Software applications for visualization territory with Web3D-VRML and graphic libraries

Eduardo Martínez Cámara, Emilio Jiménez Macías, Julio Blanco Fernández, Félix Sanz Adán, Mercedes Pérez de la Parte and Jacinto Santamaría
University of La Rioja
Spain

1. Introduction

In the last ten years, the increasing power of computers and graphics cards has stimulated developers and users to deepen Virtual Reality (Huang & Lin, 1999; Kreuseler, 2000; Bernhardt et al., 2002). One of its natural applications of interest for the academic and the industrial communities is the Terrain Visualization Systems (TVS) (Lin et al., 1999; Luebke et al., 2003; Ellul & Haklay, 2006). In this field, two-dimensional representations have been completely superseded since three-dimensional (3D) visualization is closer to reality as well as easier to interpret. Furthermore, it allows the user to interact realistically with the environment (Hirtz et al., 1999; Kersting & Döllner, 2002).

Nowadays, there exist lots of issues to bear in mind on designing a TVS: various Web3D technologies to represent the Digital Terrain Elevation Models (DTEM), several ways to provide the TVS with sufficient realism, many graphic libraries both private and open-source projects, different applications to enable the user to interact with the system, etc. For example, some recent works can been reviewed about the use of non-proprietary available Web3D technologies (Web3D Consortium, 2006), specifically VRML, X3D and Java3D (Fairbairn & Parsley, 1997; Huang & Lin, 2002; Hay, 2003; Geroimenko & Chen, 2005; Hirtz et al., 2006). The creation of a DTEM can be referred for instance in (Ayeni, 1982; Longley et al., 2001; Fencík et al., 2005). There exist also several databases that can be used as starting point (GTOPO30, 2006; ETOPO2v2, 2006; Gittings, 1996). It is necessary to operate with these databases to extract a grid according to the necessities of realism and fast screen refresh required for this type of application. Furthermore, a correct structure and nomenclature for this grid must be carried out, in order to facilitate and to expedite its management. Another important aspect is the inclusion of texture-mapping in the model to give realism to the visualization (Heckberts, 1986; Guedes et al., 1997; Döllner et al., 2000). The applied textures are the terrain orthophotographs, which are previously treated -to readjust them according to the coordinates of the VRML environment-, partitioned -with the appropriate size for the different elements that constitute the DTEM- or properly structured in order to improve the interactive visualization of massive textured terrain datasets if needed. Regarding the VRML viewers that can be used to represent the DTEM, some well-known samples are DeepView™ , CASUSPresenter™ , WorldView™ , BS Contact, Viewpoint Media Player, Emma 3D (Emma3D, 2006; g3DGMV, 2006; Universal 3D Format, 2006). Once 3D navigation system is developed, some interaction tools can be added using VRML Script and Java (Moore et al., 1999).

As it can be seen, there are several developments all over the world and very recent semantics in 3D visualization, so it is necessary to make an special effort in generating surveys and standards (Duke et al., 2005). In this chapter, we wish to contribute to clarify the process of development of a TVS in real time by providing a guide through the issues previously commented and illustrating the stages with practical examples. We explain the pros and cons of some of the different currently available options, offering criteria for an appropriate development. We come out of our experience in the Renewable Energy Research Group of La Rioja (Spain) to illustrate this guide. In order to overcome the limitations given by Web3D technologies in general, and VRML in particular, a specific graphic engine developed with open source graphic libraries is shown. Some programs - used to rename the terrain textures according to general VRML structures - and small applets, as interaction tools between the user and the 3D scene, have been implemented in a virtual TVS of La Rioja (one of the 17 autonomous regions in Spain, with a surface of about 5000 Km^2). They are used to clarify and exemplify some issues throughout the chapter.

The chapter is organized as follows. First, the basic characteristics of a TVS will be briefly commented in Section 2. The Web3D-VRML technologies are introduced in Section 3 where their strong and weak points are shown. Section 4 is devoted to explore the VRML viewers and some tips to create the DTEM and to endow the TVS with interactivity are provided. The development of the graphic engine, and its libraries, which present the 3D geometry of the scene, are discussed in Section 5. Finally, Section 6 concludes the chapter and refers to future work.

2. Terrain Visualization

The spatial distribution of the terrestrial surface is a continuous function, but for a digital storage and representation of these values it is necessary to reduce the infinite number of points to a finite and manageable number, so that the surface can be represented by a series of discrete values (GeoInformation, 2002) (surface discretization). For this purpose, Digital Terrain Models (DTM) and DTEM are used.

A DTM is a numeric data structure that represents the spatial distribution of a quantitative and continuous variable. These variables may be height, slope, contour and orientation, as well as any other data applicable specifically to the terrain and the characteristics of any given point. A DTEM is a numeric data structure that represents the height of the surface of the terrain. By definition it can be seen that a DTEM is a particular type of DTM (Kumler, 1994).

DTEM are usually stored in two digital formats: a) as a map of heights, that is, a two-dimensional matrix in which each quadrant represents the corresponding height of each point; b) by means of chromatic representation of the heights, that is, an image either in shades of grey or in colours, where they depend on the specific height of each point defined. In general, dark colours are assigned to areas with low heights, and light colours are assigned to areas of high heights.

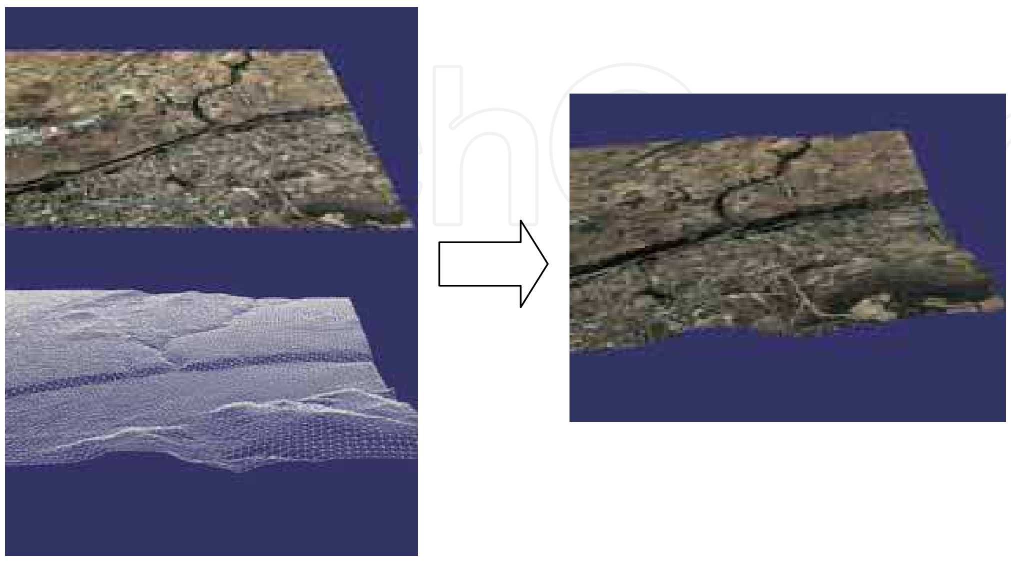


Fig. 1. Creation of a 3D terrain model from a DTEM and an orthophotograph

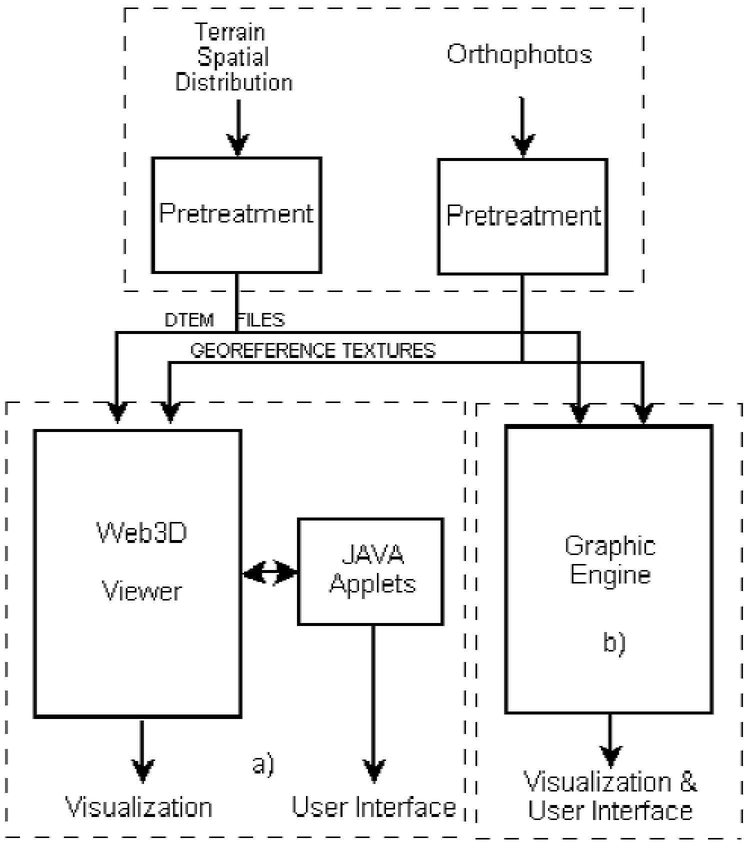


Fig. 2. Virtual Terrain Visualization Systems: a) with Web3D viewers b) with graphic engine

Obviously both formats are similar, but the main problem with this second storing method is the colour scaling assigned to the true terrain height. Starting from this point and taking any of the DTEM available on the market as a reference, it is possible to develop an own 3D DTEM. For this purpose, a polygonal surface can be created, where the vertexes agree with the coordinates taken from the appropriate DTEM (Lindstrom & Pascucci, 2001).

The next step is to achieve that this 3D model has a realistic appearance; that is to say, that it allows the user to perceive more details of any height of one given point with respect to any other one. To achieve this objective, we can think about the possibility of incorporating a specific model texture. The quickest method for achieving this realistic aspect is by using orthophotographs of the terrain.

An orthophotograph is a digitally corrected photographic presentation that represents an orthogonal projection of an object, generated from real oblique photographs. Thus, in an orthophotograph, actual horizontal measurements can be taken, the same way in which they can be taken from a map. Incorporating these corrected photographs to a DTM, an acceptable realistic representation can be obtained (see Figure 1). Figure 2 shows a diagram with the elements involved in a TVS development.

First, the orthophotos and the terrain spatial distribution data must be pre-treated, and the results are the data input to the graphic engine (case a) or to the Web3D viewer (case b). In this latter case, it can be seen that it is necessary to use Java applets, independent of the visualization, which provide the system with the capability of interaction with the user. In this chapter, Section 4 is devoted to the basic steps for a TVS implementation based on VRML, whereas Section 5 deals with a development based on a graphic engine.

3. Web3D Technologies

One of the possible ways to implement a TVS consists in using Web3D technologies. The use of any of the available Web3D technologies permits to develop a 3D environment that can be shared on Internet.

The term 'Web3D' (Web3D Consortium, 2006) refers to any programming language, protocol, archive format or technology that may be used for creating or presenting interactive 3D environments on Internet. Among these languages, used to program virtual reality, VRML (Virtual Reality Modelling Language), Java3D and X3D (Extensible 3D) are open standards.

There are also a large number of proprietary-level solutions that satisfy the specific needs of the customers, generally aimed at electronic trade and entertainment purposes, such as Cult 3D, Pulse 3D, ViewPoint, etc.

However, to use an open standard presents important advantages. For instance, the specifications and documentation are well known, and there are all kinds of applications that support these standards. Next paragraphs briefly analyse the available standards, their main characteristics, and their advantages and disadvantages.

3.1 VRML

VRML is an archive format that permits the creation of interactive 3D objects and environments. The standard VRML was created and developed by the VRML Consortium, in principle a non-profit-making organization exclusively aimed at the development and promotion of VRML as a standard 3D system on Internet. VRML appeared in 1994 as the first officially recognized technology for the creation, distribution and representation of 3D elements on Internet by the ISO (International Standards Organization). VRML was designed to cover the following basic requirements (Bell et al., 1995):

(i) To make possible the development of programs to create, publish, and maintain VRML archives, as well as programs that can import and export VRML and other 3D graphic formats.
(ii) To provide the capacity to use, combine, and re-use 3D objects in the same VRML environment.
(iii) To incorporate the capacity to create new types of objects that has not been defined as part of VRML.
(iv) To provide the possibility of being used in a wide variety of systems available on the market.
(v) To emphasize the importance of interactive functioning in a wide variety of existing applications.
(vi) To allow the creation of 3D environments at any scale or size.

VRML is a hierarchic language of marks that uses *nodes, events* and *fields* to model static or dynamic virtual realities:

– *Nodes* are used to represent particular instances of the 54 primitives of the language. Instances are defined with a collection of *fields* that contain values of the basic attributes of the primitive form.
– *Fields* are attributes that define the behaviour of the primitive forms. There are special *fields* (EventIn and EventOut) that allow the sending and reception of events to other *fields*. With these special *fields* and the command ROUTE, the flow of *events* can be controlled, directing the effect of one action among other multiple objects in order to animate a scene or simply to pass information to any of these objects.

3.2 X3D

X3D is an open standard XML (eXtensible Markup Language), a 3D archive format that permits the creation and transmission of 3D data between different applications, especially web applications.

Its principal characteristics are:

(i) X3D is integrated in XML; this represents a basic step to achieve a correct integration in:
    – Web services.
    – Distributed networks.
    – Multiplatform systems and transference of archive and data among applications.

(ii) X3D is modular; this allows the creation of a lighter 3D kernel, adjusted to the needs of developers.
(iii) X3D is extensible; this allows adding components to provide more functions, in order to satisfy the market demands.
(iv) X3D is shaped; this means that different appropriate extension groups can be chosen according to the specific needs of each application.
(v) X3D is compatible with VRML; this implies that the development, the content and the base of VRML97 is maintained.

X3D, instead of being limited to a single static wide specification - as in VRML that requires total adoption to achieve compatibility with X3D - has been designed with an structure based on components that give support for the creation of different profiles, which can be individually used. These components can be independently extended or modified, adding new levels or new components with new characteristics.

Thanks to this structure, the advances in X3D specification are faster and the development of one area does not delay the evolution of the global specification.

3.3 Java3D

Java3D™ API is a set of classes to create applications and applets with 3D elements (Sowizral et al., 1998). It offers to developers the possibility of managing 3D complex geometries. The main advantage that this application programming interface (API) presents against other 3D programming environments is that it allows the creation of 3D graphic applications, independently of the type of system. It forms part of API JavaMedia. Therefore, it can make use of the versatility of Java language, and it can support a great number of formats, including VRML, CAD, etc.

Java3D has a set of high class interfaces and libraries, which make good use of the high speed on graphic loading of many graphic cards. The calls to Java3D methods are converted into Open GL or Direct 3D functions. Though either conceptually or officially Java3D form part of API JMF, it has libraries that are installed independently of JMF. Despite Java3D does not directly support each possible 3D necessity, it permits a compatible implementation with Java code; in other cases, VRML loaders are available. They translate files from this format to appropriate objects of Java3D, which are visualized by means of an applet.

Java3D provides a high-level programming interface based on the object-oriented paradigm. This fact implies some advantages such as to obtain a more powerful, faster, and simpler development of applications.

The programming of 3D applications is based on 'scene graph models', which connect separated models with a tree-like structure, including geometric data, attributes, and visualization information. These graphs give a global description of the scene, also known as 'virtual universe' (Sowizral & Deering, 1999). This permits us to focus on geometric objects instead of on the low level triangles existing in the scene.

3.4 Comparisons

X3D takes the work carried out by VRML97 and it tackles matters that have not been specifically treated so far. From the VRML basis taken as premise, X3D provides more flexibility than VRML. The main change is the total rewriting of the specifications in three different chapters, regarding: abstract concepts, file formats, and ways to access to the programming language. Other modifications provide a greater precision in illumination and event models and they also rename some fields in order to constitute a solider standard.

The most important changes are:

(i) Expansion of the graphic capacities.
(ii) A revised and unified model of programming of applications.
(iii) Multiple files coding to describe the same abstract model, including XML.
(iv) Modular structure that permits ranges of adoption levels and support for the different kinds of market.
(v) Expansion of the specification structure.

The X3D scene graphics, the core of any X3D application, are identical to the VRML97 scene graphics. The original design of VRML graphic structure and its node types are based on already existing technology for interactive graphics. The changes initially introduced in X3D aimed at incorporating the advances in commercial hardware by means of the introduction of new nodes and types of fields for data. Later, a single unified API was developed for X3D; this means an important difference from VRML97, which had a scripting internal API apart from the external API. The X3D unified API simplifies and solves many of the problems found in VRML97, as the result of a more robust implementation.

X3D supports multiple codification archives, such as VRML97 and XML, or compressed binary (being developed at present). It uses a modular structure that provides greater extensibility and flexibility. The great majority of these applications neither need the full power of X3D nor the support for all its platforms and its functionalities defined in the specification. One of the ad- vantages of X3D is that it is organized in components that can be used for the implementation of a defined platform or specific market. For that purpose, X3D includes the concept of profiles. They are a predefined collection of components generally used in certain applications and platforms, or in scenarios like the geometric interchange between design tools. Unlike VRML97, which requires total support from the implementation, X3D allows a support for each particular need. The mechanism of X3D components also permits the companies to implement their own extensions following a rigorous set of rules.

Furthermore, X3D specification has been restructured in order to allow a greater flexibility in the life cycle of this standard, which is adjusted to its own evolution. The standard X3D is divided into three different specifications that permit ISO to achieve the adaptations of the concrete parts of the specification and their distribution in time.

One of the main differences between VRML/X3D and Java3D, at a conceptual level, is that Java3D is defined as a low-level 3D-scene programming language. This means that the creation of 3D objects in Java3D does not only require the 3D element building, but also the definition of all the aspects related to the visualization and control of the environment capabilities. For example, for the creation of the simplest scenes, the Java3D code is notably larger than the necessary code in VRML/X3D. On the other hand, the control of the different elements in the system is more powerful and natural in Java3D. This does not mean that it is not possible to control a 'virtual universe' in VRML to include user interaction, but that it is more complex. VRML has been the favourite of most Web 3D GIS researchers for over fifteen years because it is cheap, it can provide middle-quality interactive visualization, and it has high compatibility with Java applets (Zhu et al., 2003). However, recently a growing number of engineers in the graphics and design communities are using Java3D technology (Huang, 2003; Java 3D, 2007). Because of its control power, it may be interesting to use Java3D as a VRML/X3D viewer in a TVS (Lukas & Bailey, 2002; Jin et al., 2005). It is only necessary to use some of the VRML/X3D loaders developed for Java3D. At present, the Web3D Consortium is developing under GNU LGPL (Lesser General Public License), Xj3D as a tool - completely written in Java - to show VRML and X3D contents.

The main advantages of using Java3D as a VRML/X3D viewer is its execution capability in different platforms and the fact that the final user is released of installing specific VRML/X3D plug-ins for the browser. In contrast, it must be considered the loss of speed and performance when using by Java3D vs. other VRML/X3D viewers developed in C/C++ (Burns & Wellings, 2001) and vs. viewers that directly use Direct 3D or OpenGL (Mason et al., 1999). Whichever viewer used, it must be taken into account that it is necessary to choose between internal or external programming within the VRML/X3D code. This choice is subject to the VRML/X3D implementation specification chosen by the programmer of the VRML/X3D viewer. For instance, at the level of External Authoring Interface (EAI) implementation, some VRML viewers, like CosmoPlayerTM, are based on Sun's Microsystem Java Virtual Machine, and others, like BS Contact, are based on the version of Microsoft.

4. Use of VRML for the Implementation of a TVS

4.1 Selection of the VRML Viewer

The first decision to make in a TVS implementation is to choose a VRML viewer, which must be capable of supporting and managing the great amount of data to visualize with a satisfactory performance. It is important to be very clear about this issue in order to achieve the best possible results according to the needs of the specific application to develop. In the list of Web3D viewers available on the market at present, we can specially remark, among others, those represented in Table 1.

Regarding their technological characteristics, we can distinguish between those viewers based on the use of a VRML/X3D plug-in in the browser - first column in Table 1 - and those viewers that use Java applets - second column in Table 1 -. Furthermore, we can find different non-standard format solutions that use their own technologies and file formats to store virtual environments. Although these non-standard format solutions can be better adjusted to the specific needs of a particular application at a given moment, they lack the advantage to work on an open standard that is universally recognized. So, they are subject to the decisions of the company proprietary of that format and solution. However, the use of a system based on an open standard allows us to port our own virtual environment to other different developments that also support the standard.

VRML/X3D		Non-Standard Format
Plug-in	Java	
CosmoPlayer	AppletXj3D	Exel
Cortona	WireFusion	ViewPoint Media Player
BS Contact	3DzzD	Adobe Atmosphere
Octaga	BS Contact J	Deep View
Flux	Shout 3D	Emma 3D
FreeWRL	Blaxxun Contact3D	Cult 3D
OpenVRML		
Venues		
OpenWorlds		

Table 1. Web3D viewers

For instance, Viewpoint Media Player uses a file format based on XML, and includes the interaction capability through the use of scripting - continuous lines of interpreted commands -. Scripting vs. VRML presents a similar capability to interact directly with the environment in terms of execution time. On communicating with the Viewpoint Media Player plug-in from an HTML page, the possibility of using either JavaScript or Flash may be taken into consideration. Adobe Atmosphere and Deep ViewT M (Deep View, 2006) are different applications mainly used by Adobe to give to its PDF documents the possibility to include 3D contents.

Adobe stopped the development of Adobe Atmosphere in December 2004, and presently it uses the Deep View technology developed by HighHemisphere. In this case, Universal 3D (U3D) file format is used (Universal 3D Format, 2006). Emma 3D (Emma3D, 2006) is an open source development based on Ogre3D graphic engine and uses an archive format similar to VRML. Cult3D allows the visualization of models imported directly from 3D Studio and other formats, as well as basic animation and interaction with the scene. For example, if we use CosmoPlayer™ as a viewer, we must take into account that it is old software; that implies that it cannot make good use of the graphic capabilities of new 3D graphic cards, and it make mainly the rendering by using software instead of hardware.

On the other hand, if we use Xj3D, as well as any other viewer based on applets, we must remember that we use a viewer running in Java. Therefore, we must have the Java Virtual Machine (JVM) from Sun Microsystem installed and, according to the particular viewer, we may also need the Java3D library. In this case, to use the Java3D library allows us to accede to the graphic capabilities of 3D graphics cards available nowadays. However, using JVM involves certain declines in the performance of the application, since it is an interpreted programming language (Barr et al., 2005) - or semi-interpreted language because a pre-compilation is carried out at bytecode level -. In the Table 2, a comparison can be observed about the loss of performance and speed of Java3D - pure Java (with 3D) in Table 2 - against other VRML/X3D developed in C/C++ and directly using Direct 3D or OpenGL - C++ (with 3D) in Table 2 -.

Elements Used	Comparison with C++
C++ (no 3D)	0%
Pure Java (no 3D)	54%
Mixed Java/C++ (no 3D)	22.5%
C++ (with 3D)	0%
Pure Java (with 3D)	92.4%
Mixed Java/C++ (with 3D)	32%

Table 2. Comparison of performances between Java and C++ (Marner, 2002)

Another important aspect on choosing a viewer is to know on which platforms it can run (see Table 3), and then, which is the possible range of users having access to the application. Let us recall here that a viewer developed in Java is multiplatform and requires the JVM of Sun Microsystem.

As commented in the first Section of this chapter, our research group has developed a virtual TVS of La Rioja that will be used to illustrate the different stages of the process of development. In the decision-making process of choosing a viewer, the use of proprietary solutions was discarded in order to make good use of the advantages of an open standard such as VRML.

As previously shown, VRML viewers can be classified into two main groups according to the technology employed: those that make use of JVM and those that incorporate plug-ins for the browser by means of ActiveX. The principal disadvantage that the former group presents against the latter one -applications compiled at machine-code level- is the loss of performance and speed (Wellings, 2004). This is the reason for discarding the use of any VRML viewer developed in Java; in general the specific needs of a TVS demands mainly high performance in refresh rates of the visualization (frames per second - FPS) and in memory use.

Finally, once the capability of the remaining viewers to execute our developed particular application was tested, we decided to use the Bitmanagement Software viewer (Bitmanagement, 2006) (BS Contact). At present, Bitmanagement Software and Octaga develop the leading viewers for the visualization of Web3D VRML/X3D technologies. The other viewers are a step behind as regards performance and updating on the development of new standards such as X3D (Bitmanagement, 2006).

VRML Viewer	Windows	Pocket PC	Linux	Mac OS
BS Contact	X	X	-	-
Cortona	X	-	-	X
Octaga	X	-	X	-
Flux	X	-	-	-
FreeWRL	-	-	X	X
CosmoPlayer	X	-	-	-
OpenVRML	X	-	X	X
Venues	X	-	-	-
OpenWorlds	X	-	-	-

Table 3. Summary of the running capability in different platforms

4.2 3D Model Creation

Once the different available Web3D technologies have been analysed and one has been selected, as well as the necessary Web3D viewer, we have to determine the specific needs of the system that we want to implement. In this stage, the first step to develop the 3D TVS is to prepare a DTEM. In order to use this model, it is necessary to obtain the terrain heights corresponding to each pair of coordinates (X, Y) in the specific area that is to be visualized.

Nowadays, there is the possibility of knowing free the height of any point on Earth with a resolution of approximately 1 kilometre. This is possible thanks to files such as GTOPO30 (Global Topographic Data horizontal grid spacing of 30 arc seconds) which provides a global digital elevation model of the U.S.

Geological Survey's Center (USGS) for Earth Resources Observation and Science (EROS) (GTOPO30, 2006). Without any doubt this is a highly useful tool, but they do not reach the desired precision for our TVS of La Rioja; so it was necessary to resort to other local databases with higher resolution. In this case, as a starting point for the generation of the DTEM, a database with a 5-metre spatial resolution was used. This database is in dBASE format and occupies several Gigabytes. In order to work with it, it was necessary to create a program that allowed consulting automatically through coordinates X and Y, represented in Universal Transverse Mercator projection (UTM) (Longley et al., 2001).

So, it was possible to sequence the process of generation of the grid on the terrain. For this purpose, a program using PERL was created, which permitted covering the whole area, a total surface of more than 5.000 Km^2, and extracting the corresponding height coordinates. Although the program worked correctly, the consulting process was too slow since the different databases used were not correctly indexed. In order to solve this problem we had to resort to a program in C++ Builder that makes the automation of the indexation of the different databases. Subsequently, another specific application was necessary to choose the step of the grid and the area from where the data would be extracted. In the code in Figure

3, it can be seen how the Borland Data Base Engine (BDBE) is used to accede to the databases by means of the use of TTable (named as Table1 in the code).

Thus, a dynamic access to the databases and to their different index archives -previously generated is achieved, which accelerates the search of heights in UTM coordinates. This piece of program shows a nested loop that accedes to the databases, which contain the terrain elevation data. Inside this loop, another nested loop allows obtaining the grid desired. The horizontal and vertical grid steps are defined by the user as input parameters of a C++ Graphical User Interface (GUI).

```
 for(int j=initrow;j<=endrow;j++){
   ...
     for(int i=initcolumn;i<=endcolumn;i++){
    ...
          DB="Xy"+IntToStr(numdb); //Name of the Database
    ...
          for (int h=0;h<ypoints;h++){
         ...
               for (int k=0;k<xpoints;k++){
                    Table1->TableName=DB;
                    Table1->IndexName="UTMXY";  //Name of the file
         //of indexation
                    Table1->Open();  //Database open
                    ...
                    Table1->SetKey();  //Activation of the search
         //by key
                    Table1->FieldByName("UTMX")->AsString = utmx;
         //Set of the UTMX parameter for the search
                    Table1->FieldByName("UTMY")->AsString = utmy;
         //Set of the UTMY parameter for the search
                    if(Table1->GotoKey()){ //Test of existence of
         // some element with these UTM coordinates
                        utmz=Table1->FieldByName("UTMZ")-
         >Text+"\n"; //Obtaining of the corresponding height
                    }else{
                        utmz="0\n"; //If there is no existence then
         //set 0
                    }
                    Table1->Close(); //Database close
               ...
               }
         ...
         }
   ...
   }
}
```

Fig. 3. DTEM Creation code

Once we obtained the height of each one of the desired coordinates, the following step is to classify the resulting information into an appropriate structure for its subsequent treating and processing. In our exemplary application, it can be noted in Figure 6 that the region of La Rioja (Spain) was divided into different Zones with the aim of facilitating dynamic up-loading and down-loading according to the relative position of the observer/user. It was decided to build a dot-matrix structure totally adaptable to the step of the grid terrain at any moment for each zone.

From this point, different tests must be carried out to adjust the size of the grid step to the specific needs of each application. In our TVS of La Rioja, we are concerned with a terrain visualization application in which a flight at a determined height is simulated; then an excessive precision is not required, as it is not going to provide anything visually important for the observer (Ayeni, 1982).

So finally, a compromise was reached for obtaining satisfactory resolution fidelity, a required level of detail, and an admissible visualization refresh rate (the previously mentioned FPS): the value of 100 meters grid step was selected. This value is more than sufficient to maintain an acceptable realism in a topographic environment, and even provides a fluid navigation.

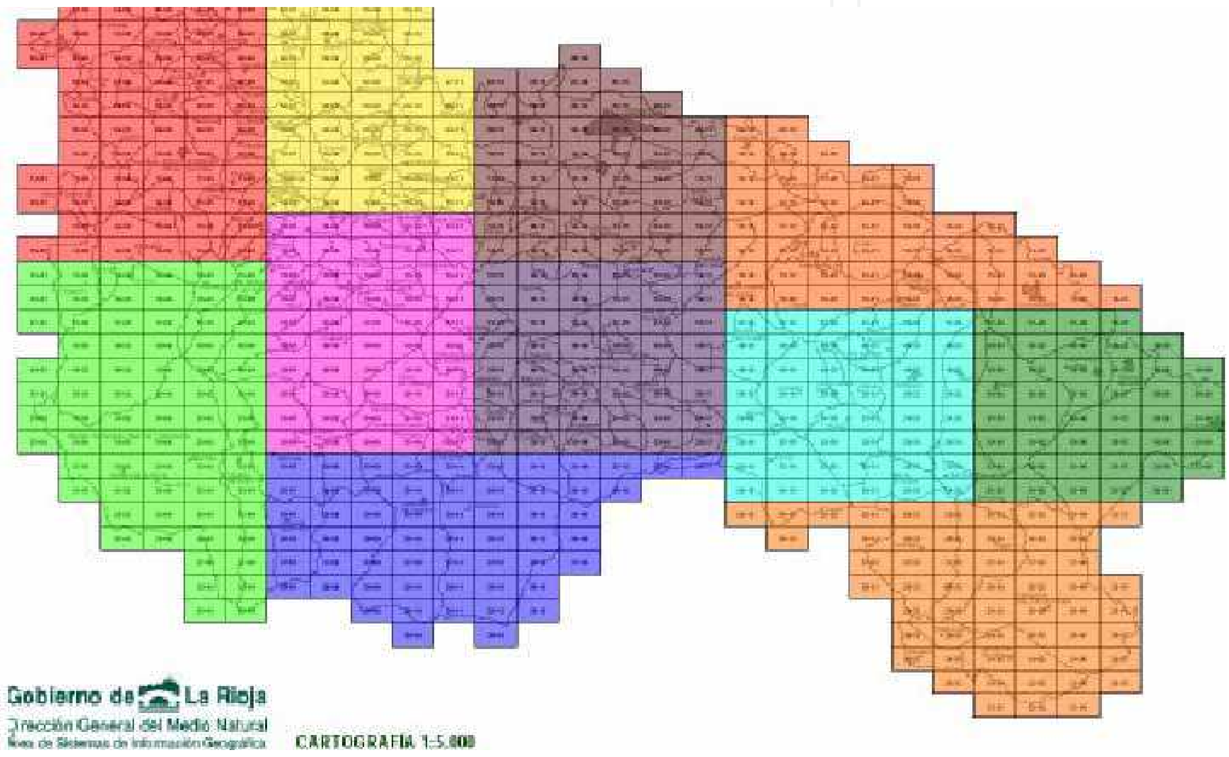

Gobierno de La Rioja
Dirección General del Medio Natural
Área de Sistemas de Información Geográfica
CARTOGRAFIA 1:5.000

Fig. 4. Division in zones of the surface to be visualized (116x75 Km). Each colour represents a different zone

4.3 Texture Treatment

The next step to achieve a realistic TVS is to map textures on the DTEM by means of orthophotographs obtained from aerial photographs (Höhle, 1996; Ewiak & Kaczynski, 2006). Moreover, some treatments must be applied to the orthophotographs before mapping them, in order to optimise the implementation. For example, in our TVS of La Rioja, the orthophotos were obtained from the Autonomous Government of La Rioja, in JPG format, covering 10 Km^2 of surface everyone. When carrying out a simulation of a VRML environment, it is necessary that the model files and texture files are not excessively large.

That is the reason why each scene is stored in dot-matrix file, which cover an extension of only 1 Km^2. Therefore, the texture/orthophotographs have to be divided into partitions. A specific C++ program was employed to obtain these partitions. This application allows the user to define on the orthophotos some parameters, such as their origin and destination directories, their new names once they are partitioned and new size. It considers their original size in case of being necessary to use data from some of them.

Another treatment required is to adjust the optimum resolution of the textures for its further visualization during the simulation. In order to find this optimum resolution, some tests were carried out from 0.5 m/pixel up to 4.0 m/pixel. Finally, it was proved that using resolutions lower than 2 m/pixel does not really provide a more realistic scene, due to the texture treatment that the different viewers carry out. Furthermore, to use high resolution textures implies that the files are heavier, more work for the viewers, and a lower visualization refresh rate (FPS). With all these issues in mind, we opted for 2 m/pixel as an appropriate texture resolution for our particular application.

Another important aspect in order to accelerate the simulation is the inclusion of levels of detail (Blow, 2000; Luebke et al., 2003), so that it is possible to lighten the viewer load without losing realism or quality for the observer user. The level of detail was established with the use of different resolution textures depending on the distance from the observer to them.

(i) From 0 to 1,500 metres: 2 m/pixel resolution.

(ii) From 1,500 to 5,000 metres: 4 m/pixel resolution.

(iii) From 5,000 metres to eye-sight reach: without texture and only the net-meshing is observed.

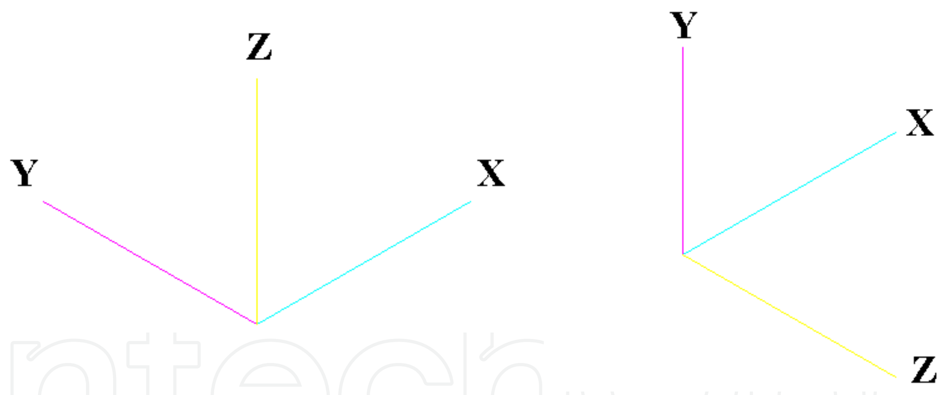


Fig. 5. Orthophotograph reference system

Another noteworthy treatment of the orthophotographs is their reference coordinates. The orthophotographs are represented in UTM (see Figure 5a) and they have to be adjusted to the coordinate system used in the VRML simulation (see Figure 5b). For that reason, it is necessary to make a 180° clockwise turn of the orthophotographs with a software application (for instance, it is sufficient to use any photo-editor application). In this way, orthophotograph UTM coordinate system and VRML environment system fit one another perfectly. Once the texture files are prepared, the graphic engine or the web3D viewer can read them for a realistic visualization.

4.4 Tools for implementing the user interaction

What provide VRML with the capability of implementing the user interaction is the JavaScript Code (usually denominated VRMLScript) and the Java code. On the one hand writing VRMLScript code requires the incorporation of different interaction elements within the VRML virtual scene; on the other hand it is possible to interact with the scene from some external applets with Java code.

Thus, the programmer is completely free to create his own user interface with Java libraries and to connect with the virtual scene with the EAI library (Gosling et al., 1996; Yu et al., 2005; Sowizral & Deering, 2005).

For the use of VRMLScript or Java, it is necessary to resort to VRML package libraries (see Figure 7): whilst VRMLScript needs the vrml.node and vrml.field packages, when using Java applets, vrml.external library is required. Let us focus on the use of applets to connect with VRML scenes by means of EAI library. The following elements are examples that may be taken into account in order to pro-vide a TVS with interactivity; in fact, they were used in the TVS of La Rioja (see Figure 6):

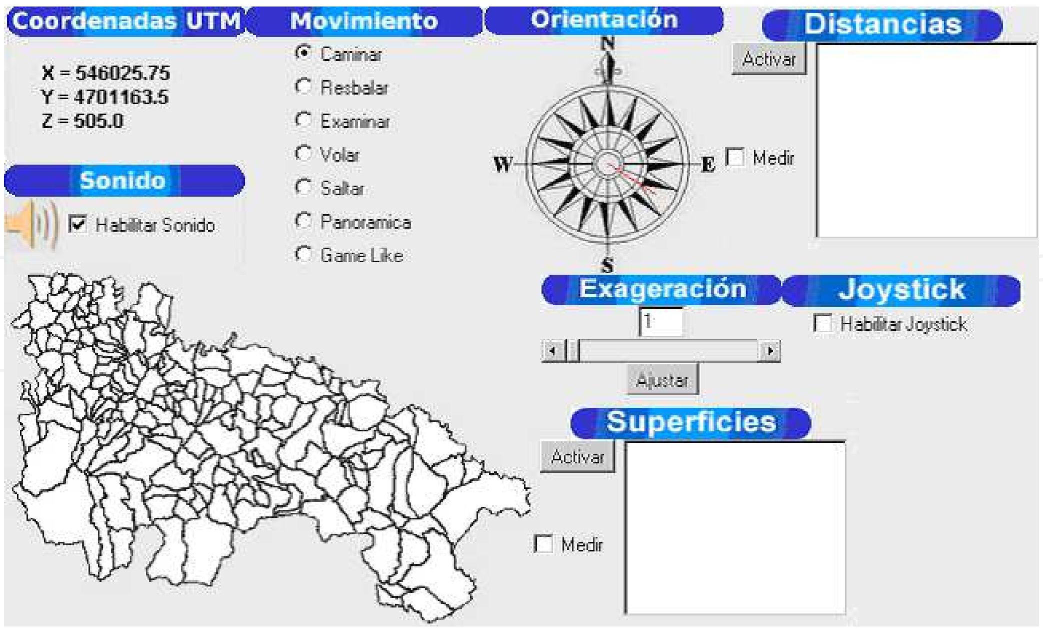
(i) HTML file: in the own HTML page, the reference to the VRML file and to the applet must be included. The reference to the VRML files is made with the label '<embed src="scene.wrl"...>' and the applets are usually inserted using the label '<applet width="150" height="40" code="joystick.class">'.

(ii) Applets: they present their usual generic code, but they must also include the necessary code to communicate with the VRML scene. This communication is achieved with the creation of an instance in the Browser class. By means of these instances, we can accede to the VRML scene and control it.

(iii) References to the nodes: in order to read certain information from the VRML scene or to control certain parameters, it is necessary to make reference to a specific node that contains this information or parameters. To achieve this, the getNode 'Node node1 = browser.getNode ("Control-Position")' is used. This way, we can make reference to a specific node that has been previously defined in the scene by means of the key-word 'DEF'.

(iv) Reading/Writing of the VRML scene: Once a specific node is referenced, their fields can be acceded with the functions getEventIn(String) and getEventOut(String): 'Orientation = (EventOutSFRotation) node1.getEventOut ("orientation changed");'. The use of these functions is limited to access to the fields defined as eventOut and exposedField. Once the reference to the field is created, its value can be read by means of getValue(): 'orientation = Orientation.getValue();' or it can be written with the function SetValue(): 'avatarSize.setValue(size);'.

(v) Receiving VRML scene events: In the case of needing to receive events produced by the scene, we must implement in our applet the interface EventOutObserver: 'public class compass extends Applet implements EventOutObserver'. The next step in the definition of the applet is to overwrite the callback method, which will reply each event produced in the scene: 'public void callback(EventOut eventout, double d, Object obj)'.



X = 546025.75
Y = 4701163.5
Z = 505.0

Fig. 6. External applets for interaction with the user

In Figure 6, the different applets that have been developed for our exemplary application are shown:

(i) UTM Coordinates: this applet shows at any time the position of the user in UTM coordinates.

(ii) Orientation: with this element, the user can know the angle from where he is watching.

(iii) Movement: this panel permits to change rapidly the way we move in the 3D scene (walking, sliding, inspecting, flying, jumping, panoramic view, Game-like view).

(iv) Sound: this application allows to activate or deactivate the background sound.

(v) Distances: with this applet, the zenith view and measure distances in two or three dimensions can be activated.

(vi) Surfaces: the option to measure the surface defined with a series of points pointed out in the scene can be used.

(vii) Exaggeration: this applet permits to increase the height, exaggerating it in order to watch the size of the different heights increased.

(viii) Joystick: it allows activating or deactivating the navigation or the scene control by means of a Joystick added to the computer.

(ix) Map: this applet includes a map of the terrain and shows us at any moment the position and orientation of the user. Besides, it permits us to move directly to any point on the map simply by clicking on it.

```
import vrml.external.Browser; //Importation of VRML libraries
import vrml.external.Node;
...
public class brujula extends Applet
    implements EventOutObserver, Runnable
{
    ...
    //Applet initialisation
    public void run()
    {
        if(browser == null)
        {
            //Reference to the VRML viewer
            for(; browser == null; browser = Browser.getBrowser(this))
                try
                {
                    Thread.currentThread();
                    Thread.sleep(5L);
                }
                catch(InterruptedException ex) { }

            ...
            //Reference to the node of position control
            Node node1 = browser.getNode("PositioonControl");
            //Reading of the output events of the orientation changes
            Orientation =
(EventOutSFRotation)node1.getEventOut("orientation_changed");
            //Definition of this applet to answer to the events
            Orientation.advise(this, null);
            ...
        }
    }
...
    //Answer of the output events generated by the VRML viewer and
    //associated to this applet
    public void callback(EventOut eventout, double d, Object obj)
    {
      //Reading of the present orientation value
      orientation = Orientation.getValue();
      //Orientation treatment
      ...
    }
```

Fig. 7. Basic structure for interconnection between an applet and the VRML scene

5. Graphic Engine for a TVS

5.1 Open Source Libraries for 3D Visualization

An alternative solution to the Web3D viewers for the TVS performance is to develop a program known as graphic engine. It executes graphic routines by calling methods from specialized libraries, like Open inventor TM, Coin3D, or OpenSceneGraph, among others. Let us focus on this latter mentioned library to explain some of their common characteristics. OpenSceneGraph (OSG) (OpenSceneGraph, 2006) is a recently-developed graphic library which incorporates the different primitive basic concepts of OpenGL (Mason et al., 1999). This library uses the programming language C++, because it is independent of the platform and open source. Among the possible uses of this library we find simulations, scientific visualizations, virtual engineering and game development.

OpenSceneGraph uses scene graph techniques to contain all the information regarding the scene generated. A scene graph is a data structure that permits the creation of a scene hierarchic structure, keeping the father-son connections among the different elements. For example, variations of position and orientation in the father node affect son nodes; thus, an arm robot with several joints can be created, with each piece dependent on the previous one, and simply applying movement to the initial piece; the rest of the dependent pieces will automatically move according to the defined structure.

Another important father-son relationship exploited by the scene graph techniques is the possibility of defining enveloping volumes, which gather close elements. Thus, during the process of rejection of the elements that will be represented on screen, it is not necessary to analyze the children of a node father already rejected.

Although the library is still under development at present, it is being employed by different users in research and commercial applications. There are even other open source developments, which extend and give support to the capabilities of OpenSceneGraph, such as OpenProducer (OpenProducer, 2006) or VT Jugger (VR Juggler, 2006), for instance. OpenProducer is a library that permits the treatment of different current representation systems and interaction devices.

Although there is other libraries providing this support, OpenProducer offer the advantage of being an open source development and it allows working with the OpenScreneGraph library. VR Juggler is a technology that supplies necessary tools for the development of virtual reality applications. It constitutes a virtual platform for the development of applications that are applicable to nearly all the virtual reality systems.

5.2 Graphic Engine Development

Once the graphic library is selected, the graphic engine consults the 3D model; so, it must be optimized for satisfactorily fast terrain visualization. At software level, the way to deal with this matter is to maintain at any time a similar amount of information (textures and DTM), which allows a fluid data management.

For this purpose, let us resort to a dynamic up-loading and down-loading of the scene according to the position and direction of the user at each moment. This process is carried out with a database that paginates the different scene areas and allows us to decide which parts are necessary to bear in mind at each moment (see Figure 8). At a theoretical level, the database limit is not defined, but in practice, the larger the size, the less performance, and the dynamic up-loading and down-loading are affected. That is the reason why a database restructuring was carried out in our TVS of La Rioja, regarding communities and provinces.

The restructuring consists in searching for a way to limit the database size to the specific needs at each moment according to the zone where the user goes. In this way, it was possible to maintain a more or less constant loading process with a reasonable order for a desktop PC with the following minimum characteristics: Pentium 4 1,7 GHz, 80 GB ATA 100 Hard-Drive, 512 Mb DDRAM, Ati Rage 128 Pro II. In order to achieve this, we can set several levels of texture resolution with a PagedLOD node. So, according to the distance between the observer view-point and the model, the appropriate level will be visualized. The PagedLOD node (see Figure 9) is a variant of the LOD node, but it also allows the up-loading and down-loading of the memory of the scene elements. Then, the scene graph that the system has to manage during the rendering process is smaller.

```
osgDB::DatabasePager* databasePager = osgDB::Registry::instance()-
>getOrCreateDatabasePager();
databasePager->registerPagedLODs(root);
sceneView->getCullVisitor()->setDatabaseRequestHandler(databasePager);
```

Fig. 8. Activation of the dynamic up-load and down-load system

```
PagedLOD {
      DataVariance DYNAMIC
      nodeMask 0xffffffff
      cullingActive TRUE
      Center 488500 4.694e+006 0
      Radius -1
      RangeMode DISTANCE_FROM_EYE_POINT
      RangeList 3 {
        5000 15000
        1000 5000
        0 1000
      }
      NumChildrenThatCannotBeExpired 0
      FileNameList 3 {
        f29c1_C.ive
        f29c1_B.ive
        f29c1_A.ive
      }
      num_children 0
    }
```

Fig. 9. PagedLOD node of a scene element

The rendering in OpenSceneGraph is divided into three stages. The first stage is the Update Process, in which changes in the scene graph regarding execution time are made. The second stage is the Cull Process, in which the list of scene elements that will be rendered in the next stage is set. Finally, the Draw Process is the last stage. With this structure, and the ranges for rendering appropriately chosen for each level, constant refresh rates from 20 to 30 FPS were achieved, even during the loading of the application (see Figure 10).

On the other hand it is important, although not strictly necessary, to generate the whole geometry of the scene in the binary format of OpenSceneGraph. This binary format (IVE) facilitates the initial process of scene loading, so the waiting time that users spend in loading the application is reduced.

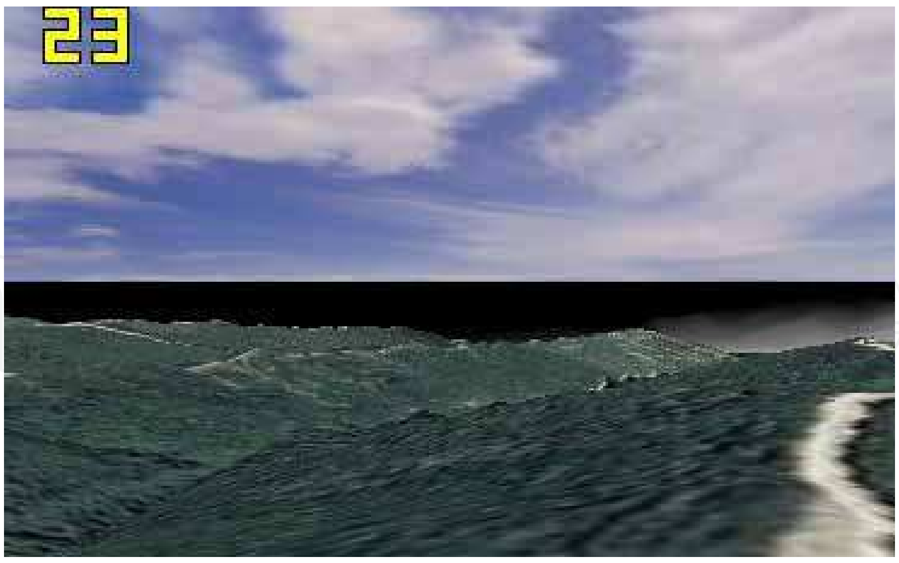


Fig. 10. Screen capture of the application at an initial moment and FPS

```
class MyKeyboardMouseCallback : public Producer::KeyboardMouseCallback
{
public:
    MyKeyboardMouseCallback(osgUtil::SceneView* sceneView) :
        Producer::KeyboardMouseCallback(),
        _mx(0.0f),_my(0.0f),_mbutton(0),
        _done(false),
        _trackBall(new Producer::Trackball),
        _sceneView(sceneView)

    {
      ...
    }
      ...

    osg::Matrixd getViewMatrix()
    {
      ...
      // Utilization of the IntersectVisitor
      osgUtil::IntersectVisitor iv;
      // Creation and initialisation of the row with present and next
      // positions
      osg::ref_ptr<osg::LineSegment> segNormal = new osg::LineSegment;
      segNormal->set(fp,lfp);
      // Addition of the row to the IntersectVisitor
      iv.addLineSegment(segNormal.get());
      // Launch of the Visitor on the scene
       _sceneView->getSceneData()->accept(iv);
      // Verification of collision detection and consequent actuation
        if (iv.hits())
        {
        ...
        }
      ...
      return osg::Matrixd( trackBall->getMatrix().ptr());
    }
...
};
```

Fig. 11. Terrain collision detection

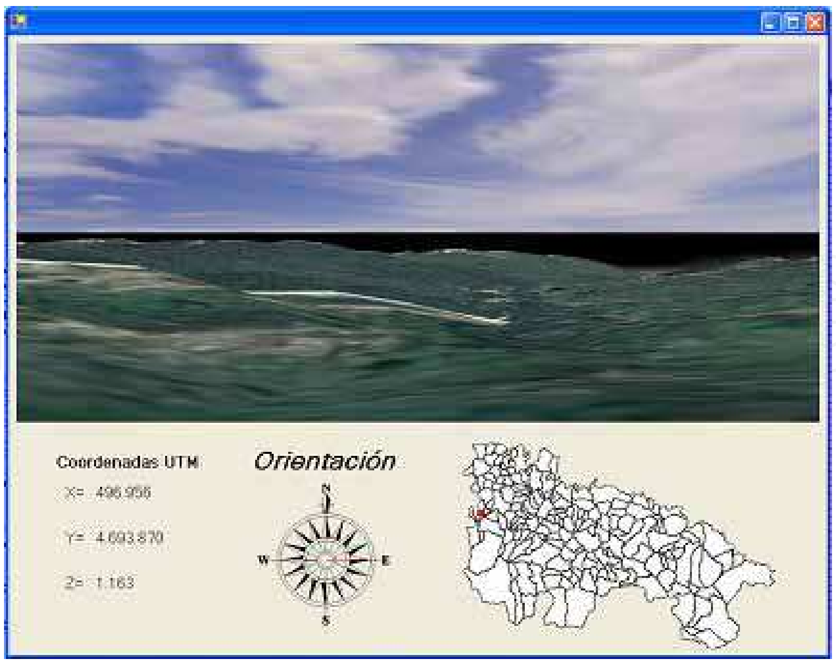


Fig. 12. User interface

5.3 User Interaction Tools

One of the most important aspects in a graphic application of a TVS is to provide the user with an easy and friendly navigation. For this purpose, user interaction is usually implemented by means of the mouse, so the cursor can be moved over the scene on screen.

Therefore, it is required to endow the application with the capability of receiving and responding to the mouse events happened on the scene. This can be achieved by creating a new class from the class 'Producer::KeyboardMouseCallback' and implementing the appropriate methods to define the interaction between this object and the rest of the objects in the environment.

For example, in a TVS, the user must always be above ground level, and, generally, at a determined height. Then, it is necessary to use a collision detection system, which prevents the user from going through the ground as he moves over the scene. For this purpose we used a specifically designed visitor in OpenSceneGraph: 'IntersectVisitor'. The visitor is a design patter of performance, which permits to define the operations that will be applied to the elements of a heterogeneous structure of objects.

A design pattern in programming is just the structure or the core of the solution of a common problem of software development. In this case it is an algorithm that allows determining whether a certain segment/line intersects any point of the geometry of the object that accepts the visitor. In the code in Figure 11, the results of the operations executed by IntersectVisitor are sent and accepted by the object that stores the geometries of the scene 'sceneView → getSceneData()→ accept(iv)'. In the code in Figure 11, the results of the operations executed by IntersectVisitor are sent and accepted by the object that stores the geometries of the scene 'sceneView→ getSceneData()→ accept(iv)'.

Apart from facilitating 3D visualization of the scene, it is also necessary to create a user-friendly interface (see Figure 12). With this interface, the user can interact in a simple way, and it provides him with the capability to control or to obtain information from the scene. In Figure 13, the screen refresh loop in C++ that has been used in our TVS is shown. The observer position can be obtained and presented on screen at any moment by means of the last two sentences in C++ code shown in Figure 13.

6. CONCLUSIONS AND FUTURE WORK

In this chapter we have set out the main steps to be followed for the development of an application for terrain visualization.

```
        while( renderSurface->isRealized()&& !kbmcb->done() )
        {
         // set up the frame stamp for current frame to record the current
         // time and frame
         // number so that animtion code can advance correctly
            osg::ref_ptr<osg::FrameStamp> frameStamp = new
    osg::FrameStamp;
            frameStamp->setReferenceTime(osg::Timer::instance()-
    >delta_s(start_tick,osg::Timer::instance()->tick()));
            frameStamp->setFrameNumber(frameNum++);
         // pass frame stamp to the SceneView so that the update, cull and
         // draw traversals all use the same FrameStamp
            sceneView->setFrameStamp(frameStamp.get());
         // pass any keyboard mouse events onto the local keyboard mouse
         // callback.
           kbm->update( *kbmcb );
         // set the view
            sceneView->setViewMatrix(kbmcb->getViewMatrix());
         // update the viewport dimensions, incase the window has been
         // resized.
            sceneView->setViewport(0,0,renderSurface-
    >getWindowWidth(),renderSurface->getWindowHeight());
          // do the update traversal the scene graph - such as updating
          // animations
            sceneView->update();
          // do the cull traversal, collect all objects in the view
          // frustum into a sorted
          // set of rendering bins
            sceneView->cull();
          // draw the rendering bins.
            sceneView->draw();
          // Swap Buffers
                 renderSurface->swapBuffers();
          // Reading of the present position value
           sceneView->getViewMatrixAsLookAt(eye, center, up, 0.0f);
          // Observer position updating
           refresCoord(eye, center, up);
          }
```

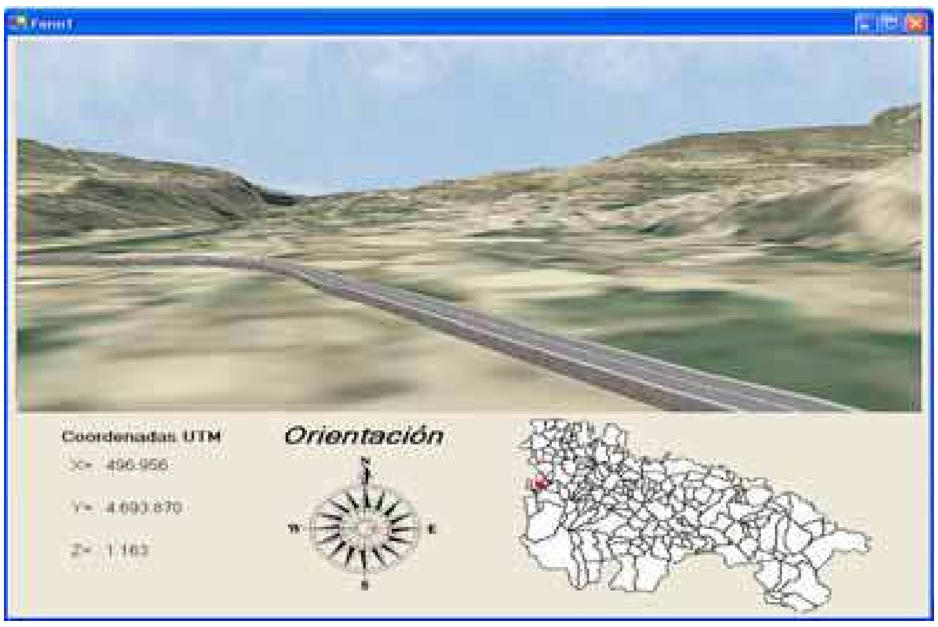
Fig. 13. C++ code for the screen refresh loop

First, the basic characteristics of a TVS and a diagram of the development process have been presented. Then, a brief study of the different applicable Web3D technologies (VRML, X3D, or Java3D) has been included. With this base, the different necessary steps to realize a TVS based on VRML have been detailed, from the choice of the viewer to the incorporation of external tools in Java for the interaction with the user. Aspects such as DTEM creation and the inclusion of photorealistic textures to the model have been also explained.

From the aforementioned, it can be deduced that the use of VRML for the creation of terrain visualization is viable, but always at the expense of depending on an external element that takes over the scene visualisation, on which neither real control exists, nor its code is known, nor its program can be modified. In order to overcome these limitations, the development of a specific graphic engine by means of the use of open source libraries has been proposed. To achieve this aim, several available open source graphic libraries and their basic functioning characteristics have been analysed.

Finally, the steps followed in the implementation of a TVS by means of OSG library have been detailed. Several tips and codes are also involved in this chapter to illustrate some stages in the development process. One of the potential capabilities of the developed system, which may be implemented in the future, is to include different 3D geometries, with the final purpose of facilitating aspects such as management, distribution and planning of the terrain, as a further onward step in geographical information systems (Longley et al., 2001). One practical example may be the inclusion of tracing of roads in the design stage (see Figure 14).

The starting point would be the road design maps, in this particular case, or any other element on which one may be working (canalisation, electricity posts and lines, railways and other forms of communication networks, etc.). From these graphic maps a previous treatment should be carried out, with any of the 3D design tools that exist on the market (3D Studio, Mayer, Blender, etc).



Coordenadas UTM
X= 496.956
Y= 4.693.870
Z= 1.163

Fig. 14. Example of the incorporation of external geometries

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