Distributed Virtual Environments for Managing Country Parks in Hong Kong: A Case Study of the Shing Mun Country Park

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Abstract

Distributed virtual environments (DVEs) are environments that are not only used for managing and delivering multi-source, multi-dimensional, geographical information, but also enable geographically distributed users to navigate in a 3D space, and to interact with objects and with other online users. In this paper, we design DVEs to disseminate 2D and 3D data and to implement public participation in the management of the country parks in Hong Kong. The system framework, geo-data model, and user's interface are discussed for designing DVEs. Based on the virtual reality modeling language (VRML), Java, and VRML External Authoring Interface (EAI) classes, a balanced client/server architecture is employed. In view of multi-source and multi-dimensional data, the object-oriented approach is utilized to design 3D geo-object models for web-based distribution. Considering the Internet bandwidth and performance of client computers, we adopt multi-block and multi-level approaches to the design of 3D geo-objects. The user's interface provides capabilities for implementing 2D and 3D view, data query and analysis, object addition/removal, and 3D avatar-based and text-based communication. This paper presents a case study of the Shing Mun Country Park in Hong Kong, where a prototype DVE, called "VirtualPark," was developed.

Introduction

Hong Kong is one of the world greatest modern cities, well known for its street life and gleaming towers. But it also has an extensive countryside, rivaling many other places for its scenic beauty and ecological interest. Approximately 40 percent of Hong Kong's land is designated as country parks (Country Parks, 2001). The parks comprise scenic hills, woodlands, reservoirs, and coastlines, and are critical ecological systems for Hong Kong's sustainable development. Country parks also provide Hong Kong residents and visitors with scenic spots to pursue activities such as leisure walking, fitness exercises, hiking, barbecuing, family picnics, and camping. In the year 2000, the country parks received approximately 10.7 million visitors, according to statistics from the Country and Marine Parks Authority. In order to manage the natural ecological resources of the country parks and provide services to the public, the Country and Marine Parks Authority has amassed a considerable variety of literature, such as contour maps, information on types of vegetation, suggested walking routes and barbecue sites, as well as documents detailing the specific characteristics for every country park. Traditionally, stand-alone geographic information systems (GISs) are suitable tools for specialists and managers to store and manage the spatial and non-spatial data for country parks. However, these systems are not appropriate for use by the general public due to difficulties in system access and the complexity of their usage (Harris and Weiner, 1998; Obermeyer, 1998).

With the rapid development of computers and communication, the Internet and the World Wide Web (the Web) are now critical media used to acquire and disseminate information (Doyle and Dodge, 1998). Web-enabling systems such as ArcExplorer, ArcView Internet Map Server, Geomedia, and Web-based visualization servers can allow the public to access, retrieve, display, and analyze 2D and 3D geographical data over the Web, using standard Web browsers such as Netscape and Internet Explorer (Plewe, 1997; Green, 1997; Strand, 1997; Richard, 1998; Evans *et al.*, 1999; Kahkonen *et al.*, 1999). Furthermore, the integration of virtual reality technology with a 3D GIS and Internet-GIS promises to provide us with the ultimate, user-centred, human-computer interface (Faust, 1995; Verbree *et al.*, 1999; Van Maren and Germs, 2000). Using the Internet and virtual reality technology, this paper aims to explore approaches to modeling and developing distributed virtual environments (DVEs) for managing country parks, and for public participation over the Web.

The rest of the paper is organized as follows. In the next section, the concept and characteristics of a DVE are presented through the discussion of relationships with the online community, networked visualization, and Internet GIS. This is followed by an elaboration of the design of the system framework, data model, and user's interface of a DVE. Then a prototype system of a DVE, called VirtualPark, and a case study of the Shing Mun Country Park in Hong Kong are presented. The last section concludes with a discussion of future work.

Related Work

In general, Internet-based GIS systems focus on handling two-dimensional spatial information. However, the development of computer graphics, visualization, and virtual reality, especially the virtual reality modeling language (VRML), makes it possible to build 3D worlds across the Web (Carey and Bell,1997; Rhyne, 1999; Nadeau, 1999; Li and Wen, 2001). DVE technology works to establish distributed 3D environments allowing geographical distributed users to virtually meet and interact with objects, processes, and other users in 3D worlds on the Web (Dykes *et al.*, 1999; MacEachren *et al.*, 1999a). In

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Figure 1. Cybertown, an online 3D community (image courtesy Cybertown).

recent years, DVEs have drawn increasing attention in academic and industrial communities (Singhal and Zyda, 1999; Blaxxun, 2001).

From the perspective of online communities, originating from the online text-based or voice-based chat rooms such as the famous Muds (Multi-User Dungeons) and Tencent OICQ in China, DVEs are now used to create online 3D communities for conducting a variety of activities such as chatting, game playing, forming clubs, house building, and shopping in the virtual mall (Cooper, 2000; OICQ, 2001). Figure 1 illustrates a snapshot of Cybertown, a well-known 3D Internet community (Cybertown, 2001). In Figure 1, online users are represented as 3D avatars, and can navigate in 3D worlds and chat with other users (i.e., 3D graphics in virtual worlds representing the identities of online users).

From the perspective of networked computer graphics, integrated with CAD and visualization technology, DVEs are applied to building distributed CAD or visualization environments for collaborative designing or visual data interpretation. Figure 2 shows a distributed CAD design environment, called DMUConference (Tecoplan, 2001). In the DMUConference environment, geographically distributed designers can meet virtually and discuss the design of cars.

The fields of geography and GIS have already begun to integrate traditional GIS, geographical application models, AutoCAD, and distributed tools such as ActiveX, VRML, Java, and Java3D to construct distributed virtual geo-environments (GeoVE) on the Internet (Fairbairn and Parsley, 1997; MacEachren *et al.*, 1999a; MacEachren *et al.*, 1999b). With regard to building GeoVE system architecture, the key issues are choice of Internet-based programming tools, user-specific interface, processing of complex and large geo-worlds and shared geo-objects, spatial analysis and data query, geographical model simulation and interpretation, and collaborative work (Arikawa *et al.*, 1999; Gabbard *et al.*, 1999). At present, most GeoVEs under development are rudimentary and focus on only a few aspects of a GeoVE. Coors and Jung (1997) used VRML 2.0 to model geo-referenced information, and Java to develop an interface to interact with the VRML geo-world. Using Java and Java3D, Hibbard (1998) designed and developed a VisAD system to create applications that enable many users to implement the visualization of a shared set of numerical geo-data and geo-computations. Dykes *et al.* (1999) used networked components to model virtual environments for student fieldwork. Batty *et al.* (1998) employed the ArcView Internet Map Server to design an Internet-GIS to deliver 2D GIS information and 3D worlds (using functions of ArcView 3D Analyst), and to provide simple spatial analysis and query, but its performance was deemed inadequate, because each operation needed to be sent to the server to be handled, and it had no ability to carry out collaborative work among distributed users. Therefore, the Activeworlds system is currently used to design the GeoVE.

In this paper, we employ VRML, Java, HTTP TCP/IP Protocol, and HTTP UDP/IP Protocol to establish a distributed virtual environment for managing and disseminating a variety of information about spatial distribution, administrative regulations, and future planning of the Country Parks in Hong Kong, and to help public participation in policy making, protection of ecological systems, and development of the tourism industry.

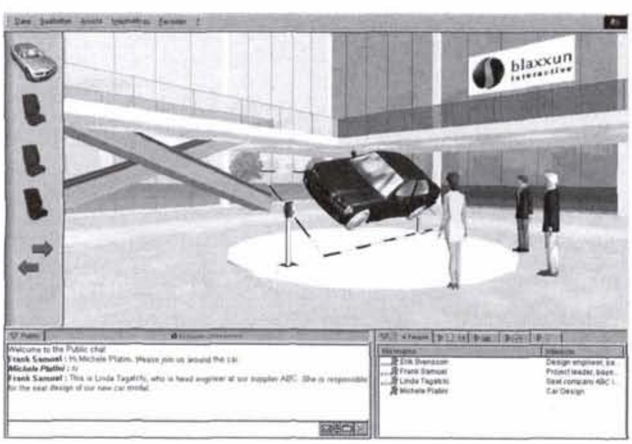

Figure 2. DMUConfernce, a distributed CAD design environment (image courtesy Tecoplan).

Design of the DVE

Virtual environment systems comprise three parts: data sets, applications, and users (Rohrer and Swing, 1997; Lin *et al.*, 1999). In view of the client-server architecture over the Internet, data sets and applications can be placed on either the client side or the server side. Placed on the client side, they may provide a thick-client/light-server solution, while placed on the server side, they may provide a thin-client/heavy-server solution (Plewe, 1997). If data sets are pre-processed on the server side, then the processed data sets are transferred to the client side to be displayed and analyzed, and they may provide a medium-weight client-server solution. With regard to geographically distributed general users, it should be easy and convenient for them to connect with virtual environments in which they can navigate 3D graphical worlds, interact with and control objects, conduct data query and analysis, as well as implement communications among themselves over the Internet in (near) real time. Thus, the design of a DVE may involve the following components: system architecture, distributed data model, server-side applications and database, client-side applications and user interface, and multi-user communication. This paper will discuss the system framework, geo-data model, and user's interface in the context of the 3D distributed, multi-user, virtual landscape, and ecological systems.

System Framework

Regarding the complicated Internet environment, in particular, the varied data-handling and 3D graphics-rendering capability of users' computers and the current limited Internet bandwidth and data-transfer speed, this paper adopts a balanced client-server approach to the design of DVE architecture.

A balanced client/server structure signifies that some tasks are handled on the server side while others are handled on the client side (Figure 3). The working mechanism is as follows. A client on the client machine sends a request such as a change

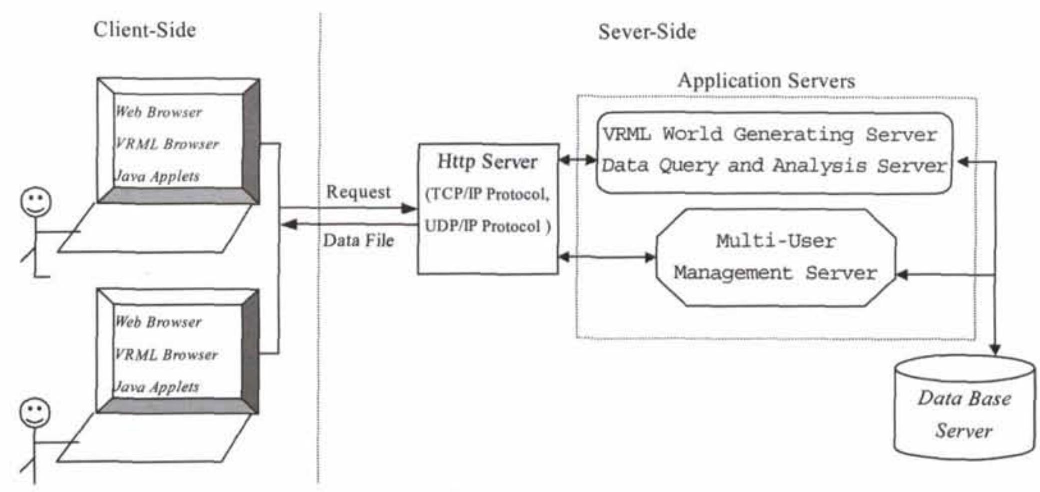

Figure 3. Framework of distributed virtual environments.

of the VRML world or spatial query on the DVE user interface via the Internet to the http server on the host machine; the http server passes the request to an application server; the application server would then connect with a database server and retrieve data from the database, if it is necessary; then the application server would prepare a response (image/graphics, text, 3D data, or other data/information) and send it back to the client; and finally a VRML browser or Java applets on the client machine would display or process the response data on the client side.

In our system design, VRML is employed to model 3D geographical worlds. Thus, in view of client-side applications, we need not develop VRML browsers (plug-ins) by ourselves, because these are freely available on the Internet; therefore, use on the development of client-side Java applications to communicate and interact with VRML worlds, or application servers on the server-side. To accomplish communication between client applications and VRML worlds, either JavaScript or the VRML External Authoring Interface (EAI) classes can be applied (Marrin, 1997). JavaScript may be used as the scripting language for a Script node in a VRML world. The JavaScript transmits and receives events between other nodes of the world through a JavaScript Authoring Interface. The EAI approach, not utilizing an event coming into a Script node, allows a currently running Java applet to control a VRML world. Here, we utilize the VRML EAI classes to design the DVE. The EAI classes can be found in the vrml.external.* packages (npcosmop211.jar) that come with the Cosmo Player plug-in (Cosmo Player, 2000). These packages contain all the classes and methods needed to access the VRML world, send events to it, and register notification methods when an event is generated in the world.

Server-side applications, as shown in Figure 3, include a VRML world generating server, a data query and analysis server, and a multi-user management server. When a client-side user navigates a large geographical space, the VRML world-generating server will constantly receive users' requests and will retrieve corresponding data from a database server. The server will then produce a new VRML world and transfer it to the client side. The data-query and analysis server handles geographical data queries by connecting with the database server and with spatial data analyses such as viewshed acquiring, buffer analysis, and network analysis. The multi-user management server retrieves and forwards messages and information about the user's name, position, and orientation from and to online users.

Geo-Data Model

As a natural way of observing and constructing worlds, the object-oriented (OO) methodology is now preferred for dealing with data modeling or system design and development. Generalization, inheritance, aggregation, and grouping (or association) are the primary means of forming classes (objects), in terms of OO methodology, that possess both attributes and methods (operations). In this paper, we adopt the OO idea to design our data model.

Each geographical entity is taken as an object that has metadata, essential attributes, perceptual attributes, and relational attributes. Metadata refers to data about data. It describes data format, object-constructed date, object owners, scale, data accuracy, etc. Essential attributes are defined as spatial location (coordinates) and topology, time and temporal topology, and geographical attributes including physical, chemical, and biological elements. Perceptual attributes demonstrate the relationship between objects and observers, and include visual, audio, tactile, and olfactory attributes. Relational attributes represent the relationship among objects in dimensions of space, time, material, energy, and information.

As for objects in landscape and ecological systems, there are two typical models: field based and object based. Field-based models include DEMs, aspect model, slope model, soil distribution model, and land-use model. Object-based models include individual discrete entities such as trees, buildings, roads, and telephone booths. In terms of a DVE, real-time navigation and interaction and realistic 3D graphics are key factors in enabling users to feel immersed and present. However, because geographical data sets are always large and complicated, geo-object modeling requires special modeling methods. Two such models are discussed in this paper, i.e., topographical landscape models and 3D entity models.

Topographical Landscape Models

Topographical landscape models can be defined as the integration of geometric and non-spatial attribute distribution models such as DEM, slope, aspect, land use, and soil type. Because of the large data volume of a DEM and its geometric and thematic complexity, as foundational 3D spatial frameworks, topographical landscape models are the keys to realistic, real-time handling of 3D scenes. This paper addresses multi-block and multi-level schemes to model complicated topographical landscape

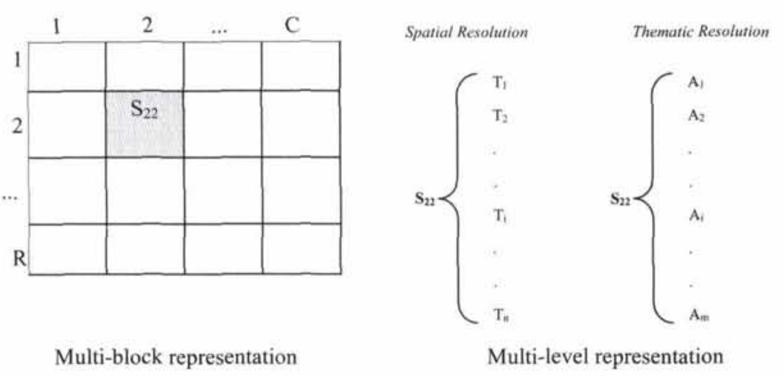

Figure 4. Multi-block and multi-level representation of spatial and thematic attributes.

models. In general, when the region of interest is too large to carry out data transference across the Internet and geo-computing and graphics rendering in real time, we need to divide this region into several blocks. In Figure 4, we design row-by-column ($R \times C$) blocks to represent a region. Each block may comprise many levels describing different geometric and thematic details (Gueziec *et al.*, 1999). Figure 4 demonstrates that the block S_{22} is represented by $T_1, T_2, ..., T_i, ..., T_n$ in terms of spatial resolutions, and by $A_1, A_2, ..., A_i, ..., A_m$ in terms of thematic resolutions. Meanwhile, we can hypothesize that resolutions increase concomitantly with an increase of i.

In practice, the number ($R \times C$) of blocks is determined by the real-time handling capacity of client computers and the highest spatial (T_n) and thematic attribute (A_m) resolutions that depend upon the data sources. The maximum observing range of users decides the lowest spatial (T_1) and thematic attribute (A_1) resolutions. When application systems are executed, users can choose the proper spatial and thematic attribute levels according to their own requirements, Internet capability, and computer performance. Given a specific computer environment, the number of triangles handled for real-time 3D graphics rendering should be certain, and is presumed to be NR. When the region defined as "R" needs viewing and is selected, users should choose a spatial level that allows the number of triangles within the region R to be equal or similar to NR. Thus, it is possible for users to implement real-time visualization and analysis.

3D Geo-Entity Models

In traditional 2D GISs, geographical entities such as buildings, trees, and phone booths are usually represented by color or 2D graphical symbols. Figure 5 demonstrates four 2D symbols conveying toilet, telephone booth, swing, and kiosk. General users are not familiar with abstract 2D symbols and worlds for representing the real 3D geographical worlds, and a conversion from abstract 2D symbols to 3D geo-entities may place a heavy load on information cognition and processing.

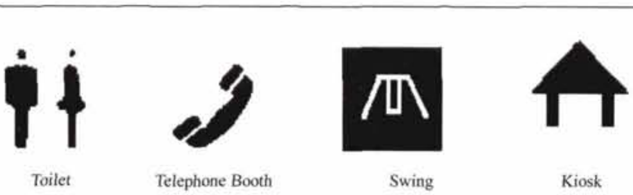

Figure 5. 2D representation of 3D geo-entities.

In this paper, we design a 3D graphical object base to simulate 3D geo-entities so that users can directly identify geo-entities, and feel immersed in their virtual environment. The building process of 3D geo-entities is as follows. Initially, 3D application systems such as AutoCAD and Cosmo Worlds may be employed to create 3D geometric objects (Cosmo Worlds, 1999). Together with the geographical coordinates, size, and orientation of entities obtained from the ground survey, the 3D geometric objects can be further processed into 3D objects for constructing a DVE. Figure 6 demonstrates the 3D graphical representation of four entities, namely, toilet, telephone booth, swing, and kiosk. These objects are stored and managed in a database server.

User's Interface

Users interact with geographical objects and worlds, implement data query and analysis and geo-model simulation, as well as communicate with other users through a DVE system interface.

In terms of navigation in 3D space, the interface should have a window displaying 3D graphical worlds and allowing users to choose ways of walking or flying. Because it is easy for users to become lost in 3D worlds, and it is necessary for a user to know other related users' current locations, a 2D map of the whole 3D world is essential for displaying users' positions. In very large worlds, the 2D map can also be used to choose different regions of interest for viewing, or to design a specific routine for 3D navigation (see Figure 7). In Figure 7, *3D View* is a window displaying 3D VRML worlds. *2D View* displays the 2D map of 3D VRML worlds. There is close linkage between 2D view and 3D view.

Figure 7 also demonstrates a window, named *Data Handling and Analyzing*, for facilitating data query and analysis, and geo-model simulation. This window enables users to select parameters, input text, edit geo-objects, and conduct geo-model computation to interact with geographical data and processes for further geographical understanding, interpretation, and planning.

A text-based chatting dialogue, called *Talking*, is designed to enable communication among online users (see Figure 7). In addition, avatars, i.e., 3D graphics to represent human bodies and body behavior in 3D virtual space, are often used for social interaction among online users. Figure 8 demonstrates avatars of different sexes, human types, and body posture. The locations and orientations of avatars change depending on viewpoint positions and view directions. VRML is often used to

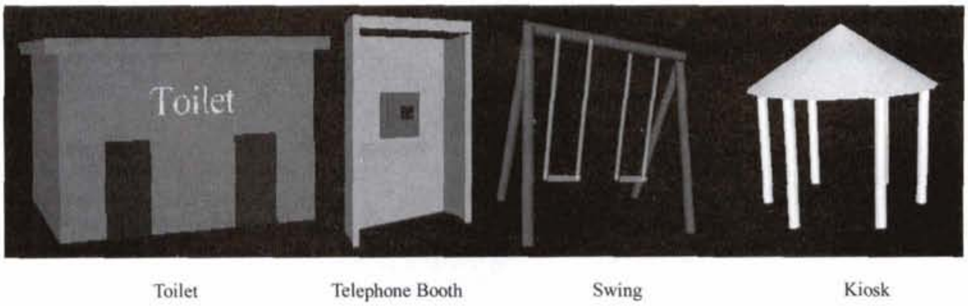

Figure 6. 3D representation of 3D geo-entities.

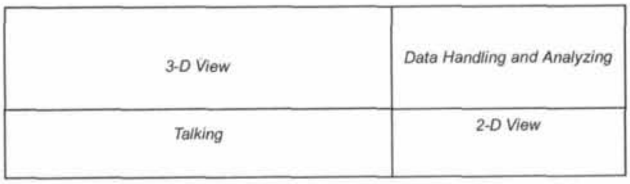

Figure 7. Interface design of distributed virtual environments.

Figure 8. Avatars with different sexes, human types, and body posture.

model avatars. Users can freely select their avatars, with their choices leading to different perception, cognition, and social behavior in each user.

A Case Study: System Prototype and Application

The Shing Mun Country Park is located in Hong Kong's New Territories Region (see Figure 9), and covers a total of 1400 hectares (Country Parks, 2001). Inside the Park, at the head of the reservoir near the former village of Tai Wai, a "Feng-shui" grove contains a rich variety of more than 70 species of trees. It has been designated as a "special area" that merits special protection. To the west of the reservoir, both sides of the stream known as Tai Shing Shek Kan are covered with a rich variety of shrubs, grasses, and trees, including several species of Camellia, Camellia Granthamiana, which bears beautiful white flowers more than 12 cm in diameter, a rare species discovered only a few decades ago.

In 1998, the Country and Marine Parks Authority and the Department of Geography of the Chinese University of Hong Kong completed a collaborative project to establish a standalone data management system for the Shing Mun Country Park using a GIS. Figure 10 gives a snapshot of the information management system. In an Arc/View environment, the system can store, edit, display, and analyze varied information pertaining to the Shing Mun Country Park, such as topographical contours, water net, roads, footpaths, public facilities, vegetable types, plant conservation areas, entertainment planning, etc. Using the completed desktop 2D information management system, we are able to further study the design and development of a prototype distributed virtual environment, called VirtualPark, across the Web for data managing and dissemination, as well as for public participation.

Building a 3D Object Database

As previously mentioned, there are two types of models in terms of ecological landscape systems. One type is a field-based model such as a DEM and land-use model, while the other is an object-based model such as trees, buildings, and roads.

In our case study, we utilize Arc/View and our own data preprocessing system to build 3D field-based objects such as a DEM. The building process is as follows: first, we use ArcView GIS 3D Analyst to produce a triangular irregular networks (TIN) model of a DEM from the contour theme. We then employ our own data preprocessing system, which is developed with VTK API (VTK, 2001), to import the TIN model and build multi-level DEM objects. In terms of the thematic aspect of the topographical landscape object, Arc/View is applied to producing multi-level raster-based models for thematic attributes. When 3D graphics rendering is implemented, these thematic raster-based models will be taken as texture images mapped onto the surface of a DEM. Figure 11 shows a 3D virtual Shing Mun Country Park with the DEM overlaid by a thematic map of vegetation conservation, while the DEM and the thematic attributes are both represented at the highest spatial resolution.

In view of 3D individual entities such as telephone booths, kiosks, toilets and swings in the Shing Mun Country Park, AutoCAD is firstly utilized to create their 3D geometric models. Then, Integrated with the geographical coordinate of the center of each entity obtained from the 2D facility map in Arc/View, and with the parameters of width, length, height, orientation, etc., acquired through field work, the 3D geometric models can be converted into 3D objects used for constructing 3D graphical worlds.

All the field/object-based 3D objects are stored and managed by the Oracle database server. In the database, exempt from the essential spatial and thematic attributes, every object-based 3D entity has additional attributes (fields) such as ID

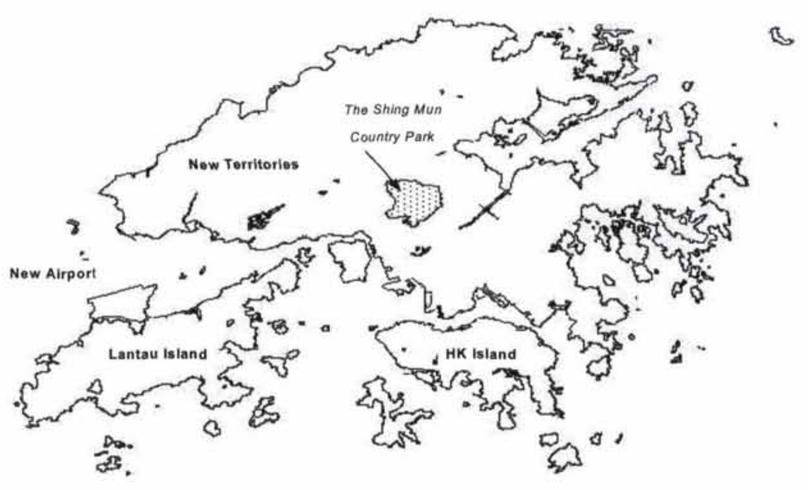

Figure 9. The geographical location of the Shing Mun Country Park in Hong Kong.

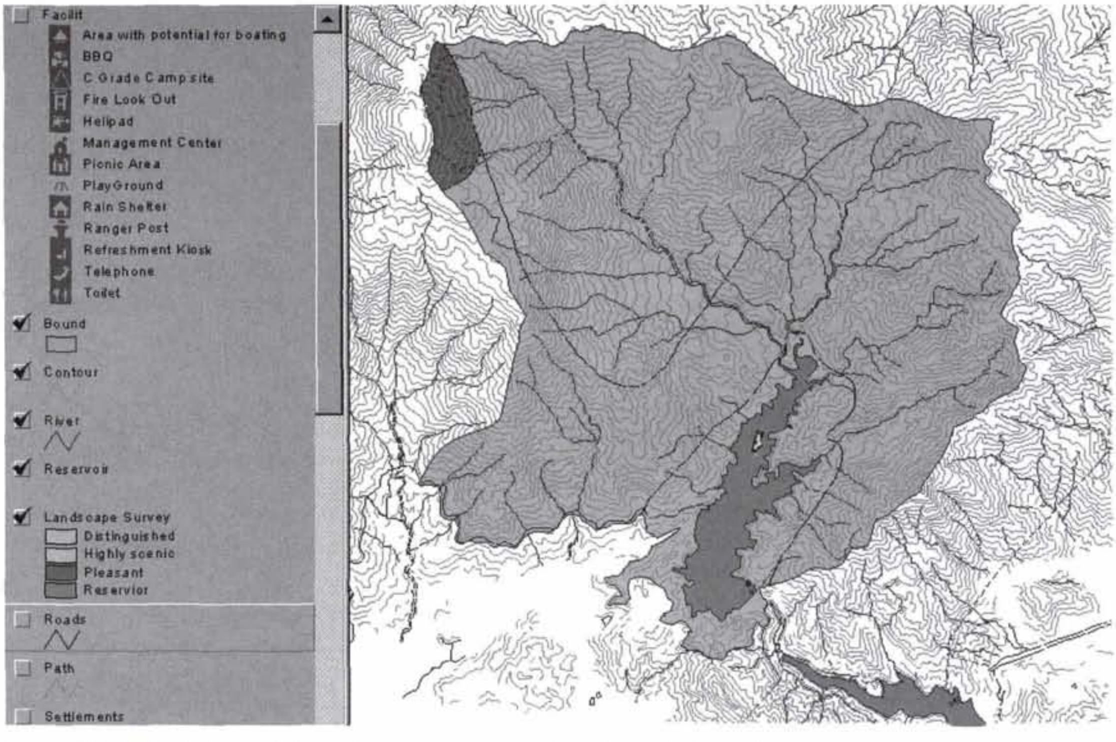

Figure 10. A desktop 2D information system managing the Shing Mun Country Park.

number, object name, metadata, center coordinate, 3D boundary box, and general description.

System Prototype

Using Java and VRML EAI classes, we developed a prototype distributed virtual environment system (VirtualPark) on the Web. The Java applet approach is applied to developing client-side functions such as coordinate measuring, data query, object addition/removal, chat room, and 2D map display, while Java servlets are applied to programming server-side application servers such as data query, added/removed objects management, and online users information management (Barkakati, 1999). All the functions of the Virtual Park are designed, coded, and tested with Java by ourselves except the multi-user management server which is mainly established on the VNET (White and Sonstein, 1999). ODBC-JDBC classes are used for application servers to connect with the database server. Figure 12 demonstrates the system prototype, VirtualPark. As discussed above, the interface of VirtualPark comprises four major windows. The upper left-hand

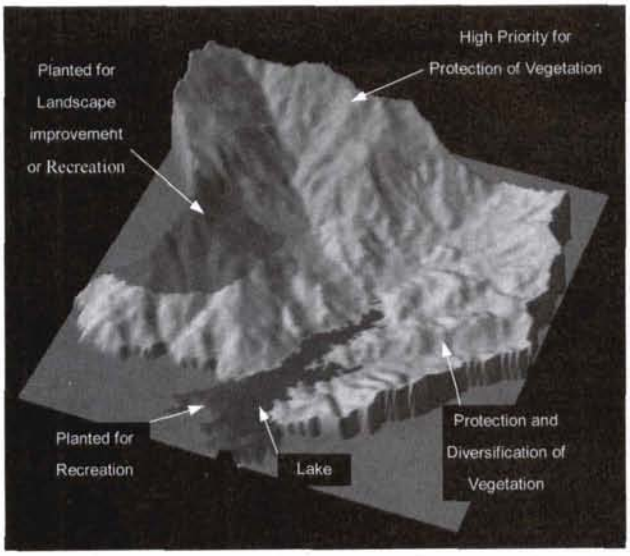

Figure 11. DEM overlaid by vegetation conservation map with both field-based models at the highest spatial resolution.

window in Figure 12 is a 3D world viewing window, the upper right-hand window is used for choosing parameters of spatial and thematic levels and thematic type and for data query and object addition/removal, the bottom-left window is used for talking among online users, and the bottom-right window is used for displaying a 2D map of the virtual country park, which closely connects with the 3D world viewing window.

Applications

On the Internet, users can enter the 3D virtual park using Web browsers such as Netscape and Internet Explorer and VRML viewers such as Cosmo Player and Blaxxun Contact which are freely available (Cosmo Player, 2000; Blaxxun, 2001). When VirtualPark is started, every user needs to choose his/her own avatar. Distributed users interact and communicate through avatars and text-based dialog. For instance, the bottom-left window in Figure 12 shows the chat content among the three online users. And there are two 3D avatars in the 3D world viewing window that represent online user names, current positions of their view points, and viewing directions.

According to the performance of a users' specific computer and the data transfer speed of the Internet, users can setup appropriate spatial and thematic levels for a rapid 3D graphics rendering and interaction in (near) real time. For example, the 3D virtual world in Figure 12 describes the terrain of the Shing Mun Country Park with the spatial level set at 1. Also, different thematic models can be added in the 3D virtual space. In Figure 12, a water theme organized in an entity-based model was selected, and it is viewable in the 3D world viewing window. In terms of thematic aspect of topographical landscape models, specific thematic levels may also be selected. But thematic level selection is effective only for field-based thematic models.

In the VirtualPark, coordinate measurement and data query can be conducted. In the 3D world, users may use the mouse to measure the coordinates of any point. The top-right output window shows the coordinates (x, y, z) of selected points. In the data query view, the VirtualPark provides users with two methods: one is spatial and allows users to select objects in the 3D world for querying the object information from the database server, and the other uses keywords to get information about keyword-related objects. For example, in Figure 12, the playground keyword was used to query information about playground-related objects, and to query results such as Range in the x, y, and z dimensions, WebUrl, Metadata, and Description are shown in the top-right output window.

The VirtualPark can allow users to add or remove 3D objects directly in the 3D scene. Before adding an object, a specific object type and a position for adding an object should be selected. For object removal, users select an object in the 3D world, and then press the Remove button to complete the object

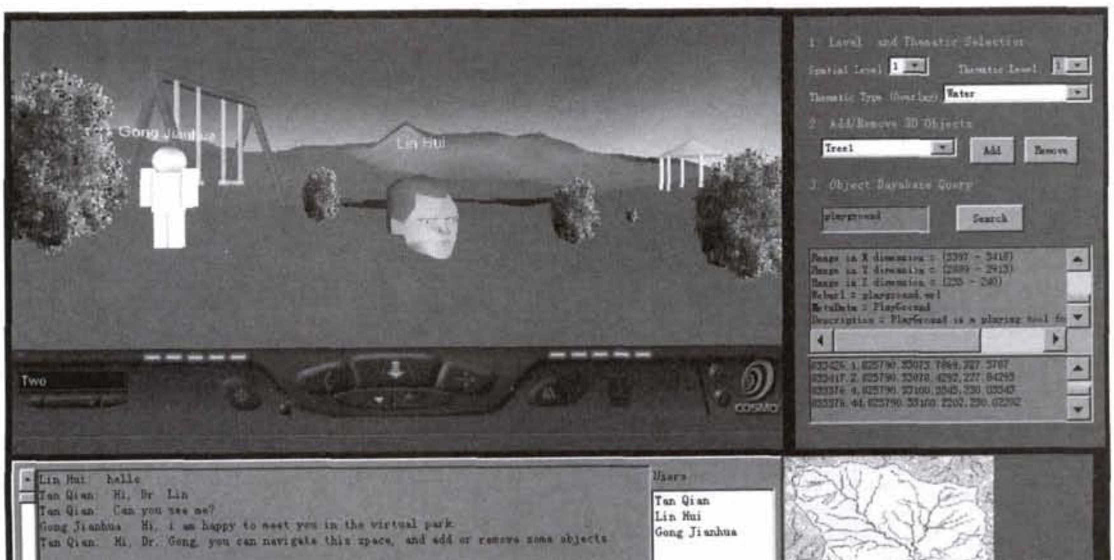

Figure 12. A distributed 3D multi-user virtual environment, VirtualPark.

removal operation. Meanwhile, the selected object disappears into the 3D world. Added/removed objects are all managed by the database server. Furthermore, the added/removed objects can be shared, i.e., when a user adds/removes an object in the 3D world, other online users can also see it. As shown in Figure 12, many trees were added to the virtual park. This functionality of the VirtualPark, together with avatar-based and text-based communication among online users, allows remote collaborative work in the virtual country park to be easily and effectively carried out.

Conclusion

The Internet and the World Wide Web provide the public convenient access to geographical data, to easily implement 2D or 3D geographical visualization, and to participate in resource management, environmental protection, regional planning, and decision making. In this paper, we aim to design a distributed virtual environment to enable the Country and Coastal Park Authority or other organizations to manage and disseminate a variety of information regarding areas such as spatial distribution, administrative regulations, and future planning for Hong Kong's Country Parks. This distributed virtual environment will also enable the public to use standard Web browsers and VRML viewers to take part in areas such as planning, policy making, protection of ecological systems, and development of the tourism industry. The system architecture, integration of Java and VRML EAI classes, field/object-based model, and user's interface pertaining to a DVE are scrutinized. Through a case study of the Shing Mun Country Park in Hong Kong, a system prototype, VirtualPark, was developed, allowing geographically distributed users to connect and share the same virtual country park on the Web, to navigate the 3D virtual space in (near) real time, to interact with each other through 3D avatars and text-based dialogue, and to implement data query and object addition/removal. Future improvements to the VirtualPark should be centered on using Geo-VRML to represent the large connected country parks in Hong Kong. We should also design specific algorithms and a sharable database to implement real-time 3D navigation and interaction, as well as smooth movement in very large 3D geographical worlds with a high spatial resolution. Other improvements should include closely connecting 2D with 3D view, adding more functions for spatial data analysis such as viewshed analysis, implementing Web-based simulation and visualization of geographical application models, and adopting multimedia technology to enrich 3D virtual worlds.

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References

Arikawa, M., S. Shimojo, A. Amano, K. Maeda, R. Aibara, K. Nishimura, K. Hiraki, and K. Fujikawa, 1999. Real-time spatial data management for scalable networked augmented virtual spaces, *IEICE Trans. INF. & SYST.*, 82-D(1):99–111.

Barkakati, N., 1999. *Java™ Annotated Archives*, Osborne/McGraw-Hill, Berkeley, California, pp. 823–826, 880 p.

Batty, M., M. Didge, S. Doyle, and A. Smith, 1998. Modelling virtual environments, *GeoComputation: A Primer* (P.A. Longley, S.M. Brooks, R. Mcdonnell, and B. Macmillan, editors), John Wiley & Sons, New York, N.Y., pp. 139–161.

Blaxxun, 2001. *Blaxxun Contact*, URL: http://www.blaxxun.com/.

Carey, R., and G. Bell, 1997. *The Annotated VRML 2.0 Reference Manual*, Addison-Wesley Developers Press, Reading, Massachusetts, 501 p.

Cooper, W., 2000. MUDs, metaphysics, and virtual reality, *The Journal of Virtual Environments (Electronic Journal)*, 5(11):January, URL: http://www.brandeis.edu/pubs/jove/HTML/v5/cooper.htm.

Coors, V.J., 1997. Using VRML as an Interface to the 3D Data Warehouse, URL: http://ece.uwaterloo.ca:80/vrml98/cdrom/papers/coors/.

Cosmo Player, 2000. *Cosmo Player 2.1 for Win 95/NT*, URL: http://www.cai.com/cosmo/.

Cosmo Worlds, 1999. *Cosmo Worlds for Irix*, URL: http://cosmo.sgi.com/worlds.

Country Parks, 2001. *Country Parks and Special Areas*, URL: http://parks.afcd.gov.hk/.

Cybertown, 2001. *Cybertown—A 3D Community on the Internet*, URL: http://www.blaxxun.com/.

Doyle, S., and M. Dodge, 1998. Toward virtual London: Developing a virtual internet GIS, *Proceedings of International Conference on Modeling Geographical and Environmental Systems with Geographical Information Systems*, 22–25 June, Hong Kong, pp. 624–629.

Dykes, J., K. Moore, and J. Wood, 1999. Virtual environments for student fieldwork using network components, *Int. J. Geographical Information Science*, 13(4):397–416.

Evans, A., R. Kingston, S. Carver, and I. Turton, 1999. Web-based GIS used to enhance public democratic involvement, URL: http://kilton.leeds.ac.uk/geocomp99/gc104.html.

Fairbairn, D., and S. Parsley, 1997. The use of VRML for cartographic presentation, *Computers & Geosciences*, 23:457–481.

Faust, N. L., 1995. The virtual reality of GIS, *Environment and Planning B: Planning and Design*, 22:257–268.

Gabbard, J.L., D. Hix, and J.E. Swan II, 1999. User-centered design and evaluation of virtual environments, *IEEE Computer Graphics and Applications*, (November/December):51–59.

Green, D.R., 1997. Cartography and the Internet, *The Cartographical Journal*, 34(1):23–27.

Gueziec, A., G. Taubin, B. Horn, and F. Lazarus, 1999. A framework for streaming geometry in VRML, *IEEE Computer Graphics and Applications*, (March/April):69–78.

Harris, T., and D. Weiner, 1998. Empowerment, marginalization, and "community-integrated" GIS, *Cartography and Geographic Information Systems*, 25(2):67–76.

Hibbard, B., 1998. VisAD: Connecting people to computations and people to people, *IEEE Computer Graphics*, 32(3):10–12.

Kahkonen, J., L. Lehto, T. Kilpelainen, and T. Sarjakoski, 1999. Interactive visualization of geographical objects on the Internet, *Int. J. Geographical Information Science*, 13(4):429–438.

Li, J., and Z. Wen, 2001. Adorning VRML worlds with environmental aspects, *IEEE Computer Graphics and Applications*, (January/February):6–9.

Lin, H., J.H. Gong, and F. Wang, 1999. Web-based three-dimensional geo-referenced visualization, *Computers&Geosciences*, 25(10):1173–1181.

MacEachren, A.M., R. Edsall, D. Haug, R. Baxter, G.O.R. Masters, S. Fuhrmann, and L.J. Qian, 1999a. Exploring the potential of virtual environments for geographic visualization, URL: http://www.geovista.psu.edu/publications/aag99vr/fullpaper.htm.

MacEachren, A.M., M.J. Kraak, and E. Verbree, 1999b. Cartographic issues in the design and application of geospatial virtual environments, URL: http://www.geovista.psu.edu/publications/ica99.

Marrin, C.,1997. Proposal for a VRML 2.0 Informative Annex: External Authoring Interface Reference, 21 January 1997, URL: http://vrml.sgi.com/moving-worlds/spec/ExternalInterface.html.

Nadeau, D.R., 1999. Building virtual worlds with VRML, *IEEE Computer Graphics and Applications*, (March/April):18–29.

Obermeyer, N.J., 1998. The evolution of public participation GIS, *Cartography and Geographic Information Systems*, 25(2):65–66.

OICQ, 2001. *Tencent OICQ*, URL: http://www.tencent.com/.

Plewe, B., 1997. *GIS-Online: Information Retrieval, Mapping, and the Internet*, OnWord Press, Santa Fe, New Mexico, pp. 215–252, 311 p.

Rhyne, T.M., 1999. A commentary on GeoVRML: A tool for 3D representation of georeferenced data on the web, *Int. J. Geographical Information Science*, 13(4):439–443.

Richard, D., 1998. Development of an internet atlas of Switzerland, *Computers&Geosciences*, 26:45–50.

Rohrer, R.M., and E. Swing, 1997. Web-based information visualization, *IEEE Computer Graphics and Applications*, (July/August): 53–59.

Singhal, S., and M. Zyda, 1999. *Networked Virtual Environments: Design and Implementation*, ACM Press, SIGGRAPH Series, New York, N.Y., pp. 1–17.

Strand, E.J., 1997. Java creates new channels for GIS information, *GIS World*, (28 May), URL: http://www.geoplace.com/gw/1997/0597/.

Tecoplan, 2001. DMUConference, URL: http://www.tecoplan.de.

Van Maren, G., and R. Germs, 2000. K2VI: A Virtual Reality Interface for the Spatial Database Engine, URL: http://www.infosystems.co.nz/k2vi/esri/p551.htm.

Verbree, E., G.V. Maren, R. Germs, F. Jansen, and M.J. Kraak, 1999. Interaction in virtual worlds views—Linking 3D GIS with VR, *Int. J. Geographical Information Science*, 13(4):385–396.

VTK, 2001. *The Visualization TooKit*, URL: http://www.kitware.com.

White, S., and J. Sonstein, 1999. Vnet, URL: http://www.csclub.uwaterloo.ca/u/sfwhite/vnet/.