tipping bucket rain gage was installed at the site to provide additional rainfall data and develop calibration curves for the weather station. Finally, collecting accurate flow data at a unique urban site for all levels of flow has required multiple instruments and flow computation techniques. An acoustic doppler flow meter is installed in a natural run of the stream before it enters a retention facility. A secondary flow measurement is provided by a weir installed in a culvert directly upstream from the outdoor LEWAS site where an ultrasonic transducer measures stage behind the weir. Data from this lab is being used for hydrologic and environmental research in addition to use in multiple courses at Virginia Tech including a senior level Hydrology course as well as freshman level courses at Virginia Western Community College.

Introduction

The LabVIEW Enabled Watershed Assessment System (LEWAS) is a remote real-time watershed monitoring lab which promotes water sustainability research and educational outreach. The LEWAS field site is located at the watershed outlet of the Webb Branch of Stroubles Creek on Virginia Tech (VT) campus. The watershed is approximately 2.78 km², encompasses portions of the Town of Blacksburg and Virginia Tech campus, and is approximately 95% urbanized. The LEWAS components of water and weather monitoring hardware, sustainable power supply, data collection hardware, and data processing software all work together to provide real-time 24/7 watershed data. The LEWAS functions as an environmental monitoring lab which collects continuous water quality, water flow, and weather data and transmits it in real time to a data server, where it is stored and broadcast to the LEWAS data viewing website.

The LEWAS lab is composed of an interdisciplinary team from a variety of backgrounds, who all work together to develop and maintain the lab. There are currently 4 graduate students and 4 undergraduate students working in the lab, and in the past the lab has graduated 3 graduate students (2 MS, 1 PhD) and 6 undergraduate students, and hosted 5 NSF REU students¹⁻⁵. Students working in the lab have come from a variety of backgrounds including engineering education, electrical engineering, computer engineering, civil engineering, environmental

engineering, chemical engineering, biological and systems engineering, biology and chemistry. The LEWAS requires an interdisciplinary team due to the diverse expertise required to design, implement and operate a real-time watershed monitoring lab. Power supply and data acquisition require the expertise of personnel from electrical and computer engineering backgrounds while water quality, flow, and weather studies require personnel with environmental, biological, and civil engineering backgrounds. The LEWAS necessitates synergy among all members to effectively maintain and promote the lab for water education and research.

The LEWAS lab equipment includes environmental monitoring sensors and data collection, storage and transmission hardware. A schematic layout of the field site illustrating the location of the sensors and hardware is shown in Figure 1. There are three primary environmental sensors deployed at the site which provide continuous real time data. A Hydrolab MS-5 Sonde collects water quality data including pH, dissolved oxygen (DO), oxidation reduction potential (ORP), turbidity, temperature and specific conductivity. Flow data is provided by a Sontek Argonaut-SW Acoustic Doppler Current Profiler (ADCP) which takes stage and index velocity measurements in a stream cross section at the site. A Vaisala Weather Transmitter WXT520 measures air temperature, barometric pressure, relative humidity precipitation and wind speed and direction. In addition, there is a camera installed at a pole near the site which provides supporting visual data of the site conditions. The data from the devices is collected with an embedded computer stored in a control box on site and transmitted through the campus wireless network to a database. Solar panels mounted on a light pole charge two 12 V batteries connected in series, which power the entire system.

Figure 1. LEWAS Field Site Layout

Data from the LEWAS lab is actively used for water sustainability research and education. Currently there are 3 PhD students and 1 Masters student conducting research in the LEWAS lab with topics covering education, electrical, computer and civil engineering. LEWAS-based

classroom modules have also been implemented into a variety of community college and university courses as part of a NSF TUES grant. These include a senior level hydrology course at VT⁶ as well as freshman level introduction to engineering courses at Virginia Western Community College (VWCC). In addition to course modules developed as part of this grant, the LEWAS lab has been used in other courses at VT including exposure to over 5,000 freshman in a freshman engineering exploration course), a hydraulics class in civil engineering, and two courses in the geosciences⁷⁻⁹. Pending collaborative proposals also seek to use the LEWAS lab in courses covering geosciences, biology, engineering, and engineering education at VT and other colleges and universities including John Tyler Community College and East Carolina University.

Hardware

The LEWAS lab equipment includes environmental monitoring sensors, as well as electrical, power supply, and data collection hardware. The entire LEWAS system works together to collect, transmit, store and broadcast live, real-time, high-frequency water quality, flow, and weather data. As illustrated in the LEWAS operational diagram shown in Figure 2, each hardware component serves a critical role in maintaining the function of the lab.

Figure 2. The LEWAS Operational Diagram

Environmental Monitoring Devices

The LEWAS lab currently has three primary watershed monitoring instruments installed at the Webb Branch of Stroubles creek which monitor water quality, flow, and weather parameters. The first is a Hydrolab MS-5 Sonde which measures water quality parameters including pH, temperature, specific conductivity, dissolved oxygen (DO), oxidation reduction potential (ORP) and turbidity. The Sonde is supported by a steel structure mounted to a cement block in the bottom of the stream and protected from debris with a metal casing (Figure 1). The second is a Sontek Argonaut-SW Acoustic Doppler Current Profiler (ADCP) which measures stage and index velocity at a cross section in the center of the stream. The ADCP is mounted to a rectangular concrete block which is secured to the channel bottom and the data cable is encased

by metal tubing to prevent damage (Figure 3). Finally, a Vaisala Weather Transmitter WXT520 mounted on a light pole near the site measures air temperature, barometric pressure, relative humidity precipitation and wind speed and direction.

Figure 3. ADCP in the stream

In addition to the three primary devices, there is also a tipping bucket rain gage which collects precipitation data at the site. However, unlike the other devices, the rain gage is not connected to the LEWAS data flow network through the embedded computer and LabVIEW programming. The rain gage provides supporting precipitation data to reduce any uncertainties in the weather station measurements. There are also plans to expand the field site with additional measurement devices and data collection hardware. An ultrasonic transducer will collect stage measurements in a weir just upstream of the site and will help to provide additional flow measurements to ensure data quality and accuracy. A power monitor will also be installed to track the power consumption of the devices in order to optimize the energy efficiency of the lab.

Data Collection Hardware

Data from the environmental sensors is collected using an industrial embedded computer (National Instruments CompactRIO) housed in the main control box at the LEWAS site. The CompactRIO runs the real time version of LabVIEW to communicate with the monitoring sensors to collect, analyze, and transmit data. The output from the three watershed monitoring sensors are sent via RS-232 serial links to the National Instruments' NI 9870 Serial input module, a plug-in module for the CompactRIO 9072 controller. An additional plug-in module, NI 9802, functions as secure removable storage for the collected data and is equipped with two slots for non-volatile memory.

A wireless bridge and 14dB directional antenna enable the CompactRIO to establish a wireless connection to the campus wireless network through a point-to-point connection from the LEWAS field site to an access point installed on a nearby campus building. Data is sent through the network to a database located on campus as well as through the LabVIEW web publishing tool to the LEWAS data viewing website.

Software

A primary goal of the data acquisition component of the lab was to have a common platform to communicate with the measurement devices and send data to a database server. Each measurement device comes with its own data collection hardware, software, and communication protocols. To collect data using each software and data collection hardware would require frequent field visits which would be expensive, cumbersome, and time intensive. To streamline the process, a common communication platform was adopted, which allowed the lab to communicate with all the devices and stream the data from all the devices to the database which could be used for data mining. LabVIEW was the initial programming environment to communicate with the monitoring equipment and was chosen due to a variety of factors. It is a simple software development environment which uses a dataflow programming model and also has a LabVIEW web publishing tool which can be used to publish real-time data online. In addition, LabVIEW was also being used in the Engineering Exploration class that all engineering freshman on campus are required to take. This gave the students a real-world application of LabVIEW being used for data acquisition and processing.

In order to streamline the collection, processing, and storage of data, the serial communication commands for each instrument were reconstructed in the LabVIEW environment. Each of the devices uses its own proprietary software to communicate through a RS-232 serial communication port. The command scripts for each device had to be rebuilt in the LabVIEW environment to properly communicate with the devices. Details for extracting data through signals sent through a serial connection using LabVIEW for the water Sonde, weather station, and ADCP can be found in Delgoshaei (2012)¹⁰. The final software product is a unified Virtual Instrument (VI) which combines the individual VI's developed for each of the three devices into a single interface. This interface is broadcast through the LabVIEW Web Publishing tool which generates a URL that gives remote users access to all three devices.

Power Supply

Energy sustainability at the site is achieved by the use of a renewable power supply via two solar panels installed on a light pole at the site. The weather station, Sonde, ADCP, camera, embedded computer and wireless antenna all run on power generated by the solar panels. The solar panels have a peak power generation of 80 Watts and charge two 12 Volt, 30 Amp Hour deep cycle batteries located in the primary control box. The batteries run the system 24 hours a day and are recharged during periods of sunlight. Using annual averages, the batteries were selected to have enough storage capacity to sustain the outdoor lab during the evening and multiple overcast days; however, during long periods of overcast days, power consumption may exceed the batteries capacity. Challenges experienced with the LEWAS power supply are discussed further in the following section.

Challenges

There are many challenges to developing and operating a continuous 24/7 watershed monitoring lab. Maintenance of the equipment requires technical expertise and man-hours to ensure that the lab is functioning properly. Consistent and accurate data collection requires software development, quality checks, and frequent equipment calibration. Maintaining reliable power at

the site requires constant power budgeting and oversight to ensure that dark, overcast days do not cause the batteries to drain out. Finally, running equipment continuously over the course of multiple years has resulted in many equipment failures which must be prevented or postponed with proper oversight and maintenance procedures.

Maintenance

Keeping a continuous real-time watershed monitoring lab operating has required regular maintenance procedures to ensure the proper upkeep and function of the lab equipment. The accuracy of the data is dependent on the condition of each monitoring device. The location of the lab in an urban stream subjects the equipment to a multitude of debris and flow disturbances that can have negative effects. To keep the equipment functioning properly, an ongoing work schedule is maintained which includes equipment maintenance, debris removal, instrument calibration, data processing, and data quality checks.

The ADCP requires regular maintenance such as debris removal to ensure that the device records reliable data. The device is often covered by sedimentation during high flow events, and can catch debris such as tree branches and rocks or man-made plastics and other garbage. These occurrences can cause errors in flow measurements by covering the flow sensors so that they cannot get proper readings or changing the characteristics of the flow within the stream. Figure 4 illustrates a scenario in which substantial debris has accumulated on the sensor and caused a scatter of velocities in the direction of flow as well as the vertical direction. The figure on the left represents the velocities during September 2012 when the stream section surrounding the Argonaut ADCP was clear of debris and the figure on the right represents the velocities during November 2012 when debris had accumulated around the sensors. These figures show the degree to which errors can occur in velocity readings in an ADCP due to debris accumulation. These findings further suggest that debris must be removed whenever possible to maintain accurate and reliable data. The ADCP at the LEWAS site is checked for debris on a weekly basis as well as after any significant storm events.

Figure 4. Velocity plots for September (left) and November 2012 (right)

In addition to the ADCP collecting debris, the water quality Sonde often collects large clumps of debris around the mounting frame and measurement device during high flows as illustrated in

Figure 5. Another major issue with the Sonde is the propensity for its sensors and its casing to collect sediment during highly turbid peak flows. Debris or sediment that gets stuck in or around the sensor casing have an impact on the accuracy of the water quality readings. Without proper maintenance procedures in place, the Sonde will not provide accurate data. Because of this, the LEWAS team also conducts maintenance visits on a weekly basis and after high-flow events to check the Sonde for any debris accumulation or sediment clogging within the sensors.

Figure 5. Collection of debris around the Sonde

Data Quality

Maintaining accurate data can be one of the most challenging aspects of a continuous watershed monitoring lab. Because of the heavy use of LEWAS data for water sustainability research and education, data quality and accuracy is of paramount importance. Consistent and accurate data collection requires maintenance, quality checks, and frequent equipment calibration. Proper QA/QC procedures have been developed for each instrument as well as data analysis procedures to ensure that all data being collected at the site is as accurate as possible.

Data from LEWAS instruments can degrade in quality over time from drift in instrument measurements or changing site conditions. Many of the probes on the Sonde require calibration in a lab to keep the parameters that each device measures from drifting. Failure to do so would result in many of the data parameters drifting outside of an acceptable range. Preliminary studies by the LEWAS team have shown that the Sonde should be calibrated every 3 weeks to maintain proper accuracy of each parameter.

In addition, changing site conditions may alter the accuracy of flow data being collected at the site. Flow is computed by multiplying the index velocity reading of the ADCP by the cross sectional area of the stream in the plane containing the ADCP and by a correction factor, i.e. the index velocity rating, to account for measured variations in velocity across the stream. Because the ADCP is located in a natural stream, there may be changes in the cross sectional area due to

sedimentation or erosion which would affect the stage-area and index velocity ratings that are used to compute discharge. To ensure proper accuracy of the ratings, routine cross section studies and flow calibrations are conducted bi-monthly to check for any drift in the accuracy of the flow computations.

To further check the accuracy of the primary monitoring devices, additional monitoring devices are used to validate their measurements. As mentioned previously, a rain gage currently installed at the site provides complementary precipitation data to check against any inaccuracies or drift in the weather station. A point velocity meter is also used to periodically check the accuracy of the velocity readings of the ADCP as well as the index velocity rating. All of this supporting equipment provides field checks against any errors that may exist in the field equipment or the methodologies used to collect data.

Computing Flow

One of the most difficult variables to compute is the flow rate at the site. There are many challenges in computing flow and uncertainties involved in the measuring devices and methodologies used. Because of changing site conditions, the index velocity rating must be continually updated, which requires velocity measurements using a point velocity meter at various flow rates. This can take many weeks or months to obtain as it is dependent on storm conditions that cause an increase in flow rates above base flow. In order to have a less cumbersome method of validating and calibrating the index velocity rating for the ADCP as well as having another continuous flow measurement method, a new ultrasonic transducer will be installed in a concrete rectangular weir located 7.5 m upstream from the Argonaut underneath West Campus Drive (see Figure 1).

Constructed in 2003, the weir in the culvert is a contracted rectangular weir at low flow with 150 degree v-notch sidewalls extending above the rectangular crest to the walls of the culvert. A scaled model of the weir was constructed (as shown in Figure 6) and calibrated in a flume to create a depth-flow relationship. The weir was calibrated in the lab with “free” or modular flow conditions where the height of the lowest point of the weir crest elevation is higher than the height of the water downstream. The weir in the model is placed 1.5 inches above the channel bed, thus creating a “free” flow condition. In this case, the water will pass through critical flow and discharge can be estimated based on the depth of water above the crest of the weir at a location upstream.

Figure 6. Weir model. The figure on the left shows the schematic for the model weir and the figure on the right shows the constructed plexiglass weir models.

Although calibrated in a lab under free flow conditions, the actual weir installed upstream of the LEWAS site has a submerged flow or “non-modular” flow condition, where the discharge is partially under water. Submerged flow occurs when the downstream water surface is near or above the crest. In this particular case, the crest of the weir is also the bottom of the channel, resulting in the water downstream water surface being above the crest in all flow conditions, as illustrated in the diagram of the weir in Figure 7. Because of this condition, changes in the downstream depth can affect the flow rate and accuracy of measurement should not be expected¹¹. To properly determine flow rates in submerged flow conditions the downstream depth as well as the upstream depth need to be measured, however this will only be an estimate.

Figure 7. Diagram of weir dimensions

Figure 8 illustrates base flow conditions at Weir #1 where submerged flow conditions are apparent as the elevation of the crest is equal to the elevation of the stream bed. Modifications to the weir were made in order to create free flow conditions in which the elevation of the water downstream of the weir is below the lowest level of the crest. A wooden block was constructed

and installed at the site to close the gap between the two wing wall sections, which then created a free flow condition (Figure 9).

Figure 8. Photos of submerged weir

Figure 9. Weir modification

A scale model of the modified weir has been constructed and studies using the model weir in a laboratory flume are ongoing. The flume studies are seeking to develop a depth-flow relationship which will be scaled to the size of the constructed weir in the field. Using the ultrasonic transducer to record depth at the weir, flows will be calculated with the use of the depth-flow relationship. This additional flow will be used to verify the Argonaut ADCP data as well as calibrate stormwater network models of the watershed currently in development.

Maintaining Power

A consistent power supply is vitally important because any intermittent power failure may cause the instruments to reset and cease collecting data. Maintaining reliable power at the site requires constant power budgeting and oversight to ensure that dark, overcast days do not cause the batteries to discharge completely. As additional equipment has been added on to the system, the

power demand has increased and resulted in increasingly frequent power failures during the past few years.

The solar panels charge two 12 V deep cycle batteries connected in series, which, in turn, power the entire system. During the winter, the electrical output of the solar panels decreases due to shorter days, a decrease in solar radiation intensity, and higher rates of overcast. These factors can combine to cause the demand of the system to exhaust the stored energy. Although the LEWAS uses deep cycle batteries to accommodate power supply variations, draining the batteries too low can still result in the deep cycle batteries losing their ability to hold a charge. Because battery failure requires the purchase of new, expensive batteries and results in the system being offline for an extended period, it is imperative to install automatic low voltage shut down protection. However, while this protects the system from damage, it still results in a loss of data. To prevent this data loss from occurring, a proper power budget must be developed and maintained. Because of past power failures and the proposed additional equipment at the site, two additional solar panels and two additional batteries are currently being installed at the site. These additional solar panels and batteries will double both the power production rate and the storage capacity, which will significantly reduce LEWAS power failures.

Another method of reducing power failures is to integrate two or more power sources. Other sources of renewable power such as wind are being explored as viable options to increase power generation at the site. However, the frequently suggested source of hydropower is not a suitable option for the LEWAS because it would create a significant load on the stream system that would alter stream flow dynamics. Although a system powered completely by renewable energy sources is often preferable, a move to grid power is being explored in order to increase system reliability. Putting the system on grid power will require significant capital to install and connect in excess of 300 feet of underground cable as well as power regulators and equipment housing. However, with an increasing power budget it may be necessary in order to minimize any future power failures.

Hardware Restrictions

There are many challenges and restrictions to using the CompactRIO and LabVIEW programming environment which have necessitated research into a possible change to the Raspberry Pi data collection device. The current CompactRIO restricts the expansion of the lab through a limited number of FPGA DMA FIFO Channels (3) which in turn means that a limited number of devices can be used at the site. While a newer CompactRIO model (cRIO-9068) does have significantly more channels, its increased power requirements are not compatible with the current LEWAS system. The current system is also restricted to using LabVIEW programming which may reduce the number of applications for which the LEWAS system can be used.

The Raspberry Pi is a low cost, single board computer, which primarily uses a LINUX kernel based Operating System. It is fully expandable which means an unlimited number of devices may be integrated into the system. It is developed in the UK by the Raspberry Pi Foundation with the intention of teaching computer programming concepts in schools. Currently, it is used in many monitoring and accessibility applications and various other applications. It does not have a hard disk but uses a SD card for booting and persistence storage. The Model B of Raspberry Pi,

which is used in our LEWAS Lab, has 512MB RAM, 2 USB ports, an HDMI port, a VGA video port and an Ethernet port. Figure 10 shows how Raspberry Pi can be connected to the sensors to collect data and how the data will be stored in the database.

Figure 10. The flowchart to show different components of the system to be developed for real-time collection and processing of data.

A new system is being developed to enhance the reliability of real-time collection and processing of data from the LEWAS Lab environmental sensors. This system deploys a Raspberry Pi as an embedded computer to collect data from the LEWAS sensors connected through a USB hub, and store these data in a database. Current development on integrating the hardware and software components of this new system using Python, PHP, and SQL programming languages is ongoing. A move to the Raspberry Pi hardware will increase the expandability of the LEWAS field site as well as the applications for which the lab can be used. It will also reduce the power consumption at the site as the Raspberry Pi uses less power than the current embedded computer in use.

Equipment Failure

Running equipment continuously over the course of multiple years has resulted in many equipment failures which can be prevented or postponed to some degree with proper oversight and maintenance procedures. However, several of the equipment failures are due to the accelerated amount of wear and tear associated with being installed 24/7 in an urban watershed subject to frequent flash flood events. Both the Sonde and ADCP have completely failed and been sent in for replacement or repair. Exact causes have not been determined as to why either instrument failed but it could be due to manufacturer error or breakdown caused by consistent exposure to the elements.

In addition to the complete failure of equipment, intermittent failures in data collection can occur for a variety of reasons. There could be physical reasons such as a data cord coming loose from the device during a storm event or an intermittent power supply causing the device to reset. There could also be failures within the equipment itself that cause the device to malfunction or fail to communicate properly. One such example is the corrosion that occurred around the pins which connected the data cable to the ADCP device. Over time the pins became corroded and

caused sporadic communication with the device and frequent failures. Although the pin connection is supposed to be water-tight and recommended installation procedures were followed, the seal still became compromised during deployment in the field. Figure 11 illustrates the corrosion that occurred on the pins of the cord connected to the ADCP.

Figure 11. Flow sensor pin corrosion

Conclusion

Design and operation of a continuous remote real-time watershed monitoring lab has required innovative approaches to data acquisition, computational techniques, and maintenance procedures. Programming and data acquisition hardware has enabled the lab to provide real-time, high resolution data from many different devices through an easily accessible online interface. Computing accurate weather, water quality, and flow data requires routine data quality checks and multiple devices and computational methods to remove data uncertainties and ensure data accuracy. Operation of the lab also requires expertise and large human capital to carry out calibration and maintenance procedures and to troubleshoot the inevitable problems that occur with a 24/7 outdoor lab.

Future work in the lab includes proposed expansion of the LEWAS lab to another site on VT campus and a site at East Carolina University. Collaboration between VT and other universities and community colleges for classroom implementation of LEWAS-based modules will continue. Ongoing research is investigating the sources and impacts of sediment transport through the urban stormwater network, the impacts of acute toxicity limit exceedance on aquatic health, and the use of real-time data in watershed model development and calibration. The lab is also working on the development of a Platform Independent Remote Monitoring System (PIRMS) which will act as a watershed data viewing platform and educational tool that promotes “active learning” through modules which connect the participants to the field site and motivate them to actively participate in learning activities focused on water sustainability. A companion paper at this conference provides details of the PIRMS including its current status of development¹².

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