Development of Service Oriented Web-GIS Platform for Monitoring and Evaluation using FOSS4G

Choosumrong, S.,[1] Raghavan, V.,[2] Jeefoo, P.[3] and Vaddadi, N.[4]
[1]Naresuan University, Faculty of Agriculture Natural Resources and Environment, Department of Natural Resource and Environment, 99 Moo 9 Tambon Tha Pho, Amphoe Muang, Phisanulok, Thailand 65000
E-mail: sittichaic@nu.ac.th
[2]Osaka City University, Graduate School for Creative Cities, 3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558-5858, Japan
[3]University of Phayao, School of Information and Communication Technology (ICT), 19 Moo 2, Tambon Mae Ka, Muang, Phayao, Thailand 56000
[4]Centre for Education and Research in Geosciences, C 2/2 Kumar Classics, Aundh, Pune 411007, India

Abstract
The usage of mobile devices has proliferated over the last decade. Smart phones now come with advanced technologies like Global Positioning System (GPS), advanced camera and sensors. Nowadays, mobile devices are used for different purposes such as individual tracking, checking current location and also collecting geo-referenced information. ~~A~~ Mobile GIS system offers geospatial functionality on smart phone devices by combining visualization with positioning. Due to these advancements, data can be collected easily in digital formats during field surveys and integrated into a desktop GIS for further processing and analysis. Further, Remote Sensing imagery and digital maps can be used as a reference backdrop for collecting data.~~—~~, As the existing GIS data can be easily accessed in the field in both offline and online modes, information from geospatial analysis can be verified and validated. In this study, we discuss the implementation of an Open Source Mobile GIS framework using the client-server model to addresses the present needs of data assimilation using smart phones. Further, geo-processing services can accessed on mobile devices and the results of geospatial analysis can be visualized in near real time. The proposed platform is generic and can be used to provide location based geospatial services for several application scenarios. The entire system has been implemented using Free and Open Source Software, and Open Geospatial Standards. It provides functionality for spatial data management and manipulation remotely. In this study, we demonstrate the utilization of the system for monitoring and evaluation of scenarios for Emergency Medical Service (EMS) tracking and management of vehicle road trips and for the monitoring and evaluation of mangrove forests. The system is easily customizable for other situations.

1. Introduction

Information technologies have gained importance in organizations worldwide, due to their efficiency and low costs in spatial data management that is vital for sustainable development. Recently, several new technologies to collect and update spatial data have become available. A wide range of web based geospatial services provide advanced platforms for distribution of spatial data. Mobile GIS is a mature technology which takes geospatial technology beyond the walls of an office. Consequently, mobile applications have extended to field use which allows the user easy access, storage, updates, analysis and real-time visualization of field data. Till recently, mobile GIS applications were mainly used as a navigation or location-aware system. Mobile GIS technology nowadays offers a potential alternative to fill the gaps of traditional GIS systems. These systems are capable of providing near real-time data pertaining to spatial features such as street networks, hospitals, cinemas, schools, and business markets. With mobile GIS technology, emergency workers, inspectors, maintenance teams, utility crews, fire fighters, and many other field workers have the potential to access the enterprise geospatial data from the server-side to accomplish their tasks with high level of accuracy. More importantly, it is also possible to update these geospatial enterprise data in real time.

Typically mobile GIS have two main categories of application; field-based data collection and location-based services (LBS). The field-based tasks include collecting, validating, and updating GIS data from remote field sites. For instance, adding new point feature or street polyline feature and changing or updating its existing attribute data are field-based GIS tasks. Unlike the field-based GIS, the key consideration of Location Based Service (LBS) is retrieving information regarding a spatial feature such as finding facilities or access paths in the context of the user's current location. The main difference between field-based GIS and LBS is that the field-based GIS is capable of editing geospatial data and/or add new spatial features in the field (Tsou, 2004) while LBS is only retrieving the spatial information in the proximity of current location. Wide availability of mobile devices and utilization of Free and Open Source Solutions for Geoinformatics (FOSS4G) has led to an increase in the gathering of near real time field data using Mobile GIS applications. In this context, mobile GIS has come to be an active area of research in the field of geospatial science. Keeping this in mind, the present study was aimed at extending the application to the field of emergency routing and mangrove forest monitoring.

Subsequently, the attempt was to develop a Web-Based GIS mobile application for multi-purpose use and provide an easy web interface based on real-time data communications, using FOSS4G. To respond to the need for remote spatial data management, web-based analytical tools to process geospatial data manipulation are used in many services and organizations. In this study, the Web application is implemented using jQuery Mobile (jQM) to interact with the spatial database on a mobile device. HTML, PHP and JavaScript are used to develop the user-friendly application for the mobile device. The system allows the client GIS to update and edit spatial data via mobile devices. jQM is not required to be installed on client devices since the Web application is executed on the server side. The utility of the developed mobile GIS system for multi-purpose field survey is discussed and demonstrated.

2. The Architecture of Mobile GIS

The mobile GIS use the client/server architecture that is common in Internet based applications. The client-side mobile GIS components are end-user hardware devices that can display maps or provide analytical results of GIS analysis. The server-side components provide access to geospatial data and perform geoprocessing based on request from the client-side components. Between the client and the server there are various types of communication networks which facilitate access to geospatial data and services. Mobile GIS is the extension of GIS technology from the office into the field. A mobile GIS system enables field-based personnel to capture, store, update, manipulate, analyse and display geographic information. Mobile GIS integrates one or more of the mobile devices technology, global positioning system (GPS) technology and wireless communications for internet GIS access technology.

Traditionally, the processes of field data collection and editing have been time consuming and error prone. Geographic data travelled into the field in the form of paper maps. Field edits were performed using sketches and notes on paper maps and forms. Once back in the office, these field edits were deciphered and manually entered into the GIS database. The result has been that GIS data has often not been as up-to-date or accurate as it could have been (Pinde and Jiulin, 2011). The jQM provides a rich set of jQuery plug-ins, widgets and a cross-platform API for creating mobile web applications. It is more or less similar to the jQuery User Interface (jUI) in terms of code implementation. The jQM is freely available as an Open Source codebase and provides a rich user experience on Web browsers running on mobile devices (Ableson, 2011). jQM uses HTML5, JavaScript, AJAX and CSS3 features to enhance basic HTML markup in order to create a consistent mobile experience across supported platforms. jQM based application work on mobile devices without JavaScript, even though a lot of redundant HTML is transferred over the network. For users who have a browser that supports JavaScript, the server only generates HTML on the first request and then subsequent requests use JSON and client-side templates to dynamically render the page. JSON is the syntax for storing and exchanging text information. JSON documents are typically smaller than XML, and faster and easier to parse (Choosumrong et al., 2012b).

The server-side provides access to geospatial data and performs online spatial requests such as spatial query, find, measure, and proximity analysis based on requests made by from client-side. On the other hand, the user at the client-side can display and navigate through different GIS layers of the geospatial data hosted by the server-side. The major components of the Mobile GIS system are presented in Figure 1.

3. Free and Open Source Solutions for Geoinformatics

The advances in FOSS4G provide an alternative approach to geospatial software development. FOSS4G has become popular as a practical alternative for developers and users and has been successfully used in many applications. The FOSS4G software stack comprises of system software, data processing tools, data delivery and user interface tools for both desktop and web-based environment.

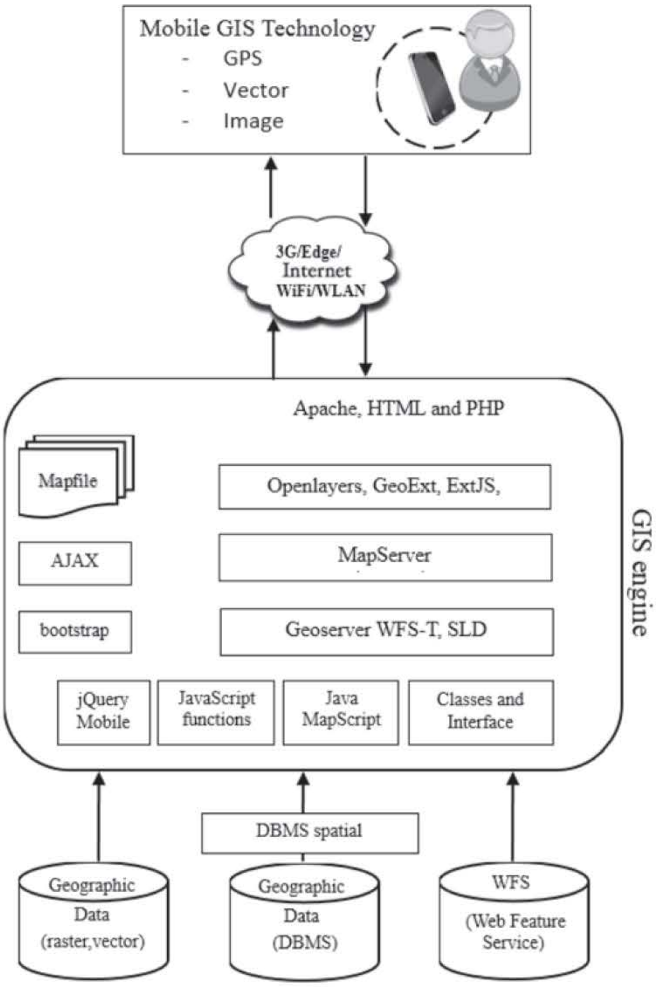

Figure 1: Mobile GIS architecture

According to Jolma et al., (2006) it is possible to support Environment Modelling and Management (EMM) workflows that involve mapping, geospatial analysis, and community based participatory procedure by using current FOSS4G software stack (Choosumrong et al., 2012a). In this study, FOSS4G stack was used to develop a comprehensive web-based application for Mobile GIS system. This study describes the integration of various FOSS4G, Open Data and OGC compliant open standards to create a comprehensive platform for deploying Web-GIS applications.

4. Mobile Positioning Technology

The cornerstone of most mobile GIS applications is location awareness. This is particularly important for LBS needed in managing emergency situations. By enabling location identification, a mobile device itself can help to pinpoint the location of its owner or event. Realizing the large and growing incidence of emergency calls made by cell phones, countries have passed legislation such as Enhanced 911 (E911) in the United States (1996) and similar legislation in Europe, which requires the telecom providers to disclose the location of emergency calls with a certain degree of accuracy. These requirements have driven considerable advances in emergency response. Presently the main mobile positioning technologies are based on GPS satellite, cellular network, Wi-Fi network, IP address, and radio frequency identification (RFID) locations.

4.1 Development of Mobile GIS for EMS

Emergency Medical Services (EMS) plays an important role in providing relief to the patients and people who meet with accidents. The EMS system is a part of the National Institute for Emergency Medicine (NIEM[1]) that provides Emergency Car (EC) and Ambulance Car (AC) etc. in Thailand.

[1]http://www.niems.go.th/

The EMS in Thailand was started by Hua Khew Poh Teck Tung Foundation (currently named as Poh Teck Tung Foundation) and provides service to transfer patients and emergency casualties. The Ruam Katanyu Foundation is another institution that provides similar services. Both the foundations have initiated emergency medical systems that people can access for emergency medical services. The EMS in Thailand has been developed in both public and private sectors and is equipped with tools and lifesaving devices in the emergency rooms of the hospitals. However, the, EMS staff need a more systematic way of identifying the real-time location of the accident point which will allow the EC or AC to easily reach the exact location and to use the optimal route to reach the accident point. The idea is to understand:

1) The exact location from where the emergency call was received?
2) The identity of the person who is calling?
3) The state of the patient?

This system is being practiced in Buddhachinaraj hospital, Phitsanulok Province, Thailand. The emergency officers have basic information of all the patients in the hospital database such as name, gender, age, chronic disease etc. that were collected during their admission. However, they were unable to identify the location of the patient when a patient was calling from home or any other location. The EMS member club system understood the necessity for implementing a system to store the location of the patient along with other important information (Figure 2). The aim of this application is to implement a user friendly Mobile GIS interface with the objective of supporting the system of EMS member club to collect the relevant data and store in a database. Moreover, this system has been integrated with Emergency Routing Decision Planning (ERDP) that is capable of determining the optimal routing (Choosumrong et al., 2014) from the nearest ambulance to the patient's location as well as from the patient's location to the hospital.

4.2 Developing Mobile GIS for GPS Tracking and as a Warning System for Road Trips

This section describes a Mobile GPS tracking and warning system which was implemented. Lately, many applications for mobile devices consist of facilities for using GPS tracking and visualizing the recorded routing. However, most of these available applications do not provide service interoperability. Crashes on rural roads are a serious issue in Thailand. The social and economic costs are high. The government's road safety strategy of 'Safer Journeys' signals that more must be done to improve safety on our high-risk rural roads. According to the Thailand's Road Safety Directing Center, crashes on rural open roads (city highways and local roads with speed limits of 80km/h or more) accounted for 31.05% of road crashes for the five-year period from 2010 to2015. The vision of 'Safer Journeys' is 'a safe road system increasingly free of death and serious injury'. The strategy gives us a roadmap for focusing our efforts on where the greatest gains can be made. Roads and roadsides are an area of great concern, and high-risk rural roads are identified as requiring early action under the strategy. Statistics provided by Thailand road safety direction centre on the rural roads accidents indicate only the number of accidents that have occurred in the previous year. Presently, these are just static maps and drivers do not get dynamic information or warnings when they are driving into high risk rural roads area (Hsueh et al., 2008). Keeping this in the mind, this study was aimed at implementing a warning system for the risk accident area by integration of data from the GPS tracking service and data on the 'risky rural roads area'. Figure 3(a) shows the system architecture and Figure 3(b) is the illustration of changes of the points once it was intersected with the rural roads risk area.

4.3 Integration of Mobile GIS and RS for Developing a Mangrove Forest Monitoring System

Mangroves are small evergreen trees that flourish in the intertidal zones of the Thai bay and Andaman Ocean coastal line. Mangroves provide a variety of ecological services to human beings, such as the protection of coasts from typhoon damage, pollutant absorption, and water purification. They are also habitats for diverse flora and fauna, including many rare species (Blasco et al., 1996, Murray et al., 2003 and Sheridan and Hays 2003). The Department of Marine and Coastal Resources (DMCR) is the nodal agency that is responsible for maintaining the sustainability of mangrove forests in Thailand and they coordinate the efforts of all other agencies who take part in the protection, management of conservation and restoration of these mangroves. However, the problems regarding mangrove forest management still exist due to their scattered locations and difficulties in accessibility for monitoring and preservation. Further, data transfer to head office does not happen in real time, as a result warnings and issues recorded in the field are not communicated effectively. About one-third of the mangrove forests, equivalent to 20.6 million hectares (FAO, 2007) have been lost worldwide during the past 40 years.

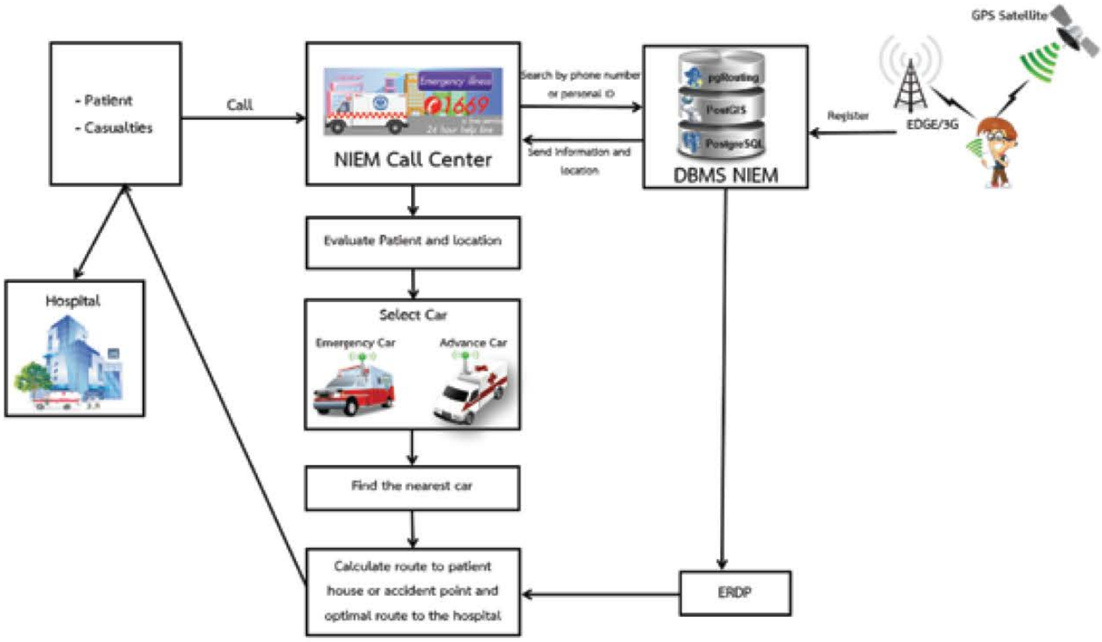

Figure 2: EMS member club system framework

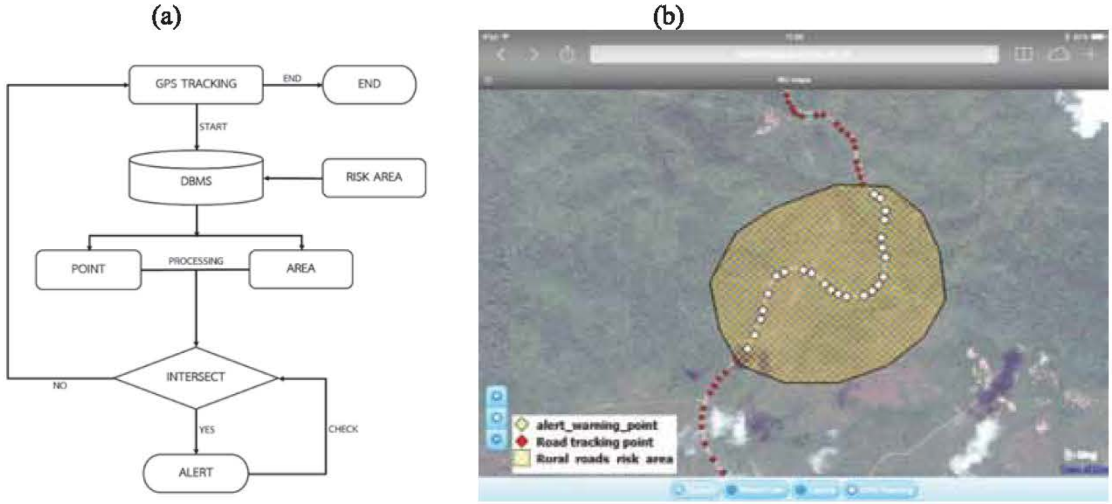

Figure3: Warning system for the risk accident area framework

The disappearance of two thirds of mangrove cover during past three decades in Trat Province is one example of the drastic decline of mangrove forests in Thailand (DMCR, 2014). Decline of mangrove forests occur mostly due to massive reclamation projects in the coastal region, destruction by tidal waves, and rapid urbanization (Linneweber and de Lacerda, 2002). Consequently, mapping and monitoring mangrove cover changes has become an essential need in Thailand. In Thailand, most areas of mangroves have been encroached upon to take up lucrative shrimp farming. Thailand had a total of about 2.3 million hectares of mangrove forests over during the past, but records indicate that in 2004 this amount has declined to 1.5 million hectares. The Trat Province consists of a total area of 61,974.19 hectares of mangrove cover. It is distributed among its districts as follows; 50,826.01 hectares in Muang district, 5,363.26 hectares in Saming district, 4,911.53 hectares in Laem Ngob district, 690.06 acres in Ko Chang island, 159.78 acres in Klong Yai district and 23.54 hectares in Ko Kood district (DMCR, 2014). Many studies indicate that Remote Sensing (RS) has advantages over traditional field investigation methods in monitoring of wide-spaced mangroves (Sader et al., 1995, Brian and Timothy 1996, Green et al., 1998, Kovacs et al., 2005 and Hirano et al., 2003).

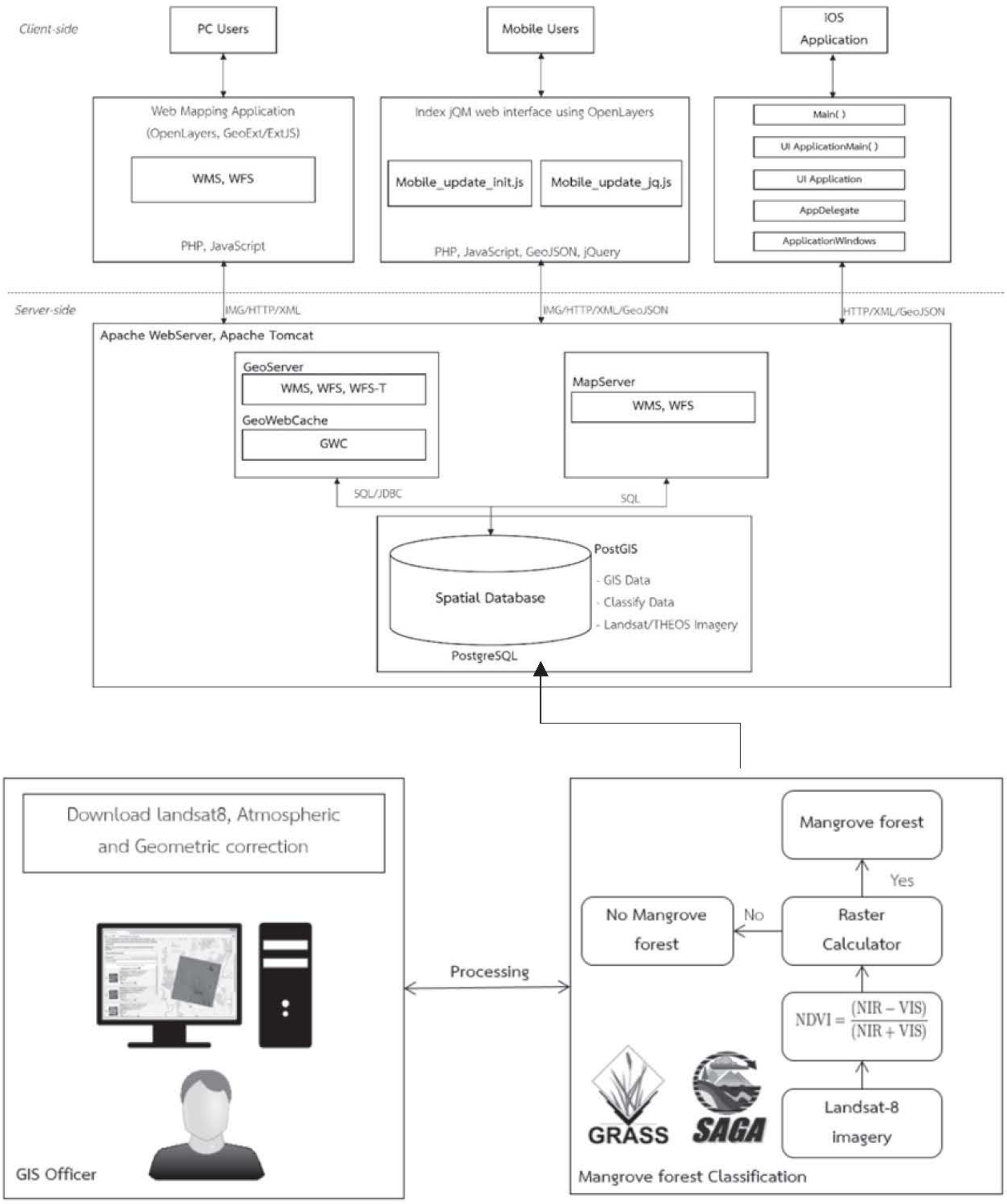

Figure 4: Mangrove Forest Monitoring and Notification system architecture

RS technology can obtain information about inaccessible areas and extreme environments (Vaiphasa et al., 2006). A number of satellite sensors have been used to identify mangrove forests, including TM/ETM (Brian and Timothy 1996), SPOT (Franklin 1993 and Pasqualini et al., 1999), SIR-C (Pasqualini et al., 1999), ASTER (Vaiphasa et al., 2006) and IKONOS and QuickBird (Wang et al., 2004). Many such studies, however, are primarily based on periodic surveys.

Simply, the prime need is to identify the land use category whether it is a mangrove area, built-up area, farm, water or others. A participatory framework for gathering field data is required for the purposes of near real time monitoring and evaluation. The technology of Mobile GIS emerged in the mid-1990s to meet the need of field work such as surveying and infrastructure maintenance. Such early systems operated mainly in an offline mode.

But with advances in wireless communications, especially the operation of 3G networks, mobile GIS is being increasingly connected to the Web GIS. The servers can be updated with latest information from the field using mobile GIS. The Web server can, in turn, support mobile GIS with rich content and advanced analytics. LBS's related to the location of a user are provided by the mapping applications used on the mobile platforms. It provides the convenience of using GIS to discover situations in the proximity, to navigate to a desired destination, and for georeferencing field data. Seemingly, Mobile GIS has become a technology that can potentially be used ubiquitously. In the present study, RS and Mobile GIS have been integrated as a means of sending and sharing the real-time data for mangrove monitoring and evaluation.. RS was used to classify the land use and land cover while mobile GIS was using for field data collection. As a result, two interesting projects were implemented, namely, Mobile GIS for Mangrove Monitoring (MG2M) and Mangrove Field Survey and Notification system (MFSNs). The aim of MG2M system was to develop a system to enable mobile computing device users to access the mangrove data. MFSNs proposed to create, at the beginning, a GPS enabled application with data exchange and remote service (WFS-T) and raster support (WMS, image) on a Windows Server platform and by using FOSS4G (Figure 4).

5. Software Environment and System Framework

The Mobile GIS for MFSNs application was designed and developed with a user friendly main interface (Figure5a). The main screen of the application provides access to the 3 tools which include:

1) Measuring distance and area (Figure 5b)

2) List of layers and legend (Figure 5c). Generally, the interface may display the map with whole data. Figure 5d is a representation of layers that were selected from the list in Figure 5c. Figure 5e shows the tool that user can show/hide any layer among selected ones (Figure 5c) and Figure 5f shows how the legend that appears on the interface for those layers

3) Reporting tool for field data which includes data and image files of current location (Figure 5 (g, h, i)).

The Web interface for MFSNs is shown in Figure 6. The user (DMCR's staff) can visualize the reporting points of real time field survey that send data, and they can make use of that data for recording and analysing purposes.

6. Discussion and Conclusion

A prototype of a Mobile GIS platform is presented in this study. The application is developed using FOSS4G. At the present stage of its development, the implemented Mobile GIS platform provides the basic GIS functionalities and location. The Client/Server GIS framework that was developed is an independent application, which can be run in every modern mobile smart phone without requiring to any other additional software. It is based on the commonly used interface that is user-friendly. It can be used as a tool for diffusion of the data among scientists and concerned citizens. The first and second scenarios illustrate the use of Mobile GIS for GPS tracking and evaluation system integrated with EMS club applications.

Table 1: Application development environment and tools

Software Used	**QGIS, GRASS GIS**
Operating System Server	Linux Ubuntu 12.04
Application Server	Apache Tomcat 7, GeoServer 2.5.2 and MapServer
Web Server	Apache2, PHP5
Database System	PostgreSQL 9.4, PostGIS2.1 and pgRouting 2.0
Development Language	PHP, HTML CSS, JavaScript, jQuery Mobile, bootstrap
Open Data	OpenStreetMap
Open Standards	OGC's Web Map Service (WMS), Web Feature Service (WFS)
User Interface	Openlayers 2.13.1, GeoExt

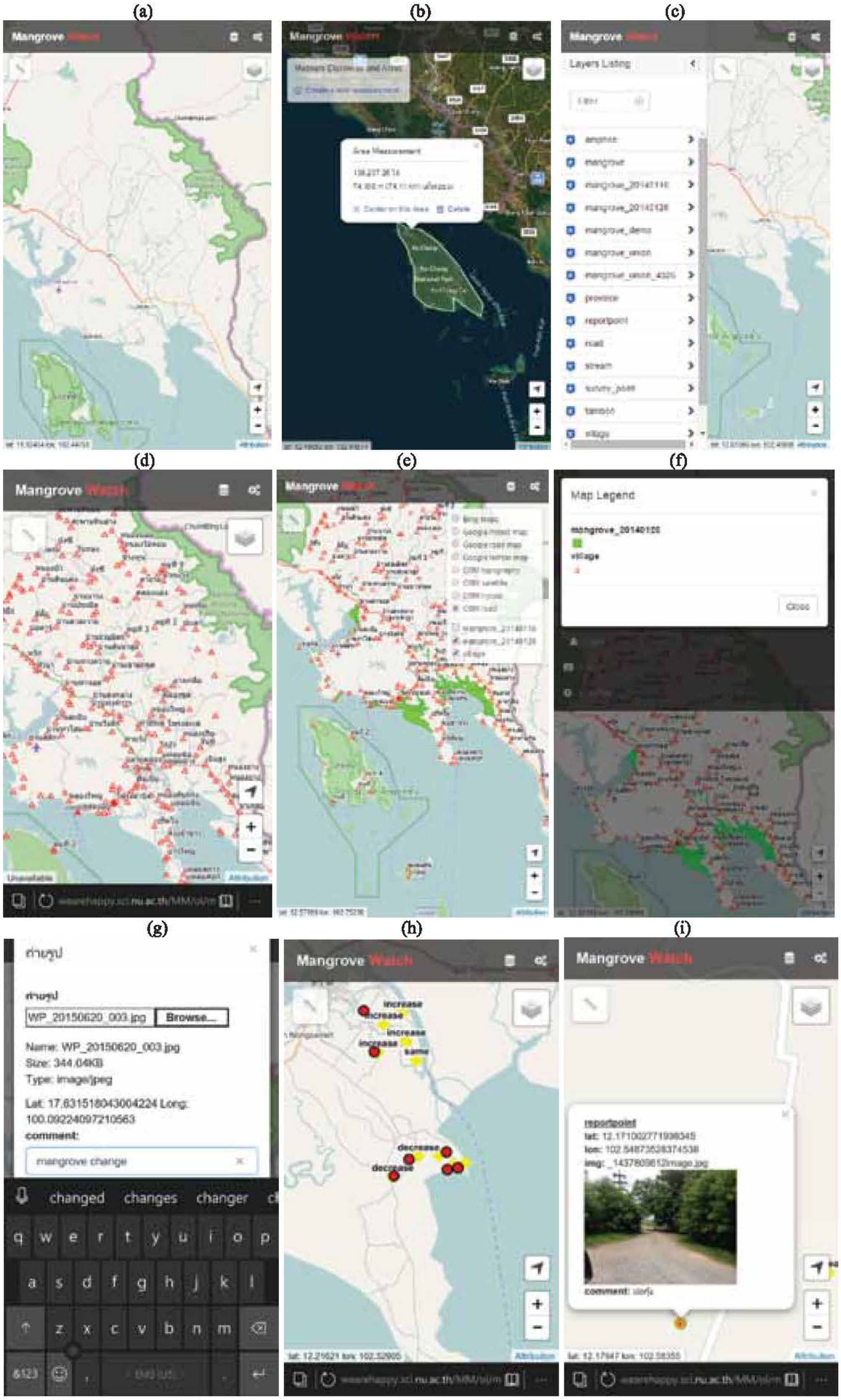

Figure 5: Mobile GIS interface for MFSNs

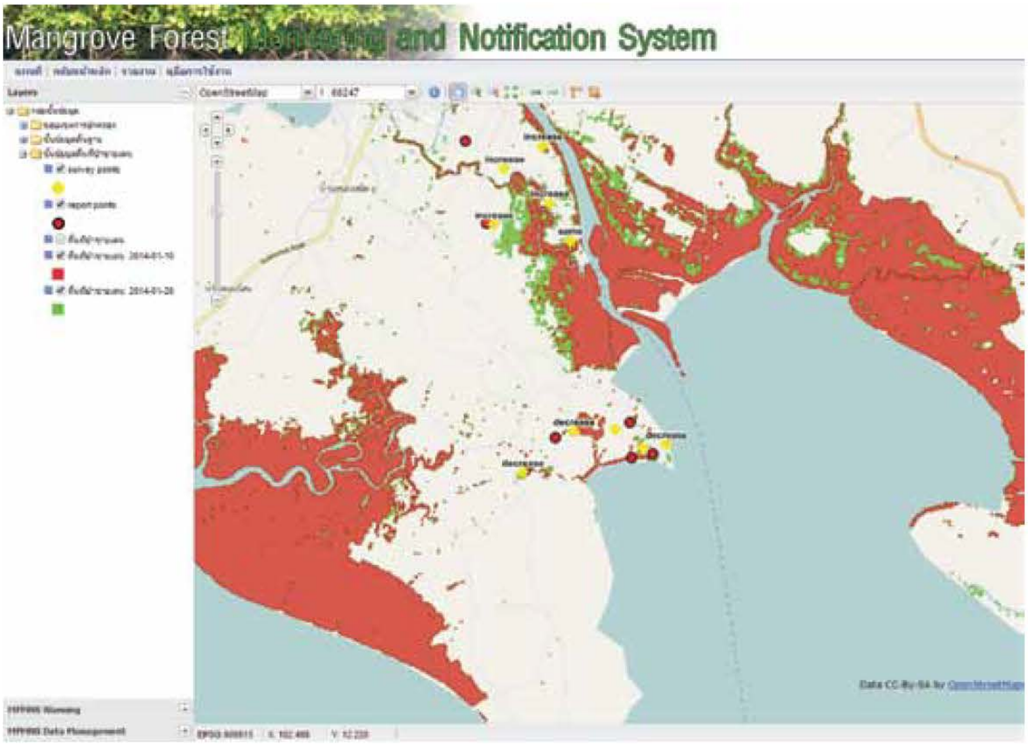

Figure 6: Web MFSNs interface

The ERDP system can be integrated with EMS member club system in order to calculate the optimal route from the nearest ambulance to the patient's house and bringing the patient to the hospital. In summary the main outcomes of this study are as follows:

- A new LBS application has been implemented by using FOSS4G. The integration of EMS member club with ERDP prototype incorporates functionality to update and query patient information, road network from mobile devices and, thereby, provide ubiquitous participatory framework wherein route reflect optimal choice depending on current conditions.

- The geospatial standards compliant EMS member club and ERDP system provide access to geospatial services via standard HTTP communication from a Web browser, thereby eliminating the need of any special software on client side.

- The efficacy of the ERDP system has been successfully demonstrated in scenarios of medical emergency.

- Successful implementation of an integrated EMS member club with ERDP system using available FOSS4G stack, Open Data and Open Geospatial Standard affords immense benefits of building interoperable, scalable and a robust platform to offer routing services in normal and emergency situations.

The third usage of the Mobile GIS is in Mangrove Forest Monitoring and Notification. This application helps the field parties to gather data from field survey and provide inputs for monitoring and protection. The application provides managers the opportunity to visualize and grasp the current situation of the mangrove forests and thereby decide the needed action plans. Some of the enhancements and improvements that need to be considered in the above Mobile GIS system in the future are:

- The risk areas such as accident points can be deployed as Web Processing Service (WPS) to automatically process and update the risk area using GRASS GIS and ZOO-Project WPS implementation.
- Integration of the EMS member club, ERDP and GPS tracking system to provide immediate support in emergency scenarios.
- Support for OGC Sensor Web Enablement (SWE) standards, wherein data from field

equipment such as CCTV cameras, weather stations etc. could be automatically received from sites and provide routing results that are based on such data inputs.

Acknowledgement

The first author would like to thank Naresuan University and Department of Marine and Coastal Resources, Thailand for the support given for this study. The authors would like to acknowledge Associate Professor Dr. Anchalee Srichamroen for motivation and constant encouragement. The authors are also grateful to Mr. Niroshan Sanjaya, Mr. Chingchai Humhong and Mr. Sakda Homhuan for their support and help in preparing this paper and for useful discussions in improving the quality of this work.

Reference

Ableson, F., 2011, jQuery Mobile and JSON, Learn how to Create Mobile Web Applications Powered by jQuery Mobile. Available from: http://www.ibm.com/developerworks/xml/tutorials/x-jquerymobilejsontut/x-jquerymobilejsontut-pdf.pdf (accessed) November 27, 2015).

Brian, G. L. and Timothy, S. D., 1996, A Technique for Mapping Mangroves with Landsat TM Satellite Data and Geographic Information System. *Estuarine, Coastal and Shelf Science*, 43, 373–381.

Blasco, F., Saenger, P. and Janodet, E., 1996, Mangroves as Indicators of coastal change. *Catena*, 27(3-4), 167–178.

Choosumrong, S., Raghavan, V. and Bozon, N., 2012a, Development of Web-GIS Application for Emergency Route Decision and Planning using AHP analysis and pgRouting Algorithm, *Proceedings of GIS-IDEAS 2012*, 414-419. (ISBN: 978-604-73-1498-8)

Choosumrong, S., Raghavan, V. and Bozon, N., 2012b, Multi-Criteria Emergency Route Planning Based on Analytical Hierarchy Process and pgRouting, *Geoinformatics*, 23(4), 159-168.

Choosumrong, S., Raghavan, V., Delucchi, L., Yoshida, D. and Vinayaraj, P., 2014, Implementation of Dynamic Routing as a Web Service for Emergency Routing Decision Planning, *International Journal of Geoinformatics*, 10(2), 13-20 (ISSN 1686-6576)

DMCR, 2014, Department of Marine and Coastal Resources. Available from: http://dmcr2014.dmcr.go.th/ (Accessed) November 27, 2015.

Jolma, A., Ames, D. P., Horning, N., Mitasova, H., Neteler, M., Racicot, A. and Sutton, T., 2006, Free and Open Source Geospatial Tools for Environmental Modelling and Management, *Developments in Integrated Environmental Assessment, 3rd edition, Chapter 10*, 163-180. (Elsevier) (doi:10.1016/S1574-101X(08)00610-8).

Food and Agriculture Organization of the United Nations., 2007, The World's Mangroves 1980–2005. *FAO Forestry Paper*, 153, FAO, Rome.

Franklin, J., 1993, Discrimination of Tropical Vegetation Types using SPOT Multispectral Data. *Geocarto International*, 8(2), 57–63.

Green, E. P., Clark, C. D., Mumby, P. J., Edwards, A. J. and Ellis., A. C., 1998, Remote Sensing Techniques for Mangrove Mapping. *International Journal of Remoter Sensing*, 19(5), 935–956.

Hirano, A., Madden, M. and Welch, R., 2003, Hyperspectral Image Data for Mapping Wetland Vegetation. *Wetlands*, 23(1), 436 –48.

Hsueh, C. F., Chen, H. K. and Chou, H. W., 2008, Dynamic Vehicle Routing for Relief Logistics in Natural Disasters. *Vehicle Routing Problem*, Edited by Tonci Caric and Hrvoje Gold (ISBN: 978-953-7619-09-1) Available from: http://www.intechopen.com/books/vehicle_routing_problem/dynamic_vehicle_routing_for_relief_logistics_in_natural_disasters (accessed) January 20, 2016).

Kovacs, J. M., Wang, J. and Verdugo, F. F., 2005, Mapping Mangrove Leaf Area Index at the Species Level using IKONOS and LAI-2000 Sensor for the Agua Brava Lagoon, Mexican Pacific. *Estuarine Coastal and Shelf Science*, 62(1-2), 377–384.

Linneweber, V. and de Lacerda, L. D., 2002, Mangrove Ecosystems: Function and Management. (Germany:Springer-Verlag).

Murray, M. R., Zisman, S. A., Furley, P. A., Munro, D. M., Gibson, J., Ratter, J., Bridgewater, S., Minty, C. D. and Place, C. J., 2003, The Mangroves of Belize Part 1. Distribution, Composition and Classification. *Forest Ecology and Management* 174(1-3), 265–279.

Pinde, F. and Jiulin, S., 2011, Web GIS: Principles and Applications. – 1st ed. United States of America.

Pasqualini, V., Iltis, J., Dessay, N., Lontier, M., Guelorget, O. and Polidori, L., 1999, Mangrove Mapping in North-Western Madagascar using SPOT-XS and SIR-C Radar Data. *Hydrobiologia*, 413, 127–33.

Sader, S. A., Douglas, A. and Liou, W. S., 1995, Accuracy of Landsat-TM and GIS Rule-Based Methods for Forest Wetland Classification in Maine. *Remote Sensing of Environment*, 53(3), 133–44

Sheridan, P. and Hays, C., 2003, Are Mangroves Nursery Habitat for Transient Fishes and Decapods, *Wetlands*, 23(2), 449–458.

Tsou, M. H., 2004, Integrated Mobile GIS and Wireless Internet Map Server for Environmental Monitoring and Management. *Journal of Information Science*, 31(3), 153-165.

Vaiphasa, C., Andrew, S. K. and Willem, F. B., 2006, A Post Classifier for Mangrove Mapping using Ecological Data. *Photogrammetry and Remote Sensing*, 61(1), 1–10.

Wang, L., Sousa, W. P., Gong, P. and Biging, G. S., 2004, Comparison of IKONOS and QuickBird Images for Mapping Mangrove Species on the Caribbean coast of Panama. *Remote Sensing of Environment*, 91(3-4), 432–440.