Mobile Augmented Reality Techniques for GeoVisualisation

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Abstract

This paper presents the first prototype of an interactive visualisation framework specifically designed for presenting geographical information in both indoor and outdoor environments. The input of our system is ESRI Shapefiles which represent 3D building geometry and landuse attributes. Participants can visualise 3D reconstructions of geographical information in real-time based on two visualisation clients: a mobile VR interface and a tangible AR interface. To prove the functionality of our system an educational application specifically designed for university students is illustrated with some initial results. Finally, our conclusions as well as future work are presented.

Keywords--- **Augmented Reality, Mobile Interfaces, Human-Computer Interaction, Geographical Information Systems.**

1. Introduction

In recent years geographic data representing real world features, more commonly used in Geographical Information Systems, has increasingly been used for virtual and augmented reality (AR) applications. GIS have established many new services and applications including navigation, decision support and modelling of the surrounding environment. However, GIS users are usually constrained to the functionality accessible through the WIMP (windows, icons, menus and pointers) metaphor as well as executable commands existing within a geo-visualization [1]. This produces a barrier that does not allow users to visualise and manipulate geographical information in a realistic and natural manner.

Although computer graphics techniques have been used in the past with GIS to visualise data and to enhance the interaction of the user with geographical information [2] there is no geo-visualisation system to our knowledge capable of engaging a mobile device user in the outdoor environment. One way to overcome these barriers is by placing the user directly in control of the geospatial display through the use of powerful but also tangible user interfaces (TUIs). TUIs are extremely intuitive to use since the real object manipulations can be mapped one-to-one to virtual object operations [3]. In other words, they can give physical form to virtual information, facilitating direct manipulation of physical representations [4].

The intuitive manipulation of tangible user interfaces with the prospects of AR visualisation is referred as *tangible augmented reality* [5]. On the other hand, the ultimate goal of an effective AR system is to enhance the user's perception and interaction with the real environment by superimposing the real world with 2D and 3D virtual information that appear to coexist in the same space as the real world [6]. The superimposed information can be presented in a number of different mobile display systems including head attached displays such as head-mounted displays and Head-Up Displays (HUDs) as well as other types of displays including PDAs and 3G phones. While a lot of work has been done in tracking and registration much less work exists in tangible AR interfaces that allow the realistic visualisation and manipulation of geographical information in a natural but also meaningful manner.

In this paper we present our first prototype system of an EPSRC Pinpoint Faraday project called LOCUS [7] aiming to extend the current map-based approach to offer a tangible geo-visualisation interface. Our first objective is to model the 3D scene around the user on the mobile device given building height/type data using photogrammetry and GIS modelling techniques. The second objective is to present the modelled information into a mixed reality environment that consists of two different visualisation interfaces; a *VR mobile interface* and a *tangible AR interface*. Participants can interact with the virtual geographical information using combinations of user-oriented and/or computer-oriented interaction techniques. Finally, based on the functionality of the AR interface we have designed and implemented, a simple but robust educational game for GI Science students studying at City University.

In the remainder of this paper we describe our system starting with section 2 which gives a brief overview of our mobile architecture, while section 3 describes the sub-systems of our architecture in more detail. Section 4 presents two different mobile approaches for visualising geographical information in 3D. In section 5, we briefly describe the basic capabilities of the human-computer interaction techniques that have been implemented. Furthermore, section 6 presents our experimental educational application, called an interactive 3D puzzle, while section 7 concludes by presenting our plans for future work.

2. Architecture of the system

The architecture of our prototype system is simple and consists of four parts including *content acquisition*; *3D model generation*; *model enhancement*; and *content visualization*. A diagrammatic overview of the pipeline of our system is presented in Figure 1.

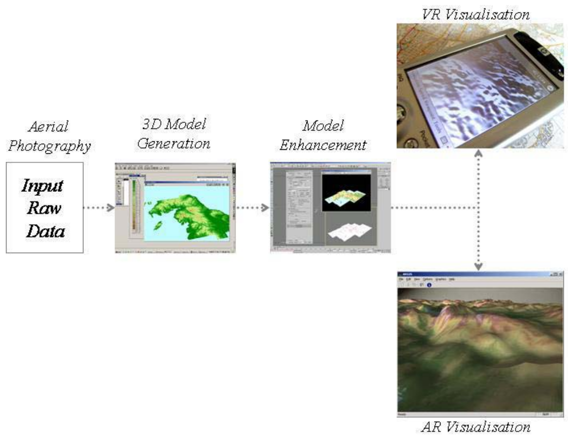

Figure 1 Architecture of the system

In the content acquisition stage (section 3.1) the objective is to collect all the necessary data (ESRI Shapefiles as rasters) in respect of their spatial relationship, in our case aerial photographic data and 2D digital maps. In the 3D model generation phase (section 3.2) the digitised map information is converted into an appropriate 3D format for visualisation (VRML). Furthermore, in the model enhancement stage the 3D maps are enhanced with more information so that they look as realistic as possible. Typical operations include texturing, re-lighting or even polygon reduction of the whole 3D scene (section 3.3). Finally, in the content visualisation phase (section 4) the enhanced geographical information can be visualised in two different mobile visualisation clients: a mobile VR interface designed to operate in 3G phones and PDAs and a tangible AR interface focused for laptop computers.

3. Content Production

Content production is a very important stage because to a great extent it determines the accuracy and the level realism of the cognitive visualisation. The framework for the generation of 3D geographical models consists of three stages including: the *input data stage*; the *3D scene reconstruction stage* and the *model enhancement stage* and are presented in the following sections (Figure 1). Finally, the content visualisation is described in section 4.

3.1 Input Data Stage

Photogrammetry is one of the most popular tools to acquire the 3D data and digital photogrammetric methods for providing automatic digital surface model or digital terrain model generation have been widely used in GIS due to the efficiency and effectiveness of the production process [8]. Therefore, the input data for the urban models of our prototype system include: *ESRI Shapefiles* and *UK Ordnance Survey mapping products* converted to ESRI raster formats.

ESRI Shapefiles have been generated using a combination of aerial photography and stereoscopic analysis to gain height information. Ordnance Survey mapping products were used to create the footprints of buildings and street geometry (Figure 6). In practical terms, multiple height readings (which can be used to model buildings with sloping roofs or spires, for example) are contained with the shapefiles attribute table. These shapefiles have been provided, under licence, by the Cambridge Geoinformation Group [9].

1:50,000 scale colour raster mapping from the Ordnance Survey was used to provide context and background mapping. This data was obtained via the JISC Edina Digimap Service [10]. For the model of the Lake District shown and for other non-urban models, 1:50,000 Panorama Digital Terrain Models were used, downloaded again from the JISC digimap service.

3.2 3D Scene Reconstruction

One of the greatest disadvantages in 3D scene reconstruction compared to 2D map production relates to the high cost and effort required to produce 3D information but benefits from a certain level of automation [11]. In this approach we have created models for both common GIS data structures: raster and vector [12].

The model for the urban London area was created using the 3D analyst extension [13] in ESRI ArcView 9. Using this extension, the height attribute for 2D polygons can be used to generate 3D objects using an extrusion procedure. In ArcView the term extrusion means changing the form of a 2D vector feature by either turning points into vertical lines, lines into vertical walls or polygons into 3D blocks [14]. In practical terms, a dialog box is opened in the 3D analyst and a field selected from the features attribute database that contains the height values for the features. These can either be used as an absolute value, or used as a component of a calculation. In the case of terrain models this extrusion technique can be used to ascribe Z-values from the surface itself (as opposed to a value or calculation from the attribute table).

Overall, buildings and constructions are dimensioned and drawn as 3D objects but the overall 3D mesh is still rather simple and not very detailed yet [15]. To overcome these limitations, we import the 3D models into a professional 3D modelling tool (section 3.3) to calculate normals, faces, lighting information, texture information, shadows, and other parameters useful for the overall realism of the geographical information.

3.3 Model Enhancement Stage

Nowadays, commercial modelling tools offer ways of creating professional-quality 3D models, photorealistic still images and film-quality animations. In this research, the industry standard 3ds max was used for two important operations. The first was to digitally enhance the geo-spatial landmarks and buildings to mimic the appearance of the real buildings surrounding the environment [16] while the second to export them into the most appropriate VRML format (triangles, Ngons, quads and visible edges).

The enhancement part involved making adjustments to the 3D models generated by the 3D reconstruction stage such as replacing the material properties (colouring information and textures) of the 3D objects. Other operations included adding extra lighting and shading information to achieve the best pre-rendered representation of the geographical information. Furthermore, small corrections are performed in the geometry of geographical topology such as smoothing and tessellation to achieve a balance between the best optimisation possible and the realism of digitised information.

4. Visualisation Techniques

In terms of visualising the geographical information we have implemented two different mobile solutions: one with low-realism and one with high-realism. The low-realism solution is targeted for mobile devices which do not have the required technical characteristics to simulate reality accurately. On the other hand, the high-realism solution is capable of rendering large datasets of geographic information in real time performance as well as presenting additional multimedia content information such as text and images to the users.

In addition the proposed geo-visualisation solutions can be combined together through a wireless network connection, so that both solutions could be used simultaneously. For example, a user can first visualise a reduced version of the virtual information on the mobile VR interface. If interested in obtaining a cognitively richer 3D representation then it can be visualised using the tangible AR interface.

4.1 Mobile VR Interface

The advantage of VR interfaces in GIS is that they can provide egocentric views of a dataset [5]. VR visualisation in our prototype platform can be realised through the capabilities of the well known Virtual Reality Modeling Language (VRML) which is built on top of Open Inventor. VRML has dominated during the last few years because it has the advantage of presenting 3D objects or 3D environments over the Internet. This allows a VRML browser or a stand-alone application (i.e. mobile client) to obtain a virtual scene locally or remotely (i.e. WWW). The main principle relates to how graphic scenes can be created, stored and transmitted and it concerns geometric objects, lights, materials and other useful information.

Figure 2 illustrates an interactive 3D map of north of England displayed on a PDA (ipaq 5450 pocketPC). The 3D map is displayed using pocket Internet Explorer with a VRML plug-in from pocket Cortona by ParallelGraphics. To increase the level of realism of the VR interface, we have added collision detection to the 3D models so that users can navigate more naturally.

Figure 2 Mobile VR visualisation

Various rendering parameters can also be manually specified by the user, e.g. what shading algorithm to apply (flat, smooth), what hardware acceleration to exploit (OpenGL, DirectX). The exact extent to which the user can control the navigation and rendering differs between viewers. In the present implementation, the VRML viewer controls are used to manipulate all 6 degrees of freedom: the observer location in three dimensions, as well as the orientation (yaw, roll and pitch).

Location-aware devices offer the potential to have the two- or three-dimensional location controlled by the mobile device's positional determining technology. The addition of a digital compass, allows yaw to also be controlled by an external sensor, hence the VR model can be registered in a real world setting without the need for visual markers. This offers a natural movement- and gesture-based approach of interacting with VR models on mobile devices.

A significant drawback of mobile devices is that they are constrained in terms of processing power, memory and graphics memory. For the purpose of our application, the VRML models and the textures are optimised so that they can be rendered in an acceptable frame-rate. In addition, typical mobile devices have screens no larger than 480 by 640 pixels, and thus the representational and communicative scope of this screen real estate need to be considered.

4.2 Tangible AR Interface

In contrast to VR interfaces, AR interfaces have the ability of providing exocentric views of information. In other words, AR supplements the real environment, whereas VR replaces it. Although there have been many different AR visualisation techniques proposed for presenting geographical information [5], [17], [18], [19] there are few AR interface systems that are focused on visualising 3D geographical information for pedestrian navigational purposes of urban environments [20]. In addition, most AR visualisation systems render either wireframe scenes or simple colour but are not capable of providing more realism.

Our tangible AR interface, called ARGIS is implemented based on the experiences gained from two previous implemented interactive AR interfaces [22][23] which can simultaneously superimpose various types of multimedia information including 3D models, images, text and sound. Furthermore, ARGIS is a C++ stand-alone computer graphics application that operates inside a Microsoft Foundation Classes (MFC) graphical user interface (GUI) that wraps ARToolKit's tracking libraries [21], OpenGL and GLUT APIs. An example of the system's visualisation interface is shown in Figure 3.

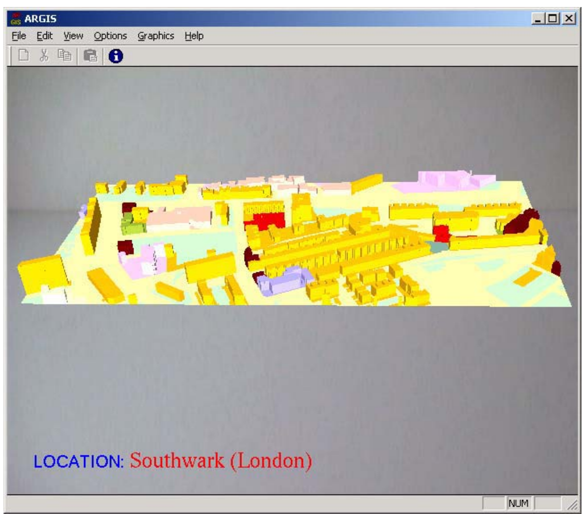

Figure 3 Model and textual augmentation

ARGIS allows the user to fully control the visualisation of the geographical information in a user-friendly manner (section 5). Another interesting feature of the ARGIS is that it allows the users to visualise the geographical information in a demonstration mode, which is in essence full screen mode, irrespectively of the display's resolution. The user can adjust the video resolution through the menu interface so that it can fit on the window size. Other parameters that can be changed in real time include the brightness, contrast and saturation of the web camera. An example of a 3D map representing the north part of England in full screen mode is presented in Figure 4.

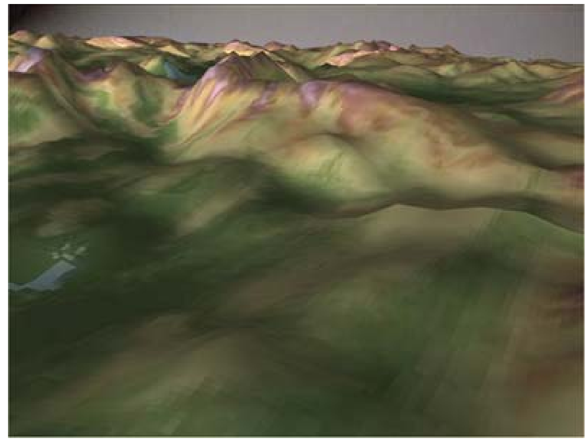

Figure 4 Landscape visualisation in AR

The VRML model illustrated in Figure 4 is approximately fifteen times bigger than the VRML model used in VR visualisation (Figure 2). However, the overall frame-rate performance varies between 25 to 40 FPS depending on the resolution of the camera (640×480 or 320×240).

5. Human-Computer Interactions

One the most important issues in computer interface design is the natural and meaningful interaction between the users and the virtual information and AR seems the most promising technology [24]. In terms of geographical interaction, it is also important to improve the performance of spatial decision making over existing 2D and 3D GIS software tools. In our tangible AR interface users can interact with the superimposed information in either a *user-oriented* or a *computer-oriented* manner.

5.1 User-Oriented Interactions

In user-oriented interactions, participants do not have to use any type of hardware to interact with the digital representation of a map and can examine it from any angle and at any distance through the use of physical marker cards [19].

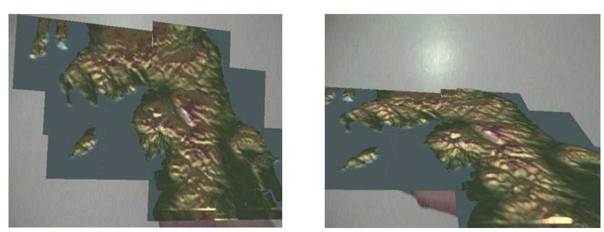

Figure 5 Natural user interactions

The major advantage of integrating this approach is that it allows the user to manipulate the superimposed information using a tangible interface (i.e. physical marker cards, pages of a book, etc). Another important advantage of this technique is that no previous experience is required or any knowledge of computer related technologies. In other words, the AR interface can be effectively used by anyone. This makes the system accessible to all kinds of users independently of their characteristics (age, technical expertise, etc).

On the other hand, the main disadvantage of marker-based tracking is that the markers must always be in the line of sight of the camera. In addition, vision-based tracking algorithms are prone to a number of sources of errors including: lighting conditions; material of the markers; and range of operation.

5.2 Computer-Oriented Interactions

Computer-oriented interactions include those on which a computer system or any other type of electronics device is involved. Based on the previous experience [22], [23] we have integrated *hardware I/O devices* such as the keyboard and the mouse; as well as *software-based solutions* including a widget menu and a GUI. The combination of these provides a powerful and effective interaction mechanism where users can examine the geographical information in a great detail. Using the interface menu on the GUI users can easily navigate using the interactive AR interface so that they can get the spatial information required. More computer literate users can make use of the keyboard and mouse to manipulate the superimposed information. An example screenshot of this exocentric navigation is shown in Figure 6.

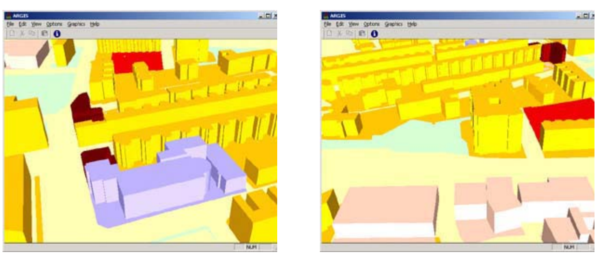

Figure 6 Exocentric views of Southwark

It is worth mentioning, that computer-oriented interactions offer the ability to perform accurately various computer graphics operations such as rotating, translating and scaling the virtual geographic information so that even the finest detail can be clearly displayed. We believe that computer-oriented interactions can enhance the cognitive perceptions and increase the ability to understanding geographical information (i.e. maps). To enhance more this, hotspots can be integrated into the 3D map so that when the user clicks on them, multimedia information like animations, images and metadata are superimposed into a context aware AR environment.

6. An Interactive 3D Puzzle Application

Based on the framework explained in the previous sections, we have carefully designed an experimental educational application for geography students called 'an interactive 3D puzzle'. Our objective is to provide a combination of educational and entertainment experiences which can be available in the future to full-time, part-time and distance learning students. For the purpose of the interactive 3D puzzle scenarios we have modelled a big part of the campus of City University in correspondence to cognitive tuning and then visualise it in both VR and AR interfaces. An example screenshot of the virtual model of City University's campus rendered in the mobile VR interface is shown in the left image of Figure 7 while the same information displayed in the tangible AR interface is presented in the right image of Figure 7.

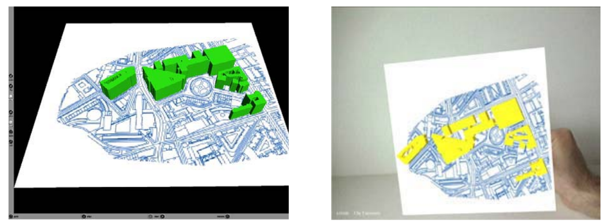

Figure 7 City's university campus

Furthermore, using the functionality of ArcGIS, the 3D mesh was split into three equal parts that represent the virtual pieces of the puzzle and exported into separate VRML files (section 3.2). Each VRML file was then imported into 3ds max for further enrichments such as scaling, smoothing and re-lighting (section 3.3). In addition, each model is first normalised and then assigned into a different marker card. During the session and as long as the camera is in sight of view with them, the virtual components of City Campus together with supplementary textual information can be superimposed into the real environment as illustrated in Figure 8.

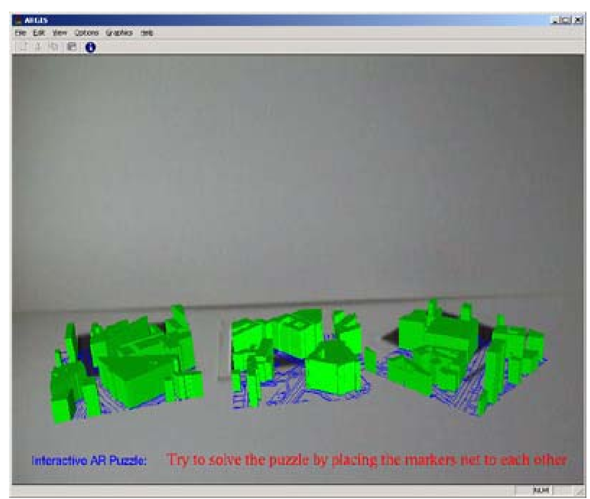

Figure 8 Puzzle demonstration in AR

Then the user can pick up the marker cards and examine the geometrical and geographical information in a tangible manner. An advantage of this application is that it is possible to collaborate with other users that could stand around the table-top environment and either give advice or play the game. Multiple users can naturally experiment with different combinations by randomly placing the marker cards close to each other as depicted in Figure 9.

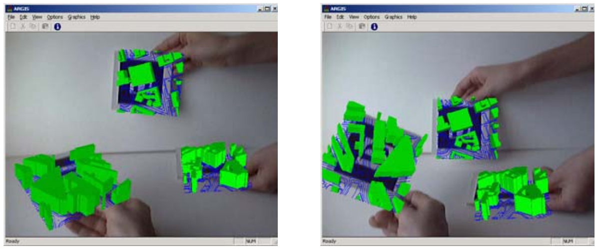

Figure 9 Collaborative educational environment

As soon as the interactive 3D puzzle is completed, meaningful textual feedback is provided again, in this time in order to congratulate the users for solving the puzzle. The size and the colour of the superimposed text can be changed interactively by the users using the interface menu or predefined keyboard keys. Next, an illustration of the solution of the interactive 3D puzzle is shown in Figure 10.

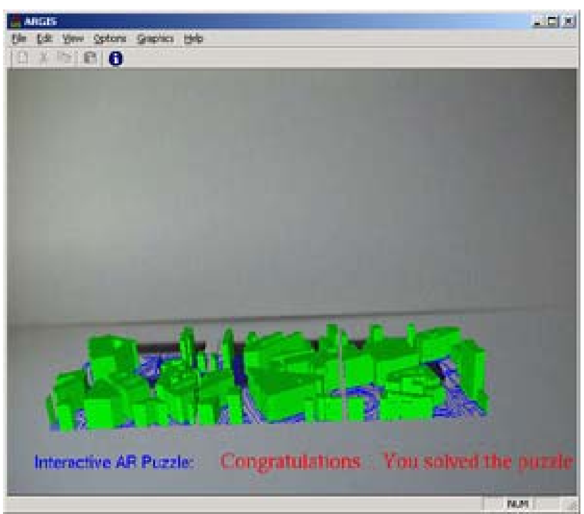

Figure 10 Solution of the AR puzzle

Furthermore, this system has been demonstrated in GeoInformation Group's Cities Revealed Event 2005 conference as well as informally to a number of postgraduate students in the department of Information Science (City University). The feedback we have received was that the AR interface is very easy to use even if there is much more work required for an educational application that can be used in practice.

Although the application has not been yet evaluated informal feedback from the demonstrations showed that the average time for solving the puzzle was measured to be around 3-4 minutes depending of the student. Nevertheless, we strongly believe that in the near future similar educational applications will start to appear in universities while in the longer term commercial 3D applications will become part of our lives.

7. Conclusions and Future Work

This paper describes our first prototype system for building and presenting geographical information using GIS, 3D modelling, AR and VR technologies. The most distinctive feature of our system is its ability to allow users to visualise the same information in a two types of mobile environments including: a mobile VR interface and a tangible AR interface. The mobile VR interface is operational on PDAs and 3G phones whereas the tangible AR interface currently works on laptop computers. Our prototype allows interaction with 3D geographical data in a range of virtual and augmented views. Position determining technology and digital compasses will be investigated as means of registering virtual models in outdoor settings.

Currently we are developing routing tools which will be based on the data mining of previous journey experiences. In addition, we are building a database to hold our geographical data as well as more educational scenarios and feed both visualisation clients on the fly. As soon as these two tools have been developed and tested appropriately then we will port our tangible AR interface to PDAs and commercial 3G mobile phones that have a camera and a GPS receiver embedded.

In the future, we plan to develop optimisation techniques in the visualisation side including level-of-detail and culling to increase the overall rendering efficiency of the system. In respect to human computer interactions additional user-oriented techniques like gestures and voice recognition, as well as computer-oriented approaches based on VR interaction devices such as inertia cube and digital compass will be integrated. In addition, more types of interaction techniques will be included such as gestures. Finally, additional educational scenarios will be designed so that they can be then properly evaluated and applied in practice for our teaching purposes.

8. Acknowledgements

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