Development of mobile computing applications for hydraulics and water quality field measurements

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Abstract

Traditional field measurements for water quality and stream gauging still largely depend upon the pencil and paper field notebook for data collection. Recent advances in scalable wireless telecommunications and the proliferation of hand-held computing devices has enabled the development of software tools to assist environmental and earth scientists in improving the collection of field data. This paper describes an electronic journal which has been developed for environmental and geolocation data collection. The objective of the mobile software application is to streamline the collection process and improve the accuracy of environmental field data as compared to current practices. The integrated system includes automated control of a water quality probe and a global positioning system sensor, mobile geographical information system software, an internal database and manual input for other hydraulic and water quality parameters through a customized user interface. In addition, wireless and Internet technologies are used for transferring and displaying collected field data. A prototype system has been completed and tested in field trials. Potential applications for the electronic field notebook include biogeochemical studies, hydraulic and hydrology studies and watershed management studies.

1 Introduction

The development of software applications for mobile computers has been recently spurred by the availability of more powerful operating systems and

the transfer of standardized programming languages on ever-smaller computing platforms. These developments have opened the door for creating new applications that bring computing power to field scientists [1, 3, 5]. One potential application area explored in this paper is the collection of environmental and geopositional data. Associating environmental parameters with a location is essential in many earth sciences. For disciplines with an active field work component (*e.g.* water resources, geology, biology), providing software tools that improve the accuracy, efficiency and quality of the data collection process can significantly improve current practices. In addition, the technology in this paper will allow users to link real-time field data collection from various devices to a centralized data server located at a remote location. This capability can lead to improvements in the management of deployed field teams.

A prototype for the integrated field data collection system has been developed in the Department of Civil and Environmental Engineering at the Massachusetts Institute of Technology. The prototype system, known as the ENVIT Field Notebook Data Collection System, consists of various mobile and wireless technologies that used in conjunction provide a robust, expandable platform for mobile data collection from environmental sensors and manual data input. The elements of the integrated ENVIT Field Notebook include:

- Ruggedized mobile computers
- Automated water quality sensor
- Automated geopositional sensor
- Other field instruments
- Mobile software application
- Wireless connectivity to mobile computers
- Outdoor wireless router
- Multiple-platform database
- Multiple-platform GIS
- Field laptop computer
- Laptop software application
- GSM/GPRS connection from field laptop
- Remote desktop web server
- Web services applications
- Lightweight field power supply

The objective of the integrated mobile system is to streamline the collection process and improve the accuracy of environmental field data. From the field site to the office, the collection and automated transfer of environmental data associated with a location can be seemlessly executed without the loss of precision that typifies transfers across various media. By using mobile GIS technology, the system adds a new dimension of spatial localization to the data collection process and provides the user with both textual and spatial cartographic displays. Finally, this integrated system can be

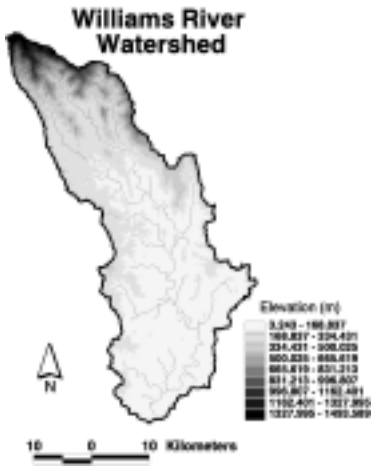

Figure 1: Williams River watershed in New South Wales, Australia, site for the field deployment and testing of the ENVIT Field Notebook.

used in the coordination of a field study from a centralized location and real-time data displayed via a web server.

In this paper, we will discuss the development of the various components included in the ENVIT Field Notebook system from an information technology perspective and its application to environmental data collection. Section 2 details the specific environmental application for which the system prototype was initially designed, a watershed quality and quantity study. In Section 3, integration of the computing platform and environmental sensing equipment is discussed. Section 4 details the wireless and web-based technology utilized for transmitting data to and from multiple platforms. Finally, field deployment and other potential applications are discussed in Sections 5 and 6.

2 Watershed Study

The ENVIT Field Notebook Data Collection System was created in the context of a watershed study designed to gather water quality and water quantity data, as well as geopositional information, at various river cross sections within a river network. The scientific objectives for the field study were to quantify the transport and flux of non-point source pollution (*e.g.* nutrient loading or bacterial transport) within a watershed impacted by agricultural runoff. Data collection during an intensive field campaign is designed to support hydrologic and transport modeling efforts in the wa-

Figure 2: Hardware components for the prototype ENVIT Field Notebook Data Collection System.

tershed by augmenting available historical data. In addition, the field campaign can be used to validate or verify GIS data layers previously gathered for the watershed and available to field workers on the mobile computers.

The site chosen for carrying out the field testing and data collection campaign was the Williams River watershed in New South Wales, Australia, as illustrated in Figure 1. In addition to confronting water quality issues due to agricultural runoff, the Williams River is an area of active hydrological research and monitoring by various Australian research groups and government agencies [4]. Moreover, a network of water quality and flow monitoring stations have been installed in the watershed that are capable of telemetering real-time data and displaying them within a GIS-enabled web browser [2]. The availability of this pre-existing infrastructure was an attraction for testing the ENVIT Field Notebook prototype.

3 Computing and Sensor Technology

The ENVIT Field Notebook Data Collection System consists of a series of ruggedized mobile computers with the capability of acquiring, storing, displaying and transmitting environmental and geopositional data. Figure 2 illustrates the hardware components for the computing and sensing tech-

Figure 3: Example of the ENVIT Field Notebook software application for mobile devices.

nologies incorporated into the electronic journal.

Conceptually, the intent is to provide mobile users with a robust and integrated system with the potential to gather data from any digital sensor and log the information onto a pre-configured database on the mobile device. To *acquire* data, the ENVIT Field Notebook has interfaces for two different sensors: a GPS sensor and a water quality probe. In addition, manual input of environmental data from other field equipment or observations from the field study are possible through the mobile device software application. To *store* data, the integrated system contains a mobile device database application which stores records gathered from both the sensors and the user interaction. To *display* data, the electronic notebook has the capability of uploading records onto ESRI ArcPad GIS for cartographic viewing. Finally, to *transmit* data, the ENVIT Field Notebook has the capability for wirelessly transferring data from individual mobile devices to a centralized laptop which is then relayed wirelessly to a remote web server.

3.1 Mobile Device Software Application

The mobile device application consists of a graphical user interface (GUI), code to support the connection to the database and code to interface both the water quality probe and the GPS sensor. Figure 3 illustrates an example screenshot from the mobile device application. The application is programmed using Microsoft eMbedded Visual Basic 3.0 and runs on the Microsoft Windows CE 3.0 OS, common to many hand-help computers.

Scientific and engineering calculations have also been incorporated into the electronic notebook, including a calculator, a hydraulic engineering equation solver, a time-series plotter and an engineering unit converter. These modules allow field users to quickly compute standard discharge rates and geochemical fluxes.

3.2 Mobile Device Database

The foundation for the ENVIT Field Data Collection System is a database application designed to store and manipulate the data gathered from the manual user input or the automated sensor input. The database is capable of simultaneously updating multiple users working on various platforms. For this purpose, we have chosen to use Microsoft SQL Server on a field laptop to serve as a central data repository and Microsoft SQL Server CE for each mobile device database. Currently, the database design conforms to the data types, instruments and locations utilized during the field campaign. The design, however, is sufficiently flexible to configure many other data collection processes. Furthermore, a laptop application in Microsoft Visual Basic.Net has been developed to serve as a database configurator to facilitate the creation of future applications. Finally, the updating and syncing of the database records occurs wirelessly through the use of wireless cards and a field router, as detailed in Section 4.

3.3 Environmental Sensor

Coupling a mobile computer with an environmental sensor is a key development of the ENVIT Field Notebook since it provides the capability of automated data collection. Rather than having a user manually input each observation or data value from an instrument, the interface to a digital sensor allows the user to control, query and receive responses from the instrument. For the prototype system, we have developed an interface to the Hydrolab Minisonde multiple parameter water quality sensor. The probe has the capability of measuring water pH, dissolved oxygen, temperature, conductivity, turbidity and depth, among other parameters. Serial communication protocols are utilized to control the water quality probe and a customized user interface has been included within the mobile device software application.

3.4 GPS Sensor and GIS mapping

The electronic journal integrates two existing geotechnologies, mobile GIS and GPS. The use of a GPS sensor and mobile mapping software is a powerful combination that allows for the spatial display of geopositional data onto pre-loaded maps of the field site. The ENVIT Field Data Collection System consists of a customized version of ESRI's ArcPad GIS that allows the user to control the GPS, view GIS data layers for the field site and

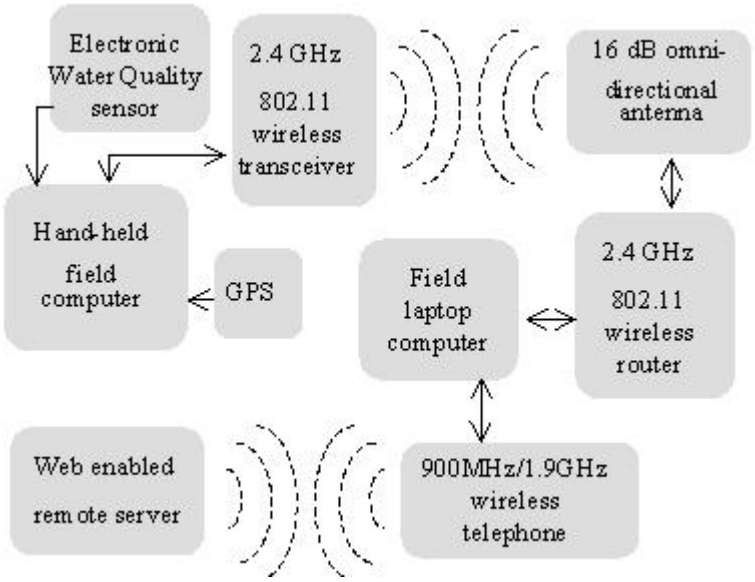

Figure 4: Wireless and Internet technologies developed as part of the ENVIT Field Notebook Data Collection System.

load records that associate the geopositional data with the environmental parameters collected at a specified location. The final product is a data layer that displays the spatial pattern of an environmental parameter and its relation to other GIS data layers (*e.g.* topography, land use). Additional data processing can be performed within ArcPad or ArcView GIS.

4 Wireless and Internet Technology

In order to seamlessly share data amongst scientists and engineers in both the field and at a remote location, the ENVIT Field Notebook Data Collection System includes a local-area wireless communications network. This network transmits data, specifically the SQL database contents, from each mobile device to a field laptop that serves as central data repository. An 802.11b field router with an omnidirectional antenna operating at 2.4 GHz and a series of wireless cards are used to provide a signal radius of several kilometers. This range permits various field teams to work independently at different locations within a watershed and update the central database instantaneously. Figure 4 displays the hardware architecture for the ENVIT system including the wireless and Internet technologies.

While transmission to the field laptop is performed through a local-area network, data transmission to a remote location requires the use of an web-

enabled device. Based on wireless coverage from various services providers, the use of a dual-frequency mobile phone was chosen as an appropriate technology. The ENVIT system prototype consists of a mobile phone utilizing a GSM/GPRS service from providers operating at 900 MHz in Australia and 1.9 GHz in Boston. The mobile phone is connected through a serial port to the field laptop and serves to transmit data periodically to a web server located at MIT. Periodic data transmissions are captured by a customized web services application and displayed within a browser for viewing by any interested party. The data display can include both time-series and maps of environmental parameters associated with a location in the field site.

5 Field Deployment

The deployment of the ENVIT Field Notebook Data Collection System is a coordinated effort between various field teams and individuals with specific data gathering tasks. For the watershed study in the Williams River, three field teams consisting of six to seven individuals were assembled. Each team was equipped with two ruggedized hand-held computers, a wireless card, water quality and GPS sensors, a streamflow gauge, a lightweight battery pack and other chemistry and biology measurement kits. As shown in Figure 4, each mobile device either operates the two sensors, or is used for wireless transmission and manual data input (*e.g.* streamflow, chemistry, biology). The integrated infrared port is used to transmit data between the two hand-held computers. During the field campaign, the three field teams gathered geopositional and environmental data at three separate river cross sections and transmitted data to a single station equipped with the wireless router and the field laptop. From this station, periodic data transmission was made to the web server at MIT and processed data displayed back to the field teams through a web browser.

In order to ensure appropriate field deployment of the technology, the ENVIT system also includes two hardware components that provide waterproofing and extend battery life. Modifications to an existing hand-held case were made so that the mobile devices, GPS and related cabling are protected from dust and accidental submergence. In addition, custom power management circuitry was designed and built to power both the mobile devices and the water quality probes from a single power source. This power pack enables approximately forty hours of continuous system use. These hardware developments are critical for field deployment since the mobile devices are susceptible to water damage and have high power consumption rates.

6 Potential Applications and Future Work

Design of the ENVIT Field Notebook has focused on creating a robust system capable of gathering environmental and geopositional data from se-

lected devices. Although the prototype is specific to a water quality and quantity study, the system design is sufficiently flexible to add other environmental sensors with ease. Only minor changes to the user interface and the creation of device drivers are required. Furthermore, the database, wireless and web technologies are transparent to a new instrument.

Work being pursued as part of this research undertaking includes the use of the system for watershed field studies, the integration of spatial data transmission and display through a GIS-enabled web application, and the incorporation of gathered GIS data layers and field data into a hydrologic model. We are also exploring the use of the system for applications other than water quality field measurements.

7 Conclusions

In this paper, we present the development of an integrated data collection system designed for acquiring, storing, displaying and transmitting environmental and geopositional data during field campaigns. The project goal is to provide a more accurate, efficient and robust method for gathering data by integrating existing hardware and software components with new mobile, wireless and Internet technologies. Field testing of the integrated system has been within the context of a water quality and streamflow study in the Williams River watershed located in New South Wales, Australia. Through field deployment, the full capabilities of the integrated system were demonstrated. A future publication will detail the results of the deployment of the ENVIT Field Notebook Data Collection System.

8 Acknowledgments

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