ON-SITE COASTAL DECISION MAKING WITH WIRELESS MOBILE GIS

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ABSTRACT:

Coastal mapping and shoreline change detection are critical to many applications, including navigation, coastal zone management, coastal environmental protection, and sustainable development. Field surveying and on-site investigation become inevitable to ensure the quality of coastal decision making. To provide innovative tools for governmental agencies to increase efficiency and reduce operation costs, a wireless mobile GIS is developed and applied to on-site decision making for coastal management.

This wireless mobile GIS system has three components: a coastal-structure permit subsystem; a shoreline erosion awareness subsystem; and a wireless on-site spatial subsystem. The coastal-structure permit subsystem has been implemented to simulate, in a GIS environment, the decision-making process for granting construction permits for coastal protection structures. The web-based shoreline erosion awareness subsystem has been developed to aid local residents in making land-use decisions. It is implemented both to describe the extent of historic shorelines and previous erosion and to predict future shoreline change due to erosion. The wireless on-site spatial subsystem helps government officials remotely access and update spatial data from field, thus allowing for decision making in real time. This system has been developed in the United States based on the environment at Lake Erie, Ohio.

INTRODUCTION

Government agencies charged with the mission of managing coastal land and water resources face a great challenge (Carter and Guy, 1980). Lake Erie is a dynamic body of water noted for the ferocity of its storm waves and the havoc they wreak along the lakeshore (Mackey and Guy, 1994). In Ohio, ninety-five percent of the Lake Erie shoreline is eroding (ODNR, 1999). Over much of the region, erosion rates have been less than one meter per year. However, local rates may exceed two meters per year (Highman, 1997). Erosion-caused economic losses exceed tens of millions of dollars per year. As an early effort to protect and manage Ohio’s Lake Erie shore, in 1955 the State of Ohio began requiring permits for the construction of structures designed to control the effects of waves, floods and erosion on the shoreline. Permits were initially issued by the Ohio Department of Natural Resources (ODNR) Division of Shore Erosion, then, after 1961, through its Chief Engineer. Today’s Shore Structure Permits are issued through ODNR’s Division of Water (USDOC, 1999). Specifically, according to Ohio's coastal management law, §Ohio Revised Code (O.R.C.) 1521.22, a Shore Structure Permit must be obtained prior to the construction of any “shore structure” along the Ohio shoreline of Lake Erie. Shore structures commonly include nourished beaches, seawalls, stone revetments, bulkheads, breakwaters, groins, docks, piers, and jetties. To apply for a Shore Structure Permit, landowners submit an application to the ODNR Coastal Services Center that includes detailed plans and specifications prepared by a professional engineer. Figure 1 shows an example of a blueprint of a structure that might be included as part of an application. Plans and specifications for erosion control structures along the shore are reviewed in accordance with coastal engineering standards. A permit to construct the structure will be issued by the Chief Engineer if the proposed structure complies with applicable laws and rules (ODNR, 1999). A site visit is usually conducted some time during the 60 days of the review process. After the permit is issued, another site inspection may be conducted to ensure the structure is constructed in accordance with the permit.

Currently, most of the permit approval process is carried out by manual inspections based on the experiences of individual inspectors. Through our National Science Foundation (NSF) Digital Government Project, a research and development effort has been made to use spatial information technology to support the decision making process in a more effective, equitable and efficient manner. The system has been designed to a) use periodical shorelines and coastal change data in an Internet-based GIS and distributed environment for analyzing the appropriateness of the proposed structure, including regulatory compliance; b) employ mobile mapping and wireless technologies to support on-site field inspection activities that require GPS field surveys through access to spatial information about the site and communication with the office staff; and, c) develop an easy-to-access, user-friendly Internet-based system for making coastal residents aware of coastal change conditions and providing information about coastal erosion.

TECHNOLOGY REVIEW

With the rapid development of mobile communications and wireless technologies, more and more mobile GIS applications have emerged from the fields of location-based services, vehicle navigation and tracking, and mobile mapping (Kaasinen, 2003; Montoya, 2003; Nusser et al., 2003; Varshney, 2003; Grejner-Brzezinska et al., 2004). Most of these applications have adopted Pocket PCs, PDAs, or handheld PCs as mobile computer devices through the installation of existing mobile GIS software such as Autodesk's OnSite, Intergraph's IntelliWhere, ESRI's ArcPad, and MapInfo's miAware and MapXtend software packages. A wireless connection requires the use of either a wireless PC card attached to the PDA or a connection between the PDA and a cell phone.

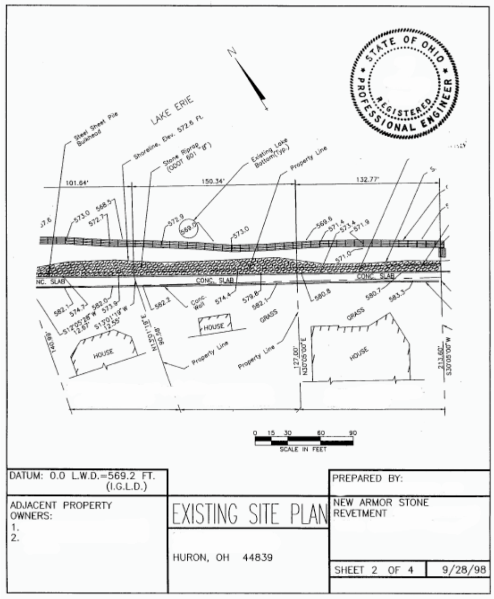


Figure 1. Blueprint of a Shore Structure.

The development of mobile GIS has been stimulated by the increasing demand for up-to-date geospatial information, along with improvements in mobile hardware performance and wireless network bandwidth (Maguire, 2001). As one of the driving forces behind mobile GIS, wireless networks can be divided into two broad classes, short range and long range, based on differences in the coverage area (Mallick, 2003). Long-range networks span large spaces such as a metropolitan area, a state, or an entire nation. Connectivity is typically provided by wireless service companies. The most commonly found long-range network is the Wireless Wide Area Network (WWAN). For data-intensive applications such as GIS, high-speed data transfer is required. The second-and-a-half generation (2.5G) networks provide the possibilities of a mobile Internet with high-speed data transfer at a rate of up to 144 Kbps. With 2.5G networks, multimedia capabilities have become possible. Two of the leading 2.5G network protocols are GPRS (General Packet Radio Services) and CDMA2000 1x (Code Division Multiple Access 2000 1x). In late 2001, the first third-generation (3G) network was implemented in Europe and Japan on a trial basis. These 3G systems provide broadband data transfer at a rate from 144 Kbps to 2 Mbps along with enhanced services such as streaming video applications, multimedia messaging services, and location-based services.

GIS technology has demonstrated unprecedented advantages in coastal management as well as other applications (Li et al., 1998). The latest advances in mobile GIS have come most notably with the support of the Internet. Access to spatial data over the Internet is growing rapidly, and web-based GIS are becoming more and more prevalent. Commercial software packages such as ArcIMS are now available for the construction of web-based GIS systems, providing effective tools for querying spatial and attribute data, displaying maps, and performing limited spatial analysis tasks. With the support of HTML ActiveX Server Page (ASP) web-design techniques, mobile devices such as PDAs are able to access specially designed web-based GIS systems through wireless connections to fulfill spatial analysis capabilities.

Despite the above developments, most web-based GIS systems have limited analysis functions. Analytical tools are essential for many comprehensive GIS applications, especially in rapidly changing coastal areas. Furthermore, mobile GIS systems that are capable of supporting decision-making processes are highly desirable. This paper presents the development of a mobile wireless GIS system to support coastal management and decision making.

SYSTEM ARCHITECTURE

Figure 2 shows the system architecture of this spatial decision-making system. The system consists of three components: a shoreline erosion awareness subsystem, a coastal structure permit subsystem, and an on-site mobile spatial subsystem. Based on historic shorelines, future shorelines are predicted and published in the shoreline erosion awareness subsystem using a shoreline prediction model (Ali, 2003). In this web-based GIS system, historic and predicted shorelines are organized on top of parcel maps. Coastal residents will be able to access this subsystem from their homes through the Internet and be able to view the current and future status of shoreline erosion, including its impact on their properties. This will allow coastal residents to inquire about coastal erosion conditions in an extended vicinity of their area, enabling them to take a proactive approach for structure protection.

For those landowners who decide to build shore structures protecting their properties, the coastal structure permit subsystem can be used to submit construction applications online. Then, state officials of ODNR will be able to review these applications, examine site conditions, evaluate approval criteria, and make objective decisions. With the support of mobile wireless communications, an on-site mobile spatial subsystem will provide officials with an effective tool for coastal site data collection, data transfer, and real-time database updates. A portable GPS receiver is attached to a PDA to collect GPS positioning data. Connection to a cell phone provides the PDA with wireless Internet connection. A specially designed, web-based, mobile spatial software system is implemented that helps officials conduct on site inspections.

The coastal structure permit subsystem is a web-based decision-making system. Coastal residents can also use this system to track their application status. This system provides government agencies with tools for managing the application database as well as evaluating plans and specifications for proposed erosion control structures. High-resolution satellite orthoimages and DEM (Digital Elevation Model) data are utilized to perform 3D visualization of the structure in a virtual environment, which may save a trip to the actual site. The implementation of the system will significantly reduce costs for such on-site inspections and enhance capabilities for making efficient coastal management decisions.

SYSTEM COMPONENTS AND DESIGN

Figure 3 shows a diagram of the integrated system, which has two basic components: the server side, and the client side. On the server side, ESRI® ArcSDE is used to manage the spatial database on the server. On the client side, three subsystems connect the spatial database through the Internet. Each subsystem is described in detail in the following sections.

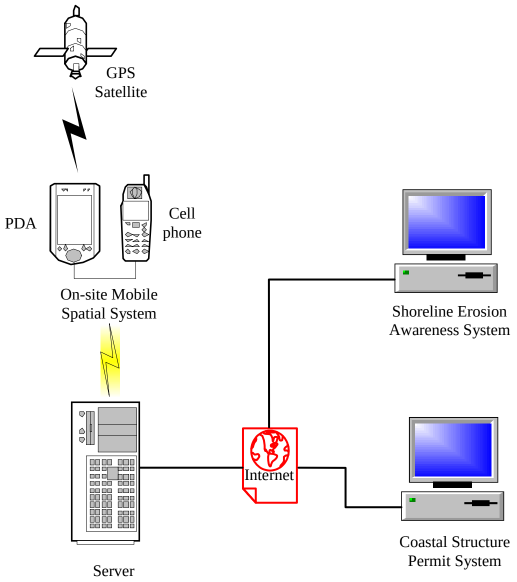


Figure 2. System Architecture.

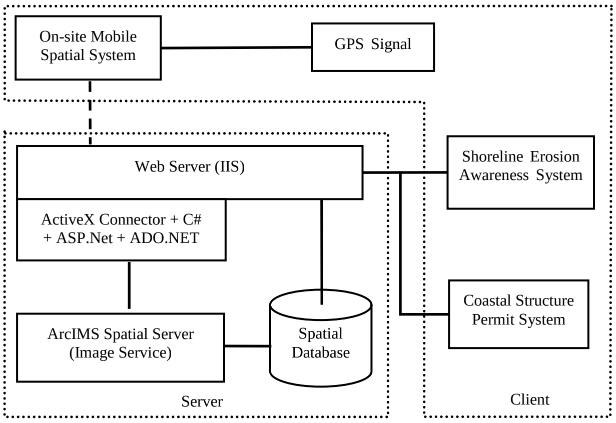


Figure 3. System Design Diagram.

Shoreline Erosion Awareness Subsystem

In the shoreline erosion awareness subsystem, observations of shoreline and bluff positions are made using satellite imagery and aerial photographs. Periodic comparisons of these features provide a basis for determining short- and long-term erosion rates. The purpose of this subsystem is to predict shoreline changes due to erosion processes. This subsystem provides fundamental information for examining environmental changes and supporting coordination between coastal management and land-use decision making. This information can be used to identify coastal areas at high risk of erosion in the present and in the future and to locate areas in need of protection.

The interface of this subsystem has been designed using Microsoft® FrontPage. The ESRI® ArcIMS HTML viewer provides users with GIS functionalities. Using ArcIMS image services, historic and predicted shorelines are overlaid onto parcel maps. With the hyperlink function, users are able to easily locate current and future erosion-impacted parcels. This helps the owner of an impacted parcel make an appropriate decision, e.g., to sell the property or construct a shore erosion control structure.

On-site Mobile Spatial Subsystem

A customized ArcIMS-based web page is designed using Microsoft® ASP.Net and the C# language. Through the ActiveX connector, the web page communicates with the ArcIMS image service that is established on the server. A PDA is used as a mobile client. The PDA connects to the server through the wireless Internet via a cell phone. The user can submit a request to the server through the web page. When the server receives the request, it processes the data and transfer the results back to the client. A portable GPS device is connected to the PDA to provide position information that can be used to locate the user's position and/or to update the database through the PDA. Figure 4 shows the equipment used in the on-site mobile spatial subsystem, including a Compaq® iPaq 3850 Pocket PC, a Pharos® Portable GPS device, and a Motorola® Star TAC 7860 cell phone.

Figure 4. Hardware of the On-site Mobile Spatial Subsystem.

Coastal Structure Permit Subsystem

The coastal structure permit subsystem simulates the decision-making process for granting Shore Structure Permits in a GIS environment. The purpose of such a subsystem is to help ODNR officials quickly and efficiently evaluate the potential impact of new structures. It also allows local residents not only to submit applications through this web-based system, but also to track their application during the review process. The subsystem incorporates geospatial data relevant to ODNR's permit approval process. It includes shorelines, aerial/IKONOS-derived orthophotos, a coastal terrain model (CTM), a water surface model (WSM), and parcel and construction design maps. It also includes USGS (U. S. Geological Survey) DOQ (Digital Orthophoto Quadrangle), DLG (Digital Line Graph), and DEM. These data are used in the application review process followed by ODNR managers. Figure 5 shows the logical data model of the coastal structure permit system. Each application includes information about the applicant, structure design, land parcel and other information.

Utilizing ADO.Net and ArcIMS, the subsystem maintains database updates and performs spatial analysis. A 3D visualization tool is developed using ESRI® ArcObjects, Microsoft® Visual Basic, and OpenGL. It can be installed locally in a computer at an ODNR office and connects to the application database and spatial data server. High-resolution satellite orthoimages and a DEM are utilized to present officials with a virtual 3D site environment. The subsystem shares the same database with the on-site mobile spatial subsystem through a wireless Internet connection.

EXPERIMENTAL RESULTS

The erosion awareness subsystem was tested in a study area along the southern Lake Erie coast that extends for eleven kilometers from Sandusky to Vermilion, Ohio. Figure 6 shows the interface of the subsystem. Linear regression techniques are used to predict future shorelines for the years 2010, 2020, and 2050 for numerous transects drawn perpendicular to the actual shoreline of 1990. The purpose was to visually overlay these future shorelines onto property parcel data obtained from Erie County. This enables coastal residents to see different erosion scenarios (Figure 7). Those parcels that would experience erosion in the future are highlighted in yellow in Figure 7. The subsystem also provides coastal residents with a 3D visualization of the coastal terrain model and the water surface, an animation of bluff erosion, a panoramic view of the test area, and a simulated fly-through of the test area.

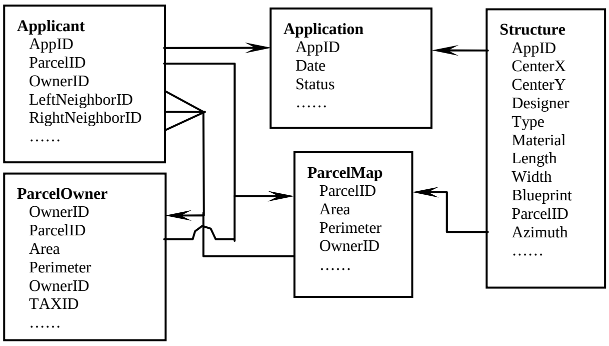


Figure 5. Logical Data Model of the Coastal Structure Permit System.

Figure 6. The Web-based Erosion Awareness Subsystem.

Figure 8 displays the first page of the coastal structure permit subsystem. An official can access and review pending applications and link to other subsystems from this web page. Figure 9 shows a snapshot of the 3D visualization and evaluation tool of this subsystem. For example, an applicant submitted an application for construction of a revetment to protect a property that was threatened by erosion. After delivery to ODNR, the original paper design map was digitized and a 3D CAD-based structure model was extracted. Displaying the historic, current and future shorelines, as well as the structure, in a 3D scene shows that there is a potential erosion threat to the property. The subsystem performed the following predefined analysis. First, by comparing the spatial extension of the structure with the parcel boundary, the structure was seen to be within the applicant's property limit. Second, by comparing the position of the structure to the severe shoreline erosion area, the proposed structure was seen to be stable, i.e., that it will not be flanked by erosion. Third, by comparing the historical mean-high-water level (MHWL), the structure was seen to be sufficiently higher than the water level, thus being of sufficient height. Fourth, by comparing the structure's position with the shoaling distribution, the structure is seen not to be subject to shoaling. In consequence, the subsystem assessment determined that the structure would remain stable and its purpose could be fulfilled. Additional site inspection will be required to examine the site's actual existing circumstances; the on-site mobile spatial subsystem will greatly aid this process.

Figure 7. Example of Future Shoreline and Potential Parcels Affected.

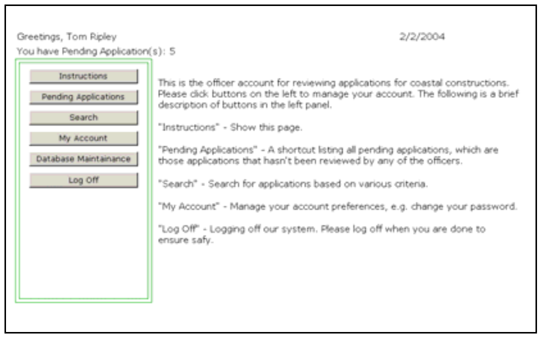


Figure 8. First Page of Coastal Structure Permit Subsystem.

Figure 10 shows the web-based interface of the mobile spatial subsystem, which has been implemented with ArcIMS ActiveX Connecter, Microsoft ASP.Net, ADO.Net, and the C# language. It provides simple map browsing (Zoom In, Zoom Out, and Pan) and query (Identify and Query) functions. Data used in this subsystem includes Erie County (OH) parcel maps, a digital T-Sheet shoreline, and a coastal structure information table. The coastal structure information table stores information related to coastal structures including parcel number, application number, center coordinates of the parcel, size and material of the structures, etc. These data are saved in a Windows 2000 server in the Mapping and GIS Laboratory at The Ohio State University. An experiment was carried out along the Lake Erie shore in Sandusky, Ohio, in early July 2003. After arriving at the designated applicant's parcel, the GPS signal was first received for the spatial coordinates of the parcel, which were (XXX422 m, XXX2966 m) in the UTM coordinate subsystem. Then, the PDA was connected to the server through a wireless network. The coordinates were input into the query interface and submitted to the server with a request for parcel and structure information. The server located the parcel that contained the given coordinates and transferred to the PDA a parcel map with the structure overlaid (Figure 11a). Detailed information about the structure can also be displayed (Figure 11b). Several additional parcels were tested with functions such as real-time database updating and on-site visual verification of the criteria checked previously in the office (Figure 12).

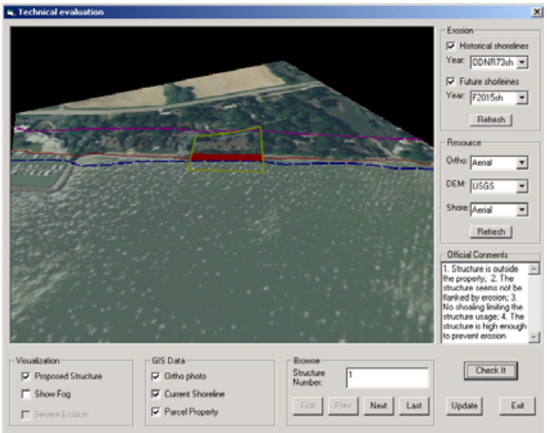


Figure 9. 3D Visualization and Evaluation Tool of the Coastal Structure Permit Subsystem.

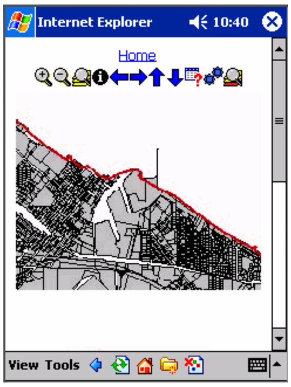
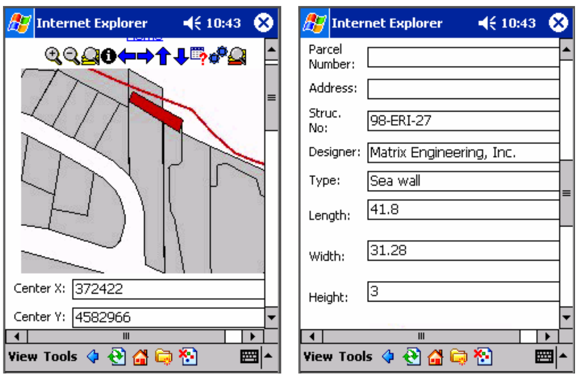


Figure 10. Interface of the Mobile Spatial Subsystem.



(a) (b)

Figure 11. Query Example of the Mobile Spatial Subsystem.

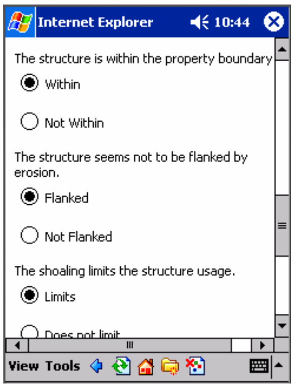


Figure 12. Criteria Checking and Updating for Site Visit.

CONCLUSIONS

This paper demonstrates an integrated system using wireless technology, Internet-based GIS, and mobile mapping in coastal management and decision making. The system consists of three components: a shoreline erosion awareness subsystem, a coastal structure permit subsystem, and an on-site mobile spatial information subsystem. The developed technology can greatly support all parties involved in coastal management for decision making including coastal residents, local communities, and state government agencies. When integrated, spatial information and relevant technologies can be utilized to improve the efficiency of coastal management activities and to make more objective decisions in, for example, the permit approval process. Although our system has been developed and tested along the southern Lake Erie coast of Ohio, it can be adapted and employed in other coastal areas.

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