GIS integration in the Sahana Disaster Management System

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ABSTRACT

Disaster Management often involves using Information and Communications Technology (ICT) to manage large amounts of data efficiently. Data gathered from disasters are often related to geographic locations, such as the affected geographic region, thus requiring special forms of data management software to utilize and manage them efficiently. Geographic Information Systems (GIS) are specialized database systems with software that can analyze and display data using digitized maps and tables for decision making. Preparing and correctly formatting data for use in a GIS is nontrivial, and it is even more challenging during disasters because of tight time constraints and inherent unpredictability of many natural disasters. This paper describes the important role of GIS in disaster management, and discusses the most common characteristics of GIS and their potential use in disaster response. We follow up with a detailed description of the GIS prototype in the Sahana Disaster Management System.

Keywords

Geographical Information Systems, Disaster Management

INTRODUCTION

The past decade has witnessed a large number of natural disasters, primarily affecting highly populated urban areas and resulting in devastating human, structural and socio-economic losses. Management of the aftermath of these disasters, along with disaster preparedness and mitigation involves dealing with large quantities of heterogeneous data. Much of this data contains spatial components, which present a need for analysis and visualization. A Geographic Information System (GIS) is a system for capturing, storing, analyzing and managing data and associated attributes which are spatially referenced to the earth, and can be used for planning and decision-making. A GIS can assemble, store, manipulate and display geographically referenced data, linking this data to points, lines and areas on a map or in a table. A GIS stores and looks up objects that have one or more spatial attributes, such as size and position, and is used to process such objects. Thus, GIS can utilize geographic data produced during a disaster, and provide location based information that can be used to support decision-making.

Though GIS is successfully used in a wide range of applications spanning various fields, its use has always been a challenge in the disaster arena, due to the adhoc nature of disasters. The major hurdles due to lack of preparation are in most cases: The unavailability of a suitable GIS, the unavailability of related accurate data, and the unavailability of GIS domain experts. Groups that have managed to overcome these hurdles have seen the value and benefits that GIS can provide at times of disasters. During the aftermath of the Tsunami in Sri Lanka, the Center for National Operations, which was coordinating the relief operations, was fortunate to have a team of experts from the Sri Lanka Survey Department, MapAction U.K (MapAction, 2005), and the International Water Management Institute working around the clock for 2 weeks to produce report maps. The involvement of the Survey Department ensured that Sri Lankan data in the correct format was readily available. During the days following the Tsunami, geographic maps were the major kind of reports that were used by the media for indication of the relief efforts and damage assessment to the general public. Here, the use of GIS data rather than non-GIS JPEG maps ensured accurate presentation of information.

During the hurricanes Katrina and Rita, the American Red Cross Society, Federal Emergency Management Agency (FEMA), and other relief organizations used GIS to assist in its relief operations. Computer mapping, spatial analysis and GIS web services were key factors in providing communities and displaced people with food, clothing, shelter, and other essential services. The technology also helped in decision support for setting up shelters, hotel housing, emotional support programs, and providing meals.

In addition to the independent use of GIS to help manage disaster response, disaster management systems were also being created at the same time to manage various aspects of disasters by making efficient use of ICT, paving the way to the merger of disaster management systems and GIS. A group of Sri Lankan volunteers created the initial version of the open source Sahana (Sahana Group, 2005) disaster management system in response to the December 2004 Tsunami in Sri Lanka. Sahana, Sinhalese for "relief," is now accepted as the defacto system for managing aftermath of disasters. It has been used worldwide in many disaster scenarios after the Tsunami, including the Pakistan Earthquake and the Philippines mudslides, to track and manage missing people, organizations, shelters and requests/pledges.

The Sahana project has gained momentum, and the development team now consists of volunteers from numerous countries. Its goals have expanded, and the team is now working to provide a comprehensive ICT solution to Disaster Management, in other words, managing all related data of a disaster. Thus, GIS will become an integral part of Sahana, and will address the challenges associated with spatial data during disasters. This paper examines the role of GIS in previous recovery efforts, and discusses emerging potential applications of GIS in disaster management and the associated challenges. We then introduce prototype GIS integration to the Sahana Disaster Management System and discuss its applicability to disaster management.

CHARACTERISTICS OF GIS USE IN DISASTERS

GIS can be used to suit needs of varying complexity. The most basic use of GIS is to provide a simple form of creating maps. The ability to assemble data together in a common coordinate system makes it easier to gather and display data together. Use of a GIS in this form is accomplished both by GIS professionals using full GIS platforms such as GRASS (GRASS Development Team, 2006) or ArcMap (Environmental Systems Research Institute, 2006), but also by hobbyists and professionals in other fields using tools like the web or Google Earth™. Moving up in complexity, a GIS allows for the creation of spatial queries and spatial analysis. A spatial query can be as simple as selecting the nearest point to a location from a list, or as complicated as pulling together various diverse datasets to create new integrated datasets that provide more information than previous datasets.

Disasters often result in major damage to infrastructure, and a significant demand for resources, labor, and information. GIS can aid in communication, planning, and operations. For example, the 2005 Hurricane Katrina killed over 1800 people and caused more than $80 billion (USD) in damage. Roads and bridges were completely destroyed, and survivors were left stranded on roofs of buildings and in civic centers. There was an urgent and overwhelming need for food, water, medical care, and transportation. People from all over the world were eager to help, but logistical issues were a major challenge. Where were the people who needed help? What routes could be used to reach them? How should resources be allocated?

Mapping can provide crucial information to responders in a disaster situation. At the most salient level, it can provide current information about locations and routes. Satellite or aerial photographs can also help responders make decisions; for example, it may be necessary to find dry land to build a helicopter pad. Flooding increases the risk of certain types of infectious diseases, and images can display areas of standing water. Relief agencies may also need to estimate the population of a particular area, and GIS supports this as well.

Difficulties in using GIS during disasters

A major problem faced in spatial analysis and GIS during disasters is the unavailability of spatial data. The time constraints associated with disaster aftermath makes it more difficult to create new data or to find and gather existing data. Secondly, even if data is available, it might be that the particular dataset is not accurate, or that its quality or source cannot be assured. In this case, it would be a risk to make use of such data in humanitarian efforts and disaster management. There is also the issue of data being available in large quantities for certain regions, but not being shared accordingly, or not being made public. This restricts the usage of these datasets by the general public, thus reducing the efficiency of the relief effort as a whole. Additionally, the availability of spatial data in various formats might require the services of a GIS expert to analyze, upload and manipulate data and maps. This is not a practical solution in a disaster scenario, as most disaster management teams are made up of an ad hoc group of volunteers. Thus, it is unrealistic to expect a GIS specialist to be at the scene at the time of a disaster. Even when a specialist is available, spatial data might not be available, which brings us back to the first problem. The development of GIS maps takes a lot of effort and time, thus in many parts of the world adequate base data is not readily available.

High cost of GIS server maintenance was also a major inhibitor to increased public GIS use in the past. The cost of maintaining high-end servers, obtaining spatial data and managing these large quantities of data was very costly, thus making it impossible for small scale GIS servers to exist. An even higher cost is associated with creating new datasets, which takes up a lot of dedicated time as well.

Currion argues that GIS is still not fully utilized in humanitarian operations (Currion, 2006). He describes problems with obtaining current, accurate GIS data, and makes some practical recommendations for preparing GIS systems:

- Develop lighter GIS applications; quicker and easier to deploy in environments characterized by resource constraints, low levels of computer literacy and weak government structure.
- Adopt a modular approach and develop targeted applications that can support individual government ministries such as health, education, and security.

Factors influencing the increased use of GIS

More Spatial Data

More public and private agencies have recently been involved in the creation of spatial datasets. Examples of data that is important in disaster situations include satellite imagery or aerial photography, digital elevation models, jurisdictional boundaries, and transportation systems. The increase in data availability has made it possible for more applications to be able to rely on various base layers so that they can focus on applying existing data to problems.

Free Spatial Data

There has also been a corresponding increase in data that is made freely available to the public. In the United States much of this is dictated by law, paving the way for government created datasets to be made available in the public domain. This can be seen in datasets such as satellite imagery and elevation data being made available through NASA, boundaries and major roads data being made available as the VMAP series through NIMA, and US roads data being made available through the Census Bureau as part of the TIGER dataset (U.S Census Bureau, n.d). As data can be the most expensive part of a GIS, the availability of this data for free has made it possible for more organizations with fewer resources.

Open Source GIS

Open Source GIS has been around for a long time providing very customizable GIS solutions that often required far more expertise than standard commercial off the shelf products. Recently, Open Source GIS has closed in on many domains typically dominated by the proprietary GIS offerings. Much of the work recently has reduced the learning curve involved in Open Source GIS allowing GIS professionals with less programming skills to make use of the Free Open Source solutions. Many of the key players in Open Source GIS have come together under the umbrella of the Open Source Geospatial Foundation (OSGeo) (Open Source Geospatial Foundation, n.d.). As with many open source projects, many of OSGeo projects follow the Unix philosophy of having several tools each of which does their intended task well rather than a stove pipe of one piece of software that can do everything. The Geospatial Data Abstraction Library (GDAL/OGR) (GDAL, 2007) provides much of the glue to many GIS projects (proprietary and open source) by providing an easy way to access and translate data between many formats. Proj.4 (Warmerdam, n.d) provides the ability to go between many different coordinate systems. GRASS (GRASS Development Team, 2006) provides strong capabilities for advanced analysis. MapServer (Lime, 2007), Mapguide (2007), and GeoServer (Refractions Research, n.d) all provide powerful server side solutions for web mapping while projects like OpenLayers (n.d.), Ka-Map (n.d.), and MapBuilder (McWhirter and Shorter, 2007) provide strong client side support. PostgreSQL/PostGIS (Refractions Research, n.d) provide an advanced GIS environment within a relational database management system. One of the keystone features of many of the Open Source GIS projects is that they rely heavily on using open standards in order to maintain a scalable modularized architecture.

Internet and Low Cost GIS servers/data

The advent of Google Maps™ and Google Earth™ has taken the GIS world by storm, providing the world with zero-cost online maps of high resolution. The major advantage here is that all the data is managed by Google and is readily available anywhere, which has taken care of much of the hassle and high cost associated with spatial data. This success has been followed by services set up by large players such as Yahoo and Microsoft. There has also been an increase in services following open standards such as Web Mapping Services (WMS) (Open Geospatial Consortium, 2007a) and Web Feature Services (WFS) (Open Geospatial Consortium, 2007a) being made available through public and private interests.

Standardization

The Open Geospatial Consortium (OGC) (Open Geospatial Consortium, 2007b) is a non-profit organization that works on many areas of GIS and provides specifications of interoperability with many other standards. This helps interoperability between GIS and spatial data, increasing the interaction between various GIS and geographic data sources. This results in the use of many interoperable GIS components to provide advanced functionality and communication between any systems whether they are proprietary or open source.

SAHANA GIS PROTOTYPE

GIS Framework and Architecture

Sahana's GIS architecture, shown in Figure 1 below, supports a modular architecture. The GIS framework contains sub-modules to handle subsets of functionality. In most instances, these sub-modules act as wrappers, extending functionality through various existing Open Source GIS tools. The GIS framework also implements a plug-in based architecture, where various plug-ins can be used as underlying layers to provide functionality. This is an efficient and flexible approach as the administrators then have the choice of selecting their preferred tool to be supported. The advantage of this is that the other Sahana modules would not have to worry about the specifics of underlying tools, and can access GIS functionality in an abstract way. The sub-modules also follow a client-server pattern, where the GIS client and server modules should run independently, so the servers can operate on the same or different hardware as the client, and a single server could support multiple clients. No LAN or Internet capability should be required for full functionality, but if either is available the system should be able to make use of them.

The Sahana GIS framework consist of the following sub-modules

- Map Viewing Client
- Map Editing/GIS Administration client
- GeoRSS Export
- GeoRSS Import
- Map Service Catalog
- Cascading Map Server
- Spatial Database
- GIS Analysis

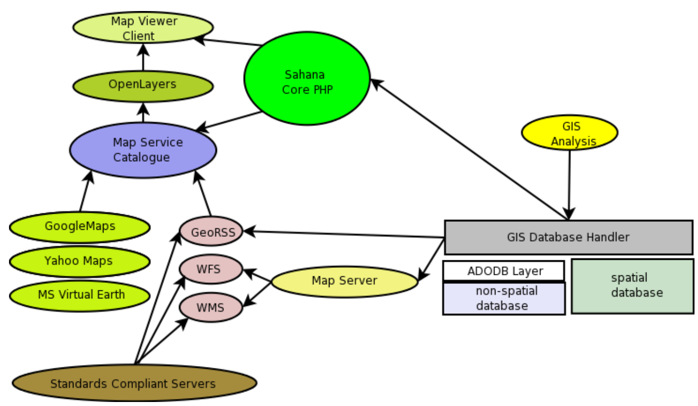

Figure 1. Sahana GIS Framework

Sahana GIS consists of client and server modules. The map viewing client of Sahana is based on OpenLayers (n.d.). The Sahana administrator has the option of choosing the various sources for maps to be displayed by the client. Sahana would also consist of a GIS server that would be based on UMN/Mapserver (Lime, 2007), which would be able to serve maps as WMS. The implication of this is that separate GIS clients, such as uDig or QGIS can access data from the Sahana server, while the Sahana mapping client can access data from various GIS servers, such as GeoServer (Refractions Research, n.d). The server module will accept data in supported formats and function as a map server. Both the client and the server will contain layer administration tools. The administrator may only want the server to provide certain layers, or the end user may wish to access map layers that are not available from the server (e.g., Google Earth™, NASA WorldWind data).

Efficiency is a major concern in Sahana. Computing resources may be limited, particularly in developing nations. The end user should be able to view maps in any computer powerful enough to run a recent web browser. It also should not be bandwidth-intensive; a disaster relief site might have a low bandwidth network connection shared by multiple users. Since Sahana uses the web browser as its primary client interface, it does address these problems. The architectural design of Sahana also allows for the option of having the GIS server and client on the same machines or on different machines.

Datatypes, Standards and Interoperability

In their paper about negotiation issues in humanitarian assistance, Bui et al. (1999) emphasize the importance of information exchange among different entities and mention the need to standardize information formats (Bui et al., 1999). This is an important issue with GIS data as well, which is what we strive to solve in Sahana.

The Open Geospatial Consortium (Open Geospatial Consortium, 2007b) defines the standards of GIS. The GIS sub-modules of Sahana support and take advantage of OGC standards (WMS, GeoRSS, Catalog Services) to serve, access and display geographic data. There are also plans for a Sahana sub-module that interacts with the database layer, thus allowing format independent access to the underlying data layers.

Sahana is built atop the AdoDB database abstraction layer, which allows for database independent functionality, which increases the flexibility of Sahana. This is, however, not suitable for GIS, as only a few DBMS are fully OGC compliant. PostgreSQL/PostGIS (Refractions Research, n.d) is an example of a full OGC compliant database, whereas MySQL's (MySQL AB,n.d) compliance and spatial capabilities are limited. We thus have to bypass the abstraction layer and identify the compliance of the DBMS in order to provide spatial functionality. We do this by detecting the underlying database server and its compliance, and accordingly decide whether to use the standard GIS data types.

Storage formats of geographic data are also of major concern when trying to support many underlying DBMS. Not all databases support geographic data types such as OGC's POINT, LINE, and POLYGON, and storing coordinates as numeric values lead to loss of spatial functionality, especially in spatial databases. The solution we developed for this problem was to store data in a geographic format such as POINT in full OGC compliant databases, which would be stored as Well Known Text (WKT) or Well Known Binary (WKB), and to emulate this in non-spatial, non-compliant databases by storing a string value of the same format. This would make migration of data from a non-spatial database to a spatial-database easier. This would also make the synchronization of Sahana across databases regardless of their spatial abilities a reality.

We also want to avoid duplicating other volunteers' efforts. For example, there are existing NGOs like GISCorps and MapAction (MapAction, 2005) that may already be used to provide GIS information. Sahana's goal is to work with their data, rather than create our own. To do this successfully, Sahana needs to be compatible with standard data formats (Wood, n.d). Below is an initial list of formats that should be supported.

- Web Map Server (WMS)
- Web Feature Server (WFS)
- ESRI Shapefile
- MapInfo
- Georeferenced raster graphics, e.g. GeoTIFF and ESRI worldfile.
- Google Earth's KML and formats for NASA WorldWind (Kim, 2006)

Sahana facilitates the sharing of available data via the server modules, which can be used by external GIS clients. Thus, the system promotes the idea of an ecosystem of many GIS servers, clients and data sources, where Sahana can act as all 3 as well, during disasters. This would allow everyone to share and use a rich source of GIS data during disasters, solving many of the problems described earlier.

GIS APPLICATIONS IN SAHANA

Situation awareness

The Sahana situation awareness module was inspired by the many websites during the hurricane Katrina that provided situational awareness facilities. These site primarily used Google Maps™ to create quick mashups , that could be used by the general public to enter information about certain locations (Scipionus, n.d.).

The situation awareness module of Sahana provides a mapping client based on OpenLayers, which would allow users to enter information about a certain location. The marker layer, which is of WFS-T type, provides clickable popups with the information on each location, allowing users to edit and add information to each location, in a wiki-like manner. The module allows users to associate information, author information, URLs and images to geographical locations. The visibility of certain markers can be controlled by the Sahana Access Control Lists (ACL), thus allowing users to store markers that are visible by a particular group of people only. The module also provides public editing facilities which can be controlled by the ACL as well, which allows the public to add/edit information regarding marker locations similar to wikis, thus being referred to as wikimaps.

The goal of situation awareness is to provide valuable information to the general public regarding various events happening at different locations. A previous version of the Situational Awareness module, which was called the Landmarks registry, was used by Sarvodaya, the largest NGO in Sri Lanka. Based on Google Maps™, this module was used to keep track of important landmarks in disaster affected regions, and was used in the Sarvodaya pre-deployment in Sri Lanka.

Currently, development is ongoing to integrate situation awareness with the messaging module of Sahana, thus allowing for situation awareness inputs to be sent in as Short Messages from mobile phones in the field.

GPS locations and coordinates

After a disaster, relief agencies (e.g., GISCorps) often visit the scene and obtain the Global Positioning System (GPS) coordinates of landmarks and other key sites. A GIS is able to plot GPS locations on an existing map, such as geo-referenced satellite image, so that responders can see where hospitals, ports, and other important landmarks are.

Sahana keeps track of various entities such as camps, organizations, people, inventory and aid. Most of these entities are mapped to geographic locations, making it vital to store this relationship as well. The mapping client, accessed from various modules, allows users to add markers of the entities on maps. These coordinates are in turn stored in the underlying database, which can then be used to create marker layers, or be used as GeoRSS feeds. Users have the option of placing markers on maps or manually entering GPS coordinates. This functionality was used heavily during the Philippines' Guinsaigon landslides, where shelters were tracked via the Camps Registry of Sahana.

Sahana also supports direct GPS connectivity. However, since Sahana is a web based system, hardware access at the client side is not trivial. For GPS connectivity to Sahana, clients should run a combination of gpsd (WebRing Inc, 2007), which handles the GPS connectivity, and GPSbabel (Lipe, n.d), which handles the format conversions. The system is intended to support import/export of waypoints as well, which could be directly used with the GIS to plot affected areas. The GPS unit is also used to obtain the coordinates of specific entities in the field, such as camps or people.

GeoRSS

In a disaster, geographic information may change rapidly. One approach to keep geographic information updated is GeoRSS. GeoRSS is based on RSS, a group of XML formats for news exchange (GeoRSS.org, n.d.). GeoRSS is a proposed standard that would allow news feeds to be tagged with spatial information. For example, if a communications center was set up in response to a disaster, GeoRSS would support a tag that provides information about the exact location of that center, which could presumably be added to a map. One European software product that monitors Tsunamis uses a GeoRSS feed from the US Geological Survey to gather current information on earthquake activity (Jackson, 2006).

Sahana supports the import and export of GeoRSS feeds. Thus, data from the Sahana databases, such as the locations of shelters, can be published as GeoRSS feeds, which can be used external to Sahana as well. The OpenLayers mapping client supports displaying GeoRSS feeds, thus information such as the locations of weekly earthquakes from the USGS earthquake feed can be displayed as markers on maps.

Visualization and GUI / Reports/statistics

The Sahana mapping client provides a consistent GUI, based on OpenLayers. The client module allows the user to view the map in a browser window and provides standard tools such as panning, zooming, and layer selection.

The mapping client is also used to display GIS reports. These reports can then be converted to PDF via the reporting module of Sahana. The entities that Sahana keeps track of, such as camps, people and organizations, can be used in conjunction with geographical coordinates to produce detailed reports. These reports are vital for decision making during disasters. The shelter registry of Sahana keeps track of the percentage of men, women, children, injured victims etc. residing within a camp. These can be used to provide map reports with colored markers according to the population density by camps, number of injuries by camps etc. which would make it easier to identify over-populated camps, and the closest camps that could accommodate the excess victims. The same report can be produced by executing a spatial query at database level as well.

CONCLUSION

Many factors have contributed to the increased use of GIS, and its potential is great in the Disaster Management domain. However, due to time constraints, problems arise that tend to reduce the effectiveness and efficiency of GIS during disasters. Standardizing GIS, and the use of existing GIS tools can help solve these problems to some extent. If the primary problems are solved, many unique and useful applications can be created using GIS during disasters. The Sahana disaster management system implements a somewhat ideal mix of GIS tools to make efficient use of existing data to manage disasters. It also focuses on allowing various other GIS tools to gather data from it by adhering to standards. Hopefully, this combination will help solve many problems during disasters, and ultimately, help manage disasters effectively.

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