A Web-based Geographic Hypermedia System: Data Model, System Design and Prototype Applications

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Abstract Geographic Hypermedia (GH) is a rich and interactive map document with geo-tagged graphics, sound and video elements. A Geographic Hypermedia System (GHS) is designed to manage, query, display and explore GH resources. Recognizing emerging geo-tagged videos and measurable images as valuable geographic data resources, this paper aims to design a web-based GHS using web mapping, geoprocessing, video streaming and XMLHTTP services. The concept, data model, system design and implementation of this GHS are discussed in detail. Geo-tagged videos are modeled as temporal, spatial and metadata entities such as video clip, video path and frame-based descriptions. Similarly, geo-tagged stereo video and derived data are modeled as interrelated entities: original video, rectified video, stereo video, video path, frame-based description and measurable image (rectified and disparity image with baseline, interior and exterior parameters). The entity data are organized into video files, GIS layers with linear referencing and XML documents for web publishing. These data can be integrated in HTML pages or used as Rich Internet Applications (RIA) using standard web technologies such as the AJAX, ASP.NET and RIA frameworks. An SOA-based GHS is designed using four types of web services: ArcGIS Server 9.3 web mapping and geoprocessing services, Flash FMS 3.0 video streaming services and GeoRSS XMLHTTP services. GHS applications in road facility management and campus hypermapping indicate that the GH data models and technical solutions introduced in this paper are useful and flexible enough for wider deployment as a GHS.

Keywords geographic hypermedia system; data model; web service; system design

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Introduction Promoting dissemination and utilization of geographic information in government, utilities, commerce and general public sectors, raises several challenges in geographic information science. The first challenge concerns the appropriate relation between the bird’s eye view and the perspective view of geospatial reality. The bird’s eye view offers a 2D geospatial model with an accurate representation of locations and spatial relationships. The perspective view offers a 3D model with intuitively ‘true’ visualization. The second challenge concerns defining the relative value of adopting a logical-spatial approach to geographic information as opposed to a visual-spatial...
approach. The logical approach makes possible spatial statistical analysis, modeling and prediction, while the other approach appeals to direct visual understanding. These challenges must be met in both thematic mapping and multimedia presentation. The third challenge is to develop geographic applications not only for communication among professionals, but also for use by the general public. Many social issues are better resolved via public participation rather than via decision making without any consultation. In all cases, 3D modeling, geographic multimedia and virtual/augmented reality, Web 2.0 and other information technologies offer new approaches to meet these challenges. In this paper, it is argued that 3D GIS, multimedia cartography, Web 2.0 mapping and ‘neo-geography’ offer potentials for current geographic applications. [1-5]

Multimedia cartography presents geographic information in an intuitive manner. [6] Compared with the object-based map layer or field-based ortho-image, the multimedia map has advantages in the representation of the micro-level geographic world. With the development of digital multimedia technology, geographic researchers have continuously integrated various multimedia resources into maps using state-of-the-art information technologies. [7] Publication of a CDROM atlas with multimedia elements became very popular in the late 1980s and early 1990s. The integration of multimedia with GIS started during the mid 1990s, e.g. the Hotlink Tool in ESRI ArcView 3.0. Since the late 1990s, multimedia GIS using mainstream programming has become popular. Traditionally, the two approaches to the design of multimedia mapping products are “maps in multimedia framework” and “multimedia in GIS”. [8] The emerging new approach is to publish geospatial data and multimedia data as web services, and present the data in interactive HTML pages or RIA documents.

Geographic Hypermedia (GH), as promoted by Stefanakis and Peterson, attempts to provide a new way for rich, open, flexible and interactive geographic representation. [9] This paper demonstrates a web-based Geographic Hypermedia System (GHS) design using web mapping, geoprocessing, video streaming and XMLHTTP services. The related data models, web services, system frameworks and application developments for GHS are discussed in detail.

1 Geographic hypermedia system

Geographic hypermedia is the integration of Web and multimedia technologies with geographic information science. It has led to the development of new forms of multimedia geo-representations. [9] Beyond the strategy of “maps in multimedia” or “multimedia in GIS”, GH emphasizes geographic applications using GIS and other geospatial techniques such as hypermaps and hypermedia atlases, multimedia cartography, geographic visualization and exploration, virtual and augmented reality, web-based and virtual way-finding services. Considering that many hypermaps are isolated from their deployment without information and services exchange, Vaitis and Tzagarakis proposed a conceptual reference model for cartographic hypermedia services. [10] Klamma, Spaniol, Jarke, et al. introduced a hypermedia framework to integrate geographic information, multimedia information and cultural heritage information in a single information model. [11] They also implemented a web-based information system designed to facilitate the conservation of cultural heritage in Afghanistan.

Technically, GH provides a type of rich and interactive map document with geo-tagged graphics, sound, video and other digital elements. Given the recent development and preponderance of web technologies, the term ‘GH’ in this paper refers to web-based hypermedia for geography. Digital maps, geo-tagged multimedia elements and geographic hypermedia systems are three related concepts. A digital map, well defined in geographic information science, refers to object-based vector data or to field-based raster data. Geo-tagged multimedia is multimedia with a geospatial description. A GHS is designed to manage, query, present and explore GH resources, and thus to support interactive geographic applications. Text, graphics, sound and video are commonly used in multimedia maps. Integration of geospatial descriptions of the multimedia data is the first step in multimedia map design. For many multimedia maps, the media elements are usually understood as map attributes or hotspot links on the map.
Along with the technical development of the Mobile Mapping System (MMS), computer vision and GPS-tagged video recording, several new multimedia data products have been introduced for geographic applications. For example, Red Hen Systems Inc. developed a video mapping system in 1998 which makes it possible for users to integrate DVD video within GIS environments. The website CITY8.COM published city maps with a continuous street view using 360-degree panoramic pictures in 2006. Google launched Street View with panorama street coverage in 2007. Li and Hu introduced a new product, the Digital Measurable Image (DMI), acquired from the deployment of a mobile mapping system, to provide spatial measurements on-demand.\cite{12} Table 1 shows several newly-emerging digital media for geography. Besides displays for local knowledge communication and geographic exploration, some media have further applications for augmented reality and on-demand image measurements.

| Media                  | Spatial description                                                                 | Example applications       |
|------------------------|-------------------------------------------------------------------------------------|----------------------------|
| Panoramic picture      | Camera location \((X,Y,Z)\), yaw, pitch and zoom, linkage to neighbor picture       | Street view                |
| General or stereo video| Video path, frame-based camera location \((X_i, Y_i, Z_i)\) and orientation \(\Phi_i, \Omega_i, K_i\) | Linear facility management |
| Rectified video        | Video path, baseline, frame-based internal and exterior parameters                  | Augmented reality          |
| DMI\cite{12}           | Time sequence of digital stereo images with exterior parameters \((X, Y, Z, \Phi, \Omega, K)\) and service APIs | High accuracy image measurement |
| Measurable image (rectified and disparity image) | Internal parameters \(f, x_0, y_0\), baseline, exterior parameters \((X,Y,Z,\Phi,\Omega,K)\), effective size of image pixels \((s_x, s_y)\) (optional) | Image measurement |

In a GH document, the map functions as both the container of multimedia resources and the interface for user interactions.\cite{6} Multimedia comes in many different formats, and many of these elements can be embedded directly into HTML pages and displayed by major browsers. For geo-tagged panoramic pictures, measurable images, stereo video or rectified video data in GH documents, new functions are needed to facilitate the interactions between the media player, web map and web services. The browser-side or server-side scripting languages in HTML, ASP, RIA or other web documents offer powerful capabilities to support such interactions.

For example, Fig.1 shows media players embedded in a web map document. The geo-video player (Fig.1(a)) communicating with the background map is designed using Adobe Flash objects and browser-side JavaScript. The image player (Fig.1(b)) supporting image measurements is developed using ASP.NET, C# and AJAX.

The GH document supports dynamic visualization and interaction of multimedia elements. Compared with the traditional multimedia maps, web-based GH is more open, flexible and interactive. First, the user can overlay the multimedia elements on the map as map symbols or markers, which can be clicked for

![Fig. 1](image-url)
media display. Second, during the media display, the player may refresh the map synchronously using the web scripting language. Third, unlike traditional multimedia designed in maps as static hotlinks, the GH document is dynamic and interactive. Last, but most important, the data and their display styles in GH can be organized separately, which is flexible for service-oriented system design.

Technically, a GHS is a web application based on the GH concept. In order to improve user satisfaction by offering a rich and engaging experience, GH data elements in data files, geospatial databases and XML documents should be integrated into dynamic HTML/RIA pages. Web services, defined by the W3C as a software system designed to support interoperable interaction over a network, have been widely used in Internet application development. Fortunately, many software products have supported web services for mapping, multimedia streaming and XML queries, and such services can be integrated using mainstream web technologies.

2 Data model and data management

2.1 GH data organization strategy

GH data organization is fundamental for GHS design. Traditionally, there are two approaches to the data organization for distributing a multimedia map/atlas. The first approach deploys a node-link hypermedia framework, where all multimedia atlas resources are generalized as information nodes with the uni-directional or bi-directional links between these nodes providing the means of information navigation. The second approach, “multimedia in GIS”, deploys the multimedia resource as a special attribute of a map layer, and GIS provides functionalities to handle the multimedia. The first hypermedia structure for multimedia map design has limitations. It is not flexible enough to support the organizing, structuring and accessing of tasks required by many applications. Multimedia in GIS is more effective in data organization, query and display. Web GIS functions, such as map identification, spatial query and attribute query, can easily handle multimedia data. However, for complex multimedia such as measurable image or stereo video, this approach still has problems.

XML is a new approach to organize geo-tagged media elements in GH. The Geography Markup Language (GML) is the XML grammar defined by the Open Geospatial Consortium (OGC) to express geographic features. GML serves as a modeling language for geographic systems and an open interchange format for geographic transactions on the Internet. It allows users and developers to describe generic geographic data sets that contain points, lines and polygons. Google’s KML is used to display geographic data in a web browser such as Google Earth, Google Maps, and Google Maps for Mobile. KML is an XML language focused on geographic visualization, including annotation of maps and images. GeoRSS is an emerging standard for encoding location as part of a Web feed. In GeoRSS, location content consists of geographic points, lines, and polygons of interest along with related feature descriptions. There are currently two encodings of GeoRSS: Simple and GML. GeoRSS simple is a very lightweight format that supports basic geometries and covers the typical use cases when encoding locations. GeoRSS GML is a formal GML Application Profile, which supports a greater range of features than GeoRSS simple, notably coordinate reference systems other than WGS84 latitude/longitude.

For complex multimedia data, such as geo-tagged videos and measurable images, a hybrid strategy for GH data organization is necessary. Generally, based on an entity-relationship or object-oriented modeling of the multimedia data, the entities and their relationships can be managed using data files, database tables, map layers, geographic XML documents or other well-designed data formats.

2.2 Multimedia data description using GeoRSS

GeoRSS is sufficiently flexible to describe quite a few types of geo-tagged multimedia data. Because RSS is prevalent as a way to publish and share information, GeoRSS becomes increasingly important so that location is described in an interoperable manner and applications can request, aggregate, share and map geographically tagged feeds. For example, FME2007 includes a GeoRSS reader and writer that support different types of feed encodings. Google AJAX Feed API is capable of reading and parsing
GeoRSS feeds. ArcGIS Explorer supports point geometries from the feed in the following formats: W3C Geo, GeoRSS simple and GML. The developer can also write code to dynamically populate data resources with graphic feature elements derived from the designated GeoRSS feed. For geo-tagged multimedia elements, the media resource and the player URL embedded in CDATA section. Such GeoRSS documents can be loaded directly into Google Maps.

2.3 Data model for geo-tagged video

Geographic video in this paper refers to video with frame-based spatial references. A conceptual entity-relationship model for geo-tagged video data is outlined in Fig. 2.[13] The geographic video data are generalized as video clips, video frames and video paths. A video clip has a video path with attribute fields like ID, name, length, image size, focal length and capture date time. A video is composed of a sequence of frames with each frame having camera location (x, y and z), camera orientation (yaw, pitch and roll) and camera parameters. A polyline map layer is designed to present video paths. Furthermore, if the time values are calibrated on the video route, the video frame at a specific point can be indexed using linear referencing functions in GIS. In addition, video caption data or a similar video description is useful for video captioning, indexing and retrieval.

Consequently, geographic video data include video clips, video paths, the frame-based location and orientation description, and the caption-like semantic description. In a GH database, a route layer with linear reference is used to manage video paths and their metadata, and XML documents are used to manage frame-based location and orientation descriptions. For some video formats, frame description and semantic description can be included in video files as a synchronous text stream or embedded cue points in Flash video streams. These data elements can be integrated with general geospatial data using a spatial, linear and/or semantic reference.

Stereo video, a newly emerging media, is a technique capable of recording three-dimensional visual information and creating the illusion of depth in an image. There are numerous stereo cameras, data-processing software programs and stereo-viewing devices on the market. Along with the technical development of computer vision, stereo video has potential in quite a few geographic applications. Geographic stereo video is stereo video with camera location and orientation obtained by a GPS receiver and 3D compass, respectively. It is often used to produce 3D surface models from image data, and is much easier and quicker than photogrammetric techniques. The derived data products include rectified video, mixed 3D video, measurable image and 3D surface models. Rectified video with frame-based location and orientation is ideal for geographically augmented reality modeling. Rectified and disparity images with camera internal, baseline and exterior parameters support spatial measurements on the image. Using a geometric algorithm, a real world 3D surface model with measurable images can be derived from the stereo video. Fig. 3 shows the conceptual data model of geo-tagged stereo video. The main data entities include original video, stereo video and rectified video. The videos share the same metadata: video path, surface model along the video path, frame-based interior parameters, exterior parameters, baseline and semantic description. Similar to the data organization for general geo-tagged video, the stereo videos and derived data management is by use of video files, map layers and XML documents.

3 Service-oriented GHS

Service-Oriented Architecture (SOA) offers a flexible framework for web system development and integration. It provides a loosely coupled mechanism of services that can be used within multiple business domains. Rather than defining an API, SOA defines the interface in terms of web protocols and functionality. SOA separates functions into distinct services,
which developers make accessible over a network in order to allow users to combine and reuse them in the production of applications.

According to the principles of the SOA framework, a GHS is designed in four system layers comprising data, service, business logic and presentation layers. The data layer provides GH data management and access. The service layer provides multiple web services. The logic layer is used to describe the functional algorithms that handle information exchange between data services and user interfaces. The presentation layer concerns the user interface and interactions with the system. The three types of data managed via the data layer, specifically geospatial data, multimedia data and geographic metadata, respectively, use a geospatial database, multimedia data files and XML documents. Within the presentation layer, these data are embedded into XHTML pages or RIA documents with rich user interfaces and dynamic interactions. The design of web services is essential for a SOA-based GHS. Applications of geographic hypermedia depend on services such as web mapping services, video streaming services and geographic XML document services.

OGC Web services provide a way that makes maps and data available in an open, internationally recognized format over the Web. OGC has defined specifications for making maps and data available on the web. The three basic services are Web Map Services (WMS) for serving collections of layers as map images, Web Feature Services (WFS) for serving data as vector features, and Web Coverage Services (WCS) for serving data as a raster coverage.

SOAP API and RESTful API are also commonly used for web geospatial data service. SOAP, a protocol specification for exchanging structured information in computer networks, relies on XML for message negotiation and transmission. In contrast, the RESTful web API is a simple web service implemented using HTTP. Geospatial data can be operated by simply using HTTP methods (e.g. POST, GET, PUT or DELETE). For example, ArcGIS Server, the leading web GIS product, provides SOAP and REST API to the services hosted by ArcGIS Server.

JavaScript map APIs are some of the most popular data services on the web today. There are many web pages with interactive and static map images powered by Google, Yahoo, Microsoft and AOL. For example, the Google Maps API lets you embed Google Maps in your own web pages with JavaScript programming. The API provides a number of utilities for manipulating maps and adding content to the map through a variety of services, allowing you to create robust map applications on your website. Based on REST services, the ArcGIS JavaScript API is a browser-based API for developing easy-to-use mapping applications. These APIs allow easy embedding of maps into web pages.

Today’s web space offers a diversified multimedia experience. The Web has become a broadcast medium, offering live video and radio, prerecorded videos, photos, images, and animations. Multimedia elements can be embedded in HTML pages using multimedia tags or specific object plug-ins. For time-based and large-volume media, Flash Media Server, Darwin Streaming Server and Windows Media Services provide video and/or audio streaming media services.

Web services are integrated as functional modules using the business logical layer. The basic modules include map controls (e.g. display, zooming, pan), map query (e.g. spatial query, attribute query and map
identify), geoprocessing (e.g. linear referencing, spatial analysis), geographic XML (GeoRSS, KML or GML) parsing and map overlay, and various geographic media players (e.g. geo-video player, panorama image player and measurable image player).

4 Application development

On the basis of the GH data model and SOA architecture discussed in the previous sections, a prototype GHS was designed using current web technologies. It is implemented as follows: (1) Preparing the map layers using ArcGIS 9.3; (2) Collecting geo-tagged videos, images and other media elements using a digital camera, GPS receiver and/or digital 3D compass; (3) After data processing, converting multimedia elements into W3C formats or other web-compatible formats; (4) Creating the geographic metadata in XML documents or map layers, and ‘injecting’ location and orientation data into media files, e.g. cue points in Adobe Flash Video; (5) Publishing all data resources as web services, e.g. web mapping service and geoprocessing service with SOAP API and RESTful JavaScript API using ArcGIS Server 9.3, HTTP/RTMP video streaming service using Adobe FMS 3, and HTTP services for XML documents and multimedia files; (6) Integrating the map service, multimedia service and XML documents into DHTML/XHTML pages or RIA documents; (7) Designing various geographic media players, which can be overlaid on the map. Further application needs can be met via the use of interaction tools.

The physical design for the CHS prototype is described as follows: (1) Server computer: PC server with 1 Dual Core Processor, 2 GB RAM, 200GB hard disk and 100 Mbs network card; (2) Operating system: Windows Server 2003 R3 Chinese version with .Net framework 3.5; (3) GIS software: ArcGIS Desktop 9.3 and ArcGIS Server 9.3; (4) Adobe Flash CS4 Professional and Flash Media Sever 3; (5) Web Server: IIS 6.0; (6) Database: SQL Server 2005 and ArcSDE 9.3. All these software products and web services are hosted on the same server.

Various general approaches to designing web applications, such as client-side scripting, server-side scripting and RIA framework, were tested. The first is AJAX mashup. The geospatial data is embedded into an HTML page by using ArcGIS Server JavaScript APIs, Google Maps JavaScript APIs and a GeoRSS parser. The second approach is server-side scripting using ASP.NET with C# on the framework of ArcGIS Server Web ADF. The third approach is RIA programming in Adobe Flex framework. Developer tools are Microsoft Virtual Web Developer 2008 Express Edition, Visual C# 2008 Express Edition, and Adobe Flex Builder 3. The players for geo-tagged videos and panoramic pictures were designed using Flash object, XMLHttpRequest object, and cross-page scripting. The players support media data access and interactions between player and maps.

A hypermedia road map of Kaifeng, Henan Province was developed. The geospatial data layers included administrative boundaries, resident points, and the road network, video paths with time reference, bridges, road culverts, signposts and other road facilities. Multimedia data included 177 road videos and over 7500 facility pictures. Application functions, such as map display, data query, map measurement, linear referencing for routes and video paths, geo-tagged media playing, and mobile video monitoring were integrated into HTML pages (Fig.4(a)). Using map identify, spatial query or attribute query, the selected multimedia element(s) is (are) shown on the map as point marker(s) or highlighted line(s). In response to a click on a marker or line graphic, the relevant multimedia data will be displayed in a popup window (Fig.4(b)). For geo-tagged videos, a click on a video path will start the video from the pointer location. While the video is playing, its camera location will be updated on the map synchronously (Fig.4(c)). This system provides rich multimedia functions such as road facility mapping, querying and media displaying for local road administrators.

Another web hypermedia of the campus of Henan University was developed using the GeoRSS standard. Henan University, founded in 1912 and one of the oldest academic institutions in China, has retained a rich historical and cultural landscape. This system aims to show the campus map deployed via vivid audio-visual media. Multimedia data resources, including general, panoramic, stereo and measurable images, videos, audios and HTML pages, were collected from
public websites or captured by the authors. The data on selected historical buildings, beautiful flora, meaningful sculptures, academic departments and campus roads were organized in several GeoRSS documents. The website was designed using Google Maps JavaScript APIs, XMLHttpRequest and GeoRSS parser (Fig.5). Besides the geo-tagged campus videos, measurable images derived from stereo videos were also implemented. A rich internet application for campus video navigation was also experienced.[14] The RIA hypermedia was designed using Adobe Flex framework and ActionScript programming.

![Fig. 4 A hypermedia road map of Kaifeng](image1)

![Fig. 5 A geographic hypermedia system for the campus, Henan University](image2)

### 5 Conclusion

Multimedia offers powerful tools for geographic representation.[15] Deployed by modern cartographers for multimedia web mapping and atlas design, much of its potential has been demonstrated.[7] The integration of the Web and multimedia technologies with GIS has recently led to the development of new forms of multimedia geo-representations. Geographic hypermedia with emphasis on web-based geovisualization and exploration represents the integration of GIS, multimedia, web technologies and geographic practices.

Development and integration of data models, web services, open standards and user interfaces are the critical issues for developing geographic hypermedia systems. This paper presents a service-oriented framework for geographic hypermedia data management, service publishing and system development. The geo-tagged video and stereo video are modeled as temporal, spatial and metadata entities. The entity data are published as video streaming service, web mapping service and XMLHTTP service, which could be integrated efficiently in an HTML or RIA document using server-side or client-side script languages. The GHS system design and implementation indicate that the data models introduced in this paper are useful and flexible, and the technical solutions, such as AJAX, ASP.NET and Adobe Flex, are practical for the development of web-based geographic hypermedia applications.

The GHS applications provide a rich multimedia geographic presentation. It enhances the traditional multimedia cartography by introducing the geo-tagged videos and measurable images, providing
open and flexible service-based architecture and improving the user experience. The authors have also realized that further research on this topic is needed: for instance, more general data models and data organization for geo-tagged multimedia resources, easy-to-use tools for geo-tagged multimedia data capture and metadata editing, and open specifications for geo-tagged multimedia data services with RESTful or SOAP APIs. With the emergence of Web 2.0 technologies and user-generated geographic content, geographic hypermedia will present an opportunity for more innovations in various geographic applications.

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