Real-Time Field Data Streaming

Abstract: This paper describes a field data streaming system and mobile computing application developed by the ENVIT student group at the Massachusetts Institute of Technology (MIT) for an environmental monitoring application. We address the following key points of the system: (1) system architecture; (2) database configuration; (3) PocketPC software application; and (4) GIS Web Services. The focus of this paper will be the software applications developed for providing geo-referenced display of data collected from multiple field teams. Web browser based GIS mapping provides the users with composite map information accessed from different map services. Specifically, we have incorporated a .NET Web services and ArcIMS to provide field workers with multiple access points to composite map data. Both services can be accessed through the mobile computer web-browser or ArcPad applications.

INTRODUCTION

A wide array of federal, state, and local agencies conduct activities that require mobile data collection and real-time mapping in the field. Mobile computing and GIS Web mapping is paving the way for solutions in many emerging applications. In particular, mobile computing is expected to be the main computing platform used in applications whose operation relies on field crews collecting data and or processing tasks in real time. Through wireless communications, mobile computers in such applications are connected to dispatch centers or other mobile computers for real-time collaboration purposes. There are many application examples of these technologies, and this paper considers one of them – an environmental monitoring application.

The system described in this paper was developed in the Department of Civil and Environmental Engineering at MIT. It is an integration of hardware and software tools that are both novel and useful. The objective of the integrated system is to streamline the
collection process and improve the accuracy of environmental field data using mobile and Web mapping technologies.

First, handheld PocketPC computers utilize software applications developed for field data collection and analysis from a water quality probe and a GPS sensor. The software design is both robust and flexible, allowing field users to adjust the configuration if the project scope changes. Second, a wireless Local Area Network (wLAN) architecture enables seamless transfer of the collected and processed data between multiple teams that are conducting the study. Third, mobile phone communication allows for real-time data transfer to the Internet for wide distribution and review using Web mapping applications. Field data mapping using ESRI ArcPad, ESRI ArcIMS and a customized .NET GIS Web service were developed for enhancing data collection and data visualization. The wireless network saves time by virtue of field teams having instant access to others' results, and due to the data streaming to an Internet application which allows project managers to have a real-time influence on the project from a remote location. In short, mobile GIS and Web mapping is extending enterprise GIS into the field.

Field Data Mapping Research Model

Historically, environmental studies have involved manual data collection with paper and pencil, and a separate analysis of the collected data upon return to the lab. Today, this has changed as enterprise systems, like GIS, can virtually be extended to any remote location by combining Internet GIS with GPS and wireless technologies. Figure 1 portrays the field research model used for the environmental monitoring field study.

Figure 1: Field Data Mapping Research Model

With GPS offering the location information, a user in the field can retrieve both data and a map of the surrounding area. Retrieving and updating the database information and
data collection can be sent to a centralized database from multiple users in real time, thus eliminating database synchronization and office input efforts. In order to achieve real-time mapping, a wireless Internet connection is required on the field computer. As long as the user can connect to an Internet provider, the communication between the field computer and the fixed server will allow dynamic map display and database access. With the technology in place, there are three main features of the field data collection system that make it superior to the traditional field study: (1) automated data entry; (2) live data sharing among researchers while still in the field; and (3) live data sharing to the Internet.

First, the automated data entry feature of the system eliminates human error from occurring during transcription of data or manual reading of instruments and maps. At the core of the system is a PocketPC-based, integrated wireless system. It allows field researchers to collect environmental and geopositional data and enter it into a handheld computer automatically or through a graphical user interface. The automated data entry also requires fewer man-hours in the field because many measurements (especially GPS) are taken without the need for human interaction.

Second, live data sharing within the field is made possible by wireless data transmission from the PocketPC computers to a mobile field laptop where it is processed and transmitted back to the PocketPC computers for instant analysis. This live data sharing among field users saves time in the field. It enables field researchers to analyze the status of the field study without the need to return to the central computer to be updated. This means that when they are collecting data at a site and have identified an interesting or important discovery, they can continue to acquire more data at that site before moving to another site. Alternatively, if a field researcher notices little or no data of interest at a site, he/she can modify his/her collection sites instantaneously to study the important sites in greater detail and ignore the unimportant sites.

Third, sharing data live on the Internet also saves time and allows for greater flexibility in the project. Normally, a project manager (or a sponsor or a client) of a field study does not get to see the results of the study until well after the study is completed. Sharing data live on the Internet allows the project manager to view the data live and make modifications on the study while the field researchers are still in the field. It also allows data analysts to begin studying and processing the data while the study is still occurring, thus permitting for a shorter time frame before the results can be published. In short, this field research model not only allows for field data collection, but also data use directly in the field.

**HARDWARE**

Hardware configurations were designed around the strategy of deploying three teams within a watershed at various locations. Each team was equipped with a HydroLab water quality monitor; a water flow meter to measure advective flow; and the mobile system components including hand-held computers – Compaq iPaq 3670 – with GPS.
components – Teletype GPS PCMCIA card – for location acquisition and wireless cards to transmit data.

Wireless and Internet Technologies

The system’s wireless data collection network (see Figure 2) was designed to allow data to pass from the PocketPC SQL Server CE database to the mobile field laptop SQL Server 2000 database (central repository). An 802.11b field router with an 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 and update the central database instantaneously. In addition, this also allows for viewing the data collected by other teams on each PocketPC (see next section on software under data transmission).

While transmission to the field laptop is performed through a wireless local-area network (wLAN), data transmission to a remote location (a fixed Web server) requires the use of a web-enabled device. The system consists of a mobile phone utilizing a GSM/GPRS service. The mobile phone is connected through a serial port onto the field laptop and serves to transmit data periodically to a fixed web server. The data is then available upon request from the Internet worldwide. The Web services application (described in the next section) provides up-to-date data and map images on request based on the live data.

Figure 2: Data Transmission between Mobile PocketPCs, Field Laptop, and Fixed Web Server.
SOFTWARE

Software configurations were designed in order to facilitate measurements and calculations needed in the field. Each PocketPC is equipped with graphical user (GUI) interfaces for unit conversions, graphing, equation solving, team member login, location login, and environmental and geopositional data entry. The data can be instantaneously viewed by many display media including the GIS Web service developed using Microsoft’s .NET platform and technologies, the GIS Web application developed using ESRI ArcIMS server, and ESRI ArcPad.

Database

The core application of the system is the database, developed using Microsoft’s SQL Server 2000 for the field laptop, and SQL Server CE for the PocketPCs. It is designed to allow multiple sensors on many different PocketPCs to record data, which will be transferred to the field laptop for data processing. It also allows for the stored data (in the central repository on the field laptop) to be retrieved and manipulated on the PocketPCs. The central database is capable of simultaneously updating multiple mobile computers, which allows field workers to be kept up-to-date. In addition, a laptop application was developed (using Visual Basic.NET) to serve as a database configurator in order to pre-configure the database with fundamental properties like equipment IDs that are to be used in the field. The updating and syncing of the database records occurs by utilizing the wLAN and through a series of wireless cards and an outdoor field router. The database application automates the georeferencing of the environmental parameters collected in the field.

PocketPC Data Entry & Data Transmission

When formulating strategies for collecting data, it is important to ensure that the process is completed efficiently but without compromising data integrity. Hence, a PocketPC application has been developed with utilities that automate business processes, which can speed field data collection. When a field researcher is more productive in the field, more data can be collected and processed in less time, thus facilitating tight budgets and shorter deadlines. This PocketPC application, developed using Microsoft eMbedded Visual Basic, allows field researchers to collect valuable spatial and tabular data by providing an easy-to-use interface for streamlining workflow. Additionally, it automatically captures input streaming from GPS devices, which enables real-time data collection. The user can use both automated and manual data entry tools as the application has manual inputs for external measurements a user might take. Furthermore, there are separate GUIs specific for manual data entry associated with biology, chemistry, and water flow parameters (see Figure 4).
The PocketPC application has the capability of “pushing” data to and “pulling” data from the mobile laptop field server. Once the main database located on the field laptop is configured with fundamental project parameters (i.e., equipment, location), the PocketPC application “pulls” the data from the SQL Server 2000 central repository to the SQL Server CE local database. This allows the PocketPC application to read the data so that the user can associate the fundamental project parameters with the environmental and geopositional data collected in the field.

The process and the associated system components are shown in Figure 3. When the user completes the welcome login screen (Figure 4), the PocketPC application signals to the SQL Server CE Client Agent (running on the PocketPC) to request the database from the field laptop. After the PocketPC detects that it is within range of the wireless network and that the IP address of the field laptop (the SQL Server CE Server Agent that it wishes to pull the database from) is available, it sends a request to the SQL Server CE Server Agent (on the field laptop) to transmit the data. The Server Agent accesses the SQL Server CE Database via the SQL Server ADO and retrieves the data to be sent. The data is then packaged and transmitted through the wireless network to the PocketPC. The Client Agent then enters the data into its local database via the local Database Engine. The data is now available on the PocketPC for entry, viewing, and manipulation. Every time a record is changed or added to the local database, a note is made in the database that this record needs to be updated in the server database.

![Figure 3: SQL Server CE “Push-Pull” Model](image)

Once the user has finished entering and manipulating data on the PocketPC he/she can “push” the data back to the field laptop using the PocketPC application. The application
initiates its SQL Server CE Client Agent to gather data to be pushed from the local database via the local Database Engine. The Client Agent then packetizes the data and sends it to the Server Agent on the field laptop. The Server Agent then enters the data into the field laptop database via its SQL Server ADO. This data is now available to be “pulled” by other users or transmitted to the fixed Web server for viewing over the Internet.

Figure 4: PocketPC Application Screens

Internet-based GIS and Mobile GIS

GIS is shifting its paradigm very fast from desktop-centric GIS to network-centric GIS. The wide adoption of network and application standards introduced and supported by the Internet initialized such a shift. An advantage of network-centric GIS is that it is able to provide GIS services in a networked environment, typically the Internet. Internet data publishing has become a popular trend in the GIS industry. Users can retrieve mapping and database information in real time using a common Web browser.

There is a wide variety of ways in which geographic information can be distributed on the Internet (Plewe, 1997). They are all founded on the same general design – basic architecture is similar to the client/server model, upon which the WWW and most other Internet services are based, including Web GIS and Web Services. Unlike traditional desktop applications, Internet-based GIS uses client/server technologies and requires distribution of computing tasks between the publishing server and the client browsers.
The client/server architecture model has been used widely since mid-1990s for on-line GIS service systems, in which a client submits a request to the server and the server processes the request and returns the result to the client. This client/server model is still widely used, and it has been implemented into the system.

Specifically, an ESRI ArcIMS 3.1 GIS Internet server is used to make the data available over the Internet. ArcIMS components were used to produce a Web mapping website, which allows users with Internet access to view, download, and perform spatial queries, all via a Web browser. In order to perform more advanced GIS functions such as spatial queries on geographic features, a Java-plug in is required to enable the Web browser (the client) to have more computing power. Unfortunately, Web browsers on a mobile device don’t support plug-ins, which in turn, result in lack of GIS feature data type support (only image data type). However, ESRI ArcPad can be utilized for both GIS image and feature data type for mobile GIS work, and has been tried out as part of the overall system. The use of a GPS sensor and mobile GIS mapping in ArcPad is a powerful combination that allows for the spatial display of geopositional data onto pre-loaded base maps. ArcPad includes wireless data acquisition and can act as a client to ArcIMS; GIS data (image format only) being served on the ArcIMS website can be accessed and downloaded.

Web Services

The distribution of GIS data is enhanced in the system with the use of Web services. Web services are a new type of Web applications that are self-contained, self-describing, and modular or component blocks for distributed applications. A few years ago, the idea of linking different applications could be solved with COM when dealing with Windows based Web applications. Web services are the new integration solution – information and data are exchanged using Internet standards XML, SOAP, WSDL over the HTTP protocol so that they are fully compatible with the Internet.

The key promise of Web services is the standards-based interoperable framework that allows the services to be accessed anywhere at any time, using any computer platform. Web services provide a simplified solution to multi-vendor interoperability by avoiding the necessity for standard data formats or standard data storage schemas. Web services will be a major driver for mainstream information technology's adoption of spatial technology. The ease of integration made possible by Web services knocks down barriers and exposes the power of GIS as a broader integration tool to combine GIS systems.

With so many benefits, the Web service architecture model has been incorporated into the system. A GIS Web service has been developed using the Microsoft .NET framework. In addition, a GIS Web application build on top of the Web service has been developed using ASP.NET, which leverages the Web server’s HTTP services. As shown in Figure 5, attribute data are retrieved from the central database on the server via the Web service. The geographic data (a suitable map) is fetched from Microsoft .NET TerraServer according to the latitude and longitude of the field site. The ASP.NET Web application
combines the two formats of data into a whole, and then broadcasts it over the Internet for display on the client (a Web browser on a PocketPC, for example).

Periodic uploading of field data, in the form of the database contents, is processed by the .NET Web service that can then display the field samples overlaid onto base maps. The custom-tailored ASP.NET Web application provides a flexible tool for distributing and displaying the field and image data in near real-time via the Internet (see Figure 6). The mobile Web browsers used by each field team could also access the ASP.NET Web application using the wireless local-area network. In this way, field personnel have methods of accessing the data collected and integrated from multiple field teams.
In short, the system integrates mobile, desktop and Internet tools for GIS capabilities while in the field and in the research lab. Making the data available “live” on the PocketPCs from the fixed Web server allows field users among different teams to view other groups’ data live through a graphic interface. Also, serving the data over the Internet makes it available “live” worldwide (i.e., back in a laboratory). Lab researchers spatially distant from the field are able to see what is going on immediately, and decide where the field teams should go and do next.

**Future of On-line Geoprocessing – Interoperable GIS Web Services**

Many on-line GIS service systems, primarily geodata service systems, have been developed in the past few years (Limp, 1999). Many systems, such as Autodesk Mapguide, ESRI Internet Map Server (IMS), Intergraph Geomedia Web, etc. are commercially available. However, there is a lack of research and development of geoprocessing service systems (Open GIS, 1998). Due to this reason, the OpenGIS Consortium, Inc. (OGC) is working on open source standard Web interfaces that leverage the power of the Web Services movement to enable seamless integration of online geoprocessing services. This framework will allow the ‘spatial Web’ – future geoprocessing applications assembled from multiple, network-enabled, self-describing Web Services.
Conclusion

This paper presents the development of an integrated data collection system designed for acquiring, storing, displaying and transmitting environmental and geopositional data during field operations. 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. Mobile and Web mapping are useful for summarizing and displaying field collected data while still in the field.

REFERENCES


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