Web GIS: Technologies and Its Applications

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ABSTRACT

Distributing geospatial information on the Internet is an enforcing factor for information providers. Internet allows all levels of society to access geospatial information, and provides a media for processing geo-related information with no location restrictions. Web-based GIS is evolved from different Web maps and client-server architecture to distributed ones. As such, Internet reshapes all functions of information systems including: gathering, storing, retrieving, analyzing, and visualizing data. The high cost of GIS system, the release of system specific databases, and the enormous software developer efforts on upgrading the system are fading with the introduction of web-based GIS. Moreover, disseminating spatial information on the Internet improves the decision-making processes.

This paper examines the current Web GIS technologies with emphasis on architectures. Eight state-of–the-art Web GIS products from leading GIS companies have been scientifically assessed. This paper also proposes a web GIS development strategies starting from requirement analysis, and ending in GIS use and maintenance. Disseminating Iranian Road information on the Internet has been presented as a successful implementation of the strategy.

It is concluded that the Internet based information delivery adds the margin of profitability of the Transportation and Terminal Organization. The proposed strategy has been tested successfully. Civilian can get to their destinations faster.

Key Words: Web GIS, Technologies, Architecture, Development Cycle

1   Introduction

GIS software has enabled users to view spatial data in its proper format. As a result, the interpretation of spatial data has become easy and increasingly simple to understand. Unfortunately, everyone does not have access to GIS, nor would he be able to spend the time necessary to use it efficiently. Web GIS becomes a cheap and easy way of disseminating geospatial data and processing tools. Many organizations are interested to distribute maps and processing tools without time and location restriction to users. Internet technology has made its way to many government organizations as well as numerous households. The ability to get information through Internet made spatial data providers to explore the Internet resources for disseminating spatial information. To provide a successful web GIS implementation it is required to consider the implementation as a process rather than a step. The implementation should also respect the available technology and the application requirements.

In this paper an overview of the current Web GIS technologies is presented. Available Internet GIS software is compared. A web GIS development cycle has been proposed and tested through publishing Iranian road information.

2   Web GIS Technology

Development of the Web and expansion of the Internet provide two key capabilities that can greatly help geoscientists. First, the Web allows visual interaction with data. By setting up a Web Server, clients can produce maps. Since the maps and charts are published on the Internet, other clients can view these updates, helping to speed up the evaluation process. Second, because of the near ubiquitous nature of the Internet, the geospatial data can be widely accessible. Clients can work on it from almost any location. Both of these features altars the way geoscientists do their work in the very near future. The combination of easy access to data and visual presentation of it addresses some of the primary difficulties in performing geosciences evaluations (Gillavry, 2000).

Web GIS is not without its faults. The primary problem is speed; GIS relies on extensive use of graphics. Connection speeds over the Internet can make heavy use of graphics intolerably slow for users. It will not match the complexity of

dedicated GIS programs such as "ArcView & ArcInfo", or "MapInfo" in near future. On the other hand, Web GIS does not require the same resources as these programs. Powerful computers, extensive training, and expensive site licenses are not required for a site wide GIS solution (Strand, 1998).

2.1 Transferred Geo Data

Except attribute data, a decisive question for using GIS in the Internet is the data format (vector or raster), which is used to transfer data to client. For data transmission to the client, map is converted in to no space raster or a suitable vector format. When raster data is transferred, a standard Web browser without extension can be used, since Web browser displays GIF and JPEG. That means the data on the server has to be converted to a raster format. The data volume due to the known image size and the original data on the server is safe as only an image is sent to the client. The disadvantage of using raster data is the lack of comfort of handling and regarding cartographic aspects, like font problem. Moving over an object with mouse cannot highlight single objects. In addition, a server contact is necessary per each request from the client.

Because of low vector data volume, it transmits faster than raster. Vector data handled by a standard Web browser with extended functionality (e.g. using plug-ins). The user gets a more functionality with vector data. For example, single objects can be selected directly or highlighted. One more advantage of using vector data is the possibility of local processing; it is not necessary to contact the server per executed browser action. The amount of vector data sent over Web could be three to four times less than the amount of raster data needed for equivalent resolution resulting in faster response time and greater productivity (Nayak, 2000). Disadvantages of vector data are manufacturer dependence, as well as, changing data volume; the amount of data varies with the selected area. To avoid data redundancy in client side, dynamic generalization must be provided. Distributing vector data may also endanger copyright rules. The choice of transferring data form (vector or raster) varies with applications and the existing infrastructures. Software products, which offer optional transferring of vector or raster data, may provide advantages. They may allow a pre-selection with raster data, and afterwards, loading of the actual vector data with the possibility of subsequently local process (Leukert & Reinhardt, 2000).

Different consortia are developing future standard formats for transferring data over the Internet. The Open GIS consortium, for example, presents Geography Markup Language (GML). GML shall enable the transport and storage of geographical information in eXtensible Markup Language (XML). Geographic information includes both properties and the geometry of geographic features (www.opengis.org). The W3C submits Scalable Vector Graphics (SVG), which is a language for describing two dimensional vector and mixed vector/raster graphics in XML (www.w3.org).

2.2 Interactive Web Maps

There are several technology levels to publish map data on the Web, ranging from sites that simply publish static Web maps to more sophisticated sites which support dynamic maps, interactively customized maps and multiple computer platforms and operating systems. In terms of Web GIS, the most challenging map is the interactive one. Within the Open GIS Consortium, a Special Interest Group (SIG) for WWW Mapping is working on issues of Web-based GIS publishing. This group has recently developed an essential model of interactive portrayal (Figure 1).
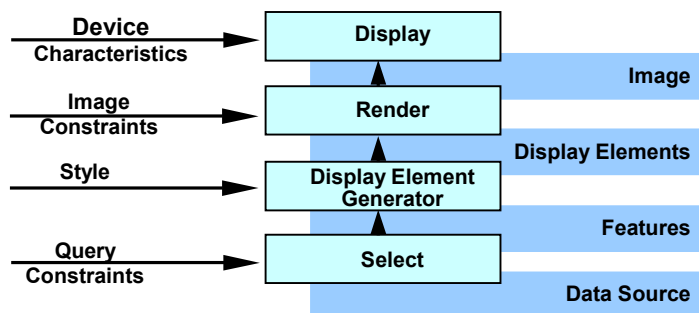

Figure 1: OpenGIS model of portrayal workflow (Doyle, 1999)

This model is a very useful tool to analyze and compare different architectures for Internet Map Servers and other Internet based GIS applications. Moreover, it is more precise than the common expression, which often leads to misunderstandings. The interactive portrayal model has four tiers:

- The Selection process retrieves data from a geospatial data source according to query constraints such as a search area or thematic selections

- The Display Element Generator process turns the selected geospatial data into a sequence of display elements. It attaches styles such as symbols, line styles, fill styles to spatial features, generates annotation from alphanumeric attributes, sorts the display elements in a certain order and does other graphical processing
- The Render takes the display elements and generates a rendered map. Examples of rendered maps are In-memory display lists, GIF-files or postscript files
- The Display process makes the rendered map visible to the user on a suitable display device

Between these four tiers, there are three different types of data:

- Features and coverage's (e.g. raster data) retrieved from the Selection process
- Display elements generated form the Display Element Generator
- Images produced by the Render

The next capability for interactive Web maps is to allow users to add new themes to the map from a catalog of available data sources. This can be accomplished by specifying the entire theme, or by querying the spatial or attribute data and returning all those features that satisfy the query criteria (Strand, 1998). When maps are comprised of multiple themes, each theme being displayed as a graphical layer in the map image, the displayed map can become too complex to be of value, unless users are allowed to select which themes are displayed.

2.3 Internet Map Servers

Internet Map Server (IMS) applications allow GIS database custodians to easily make their spatial data accessible through a web browser interface to end-users. High-speed corporate intranets make an ideal network for distributing data in this manner, given the fact that bandwidth requirements can be high. Making data available to the entire world is certainly feasible and any organization that has a public website can certainly add an IMS without opening up too many additional security holes.

For a working IMS, software requires two components to function. A geospatial data processing engine that runs on the server side as a service, Servlet or Common Gateway Interface (CGI) application, and processes the raw spatial data into a map and a standard web server that manages the incoming requests and replies with the proper map data back to the client side browser or application window. The end product is either a JPEG or GIF image or vector, which is transmitted back to the client browser or a stream of data that is interpreted by a plug-in to the client browser. IMS that transmit back an image have a limited capability that does not extend much beyond pan, zoom, and basic vector attribute query. The feature streaming IMS requires a downloadable plug-in, but allows for advanced buffer, query, labeling and sub setting operations to be performed. Some IMS sites offer both a plug-in and a simple HTML version, which is nice for plug-in weary surfers. An overview of the eight most commonly used Internet Map Servers is provided in Table 1.

Table 1: Selected Internet Map Servers

Internet Map Server	Transferred Geo data	Platform of IMS	Browser Extension	Data Interface
ArcView IMS 1.0a (ESRI)	Raster	UNIX, WIN 9X, NT	Html, Applet	Shapefiles, Coverage's, SDE Layer, …
MapObjects IMS 2.0 (ESRI)	Raster	WIN 9X, NT	Html, Applet	Shapefiles, Coverage's, SDE Layer, …
Arc IMS 3.1 (ESRI)	Raster, Vector, (Internal ESRI formats)	WIN 98,NT	Html, Applet	Shapefiles, Coverage's, SDE Layer, …
MapXtreme NT Ver 2.0 (MapInfo)	Raster	WIN NT	Html, Applet	MapInfo format map, Shapefiles, SDE Layer, Raster format
MapXtreme Java Ver 2.0 (MapInfo)	Raster, Vector	WIN NT, UNIX, …	Applet	
MapGuide 4.0 (AutoDesk)	Raster, Vector	WIN NT	Plug-in, ActiveX, Applet	DWG, DXF, DGN, Shapefiles, Coverage's, MapInfo...
GeoMedia Web Map / Enterprise 3.0 (Intergraph)	Raster, Vector	WIN NT	Plug-in, ActiveX	MGE, Shapefiles, Coverage's, MapInfo, Oracle, Access, …
Map Server 3.5 (Minnesota DNR)	Raster, Vector	WIN 9X, NT WIN 2K	Html, Applet	Shapefiles, SDE Layer, Raster format

In the Internet Map Servers product suite contains: IMS as out-of the-box but customizable and expandable tool or IMS as development environment. When deciding for IMS, one should pay attention to the offered data interface to use existing geodata without problems.

3   Web GIS Architectures

In performing the GIS analysis tasks, Web GIS is similar to the client/server typical three-tier architecture. The geo-processing is breaking down into server-side and client-side tasks. A client typically is a Web browser. The server-side consists of a Web Server, Web GIS software and Database (Figure 2) (Helali, 2001).
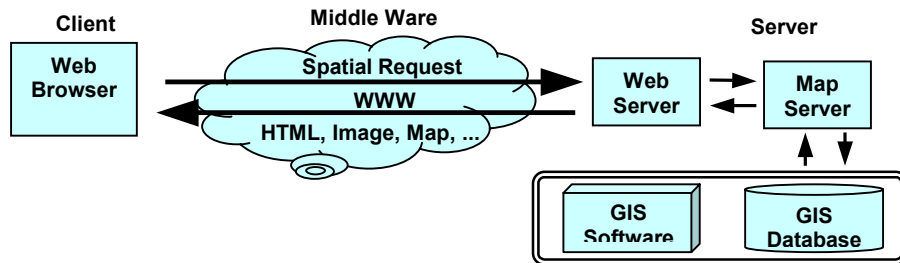
Figure 2: How a typical Web GIS model works

This model of network widely exists within enterprises, in which some computers act as servers and others act as clients. Sever simply have the proprietary GIS running, and add a client interface at the client side and a middleware at the server side to communicate between the client and the proprietary GIS software.

Recent development in object oriented programming make it possible to produce software components, and send them to the client before running it in the client machine, such as Java classes, ActiveX components and plug-ins. This comes out to the thick client GIS. The thick-client architecture let the client machine do the most processing works locally. Both thin and thick-client systems have some advantages and drawbacks, but they are not the best solution in terms of taking advantage of network resources.

3.1 Thin Client Architecture (Server Side Applications)

The thin client architecture is used in typical architecture. In a thin-client system, the clients only have user interfaces to communicate with the server and display the results. All the processing is done on the server actually as shown in Figure 2. The server computers usually have more power than the client, and manage the centralized resources. Besides, the main functionality is on the Server side in thin architecture there is also the possibility for utility programs at the server side to be linked to the server software. Figure 3 shows schematic communication between Web browser, Web Server and GIS server. On the Web Server side, there are some possibilities to realize the GIS connection to the World Wide Web; CGI, Web Server Application Programming Interface (API), Active Server Pages (ASP), Java Server Pages (JSP) and Java-Servlet. The descriptions of the five possibilities mentioned above are in Helali, (2001).
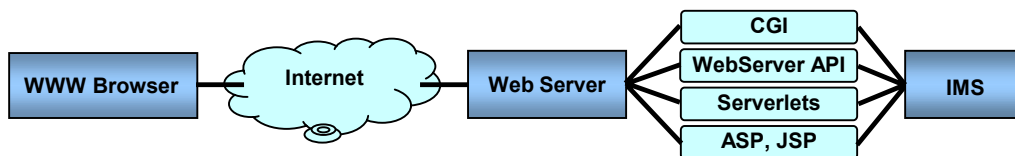
Figure 3: Server Side Applications

The user on the client side does not need any knowledge about the linkage of the IMS at the server side, but the system administrator or application developers should be familiar with these techniques. This Architecture used in ESRI ArcView IMS, MapObjects IMS and MapInfo MapXtreme systems.

Major advantages of this model driven form Data Base centralization and are:

- Central control
- Easy for data eminence/updating
- Keep the latest version

- Generally cheaper
- Integration possibilities
- Regarding some cartographic aspects such as font

And disadvantage are:

o Not responsive to local needs: users have different invokes

o No local accountability: accountability need application in client side

o Large data volume (size of the database)

o Response time slow: users use a browser and it take long time to download new HTML frame

o Less interactive: in client side there is limited application and browsers abilities

o Vector data does not appear in client side: browsers without additional plug-in can not read vector files

3.2 Thick Client Architecture (Client Side Applications)

In general, a Web browser can handle HTML documents, and embedded raster images in the standard formats. To deal with other data formats like vector data, video clips or music files, the browser's functionality has to be extended. Using exactly the same client sever communication in Thin Client architecture, vector files format could not be used. To overcome this problem most browser applications offer a mechanism that allows third tier programs to work together with the browser as a Plug-in.

The user interface functionality has progressed from simple document fetching to more interactive applications. This progress is as follows: HTML, CGI, using HTML forms and CGI, Java script to increase user interface capabilities, Java applets to provide client-side functionality. Currently user interface capabilities combined with remote invocations (Figure 4) (Byong-Lyol, 1998).
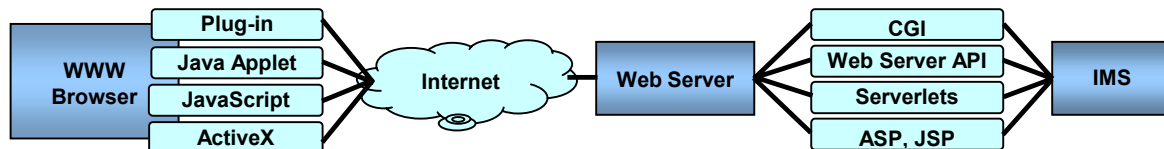

Figure 4: Client Side Applications

Major advantages of this model are:

- Document/graphics standards are not required
- Vector data can be used
- Image quality not restricted to GIF and JPEG
- Modern interface is possible; it is not restricted to single-click Operations

And disadvantages to Client Side GIS

o Nonconformance cans limits

o User base

o Users require to obtain additional software

o Platform/browser are incompatible

3.3 Medium Client Architecture

For avoiding vector data in client side and reducing problems of previous architectures, Medium Client is suggested. With using extensions in both client and server side, clients may have more functionally than Thin client architecture. In Figure 5 these four components in interactive map are pictured as services, each with interfaces, which can be invoked by clients of that service.
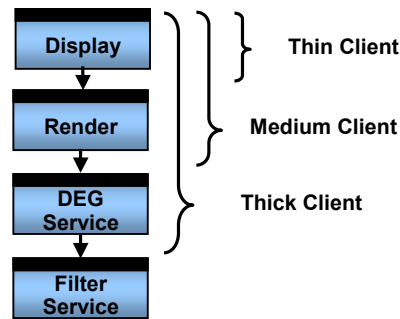
Figure 5: Medium Client position in Open GIS point of view

In other words, if a user's computer contains just the display service, then that user would be said to be using a thin client. If the user's computer additionally contained a render service, then that user would be said to be using a medium client. And finally, if the user's computer also contained the display element generator service that would indicate the user is using a thick client. After some consideration, it was decided that while this distinction may be somewhat helpful in describing web mapping, the terms "thick client" and "thin client" were already encumbered by very imprecise definitions used in marketing literature and were therefore not suitable for continued use in some cases (Doyle, 1999)

3.4 Distributed Architecture

Recent developments in information technology have resulted in a number of distributed object architectures that provide the framework required for building distributed applications. The framework also supports a large number of servers and applications running concurrently. Many of such frameworks provide natural mechanism for interoperability (Kafatos, 1999). For example, Distributed Component Object Model architecture in windows platform and Java Remote Method Invocation (RMI) in Java Virtual Machine (JVM) are the most popular protocols that are used in different cases. These architectures may be applied to GIS to improve the traditional client/server GIS model and develop scalable distributed GIS model. Some attempts have been made in the academic area (Zhang, 1998).

The general idea of the distributed GIS service model is that a client program, in either an Internet browser or an independent application, should be able to access the resources distributed in the entire network. The resources here refer to both geodata and geoprocessing components available in the network. The client and the server in this context do not refer to a specific machine. Any machine, when it requests the remote resources during the processing, is a client, and any machine that provides such resources is a server. In a specific program, a client may connect to several servers if needed and a specific machine may be the client at one time and the server at another time. An ideal distributed GIS service model should be a "geodata anywhere, geoprocessing anywhere" model, which means the geodata and geoprocessing tools could be distributed with the largest flexibility virtually anywhere in the network. The geodata and geoprocessing components do not have to be in the same site, but they should be able to cooperate or integrate whenever they are needed to finish a specific task (Yuan, 2000).

4   Web GIS Development Cycle; Case Study

Developing a Web GIS is more than simply buying the appropriate hardware and software. Several strategies have been proposed to provide successful implementation (Alesheikh & Helali 2001). The implementation strategies have been scientifically assessed and modified so that the requirement of the TTO project can be met with minimum cost and time. Figure 6 shows the Web GIS development cycle, which is described in terms of 8 major activities starting with the requirement analysis and ending with on-going use and maintenance of the Web GIS system.
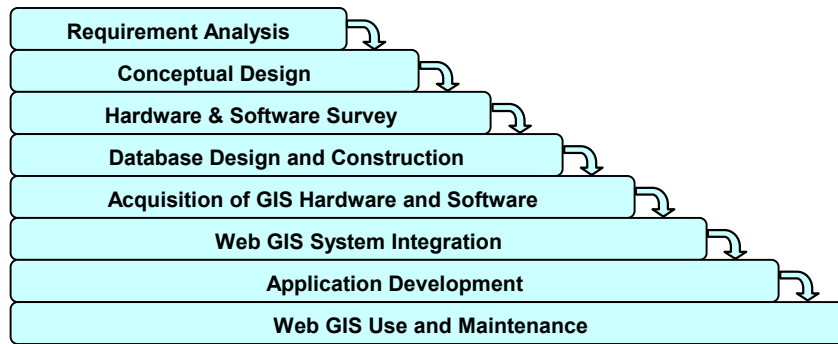
Figure 6: Web GIS Development Cycle

4.1 Requirement Analysis

The object of the TTO project is to disseminate Iranian road information through the Internet, so that constituents can easily access the data. The requirement analysis step has been performed through interviewing potential users. This step produced two critical pieces of information:

- A list of functions that is needed. The required functions are the basic visualization functions such as Pan, Zoom, and more advanced functions such as object identification, spatial query, and shortest path. Clients can use these functions to view road information, and peripheral constructs such as gas stations and rest areas.
- A master list of available/needed geographic data. TTO has captured several layers of road information using GPS. In this project, only 25 layers of information have been used that includes; police station, restaurants, gas station, mosques, etc.

The information gained in the requirement analysis activity went directly into the Conceptual GIS Design activity.

4.2 Conceptual Design

Once the required data has been identified, the data model that identifies the entities and their relationships were designed. Since, the data will be delivered through a central server, and clients will have access to raster formats, Medium Client architecture was chosen providing the users with access to interactive maps.

4.3 Survey Of Available Software And Hardware

Selecting suitable software is an important step in a successful implementation. Software was evaluated on functionality and performance, and independent of the hardware and operating system. With respect to the required functions, cost, and what has been mentioned in Table 1, two software; ArcIMS 3.1, and MapObjects IMS were selected for further evaluation. Web GIS requires specific hardware configuration. Since the volume of transferred data is huge, the speed of Internet connection is vitally important. Most of the data are sent from map server to clients, as such the Send speed has been identified to be more than 128kbs. Based on a pilot project and the experienced gained through similar projects, a Dual Processor computer with 512 MB Ram has been selected for this project.

4.4 Database Design And Construction

The primary purpose of this phase of the Web GIS development process was to specify "how" the Web GIS performs the required applications. Database design involved defining how graphics will be symbolized (i.e., color, weight, size, symbols, etc.), how graphics files will be structured, how non graphic attribute files will be structured, what is the active layer, in what scale shall the layers expose, how GIS products will be presented (e.g., map sheet layouts, report formats, etc.), and what management and security restrictions will be imposed on file access. Completing the following activities does this:

- Selecting a source (document, map, digital file, etc) for each entity and attribute included in the Entity-Relationship diagram
- Setting-up the actual database design (logical/physical design)

- Defining the procedures for converting data from source media to the database. Since the formats of the data were selected to be ESRI compatible, the needed data were converted to such format
- Define procedures for managing and maintaining the database.

4.5 Acquisition Of GIS Hardware And Software

The database design activity was conducted concurrently with the pilot study and benchmark activities. Actual procedures and the physical database design cannot be completed before specific GIS hardware and software has been selected while at the same time GIS hardware and software selection cannot be finalized until the selected GIS can be shown to adequately perform the required functions on the data. Thus, these three activities (design, testing, and Hardware/Software acquisition) have been conducted concurrently and iteratively.

Based on the functional capabilities, vendor support, cost/maintenance fee, and the survey of available hardware/software, those have been purchased, and all necessary renovation of space, wiring, and environmental remodeling has been carried out.

4.6 Web GIS System Integration

At this point in the Web GIS development process the Web GIS hardware and software have been acquired and data conversion is complete. The object of this phase was then to integrate different components of the hardware and software, to test them to make sure they work as expected, and to initiate all procedures necessary to use the GIS.

4.7 Application Development

The initial Requirement Analysis contained some applications of a complex nature. However, the majority of initial applications was straightforward, and can be implemented using the basic functionality that is part of the Web GIS software (e.g., display). The more complex applications were not supported by the basic functions of Web GIS but have been programmed. Ease of use, user-friendliness, and reducing the volume of data transfer were the critical issues considered in the development. Figure 7 shows the initial user interface that has been programmed using HTML, Java Script, and Java.
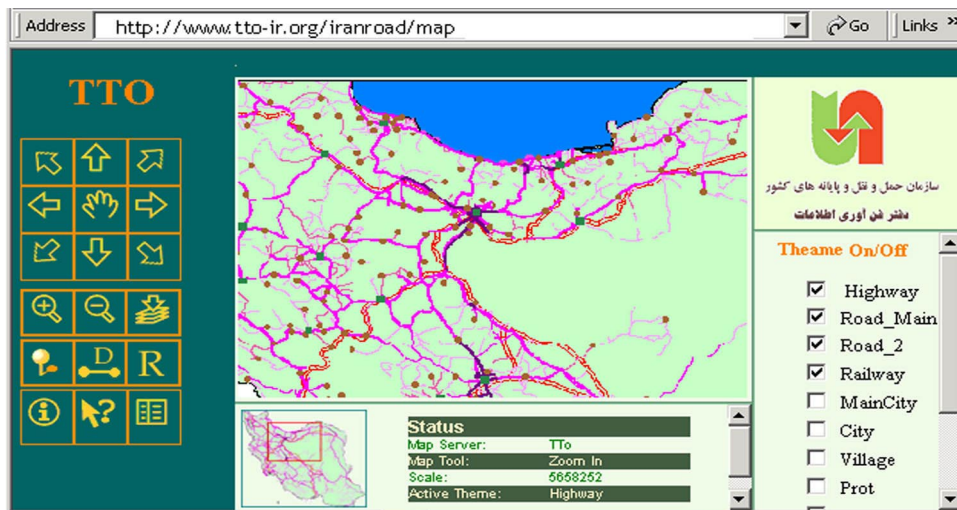

Figure 7: The Initial User Interface

4.8 Web GIS Use And Maintenance

The final step in web GIS implementation was to put the system to use. With system integration and testing completed and all applications available for use, the system was released to users. Two activities were in place:

- User support and service, in which new applications will be determined, and
- System maintenance (database, hardware, software), in which the Web GIS must run smoothly

5 Conclusions and Recommendations

This paper analysis the current Web GIS architectures, and proposes a Web GIS development process. A case study has been developed in which the Iranian road information has been disseminated to the Internet following the identified strategies. Web GIS development processes faces new challenges such as technology innovations, voluminous data transfer rate, and non-specialist users. The following observations have been made:

- Web GIS development is more than buying GIS software and hardware. In order to succeed, the implementation phase must be considered as a process rather than a step. The process starts with requirement analysis ending in web GIS use and maintenance.

- Requirement analysis will expose the needed functions, and consequently the web GIS architecture. Medium client architecture has been developed for the case study as it optimizes the projects requirements.

- As the data transfer rate is high from server to client, Internet band must be selected high; moreover the amount of data dictates a high processor computer.

It is expected that with full release of the project:

- Recapturing of the available road data will be minimized
- Clients can access to road data with no time/place restrictions
- Passengers can plan and manage their trip efficiently

Acknowledgement

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