

New Perspectives on Ancient Landscapes: A Case Study of the Foulness Valley

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Abstract

The standard method for gathering and representing archaeological information consists of two-dimensional layer managers. This paper presents an archaeological Geographical Information System (GIS) based on an immersive virtual environment. Our goal is to provide an immersive visualisation of multiple datasets relating to the Foulness Valley in East Yorkshire. By maximising the user's visual bandwidth within an immersive virtual environment, we have provided archeologists with greater insight into the Foulness Valley datasets using both existing and novel visualisation tools and techniques.

Keywords: Archaeology, Virtual Environment, Immersive, CIDOC CRM.

Categories and Subject Descriptors (according to ACM CCS):

I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism

1. Introduction

The modern archaeologist can be overwhelmed with the huge quantity of data generated from contemporary scanning and measurement technologies as detailed in [Ash03]. The problem is further compounded by the vast quantity of data types, format and representations in use today. Two-dimensional Geographical Information Systems (GIS), for example Arcview and its successors, are nowadays widely used by archaeologists in order to gather a large amount of data into a single visualisation. These software systems remain a simple layer manager that do not provide high level visualisation and navigation tools.

This paper initially describes the dataset used within the case study and then describes the hardware architecture we relied on to create a sense of immersion. We subsequently describe the terrain modelling and the metaphors used for representing the varied datasets. Finally we explain the various immersive navigation methods used and describe how we evaluated the system.

2. Dataset: The Foulness Valley

Our case study site is located in the 'Foulness Valley', East Yorkshire, UK. This is one of the most detailed landscape studies yet undertaken in Northern England. Discoveries include the Hasholme log-boat and an internationally significant prehistoric iron industry [HM99]. Data generated and used within this project include:

- Digital Elevation Model (DEM) – accuracy: 1m.
- Colour Ordnance Survey (OS) maps.
- 200 air photos.
- Rectified crop-mark plots covering c. 20x30km from the English Heritage Vale of York/Yorkshire Wolds National Mapping Programmes.
- Detailed field-walking results over 64 km².
- Soil survey maps/manuscript data at various scales.
- Information from excavation of a range of sites: texts, pictures and numerical databases.
- Three-dimensional records and reconstructions (including a Roman Fort).

Elements of this data have been integrated into a two-dimensional Geographical Information Systems (GIS): Arcview. Although Arcview and its successors contain a ba-

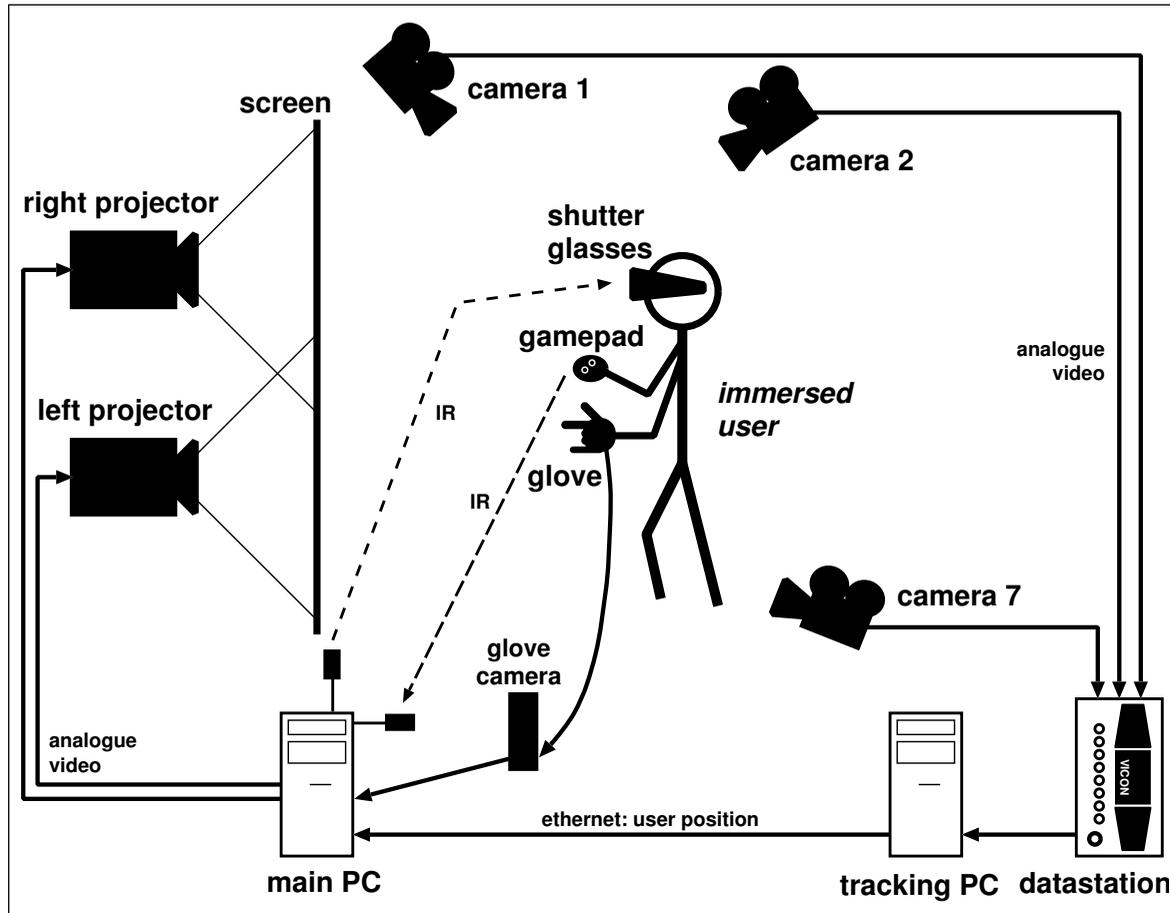


Figure 1: *Hardware architecture*

sic three-dimensional facility, it remains a simple layer manager.

Importing the above data into a multi-layered, three-dimensional stereoscopic immersive virtual landscape has enhanced the resource provided by our data both for researchers and the wider community far beyond the scope of the printed page or current GIS. In achieving our aim, we have used existing and developed new research tools and techniques for the visualisation and improved understanding of archaeological sites and landscapes.

3. Architecture

This section briefly describes the hardware and software architecture.

3.1. Hardware

In order to reach a state of immersion we used the HIVE (Hull Immersive Visualisation Environment) [HIV] facilities

provided by the University of Hull, UK. The main HIVE display is based on a rear-projected wall (6m wide by 2.5m high) that eliminates any user shadows. A pair of video-projectors ensures a good coverage of the entire work wall. Seven infrared cameras and a Vicon DataStation [Vic] were dedicated to the tracking system. The viewer, wearing stereo NuVision glasses walks around the stage area (which houses the work wall) and feels a high sense of presence due to the stereo display and large dimensions of the projected environment. For this case study we are using state of the art VR stereo projection systems and tracking technologies (the system architecture can be seen in Figure 1). Doug Bowman and his colleagues provide an excellent review of 3D user interface design and contemporary VR hardware systems in their SigGraph 2001 course notes [BLMP01].

The computer handling the rendering of our virtual environment consisted of an Intel Pentium 4 Extreme clocked at 3.2Ghz with 2GB of memory and a NVIDIA Quadro FX3000 video card. This card includes 256MB of texture memory and two video outputs which can display a total of

2560x1024 pixels. This powerful graphic station ensures an acceptable frame rate in stereo mode. In order to improve the sense of immersion, a wireless gamepad interface (Logitech WingMan Cordless) was also integrated [Log].

3.2. OpenSceneGraph

Our application has been built using OpenSceneGraph (OSG) [Ope], a portable, high level graphics toolkit for the development of high performance graphics applications such as flight simulators, games, virtual reality or scientific visualisation. OSG provides an object oriented framework that sits on top of OpenGL and frees the developer from implementing and optimizing low level graphics calls. OSG also provides many additional utilities for rapid development of graphics applications and is a popular graphics toolkit used within our graphics laboratory. We selected OSG as the foundation for our graphics architecture because of its proven improvements to performance, productivity, portability and scalability. OSG also enables access to the underlying OpenGL and shader languages.

3.3. CIDOC-CRM

The CIDOC (International Committee for Documentation of the International Council of Museums) has developed a 'Conceptual Reference Model' [CID04] referred to as the CRM. This emergent model provides definitions and formal structures for describing the implicit and explicit concepts and relationships used in cultural heritage documentation. By providing such a framework, it aims to integrate all sources of documentation from museums to libraries.

We selected the CRM as the model for documenting and associating all the sources of information available in our case study. The Extensible Markup Language (XML) [W3C], was chosen to implement the CRM. XML is a popular choice for storing CRM data. An interpreter of the CRM (version 4.0) was developed based on libxml2 [lib]. The interpreter can load CRM files stored in XML format on the proviso that each object is specified as a reference document and contains a location in GPS coordinates. Any collection of items that have been stored in the CRM-XML format can be loaded directly into our system.

4. Visualisation

Our virtual environment representation is based on a three-dimensional terrain surface, overlaid with other kinds of archaeological data, such as crop marks and multidimensional databases. Immersive visualisation of archaeological data is not new and is becoming more and more popular by archaeologists. For example, Vote et. al. [VFLJ02] provide an excellent description of the immersive visualisation and interaction of archaeological datasets relating to the Petra Great Temple in Jordan.

4.1. Terrain

Our implementation of the GIS representation is based on a Digital Elevation Model (DEM). The terrain, represented as a three-dimensional surface, can be draped with different kinds of textures such as satellite, aerial photographs, Ordnance Survey (OS) maps or crop marks. When two textures are applied simultaneously, they are blended together. These texture maps may be toggled on and off in real-time by the user. Certain textures can be defined as being visually more predominant than other textures which may be useful if a high quality texture is available.

Other user facilities include changes to the vertical exaggeration and providing the user with a variable sea level that masks the underwater terrain (Figure 2) in order to provide the viewer with the potential of viewing varying sea levels over time.

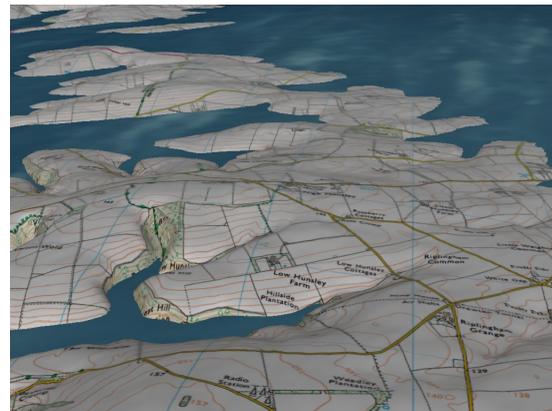


Figure 2: Variable sea level. OS map section used with permission - Ordnance Survey ©Crown Copyright. All rights reserved.

4.2. The 'map table' paradigm

A standard immersive visualisation method consists of representing the scene behind the screen, synonymous with standing against the window of a large aquarium. This representation does not take into account the point of view of the user.

The 'map table' display method represents the terrain as if it were a map laid out on a table, as demonstrated in Figures 3 and 5. This map appears half behind and half in front of the screen. The user is able to move around the virtual table and to perceive that they could touch the map object itself. This map appears to remain stationary from the user's point of view. In our above example, our user now becomes part of the aquarium.

For this purpose, active head tracked stereo has been used and the display is updated according to the user's location.

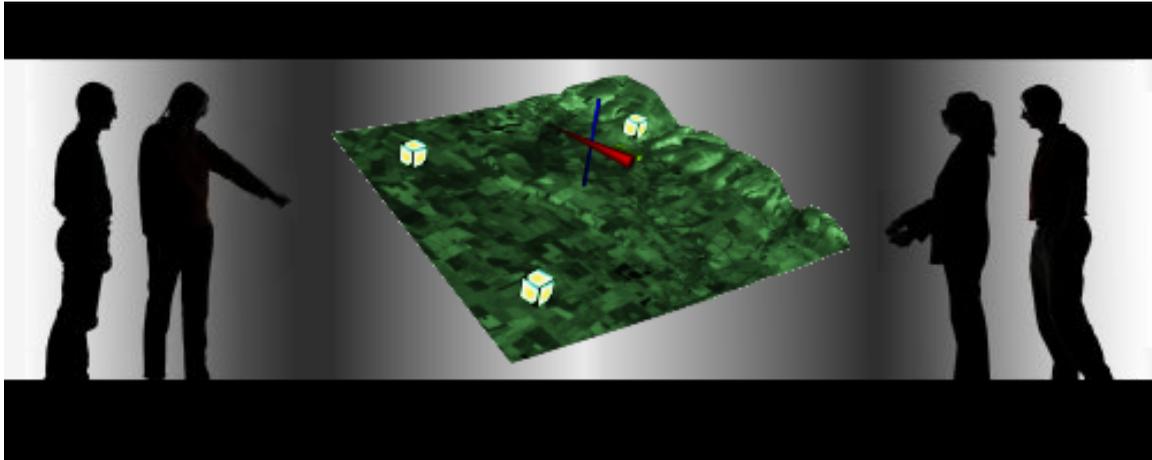


Figure 3: Users immersed in the HIVE

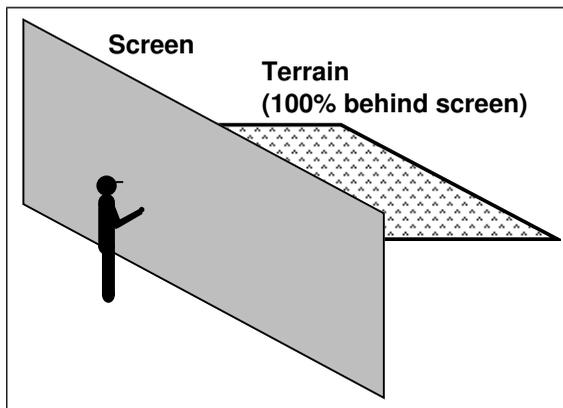


Figure 4: Standard navigation

For example, if the user stands to the right of the scene, then the right side of the terrain will be displayed. This is achieved by tracking the position of the user's stereo glasses using the Vicon tracking system.

Figure 3 shows a number of users collaborating together and interacting with the Foulness Valley datasets using our immersive system. It should be noted that the 'head tracked stereo' element described above is only applicable to a single user as 'head tracked' implies a stereo display specific to a tracked pair of flicker glasses. Immersive stereo is still possible with large groups but the same stereo display is shared by all participants.

4.3. Enhanced crop marks

Crop marks are remains of the past under the ground that are visible only from their effects on the vegetation growth. Given the importance of these crop marks, an enhancement

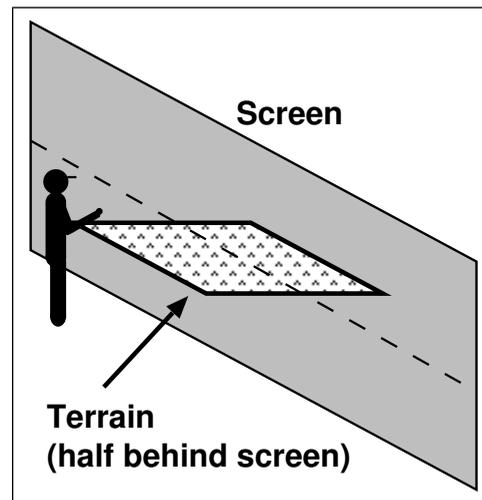


Figure 5: Map table paradigm: the terrain seems to be horizontal

of their representation has been developed. This consists of extruding the crop marks in the third dimension (Figure 6). The user should be careful with this functionality. Overall, the height or depth of a current crop mark is not representative at all of its ancient dimension.

A basic automated morphological classifier of the crop marks has also been implemented, using the definition given by C. Stoertz [Sto97]. This process allows the automatic display of crop marks using colours depending on their shape. Two steps are necessary to reach this objective: first the crop marks need to be clustered into small entities and secondly, each of these entities have to be classified.

A simple technique for clustering was developed that con-

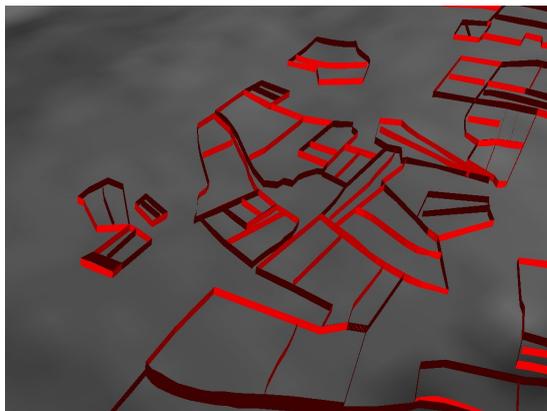


Figure 6: *Crop marks*

sisted of gathering all the segments that intersect together into a single entity. The algorithm fails to gather crop marks entities that can be composed of two separated parts, for example the typical case of a house ‘cropped’ by its gates. However, this does not generally affect the classification process. After some tuning of the parameters, the simple crop marks were fairly well classified and represented using various colours in the main application.

4.4. Stick fields

One technique we used for the visual representation of the numerical datasets, for example the geographical density of finds was to use sticks ‘planted’ vertically on the virtual terrain maps. The size of each stick is proportional to the represented value of the find density at a particular geographical location. All dimensions of the stick have been scaled according to density value. Therefore the user can interpret the three-dimensional data visualisation from all viewpoints. An example of this visualisation can be seen in Figure 7.

In the case of multi-dimensional values, one can choose between visualizing only one value at a time and letting the user swap between values or stacking the sticks representing different values by using different colours. Note that this metaphor is not appropriate for more than four values as the blend of colors becomes confusing.

4.5. Density map

In order to improve the perception of the finds from a significant distance, widget gathering and crop mark enhancement have been developed. These techniques were developed for providing an improved interface relating to zoomed out views. That is when theoretically a large amount of data metaphors would clutter the display.

For this reason, a global density map was used. It unifies all the information about the finds such as crop marks, stand

alone finds, etc, into a single global texture map that can be applied to the terrain. In order to construct the density map, a dilatation function was applied on these finds by expanding each point to a surface. Linear, inverse, square inverse and gaussian function have all been tested for this purpose. Due to their strong variations, both inverse functions were rejected.

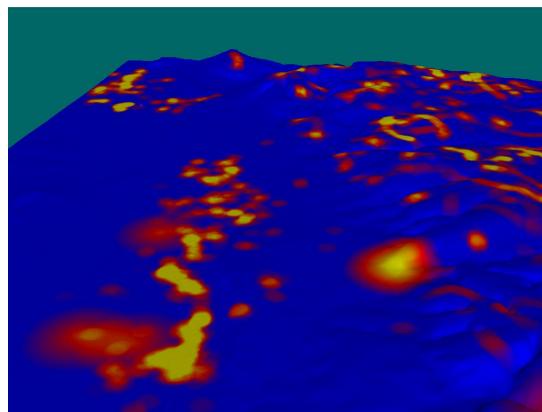


Figure 8: *The density map*

A colour palette scale blue–red–yellow has been chosen to represent the intensity of the density, as shown within Figure 8. The blue areas are low in finds, whereas the yellow are very rich. This helps archaeologists to focus on interesting regions.

5. Navigation

The navigation tasks in a GIS-based virtual environment generally include at least the movement, the object selection and information query, as described in [Fel99]. Initially we will describe the navigation devices: wireless gamepad and tracked glove. We then consider information query and collection using widgets and billboards. Our system uses tried and tested interaction techniques such as pickable widgets and point and click metaphors [BLMP01]. We also describe how the density map described in the previous section was used to develop a novel navigation tool: the density compass.

5.1. Wireless gamepad

Standard methods of interaction such as the mouse and keyboard were developed but found not to be intuitive user interfaces, especially for novice users of the system. We subsequently developed a wireless gamepad (Logitech WingMan Cordless) interface in order to provide a more intuitive method of navigation. This interface has the advantage of letting the user move freely into the room instead of remaining seated at a desktop computer.

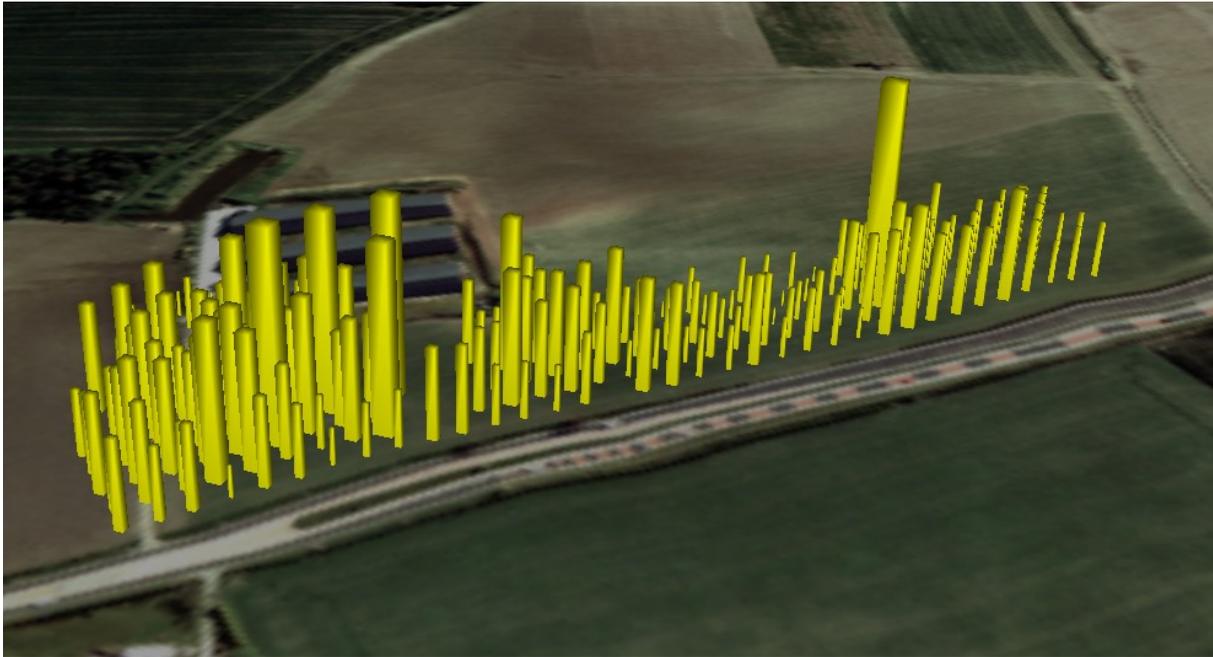


Figure 7: *A stick field*

5.2. Finger-bend tracked glove

A 'P5 glove' device, produced by Essential Reality [Ess] has been integrated into the system in order to provide the user with a more intuitive interface into the archaeological datasets. This glove includes an optical three-dimensional tracking system and bend sensors on each finger. A noticeable weakness is that the glove is linked to the camera by a wire (length: 180cm). It is important to note that this low-cost glove has been specifically designed for video games, and therefore its accuracy does not reflect state of art contemporary tracking systems.

The finger sensors measure the bend in the fingers independently, therefore it is impossible to retrieve the angles between the fingers. It provides an accuracy of 0.5 degrees for a refresh rate of 60Hz. This is sufficient to recognize simple movements or static postures of the hand, but not for complete gesture recognition.

This tracking system was not very accurate, and was only used for prototyping the initial system and was finally replaced by the Vicon system. The Vicon system also provided a much larger work area as the tracking cameras are located throughout the HIVE auditorium.

Three main navigation methods based on this glove have been developed:

First, around fifteen static postures were defined and could be used to dynamically link to any navigation task in the

environment: for example raising the sea level, toggling the textures or changing the light.

Secondly, the classic 'grab-and-move' metaphor [BLMP01] was implemented which consisted of grabbing the terrain by closing the fist and then moving the hand horizontally which moved the terrain accordingly. When relaxing the hand, the terrain remained stationary. A zoom control was developed, using a similar interface.

Finally, the popular 'point-and-pick' metaphor was used for interacting with the virtual world [BLMP01]. It consisted of selection using a virtual index finger. A small stick representing the hand moved into the scene, reproducing the movements of the user's glove. When the user bent all their fingers excluding the index finger, the object under the pointer was selected (picked up).

User trials to date have proved the glove to be a really intuitive and powerful device for interacting with our archaeological data, in particular navigation tasks such as moving and selecting objects. A wireless glove implementation would have the advantage of reducing any physical constraints on the user.

5.3. Pickable widgets

In order to avoid an overload of information displayed at the same time, some pickable widgets that represent data have been used. This is a popular technique for the abstract visualisation of data elements (for example Vote et. al. [VFLJ02]

used 3D widgets to represent various artifacts from an archeological site).

Our archeological widgets can be selected by the mouse pointer, the gamepad or the glove. Two symbols for the pickable widgets representation have been implemented: a two-dimensional icon that always faces the user (for the common finds) and a spinning cube (for more important items). Important items are pre-defined by the archaeologist and flagged in the CRM-XML file.

A selection of widgets is demonstrated in Figure 9. In the foreground, a spinning cube containing a hyperlinked picture and a two-dimensional icon. In the background, a large spinning cube represents a collection of widgets. This clustering of widgets into a single element allows the user to see an interesting group of widgets even though they may be far away. When approaching the group, a threshold is passed and the main group widget is replaced automatically by all the cluster widgets. This process is animated so as not to spatially confuse the user.

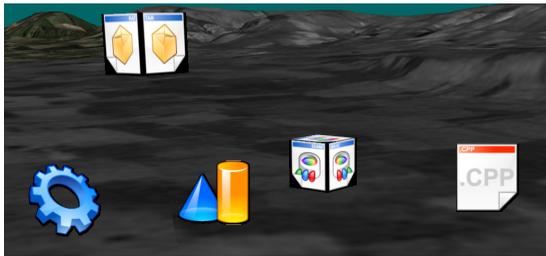


Figure 9: *Pickable widgets*

When these widgets are selected, the information they contain is displayed. In the case of text or image files, a billboard is used (see next section). In the case of a three-dimensional object, the item will be displayed and automatically rotated.

5.4. Billboards

A billboard is a two dimensional container encapsulating text or images. A billboard will face the user at all times. It can be attached to another object, collected and manipulated. Billboards are a popular technique for visualizing 2D information (or pseudo 3D) to a user in a virtual environment. They are also commonly used in games to improve rendering speed by simulating complex 3D objects with simple 2D texture maps.

The billboard has been selected as the standard way for representing and interacting with an image or a text file in the interface. When a widget representing one of these objects is selected, the associated billboard pops up smoothly and remains attached to the widget. The user may then decide to add it into their billboard set (see below).

A billboard set is a tool allowing the user to collect and gather numerous billboards. A rotational billboard interface has been implemented. This can be considered as the first level of a cone tree [CM00]. All the billboards are facing the user, grouped in a circle with a definable axis. The smooth rotation of the billboards leads to a three-dimensional slide show. Other operations like billboard removal are also available. Figure 10 demonstrates a rotational billboard set.

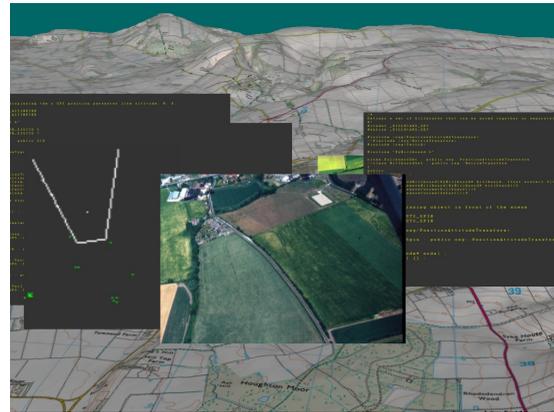


Figure 10: *A billboard set - OS map section used with permission - Ordnance Survey ©Crown Copyright. All rights reserved.*

5.5. Density compass

Visualising the density map provides the user with a global view of the scene. However, in the case of important zoom factors (navigation close to the terrain), the contrast of colours is not really obvious. For this reason, a compass that indicates the nearest maximum of density has been developed.

5.5.1. Field of ‘force’

As a traditional magnetic compass would behave, this device reacts to a field of force. The density of finds is considered as a potential, and the force then derives from this potential. The standard model of the gravitational and electrostatic fields was followed:

$$\vec{f}(\vec{x}) = C \cdot \sum_{\vec{v} \in \xi - \{\vec{x}\}} \frac{\rho(\vec{v})}{\|\vec{v} - \vec{x}\|^3} \cdot (\vec{v} - \vec{x})$$

where:

- $\vec{f}(\vec{x})$ is the ‘density’ force at the point \vec{x}
- \vec{v} is a point of the considered space ξ
- $\rho(\vec{v})$ is the density potential at the point \vec{v}
- C is a constant (optional)

The force is steered in the direction of the emitter point, and its intensity is proportional to the inverse square (note that the cube power in the sum compensates for the length of the steering vector) of the distance to this point. This strong

decrease with the distance is prone to a substantial scalability: the main field lines associated to the main maxima of density are detected when navigating with a low zooming rate, but this main tendency does not affect the minor maxima visualised while zooming in.

The computation of such a field is processor intensive as all the points of the space must be integrated (summed) for each point of computation. Due to this significant computation time, the calculations are processed off-line.

5.5.2. Representation

In map table mode, a representation of a traditional compass has been developed. It consists of a static vertical blue axis, a red horizontal arrow that shows the direction of the field at the current point and a yellow stick remaining parallel to the main arrow (its size depending on the intensity of the field). These elements are presented within Figure 11. The compass stands over the terrain, remaining centered in the visible part of the terrain.

Some effects associated with traditional magnetic compasses were observed. For example in the areas containing a lot of finds, the compass becomes difficult to interpret (such as a magnetic compass in close proximity to multiple magnets).

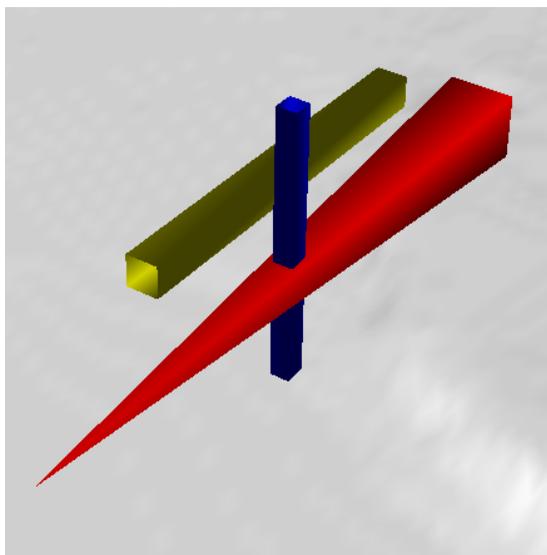


Figure 11: *Density compass*

6. Evaluation

A scientific survey was carried out in order to evaluate the navigation (movements and object selection) within the immersive archeological environment by both experienced and novice users. The survey considered both wireless gamepad and tracked glove interaction techniques.

6.1. Method

For our evaluation, we developed a simple navigation experiment within the immersive environment. The user can only move and select widgets (referred to as 'targets'). Their objective was to follow a path containing fifteen targets and select all of them in a pre-defined order.

6.2. Qualitative results

The most common criticism of our immersive system was related to the picking technique (for both glove and gamepad) that did not clearly define if the user was close enough to collect a target. Most of the testers would have preferred to see a color change of the compass or target. Considering the comments of users at the end of the experiments, we could classify their preferences into those users who preferred the glove and those who preferred the gamepad. The former group tended to physically fit the glove better and were more able to achieve the picking posture. In the latter group, we found users who were better adapted to using the gamepad interface from past experience. For example, other VR immersive interfaces and gaming systems.

Over half of the testers said that they were more confident using the navigation tools by the end of the experiment (approximately 15 minutes).

The Head of Aerial Survey of English Heritage, Peter Horne was invited, during the pilot phase, to trial the Foulness Valley virtual landscape. After a brief period of orientation to acclimatise to the immersive stereo, he was extremely impressed by the real-time capabilities of the environment, which allowed him to revisit archaeological sites he himself had photographed and view them more rapidly from different perspectives than he could in an aeroplane. He also found the incorporation of the field walking data and the ease with which it could be compared with crop mark data impressive and useful.

The immersive nature of the virtual landscape enabled the archaeologist involved with this pilot study to gain new insights into his own data far beyond the capabilities of conventional GIS.

6.3. Quantitative results

Figure 12 provides an overview of the experiment: it represents target after target the average speed of the users with the glove and the gamepad. Note the improved learning effect can be clearly seen in the graphs trend.

Considering the average time needed to reach a target, a mean of 6.5s was recorded with the gamepad against 11.4s using the glove. However, the standard deviation was only 2.5s for the glove, compared to 2.9s for the gamepad (although its value is half of the glove). This is due to the fact that the gamepad was already well known by a couple of

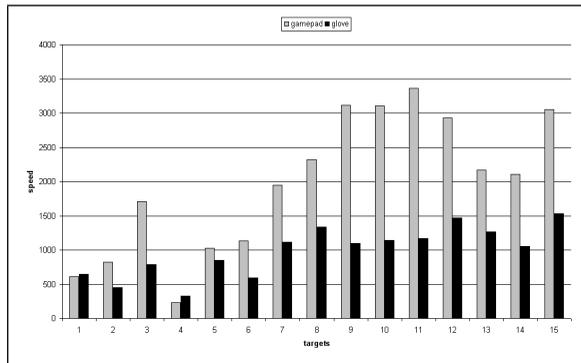


Figure 12: Speed against target number

testers, whereas the glove was a novelty for all users. This therefore moderates the difference of results between glove and gamepad.

The number of mistakes when attempting to select an object with the gamepad is very low: the mean is 3.4, which equates to 16%. The average number of mistakes using the glove equals 249. It does not make sense to calculate a proportion or to compare this figure with the gamepad: the glove uses a continuous picking method (tries to pick all the time as far as the index is pointing), whereas the gamepad's picking is discrete (picks once when pressing the button).

The average speed to reach a target against the distance to cover is shown in Figure 13. It can be seen that for the large distances, the gamepad is faster, whereas for the short distances the glove was marginally better.

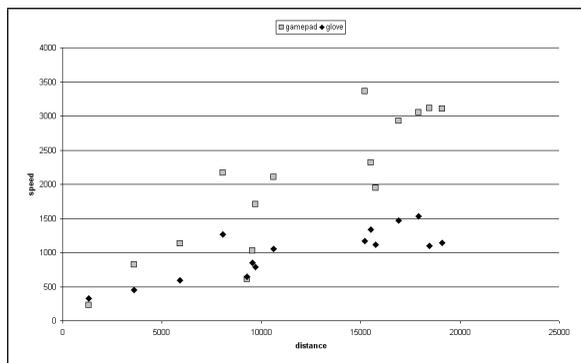


Figure 13: Speed against distance to cover

6.4. Summary

Table 1 sums up the comparison between gamepad and glove according to the quality factors proposed by [BKH97] that are often used to represent specific attributes of effectiveness for virtual travel techniques.

Quality	Glove	Gamepad
Speed	--	++
Accuracy	++	-
Spatial awareness	No evaluation	No evaluation
Ease of learning	+	++
Ease of use	-	+
Information gathering	+	+
Presence	No evaluation	No evaluation

Table 1: Compared features

The test that has been carried out, in order to evaluate the navigation metaphors, demonstrated that the glove could be useful for precise movements, whereas the gamepad is more adapted to gross movements. The compass metaphor could also be improved.

7. Conclusion

Our aim of producing a pilot immersive virtual environment for the visualisation and interaction of data relating to the Foulness Valley has been successful. Most of the pieces of information that are typically available to the archaeologist have been integrated. This includes data such as aerial pictures, OS maps, crop marks, soil maps and DEM (Digital Elevation Model). However, this kind of information has been strongly enhanced to use the full power of a virtual environment: three-dimensional terrain, enhanced crop marks, etc. According to most of the trial testers of the application, the visualisation of the terrain on the large work wall, even without the head-coupled mode switched on, provided a radical new perception of the landscape which will greatly facilitate archaeological research.

Gathering stand-alone pieces of information like short texts, single pictures or three-dimensional objects (such as a three-dimensional Roman Fort reconstruction) is the other main strength of the application. The use of the rotative billboard set and other popular immersive visualisation techniques provided a useful and intuitive method for interacting with the large multidimensional datasets relating to the Foulness Valley.

Although only in a pilot stage, the immersive representation using the HIVE wall screen and the head-coupled stereo already proves how valuable the immersion feeling could be by maximising the human visual bandwidth available. Our immersive visualisation of multiple datasets has provided archaeologists with an improved understanding of the Foulness Valley. We have successfully implemented existing visualisation tools and also proposed new techniques such as

the virtual compass that helps users locate areas of interest in large complex archeological sites. Although the visualisations described in this work have been developed for the HIVE, it should be noted that the software will also run on a desktop PC and traditional monitor. For example, our archeologists do not need to have access to an expensive VR centre in order to visualize their data. The same software and gamepad device will run on a desktop PC. Stereo glasses can also be used with desktop monitors so a level of immersion is still feasible if required.

Some experimentation has also been carried out embedding pre-rendered reconstructions, such as the Roman fort at Hayton into the landscape as a layer generated from the crop mark. It will soon be possible to stand on the virtual wall-walk of the Roman fort and view the virtual landscape in a similar way to a Roman soldier in the environment of the past. Although the 3D visualisations provided by such packages as ARCVIEW can help with such aspects of landscape archaeology as view-shed analysis and phenomenology [Til94] this again is greatly enhanced by the immersive nature of the virtual landscape.

The work described in this thesis forms the major part of a one year MSc thesis by research [Pan04] completed by Julien Pansiot within the SimVis research group based at the University of Hull, Department of Computer Science. Interested readers may download animations and material related to this paper from the SimVis research web site [Sim04].

8. Acknowledgements

Many thanks to James Ward and Mike Bielby for their help with the HIVE hardware and software. Thanks also to the collaboration between the Computer Science Departments at The University of Hull and the Institut d'Informatique d'Entreprise in France. Special thanks to Mark Faulkner for his 3D modelling and reconstructions.

Thanks to The Landmap Project and Manchester Information and Associated Services (MIMAS) for the DEM data and satellite photographs used in this project. We also acknowledge data used from Ordnance Survey. Ordnance Survey ©Crown Copyright. All rights reserved.

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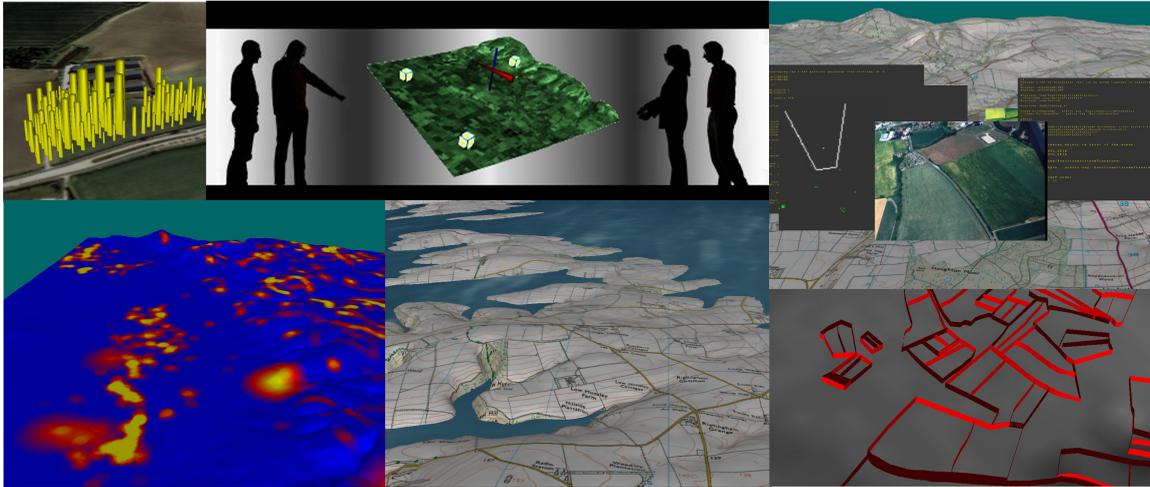


Figure 14: *New perspectives on ancient landscapes: A case study of the Foulness Valley*