# GIS-based Interactive 3D Visualization and Analysis on the Internet

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## Abstract

This paper explores the use of World Wide Web (WWW, or simply Web) as a means of designing and developing a toolkit, GeoV&A, for interactive 3D visualization and analysis of existing 2D Geographical Information System (GIS) data. The toolkit is mainly composed of two parts. One is a 3D visualization tool and the other is a 3D analysis tool, including profile creation, viewshed analysis, volumetric calculations and other related functions. This toolkit is implemented by integrating Internet GIS and HTML programming under a client-server architecture. The client front-end of this toolkit residing with the standard Web browser provides several HTML forms for users to enter parameters, while the server back-end including a set of ArcView's Avenue programs processes the parameters, performs visualization or analysis functions and sends back the results to the clients. Both 3D visualization and analysis functions are carried out based on 2D GIS maps. The results can be interacted in both 2D map/graph and 3D Virtual Reality Modeling Language (VRML) formats. It is demonstrated that this toolkit adapts the current GIS 3D visualization and analysis capabilities to the increasingly popular Web environment, thus offering new opportunities for users to build applications that benefit from the integration of GIS and virtual reality technologies.

## 1 Introduction

Over the past decades, large volumes of digital spatial data have been created using geographic information system (GIS), computer-aided design (CAD), and image processing systems. The need to leverage this spatial information is becoming widely recognized in application areas. To achieve this, 3D visualization and analysis is one of the important means that turn traditional 2D spatial data into more evident and usable information.

There has been an increasing interest in 3D visualization and analysis by using GIS and virtual reality (VR) technologies (Hearnshaw and Unwin, 1994; MacEachren and Kraak, 1997; Rhyne, 1997]. As Internet has become very popular, GIS and VR tend to integrate with Internet technologies to allow wide access to geo-referenced data. Through the Internet, the problems associated with vendor specific alternatives could possibly be avoided.

The integration of GIS, VR and Internet technologies for 3D visualization and analysis can now be achieved by integrating Internet GIS and Virtual Reality Modeling Language (VRML) since Internet GIS provides 2D mapping and basic communication functions on the Internet, while VRML enables the 3D scene to be navigated with a Web browser. Of course, the Internet GIS must incorporate or can be easily integrated with 3D capabilities such as perspective viewing, profiling and viewshed analysis.

Although Internet and VR are, to some extent, still new to GIS, some applications have been explored by integration of Internet GIS and VRML. Martin and Higgs (1997) discussed the use of "realistic" environments for the visualization of GIS related statistical and socio-economic data, and demonstrated the use of VR tools for the visualization of urban environment. They further suggested that the integration of GIS and VR has opened up the potential of new ways for interacting with the existing GIS databases. Recently, Batty et al. (1998) and Dodge et al. (1998) described the modeling of urban environments by marrying a range of VR and Internet GIS

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technologies. The virtual worlds on the Internet provides planners with an environment to interface with the complex physical and social data for planning and managing cities in meaningful and intuitive ways.

Besides the applications discussed above, there are also a number of other applications in landscape and environmental studies on the World Wide Web (WWW) (see Fairbairn and Parsley, 1997). While these Web sites offer a graphic interface to the related VRML files, these applications are static in nature. There are very few which try to integrate VR technology with the spatial databases held within GIS to interactively create what we see as virtual environment, and to interactively perform 3D analysis such as profile graph creation and viewshed analysis.

This paper describes the design and development of a toolkit called GeoV&A which is able to provide an environment. In this environment, users can carry out interactive 3D visualization and analysis from existing GIS databases, and browse the corresponding results, whether in 2D map/graph or 3D VRML form, on the Web. The selected 3D analysis functions are the commonly used ones such as profile creation, viewshed analysis and volumetric calculations. This toolkit is implemented by using a suite of ArcView products through Avenue programming as well as HTML programming.

This paper highlights the integration of Internet GIS and VR technology, and introduces the framework of GeoV&A. The implementation of GeoV&A prototype including both 3D visualization and analysis functions are also described. Finally, the features of GeoV&A are summarized, and potential for future work is suggested.

## 2 Integration of Internet GIS and VR

The recent years have witnessed an explosive development of the Internet, which has now become an important means for acquiring and disseminating information. Most GIS vendors and some commercial spatial data providers have realized that the WWW will be the next-generation GIS platform, providing a powerful medium for geographic information distribution, as well as a particularly lucrative new market to exploit (Dodge *et al.*, 1998). Correspondingly, a number of Internet GIS solutions for deploying maps have been developed. Plewe (1997) provides a timely review of the integration of Internet mapping and GIS and discusses the possible services that such integration could offer.

While computer graphics techniques have been extensively used in GIS, VR technology, which enables users to move towards a finer emulation of the complexities of the "real world", offers new and exciting opportunities to visualize and explore GIS spatial databases (Fairbairn and Parsley, 1997; Faust, 1995; Verbree *et al.*, 1998). Recent developments on the WWW provide a cost-effective alternative for the application of VR technology. The commodity solution is based on the VRML standard (Rhyne, 1997).

VRML is a developing language for describing 3D scenes across the Internet (Broll and Koop, 1996). Typically, a VRML plug-in (e.g., Platinum Technology, Inc.'s WorldView plug-in) is required in order to view VRML scenes within a Web browser. VRML browsers enable a user to interact with a virtual world via scaling, zooming, rotation, etc. in three dimensions.

The emergence of affordable Internet GIS and virtual reality toolkits is providing a fundamental infrastructure to set up a generic tool that can offer an interactive environment for Web-based visualization of GIS data, whether in 2D or 3D form.

ArcView Internet Map Server (IMS) (ESRI Inc., 1997a), developed by Environmental Systems Research Institute (ESRI), is one of the most popular Internet GIS products. As an extension of ArcView, it enables users to put maps and interactive mapping applications on the Web. A user can employ this extension to provide information services based on dynamic maps and GIS data.

Besides ArcView IMS, the basic package of ArcView also has several other extensions, including ArcView 3D analyst (ESRI Inc., 1997b). The ArcView 3D Analyst enables users to create, analyze, and display surface data. Additionally, ArcView provides the object-oriented Macro Language Avenue (ESRI Inc., 1996) for customizing users' specific applications. These are some advantages that ArcView products are selected as a basis to build the GeoV&A toolkit.

## 3 The Architecture of GeoV&A

The design concept of GeoV&A consistently supports a Data-View-Controller scheme, shown in Fig. 1. The "view" is the intermediate result of data analysis and the "controller" is the interface of GeoV&A. Such a scheme enables users to have several simultaneous views and analyses of the same data source, thus greatly enhancing data visualization activities to achieve a high degree of interactivity. Therefore, the data, analysis and visualization "flow" together in a seamless process of visual data exploration.

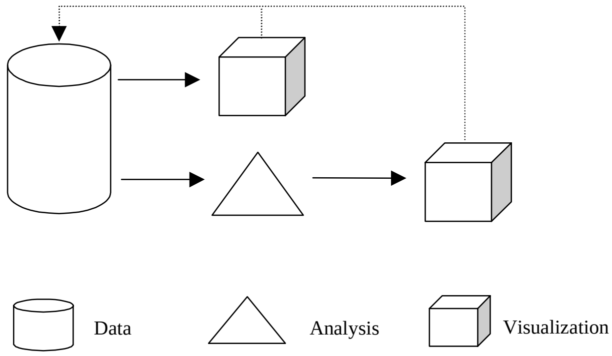


**Figure 1. Data - View - Controller Scheme**

The development of GeoV&A is based on a client/server architecture, which has a typical three-tier configuration (Fig. 2):

a) A WWW client residing with the Web browser: Internet Explorer or Netscape Navigator
b) A Web server (e.g., Microsoft Internet Information Server for Windows NT Server)
c) A 3D visualization and analysis server (V&A server), i.e., an application server using ArcView IMS and ArcView 3D analyst via Avenue programming.

The client of GeoV&A provides several HTML forms, which allow users to select operations, to define properties of 3D scenes or to input parameters for 3D analysis, and then to submit the request to the V&A server via the ESRIMAP Web server extension (esrimap.dll) within ArcView IMS. The ESRIMAP Web server extension, running on the Web server, is a Common Gateway Interface (CGI) script *per se*, which enables the communication between the Web server and the application programs within the V&A server. After receiving and processing the request, the V&A server delivers the responses to the client for display and interaction.

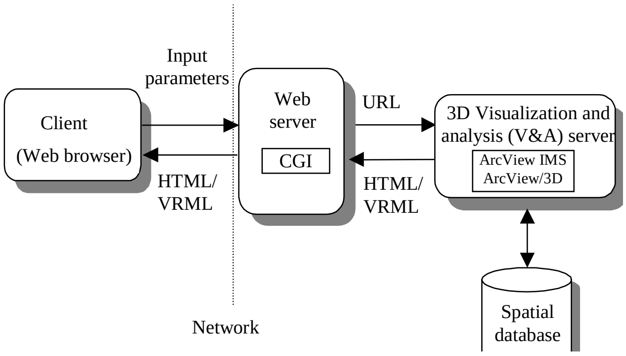


**Figure 2. Three Tier Client/Server Architecture of GeoV&A**

The V&A server has been developed into an ArcView extension (Fig. 3), which is similar to other common extensions of ArcView such as spatial analyst and network analyst. After making sure that

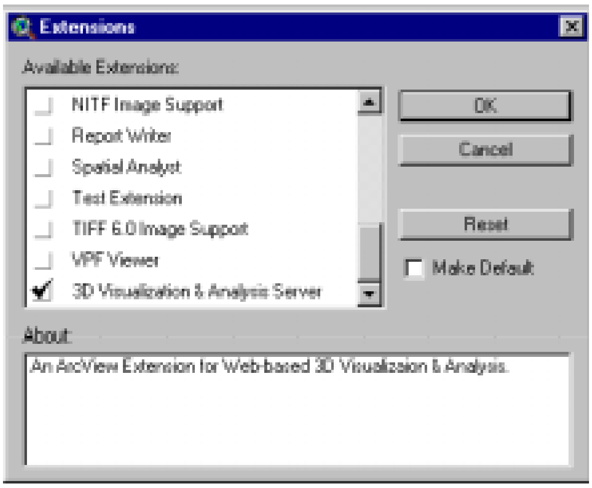


**Figure 3. GeoV&A has been implemented as an extension to ArcView**

this extension is on (Fig. 3), users just need to choose a Web server and connect it with the V&A server (Fig. 4), then this visualization server can provide services to the clients across the Internet.


**Figure 4. GeoV&A's visualization and analysis server setup**

## 4 Implementation of GeoV&A

The main control interface of GeoV&A is shown in Fig. 5, which is the first form (frame) a user encounters. This form provides a drop-down menu, where users can select either 3D visualization or 3D analysis functions. Then, different forms are presented for further running of the software. After a series of operations, users still can go back to this interface for further visualization or analysis.


**Figure 5. The starting interface to 3D visualization and 3D analysis functions**

**Fig. 6. Parameters input for creating a 3D scene in the form of VRML or image**

### 4.1 3D visualization

The 3D visualization in GeoV&A, which is used for creating 3D perspective displays from 2D GIS maps, includes several procedures such as setting 3D scene properties in the HTML form, browsing a 2D map, and creating a 3D scene in the form of VRML or image. Attributes of spatial features (objects) (e.g. stories of buildings) in 2D GIS maps are usually employed for height (Z-value), facilitating the extrusion of the features. The 3D visualization procedures are described below.

#### *4.1.1 Setting 3D scene properties in the HTML form*

GeoV&A uses an HTML form to provide an interactive front-end for 2D map browsing or 3D scene generation. Like the example shown in Fig. 6, the user first begins with the parameter input and selection page. The HTML form in this page is a Common Gateway Interface (CGI) form, which connects with the visualization Avenue programs via the ESRIMAP Web server extension.

This form comprises seven items, which are properties for building a 3D scene from 2D GIS data. The first item is the selection of a 2D GIS data theme for viewing in perspective, which can be of shape, coverage, image or any other ArcView-compatible file formats. Once the 2D theme is selected, it can be browsed without the input of the following parameters. The second item assigns base height as reference information to the selected 2D theme. It can be a value, an expression or a surface name. In Fig. 6, "dtm_tin2" is a Digital Terrain Model (DTM) - based Triangular Irregular Network (TIN) surface representing the terrain. The third item adds an offset height to the base height by value or expression. The fourth item allows the user to give a height (Z-value) in the form of value or expression to the spatial features in the 2D theme. The "[height]" is an attribute of the spatial features in the "bldg2.shp" theme.

Such an extrusion changes the form of a feature: points into vertical lines, lines into vertical walls, and polygons into 3D blocks. Sun azimuth and altitude are respectively set by the fifth and sixth item to define sun position for shading. The vertical exaggeration factor for the 3D scene is defined by the seventh item.

In addition to the seven items, there are four buttons in the form. The "Browse 2D Map" is pushed to browse the selected 2D theme, the "Create 3D-VRML" to generate a 3D scene and its VRML model, the "Create 3D-Image" to generate a 3D scene and its image file, and the "Reset" to define all the parameters with their default values.

All the items including their names and values are encoded in the Universal Resource Locator (URL) when the form is submitted. The URL will be parsed by an Avenue script within the V&A server to invoke different executions. This Avenue script can identify which button is selected, whether it is "Browsing 2D Map", "Create 3D-VRML", "Create 3D-Image" or "Reset".

### *4.1.2 Browsing 2D GIS data*

After a 2D theme is selected in the first item of the HTML form, and the "Browse 2D Map" button is pushed, an HTML file including a 2D map and its legend is created on the fly (Fig. 7). By clicking one of the four "radio" buttons above the 2D map, the user can pan, zoom in, zoom out or identify a feature in the map. The "identify" option is used to show the attributes of a clicked (selected) feature in a table underneath the map (Fig. 7). These attributes can be employed in defining the properties of 3D scenes. For details about the working process of browsing 2D GIS data by using ArcView IMS, see ArcView IMS on-line help.

**Figure 6. Parameter input for creating a 3D scene in the form of VRML or image**

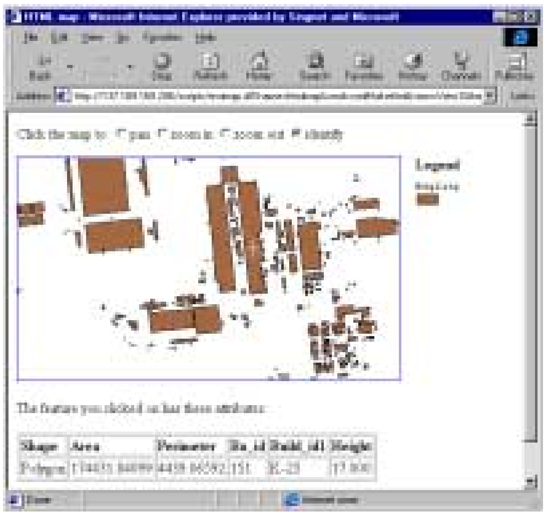

**Figure 7. Identifying a selected feature when browsing the selected 2D map**

It is noted that the creation of an image file for the 2D map legend is not an easy task because the legend of a 2D map appears in a special Table of Contents (TOC) window, which is neither an image nor a geometric feature theme that can be extracted straightforward. A special method is adopted accordingly.

The legend in the ArcView TOC window is first transformed to a graphics file by calculating the width and height of each legend items. The graphics file is then drawn in a new ArcView layout window. The size of this layout window should just cover all the legend graphics because the graphics in the window will be exported to a legend image file. Finally, the legend image file is created, which is then linked to the HTML file for display beside the corresponding 2D map. Such a method is also applicable to the VRML legend creation process in Section 4.1.3.

#### *4.1.3 Creating a 3D scene in the form of VRML or image*

After the "Create 3D-VRML" button is selected, the URL request comprising of the seven parameters is sent to the V&A server via the Web server. Like the example in Fig. 6, the corresponding URL request is thus:

http://137.189.169.206/scripts/esrimap.dll?name=htmlmap&cmd=vrmlCreDis&shpfile=bldg2.shp &baseht=dtm_tin2&offht=0&feaht=[height]&azimuth=45&altitude=30&zscefactor=1.5

Since the variables such as shpfile, baseht, offht etc. are not defined in the ESRIMap Web server extension of ArcView IMS, they are specifically encoded in the URL request by using the "POST" method. Through parsing by a "dispatch" script, the vrmlCreDis command (script) is invoked. The vrmlCreDis script first extracts the parameters for assigning base height, offset height, feature height, sun azimuth and altitude, and vertical exaggeration factor from the URL request, then generates a 3D scene by using these parameters. Finally the 3D scene is transformed into a VRML file (with .wrl extension). Meanwhile, a legend in JPEG image file format for the VRML model is also created. Both the VRML and legend files are linked to an HTML file and sent back to the Web browser for display. By using a WorldView plug-in that has already been established on the Web browser, the VRML model can then be navigated and interacted. Fig. 8 shows the result of the submission of the "Create 3D-VRML" button (see Fig. 6), where buildings are placed on top of the terrain model. Certainly, if an orthophoto is selected as a 2D map instead of the building theme, the VRML presentation (Fig. 9) is an image draping over the same terrain surface as that in Fig. 8.

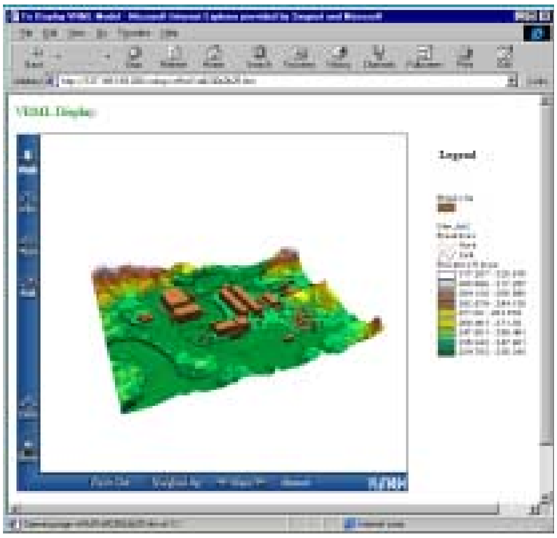


**Figure 8. A VRML presentation of buildings on top of the terrain surface**

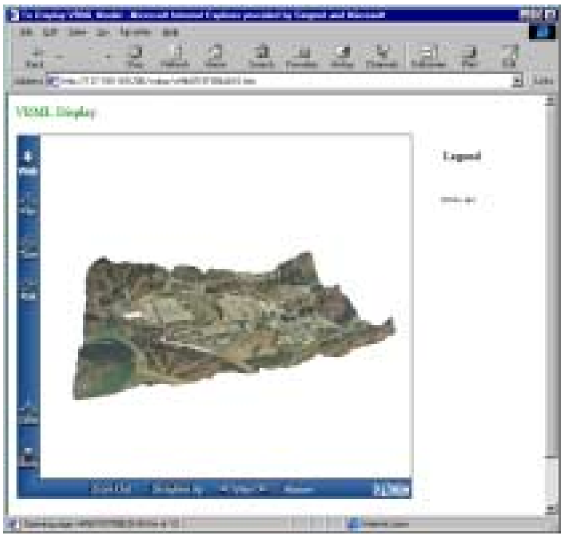


**Figure 9. A VRML presentation of an orthophoto draping over the terrain surface**

Unlike the "Create 3D-VRML" function, "Create 3D-Image" function sends back an image of the 3D scene for a quick look of the result. But the image in 2D format cannot be interacted like a VRML model via scaling, zooming, rotation, etc. in three dimensions within a Web browser environment.

### 4.2 3D analysis

Many types of geographic analysis use terrain surfaces - suitability studies, hydrologic analysis, line-of-sight determination, and more. Other types of analysis use other kinds of surfaces, such as average rainfall, chemical concentration, and population density. Since so many phenomena are principally made up of surfaces, analyzing those surfaces is obviously an efficient way to understand the phenomena.

3D analysis or 3D surface analysis functions in GIS usually include slope and aspect calculations, volumetric calculations, contouring, profiling, and visibility analysis. GeoV&A provides most of these functions, but here, we take two of them, i.e. profiling and viewshed analysis, as examples to illustrate the implementation of 3D analysis functionalities. The results of 3D analysis are usually sent to the 3D visualization tool by URL encoding for display and interaction.

### *4.2.1 Profile graph creation*

The profile graph tool uses a line file ("road.shp" here) and a DTM TIN file ("Dtm_tin2" here) entered by the user in the form shown in Fig. 10 to create a graph that shows the height measured along the road line. Fig. 11 shows the result after submitting the "Browse maps" button (see Fig. 10), and Fig. 12 shows the result after submitting the "Create profile graph" button. This graph is used to evaluate the difficulty for building such a mountain road.


**Figure 10. Profile graph creation form**

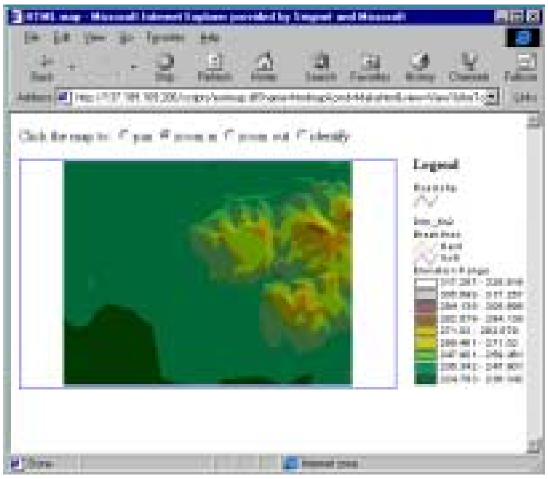


**Figure 11. Browsing 2D maps for profile graph creation**

### *4.2.2 View shed analysis*

Determining what is visible on a surface from a set of one or more locations is useful for a wide range of applications, from estimating real estate value to locating communicating towers or placing military troops.

The viewshed analysis function identifies either the observation points that are specified on the input observation theme that can be seen from each cell in a surface or cell locations which can be seen from each observation point. In GeoV&A, after users input two themes: an observation points file and a grid or TIN surface file in the form shown in Fig. 13, they can proceed to either browse the input maps or create viewshed. Fig. 13 shows the result of browsing two input maps. The result of viewshed can be shown in both 2D map (Fig. 14) and 3D VRML formats (Fig. 15). From 2D visualization, it is found that the tower cannot be seen by most of the right part in the map, but it is difficult to understand the reasons. Through the 3D VRML model and the interaction like "zoom in" and "tilt", we can, however, easily find that there is a steep slope on the right of the tower, which hides the tower from the right part of the map.

## 5 Conclusions

This paper has demonstrated a viable approach to developing a visualization and analysis toolkit in the Web environment by using an off-the-shelf Internet GIS and its 3D visualization extensions. The design and development of GeoV&A enhances the accessibility to the current GIS 3D visualization and analysis functions, and on the other hand, this effort demonstrates how ArcView 3D extension, ArcView IMS, Avenue and HTML programming work together to provide a convenient environment for Web-based 3D visualization, analysis and interaction.

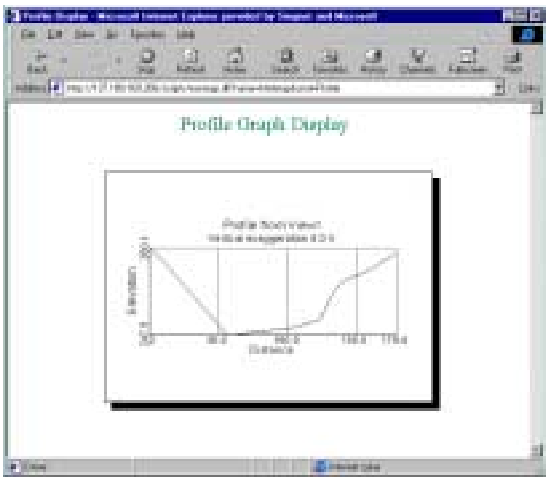


**Figure 12. Result of a profile graph**

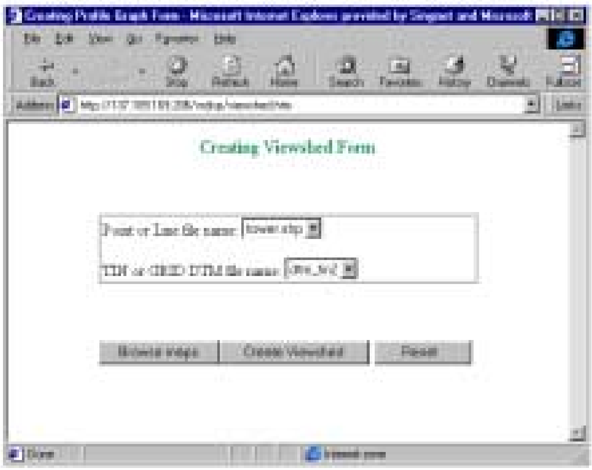


**Figure 13. Browsing 2D maps for creating viewshed**

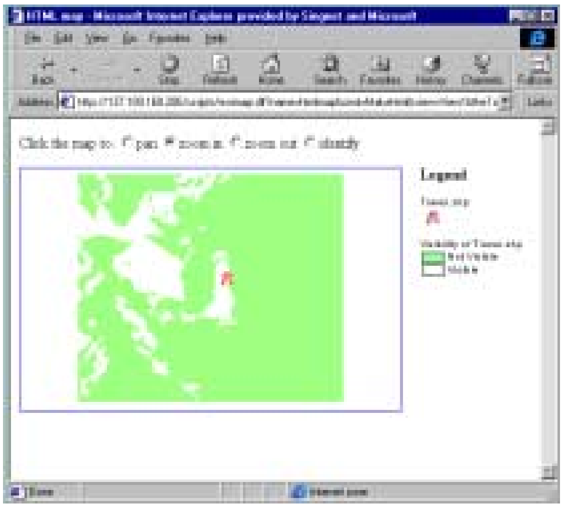


**Fig. 14. The 2D visualization of the view shed analysis result**

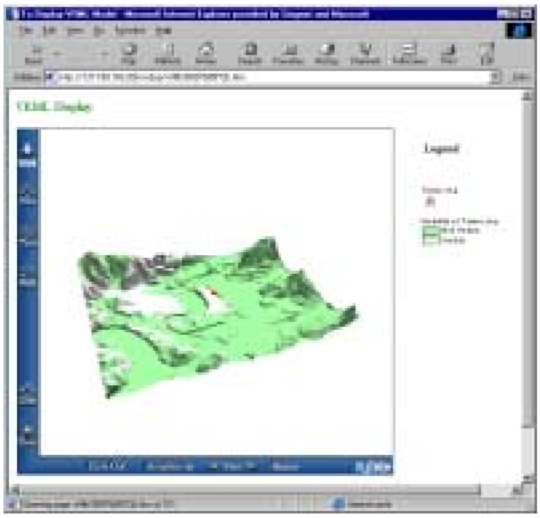


**Fig. 15. The 3D visualization of the view shed analysis result**

3D visualization and analysis become more powerful when combined with Internet-based technologies. Through the network, data, analysis and interaction can be distributed to the desktops of decision-makers who are able to act upon the most recently available information.

The design of GeoV&A adopts a CGI method, which makes full use of the current GIS 3D visualization and analysis functions. Meanwhile, GeoV&A provides a platform-independent interface within the Web browser to access these functions. For the software development of this toolkit, a critical element lies in how to fit the parameters that are not supported by ArcView IMS into the URL request, which is then extracted by the application server programs.

While GeoV&A provides a set of useful 3D visualization and analysis functions, its user friendliness can still be improved by using the Java language to facilitate formulation of some expressions in the HTML form. The 2D map legend and the VRML legend can also be enhanced by adding the interactive editing function. Furthermore, it is worthwhile to explore the interaction such as direct queries on the 3D VRML model for linking spatial database information, and to explore the integration of GeoV&A with environmental modelling.

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