REAL-TIME VISUALIZATION OF GEOSPATIAL FEATURES THROUGH THE INTEGRATION OF GIS WITH A REALISTIC 3D TERRAIN DYNAMIC VISUALIZATION SYSTEM

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During the last years, several computational tools arose allowing the users to fly interactively over realistic simulations of the terrain using DTM, aerial pictures and satellite data. One of them, the Advanced Interactive Terrain Navigation System (SANTI) was developed by the authors. This system stood out because of its submetric resolution, real-time refresh rate over 60 fps and performance non-dependent of the size of the database to be displayed.

After this experience, the authors opened a new line of research that integrates this dynamic visualization system with GIS. This article presents an open architecture that easily integrates any GIS with SANTI, taking advantage of the potentiality of both technologies. This way, it is possible to visualize geospatial features while flying over the realistic model of the land for a better understanding and analysis of the data. It is also possible to query the GIS database from the visualization interface, interactively selecting features within the 3D view of the terrain.

We describe an application using this software architecture for regional planning and resource management.

INTRODUCTION

Traditionally, GIS and terrain visualization systems have evolved independently, in spite of being part of clearly related fields. Probable causes for this can be found on the differences of the kind of data to be displayed (symbolic vs. realistic) the goal of the visualization itself (clearness and intelligibility vs. realistic visual appearance), the different kind of users and the very different technical issues of displaying static layouts versus moving 3D models in real time.

Trying to put together the enormous power of both fields is an amazing challenge that can be accomplished following different approaches. An existing GIS system can be empowerd to display 3D terrain models en real-time; an existing terrain simulator can be adapted to manipulate, analyse and visualize GIS data, or a link subsystem can be developed to allow an existing terrain visualization system (SANTI) to display GIS data generated by an external GIS tool. The work presented in this paper represents an effort in that direction.

BACKGROUND. SANTI

The development of the Advanced Interactive Navigation System over Terrains (SANTI) [1] begun in 1998. The first application was based on SGI Onyx2 graphic supercomputer architecture and used the clipmapping technique [2] for mapping huge textures over the terrain. The current SANTI engine is working on PC architecture using common graphics cards.

SANTI is an interactive terrain visualization system that allows the user to navigate freely through the entire geography stored in its data base. This data base contains a digital terrain model composed by elevation data and image used to map the three-dimensional terrain. The access to the data and the rendering is made in real-time at a rate of at least 60 frames per second.

Because of the huge amount of information stored in the data base, it is only loaded in system memory a subset of the complete data base. Also, a level-of-detail technique [3] is used to allow the efficient visualization of this data. The levels of detail are organized around a point that places the center of the finer detail area. The content of system memory is actualized in real-time to show the best possible quality around this center of detail, depending on the available resources of the hardware used. The center of detail is placed depending on the camera's position and orientation to reach the finer level in the foreground. This level progressively decreases in further areas where the needed resolution is clearly coarser.

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This visualization system is independent from the data base and highly scalable, so the performance is sustained even if the resolution of the data or the extension of the digital model is increased

Navigation can be controlled in several ways, depending on the application, and using different devices, from keyboard, mouse or joystick to tracking systems or even custom made devices for exhibitions. The user can guide the camera with six degrees of freedom and control the velocity of the movement. It can be made by simulating the behaviour of an airplane (interesting for educational or entertaining applications) as well as moving over the terrain in an immediate manner to reach the view he or she needs (more adequate for professional use). In addition to this navigation mode, there is an automatic navigation mode through fixed paths, or flight from the current location to any place requested by the user.

In addition to the navigation control, the user can send commands to the system through a menu system. It has been used in several applications to the location and flight to special interest places, activation of automatic paths, etc.

This system has been used with different data bases, with texturing detail ranging from 30 m/pixel of satellite image to 0.25 m/pixel aerial photograph, with geometric detail ranging from 200 meters to 5 meters of resolution. SANTI has been used to display several databases representing geographical areas of different sizes up to 225.000 km^2, including digital models from several regions of Spain such as Galicia, Castilla-León, Asturias, Cantabria, País Vasco, Navarra, La Rioja and Aragón. The higher detail level has been applied to Galicia, where this system is being used for cultural applications since 1999.

SYSTEM FEATURES

The integration of the described system (SANTI) with Geographical Information Systems allows the visualization of geographical characteristics in a virtual three-dimensional terrain model.

There are two ways to represent information in GIS: vector and raster. Both of them are integrated in SANTI being used in a layer-like way as GIS do, meaning that they can be activated or deactivated, mixed with different transparency values, etc. (Figure 1).

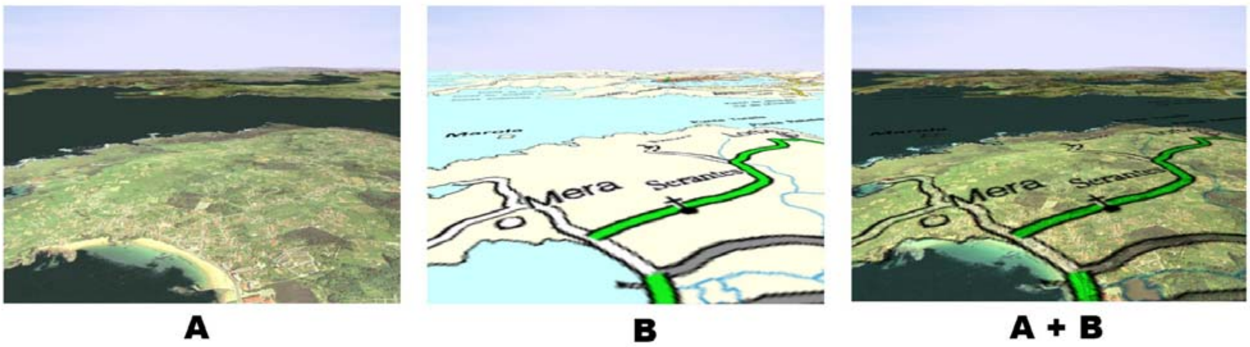

Figure 1: Multiple layers mixing

The raster information is generated from georeferenced images, which constitute a texture layer that can be applied to the terrain relief. For vector information there are several representation strategies for each primitive, so that information will be viewed in the most suitable way.

Points: they represent specific locations in the terrain. There are two visualization strategies which can be combined to display them (Figure 2):

- **Circles**: drawn on the terrain, with user-defined radio and color.
- **Billboards**: labels floating over the terrain, composed by images or text which can be retrieved from a database.

Figure 2: Visualization of points using circles and billboards

Lines or polylines: they are represented over the terrain with a user-defined width and color (Figure 3).


Figure 3: Visualization of lines

Polygons: they enclose different areas over the terrain (Figure 4).

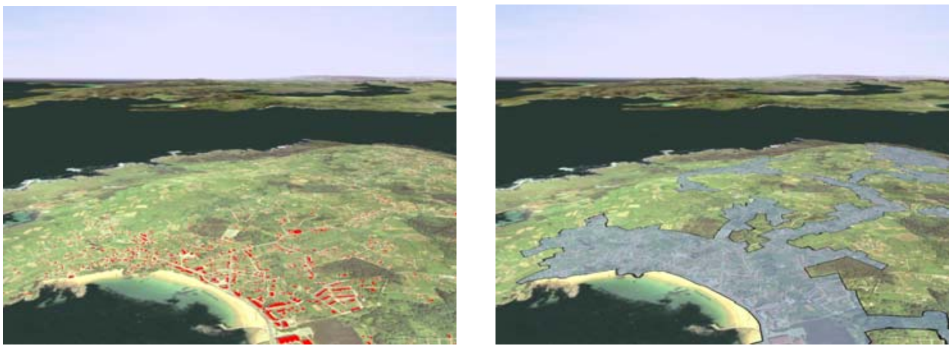
Figure 4: Visualization of polygons

SYSTEM ARCHITECTURE

The proposed system handles independently raster and vectorial information. Raster information is visualized by the multiresolution texture system as described in the *Background* section. This system has been extended to support multitexture, mixing several layers over the terrain simultaneously. The vector information management system is structured in three stages. This architecture is illustrated in the Figure 5.

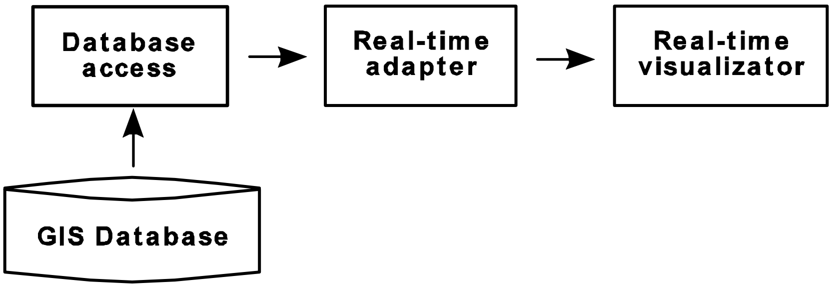

Figure 5: Vector data management global architecture

- The first stage is the responsible of accessing the databases where the geospatial information to be shown is stored.
- The second stage adapts the information coming from the databases to make is suitable for real-time display.
- Finally, the third stage visualizes the geospatial information over a digital terrain model.

Database access

Database access can be achieved by several ways, such as a file stored on disk, or a GIS server in Internet. The database access stage provides its output using an ad-hoc protocol that feeds the *Real-time adapter* stage, isolating the task of interpreting specific formats or protocols. This separation enables the access to other information sources in a way absolutely transparent to the rest of the system. Examples of different implementations of this module include ShapeFile [4] access or geospatial server queries using GML.

Database access is done only once for each set of vectorial data. The information that feeds the next stage is stored in memory to allow later queries.

Real-Time adapter

The stage that adapts data for real-time display is one of the most critical, since it will directly influence the performance and, therefore, the end user experience. In this stage three processes are performed, as shown in the Fig. 6.

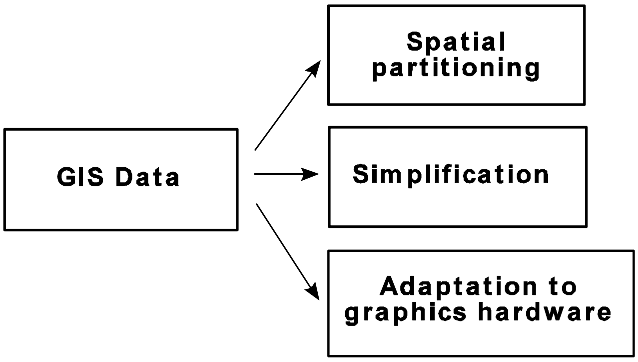

Figure 6: Real-time adapter

The first step towards that adaptation lies in building an efficient spatial organization, so that any request of information for a given area involves a database access as fast as possible. The visualization stage needs access to rectangular regions of the geospatial information at different scales, as will be shown hereinafter. Therefore, the most efficient spatial organization is one that splits the space in a tree structure, like a quadtree.

In some cases the information is so dense that it increases considerably the time needed to show it over the terrain. In this case, it becomes essential to perform a simplification. This simplification consists of a new sampling of the geospatial information at a different resolution, and requires establishing a balance between the rendering time and the desired quality.

Moreover, geospatial information can't always be sent directly to the graphics system. Newest systems still draw triangles, lines and quads. That's why it becomes essential to perform a geometry tessellating process, which turns complex polygons, possibly convex and probably containing holes, into lists of triangles.

Our system allows adapting the different vectorial primitives to real-time, employing different algorithms that can be combined.

Real-Time Visualization

In most cases the vector information represented in this system must be projected over the terrain. That issue implies several problems, as will be shown in the next section, specially, due to the dynamic nature of the geometry in SANTI, which uses levels of detail. There are, nevertheless, some cases where the GIS information can be shown using other techniques, as points, which can be viewed using floating billboards with associated information. In that case there are no terrain-adaptation problems because information is floating in the air and doesn’t have to be adapted perfectly to all the terrain levels of detail.

For real-time visualization of vectorial elements over the three-dimensional terrain model, two alternatives were analyzed:

- **Visualization using three-dimensional primitives**. It consists in drawing vectorial elements using the graphics system drawing primitives. These elements must be triangulated, multiplying the quantity of polygons that must be drawn on each frame. Besides, another problem derived from the terrain drawing algorithm used appears: for visualization of complex digital models it is necessary to apply some levels-of-detail-based technique. The drawing of geospatial elements using three-dimensional primitives requires adapting those primitives to levels of detail used for drawing the terrain.

- **Visualization using texture-mapping over the digital model**. It consists in turning the vectorial elements into a raster image, which is applied as a texture over the three-dimensional model. This technique allows vectorial elements to be adapted over the geometry, independently of the digital terrain model.

In the case of the application shown in this paper, we used a technique that modifies the detail of the three-dimensional geometry, depending on the quality required at each moment. That allows complex digital models visualization that otherwise would be impossible, because it surpasses the power of the graphics system. Nevertheless, this issue makes really difficult to apply the first alternative, so the second one was chosen.

A *clipmap*-based technique was used to visualise vector information. The original texture system of SANTI was modified, so that the texture fragments that feed the cache could be obtained from the *Real-Time Visualization* stage as well.

APPLICATIONS

Nowadays, advances in computer technology allow to increase the capacities and the use of the third dimension in GIS visualizing territorial information in a way that non-expert users can understand it [6] [7]. The visualization of geographical elements on a 3D digital model, instead of using a 2D flat map, causes changes in the way to see, to distribute, to communicate and to analyze the geospatial data, opening doors to new uses of GIS. Using these new possibilities, Hudson-Smith and Evans [5] distinguish four types of potential users:

- Professionals that need all the capacities of visualization and analysis to develop their works (planning, urbanism, architecture, engineering, transports, etc.) and to find the best locations for new infrastructures, or to value the visual impact of new projects (a building, a highway, etc.)
- Students or investigators that need to know different aspects about a region, their geographic elements, urban elements, historical aspects, social characteristics, or anything necessary to be shown on the virtual model.
- Citizens that exercise the right of public participation, where they can know and value different proposals or projects to develop on their region.

- Tourists interested in knowing the characteristics about a country or region, so they can do a virtual navigation and see the most interesting places with their information.

In every case, it would be possible to use a generic system for a region, with different capacities from interaction according to the user, or to have different systems for specific needs. Internet connection appears as the most appropriate medium to obtain greater diffusion and also greater use of the system, although the requirements of the user can recommend local applications.

Although it is in the initial development phase, SANTI-GIS project has already allowed developing different applications focused to data evaluation by professionals about a region with the purpose of planning new projects, as well as making presentations to show people the projects developed. In this sense, we can briefly mention some of the applications carried out with this system.

The Dirección Xeral de Comunicación e Audiovisual of the Consellería de Cultura, Comunicación Social e Turismo of the Xunta de Galicia is planning the basic infrastructures to improve the cover of the Terrestrial Digital Television signals in Galicia. In order to support this work, the cover obtained in raster format with a third program (COBRA) was shown in SANTI. This capability of visualization is extremely useful for technicians, because it shows the urban zones which have worse television signal quality quickly and effectively, allowing analyzing on this three-dimensional system the reasons of the low cover. Moreover, technicians can use SANTI to choose possible locations to install the antennas or necessary communications equipment.

The Empresa Pública de Obras y Servicios Hidráulicos dependent of the Consellería de Medio Ambiente of the Xunta de Galicia needed to show technicians, politicians and the rest of society, the projects developed in the Plan of Sewage and Recovery of Rias of La Coruña and El Burgo. From the graphical elements in CAD format, the necessary features were developed through the treatment in GIS and they were show in SANTI. This application allows activate or deactivate, whenever it is needed, anyone of the new elements of the sewer network in relation to the existing ones. That confers agility on presentations, because it can be individualized in real time any work, the projects of one area, or any aspect that must be commented with greater detail. The use of images of 0.25 m/pixel allows SANTI to show any territory area with great quality, which along with their handling in real-time, makes especially attractive to design presentations of any territorial infrastructure and any planning about a whole country, region or a part of it.

CONCLUSIONS AND FUTURE WORK

The application described in this paper shows the power of visualizing GIS data over an interactive three dimensional representation of the terrain. Due to the extreme requirements of efficiency that are necessary to display information on a real time application, GIS data is processed, transformed and adapted to fulfil the requirements of the visualizer by converting any combination of vector data to a composed raster image that is mapped onto the geometry, together with the satellite or aerial pictures. Other types of data such as points and billboards can also be displayed.

The system has proven useful for technical purposes as well as for diffusion of projects to public stakeholders. This has been tested on two real cases in which SANTI-GIS achieved very successful results.

Authors are currently working in the improvement of the system to make it capable to visualize buildings. Initially they are extruded from each polygon that represents a construction in GIS cadastre data, using its corresponding height and being mapped with generic façades Hence, a 3D virtual image of any urban zone of the territory can be displayed,. Moreover any 3D digital model of any special building, block or district, existing or planned, can be included, making SANTI-GIS a very useful tool for urban planning, land development, tourist guiding, etc.

Instead of the height of the buildings, it would also be possible to use another kind of information associated with the polygons in GIS, for example the number of shops in a district. It can use any data type as building height, which allows generating 3D representations of great value for analysis, compared with the commonly used maps.

In the future, SANTI-GIS should connect the 3D navigation system with a Web Feature Server (WFS) which will allow working with a great amount of GIS formats and spatial data bases. The next step would be to allow Internet access to this system, enabling users to get the information quickly. One step beyond would be trying to work in real time with data provided by other organizations, representing any territorial phenomenon (temperature, rain, pressure, humidity, wind, fires, etc.) on the SANTI.

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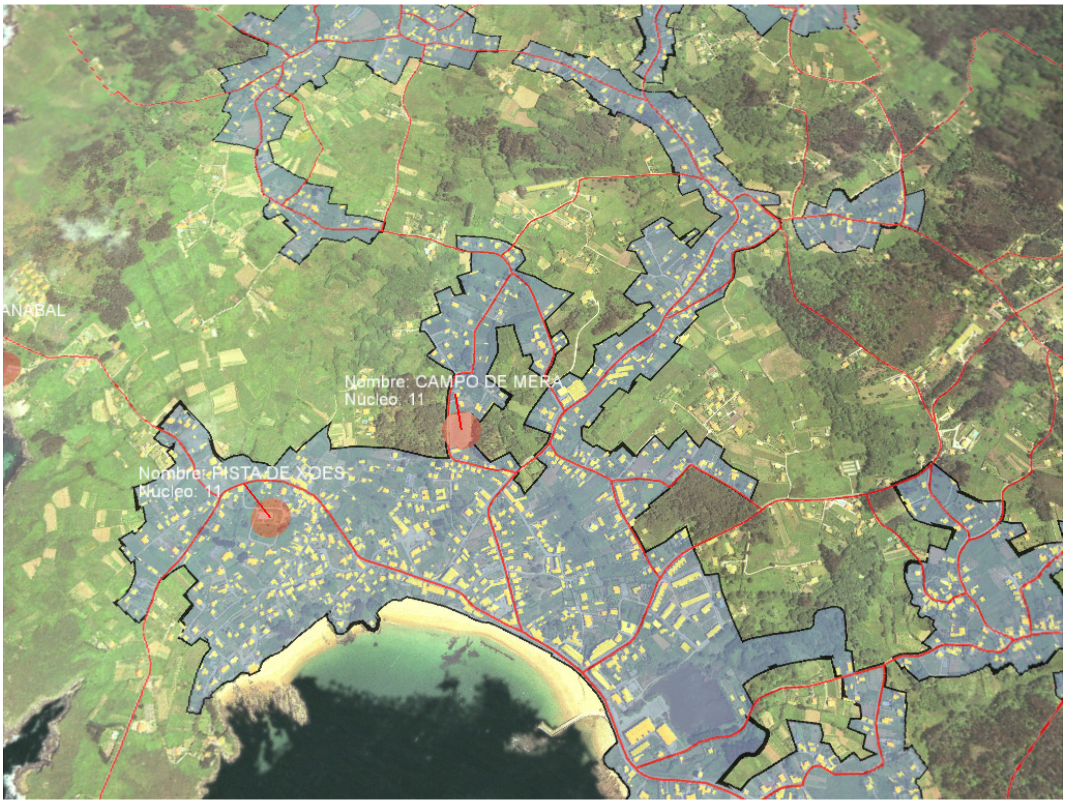
Example of the whole system



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