VIRTUAL REALITY INTERFACES APPLIED TO THE EDITING OF DIGITAL ELEVATION MODELS

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Abstract. This paper presents a methodology for visualizing, analyzing and editing digital elevation models through the use of a virtual reality interface that offers a three-dimensional view of the data, and a set of interaction tools. These tools allow experienced remote sensing data users to manipulate the information in an intuitive and realistic way. An API offering analysis functions commonly used during the manipulation of such kind of data is implemented and assessed. An editing component has been created to modify the data being visualized, and some techniques, including Taubin's $\lambda|\mu$ smoothing algorithm, are described in detail. Once generated, digital elevation models frequently present errors due to problems that occurred during the imaging process or raw data processing. These errors need to be removed as efficiently as possible in order to produce a reliable product. This is currently achieved by making a difficult and subjective analysis of the model through a two-dimensional interface and using line command based instructions. A software prototype, called DEMEditor, has already been developed and used to validate the newly adopted methodology.

Keywords: remote sensing, virtual reality, digital elevation models, elevation correction.

1. Introduction

A Digital Elevation Model (DEM) can be defined as "any digital representation of the continuous variation of relief over space" Teichrieb et al. (2002). A DEM can be conveniently stored as a real matrix, where the value at position x, y describes the measured or estimated height z of the terrain in the corresponding coordinates.

DEMs are generated based on data collected through an imaging process. Depending on the type of remote sensing system applied to obtain these data, they can obtain information about the imaged earth surface (with different orders of precision, ranging anywhere from centimeters to meters) or about the surface of objects over the terrain, such as vegetation or man-made objects (houses, fences, vehicles etc.). Currently Interferometric Synthetic Aperture Radar (InSAR) systems can provide data for the generation of centimeter precision DEMs Wimmer et al. (2000). After the data collection, raw data have to be processed using sophisticated algorithms in order to produce several kinds of products, including DEMs. High resolution DEMs can be used in different applications, as they become especially relevant to supply information about regions where there are no detailed, precise and updated topographic maps available.

Once the imaging process of the surface and the raw data processing method are very complex and depend on a series of combined parameters (airborne parameters, radar parameters etc.), several error components may be added to the data, impairing the generation of elevation models with inaccurate height values. Performing a quality control of the product by comparing height values of specific coordinates in the model with their corresponding values in the real surface may help SAR users to detect most of these errors. A critical problem is the fact that these errors can be caused by many different reasons for each generated DEM, what makes its correction very difficult to achieve. Experienced SAR data users employ their previous acquired knowledge about the data combined with some powerful

analysis tools to make final adjustments to the models and, therefore, construct more precise DEMs.

This paper presents methods that aim at enhancing and turning more efficient the editing process of DEMs. The methodology that supports experienced SAR data users in the visualization, analysis and editing of DEMs is presented in section 2. The system that implements the proposed methodology is described in section 3. Section 0 describes the editing process in more detail. Finally, some conclusions and future work are presented in section 5.

2. Digital Elevation Models and Virtual Reality

The proposed methodology suggests the use of Virtual Reality (VR) interfaces to support visualization, analysis and editing of DEMs. Three design aspects are considered:

- information representation through the use of rich semantic 3D icons;
- the use of spatial navigation strategies to make the analysis and editing process more intuitive and efficient;
- editing of DEMs through its representation as interactive data models and through the use of metaphor-based editing tools.

The remote sensing community employs a set of powerful software tools to manipulate SAR data. These tools allow the user to visualize the DEM and analyze it. Most of the used software shows the model as a two-dimensional (2D) grayscale image, as a collection of contour lines or as a perspective image Kelner et al. (2001), such as in the ENVI Research Systems (2002). Although these kinds of representation allow the user to obtain a mental representation of the surface's shape, they are not comprehensive because of their presentation of 3D information as flat images.

VR technology introduces a new paradigm for visualizing and exploring information: the three-dimensional (3D) paradigm. Its main advantage over classical interfaces is that it offers high interaction with the virtual environment that represents the information. A second advantage is its ability to offer more realistic presentation of the information than the one attainable using 2D interfaces. Representing elevation information as 3D surfaces will make the visualization, analysis and editing process of the data more realistic than conventional 2D projections.

Due to the fact that the DEMs represented as 3D models can be presented along with other 3D objects in the same virtual environment, a collection of such objects can be constructed to make the analysis and editing process more efficient for the user. For example, a 3D icon representing a compass shows the user the north-south direction of the data, so that it easily can be compared with a cartographic map of the same region. This example illustrates another aspect of the development of icons, namely the use of metaphors. Using concepts known from the real world makes it easier to understand specific tasks often not immediately intuitive for less experienced users.

As earlier stated, VR interfaces allow a high interaction level between the user and the environment. The 3D objects that compose the virtual world can be, for example, associated to sensors. Hence a user could remove elevation data from a DEM by merely moving a height indicator to the desired value. This functionality could be used in situations were the raw data used to generate the DEM had information about the elevation of objects over the surface (for example, height values from a forestry), and only information about the height of the surface itself was required, making it necessary to change these values.

Another relevant interaction type in VR environments is the use of navigation tools to move through the world. It is very important to develop this navigation functionality taking into account some strategies Frery et al. (2002), such as the definition of points of view in the

environment that take the user to relevant parts of it. A point of view, also called overview, presents a generic view of the environment. This viewpoint normally positions the user at a high point from where the whole objects that compose the world can be observed. This will help the user to obtain information about the spatial organization of the virtual environment. A tour composed by the main points of view is also a navigation strategy that should be offered by the environment.

3. The DEMEditor

The DEMEditor is a VR based DEM editor. It intends to allow SAR data users to visualize, analyze and edit DEMs.

A set of requirements were collected and structured, in order to define a user-friendly interface and to develop a system that offers functionality for editing elevation models.

The system is implemented in IDL (Interactive Data Language IDL (1998)) version 5.3, a language developed by Research Systems Inc. Research Systems (2002). SAR data users largely use IDL because it has several built in functions for data analysis and visualization.

The DEMEditor is based on a three level architecture, illustrated in Figure 1.

Figure 1: Architecture of the DEM editor.
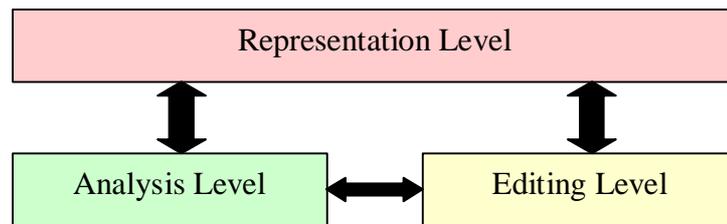
The main level is the Representation Level. This level, as illustrated in Figure 2, is responsible for providing different representations for the data to be visualized. For example if the user wants to visualize the DEM as a 3D surface, the Representation Level constructs the 3D object and presents it to the user. Similarly if the user wants to make some analysis of the data using a 2D representation, a raster image is presented. The Representation Level also contains predefined 3D objects embedded in the system that perform functions such as editing icons, guide avatars etc.
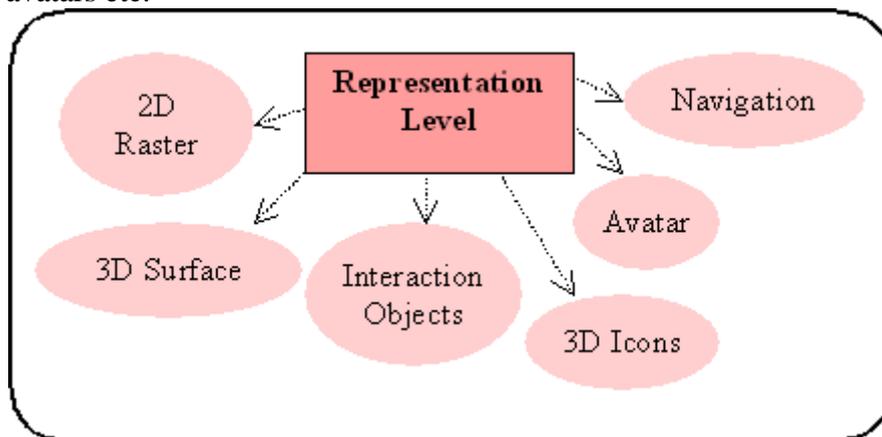

Figure 2: The Representation Level and its components.

The Analysis Level (Figure 3) implements a set of tools that the user can use to analyze the DEM. As mentioned earlier, the requirements were collected from SAR users and, based on them several analysis functions were developed. Examples of functions implemented by this level are the generation of histograms, the definition of profile lines, verification of positions and their height values in the model, and verification of values such as mean and kurtosis of the data etc. These analysis tools provide the user with information about the

DEM, helping him/her to find error areas or simply areas that do not correspond to his/her interest and should therefore be removed. Both the Analysis and the Representation Levels cooperate with each other in order to allow a user to visualize the data, make a visual interpretation of them, and through the realization of this visual analysis he/she will be able to choose regions to be analyzed with the appropriate analysis tools. The results returned by these tools will again be represented as 2D and/or 3D objects and presented to the user.
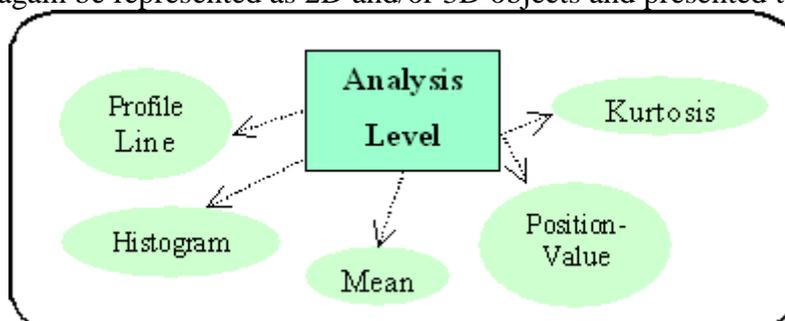

Figure 3: The Analysis Level and its components.

The Editing Level focuses on the editing of the DEM. Figure 4 shows some components used to edit the model: the "select" tool allows the user to select a region of interest from the model, which corresponds to the area to edit; the "cut" tool is used to remove the data inside the selected region, creating a hole on the model; the "interpolate" tool closes the hole produced by the cut tool using a predefined interpolation method; and finally the "smooth" tool smoothes out the cut out area, removing undesired data from the model.
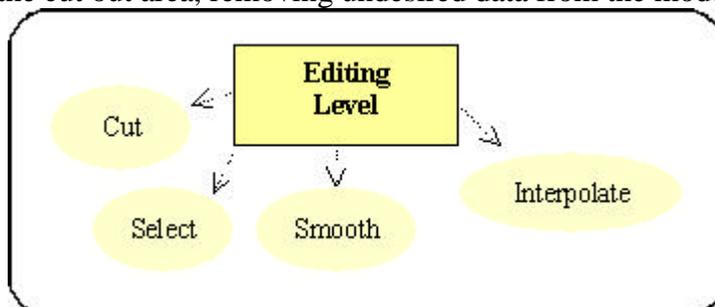

Figure 4: The Editing Level.

4. Editing of Digital Elevation Models

The authors propose the use of a 3D interface to visualize, manipulate and edit DEMs. Indeed, the 3D paradigm offers sophisticated resources for the exploration of important information such as the height of a terrain.

Visualization and analysis tasks are performed more efficiently by navigating through the environment and manipulating directly the 3D objects. For example, let's consider a user who wants to explore a surface object that represents a specific area of a DEM. Making a flight through the environment gives him/her an overview about the model, and picking the object with the mouse allows the user to rotate the surface in any direction in order to visualize details of its geometry. The exploration of the DEM, associated to additional information such as hardcopy maps of the same region, helps the user to identify areas where there are no height data available, and areas that present inaccurate height values. These locations have to be edited in order to produce a DEM as accurate as possible.

Next some techniques are described to interpolate, smooth and edit DEMs.

4.1. Removing "Dummy Values"

DEMs commonly present positions where there are no height data available. This happens

because the sensor (e.g., radar) could not collect data for these points. If no value for a specific position can be obtained, a so-called "dummy value" equal to –9999 is assigned to it.

Obviously these dummy values do not correspond to the correct height values of the terrain at that position, and have to be removed. In order to achieve this, a method known as bilinear interpolation is used to compute a new value for the pixel. Bilinear interpolation performs one linear interpolation on the row of the image that holds the pixel, and one linear interpolation on the column of this image Gomes and Velho (1994).

Figure 5 shows a 3D surface representing a DEM from a perspective point of view, and illustrates the result of removing the dummy values from the model using the bilinear interpolation method. **Figure 5a** presents a zoomed view of an area of a terrain that holds several coordinates with values equal to –9999, as there were no height data available for them. Height information is represented by different colors, where the lowest parts of the surface presented as black-blue areas, and the highest ones as yellow-white areas. The whole color scale can be found on the color bar situated at the left side of the figure. Positions with dummy values represent holes in the surface, hence that they are not colored and it is possible to see the background of the scene (gray color). **Figure 5b** shows the same area after the substitution of the dummy values using the bilinear interpolation technique.
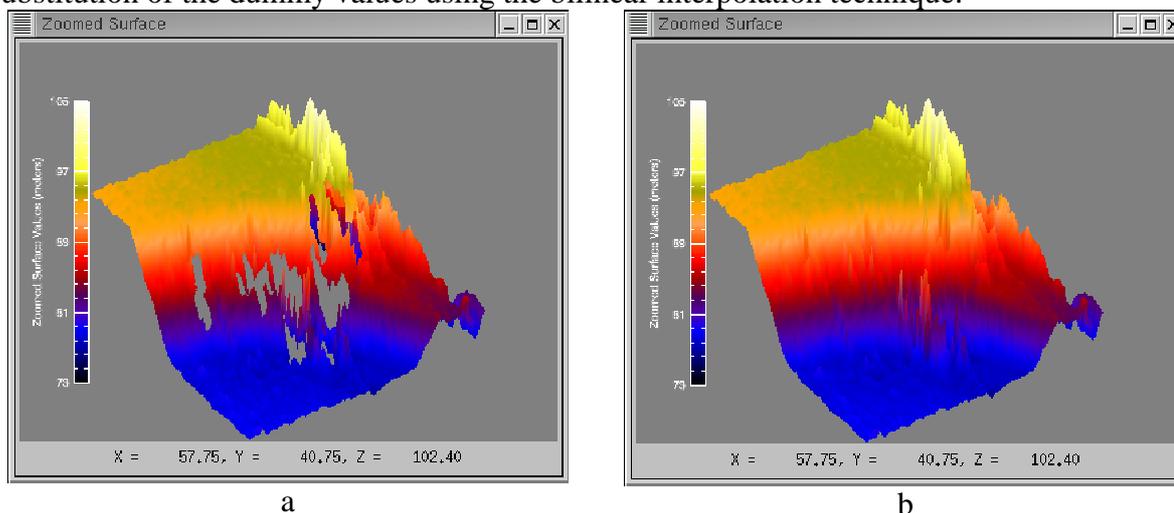

a   b

Figure 5: a) A zoomed view of an area of a DEM with dummy values; b) The same area after removal of dummy values.

4.2. Smoothing

Another functionality associated to editing DEMs is terrain smoothing. Different types of filters may be used to perform the smoothing of a surface. These include the median, mean and sigma filters. For example, the median filter is a filter classified as a statistical one. Statistical filters use statistical properties of an image to define its value at each pixel. Statistical filters are used to remove noise on an image. The median filter of order n takes for each pixel p an 8-connected neighborhood of p, with n pixels $p_1, p_2, \ldots, p_n$. The median m_p of this set is computed, by sorting the pixels p_i according to its intensity value. The value of the filter at p is defined as m_p. Additional details may be found in Burdick (1997).

Figure 6 illustrates a perspective view of a part of a DEM, where the elevation information can be observed due to the 3D modeling of the terrain and also because areas with different heights are presented with different colors. The amplitude image corresponding to the model is mapped onto the surface, considerably enhancing the visual interpretation of the terrain. **Figure 6a** shows the original data of the terrain, where several areas with dummy

values can be observed. After the interpolation of unavailable height values and the application of a mean filter, the terrain becomes very smooth and without dummy values (see **Figure 6b**). The width of the smoothing window of the filter used in each dimension, in this case, was 13. The minimum value of the original data was 15.3280, and the maximum value was 105.719; after the application of the filter the data became between the values 44.5634 (minimum) and 96.4629 (maximum).

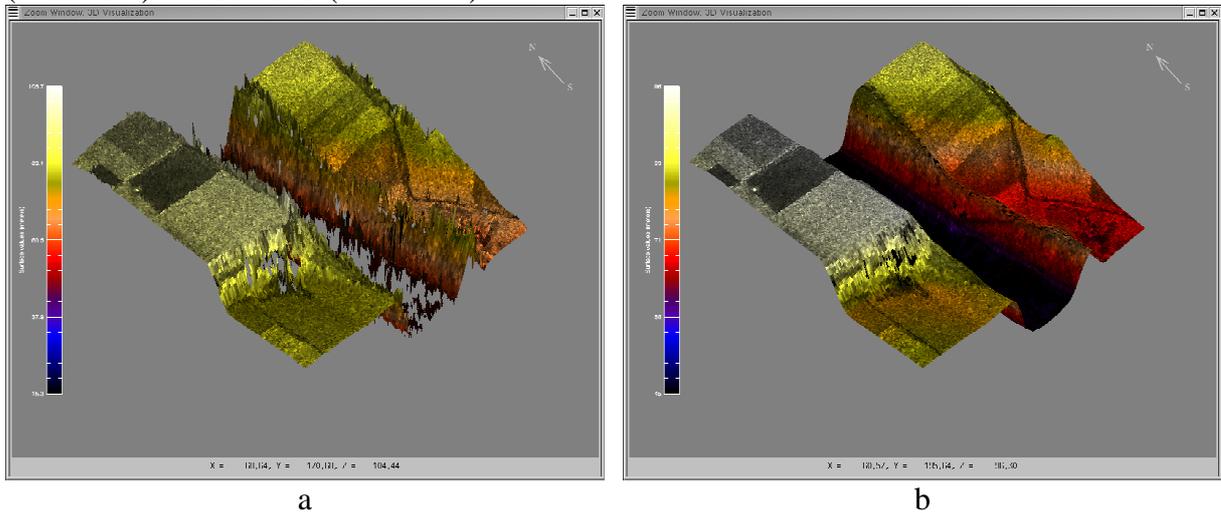a   b

Figure 6: a) Surface with dummy values; b) The same surface after interpolation and smoothing.

4.3. Taubin's Smoothing Algorithm

Taubin (2000) proposed a smoothing algorithm called $\lambda|\mu$ that intends to solve the problem of shrinkage presented by other smoothing algorithms, such as the box filter.

This algorithm can be seen as an extension to the Laplacian smoothing, which is a well-established technique. Using the Laplacian smoothing, boundary vertices of a mesh are constrained not to move, but internal vertices are simultaneously moved to the barycenter of its neighboring vertices. Then the process is iterated a number of times. When Laplacian smoothing is applied to a noisy 3D polygonal mesh without constraints, noise is removed, but significant shape distortion may be introduced. The main problem is that Laplacian smoothing produces shrinkage, because at the limit, all the vertices of the mesh converge to their barycenter. More details about this technique can be found in Taubin (2000).
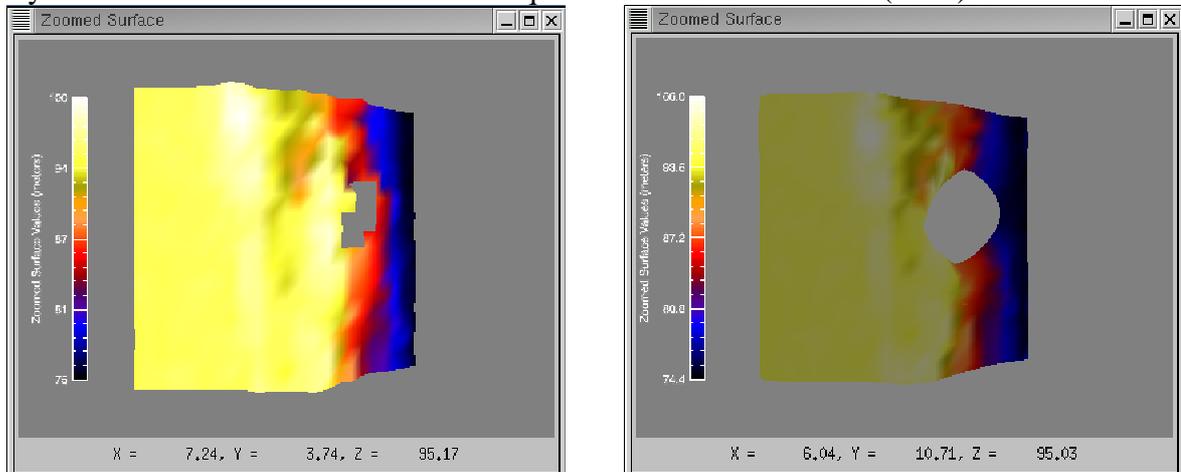

Figure 7: Smooth of a surface that contains a hole, using Taubin's $\lambda|\mu$ algoritm.

The $\lambda|\mu$ algorithm proposes the following second-degree transfer function to solve the problem of shrinkage

$$f(k) = (1 - \lambda k)(1 - \mu k),$$

which can be implemented as two consecutive steps of Laplacian smoothing with different scaling factors; the first one with $\lambda > 0$, and the second one with $\mu < -\lambda < 0$.

Figure 7 presents a surface smoothed with Taubin's $\lambda|\mu$ algorithm. It can easily be observed that this algorithm produces less shrinkage then another smoothing algorithms frequently used by the community. The minimum value of the original data was 74.4041, and the maximum value was 99.9769; after the application of the filter the data became between the values 72.2868 (minimum) and 97.8596 (maximum).

4.4. Defining and Editing Regions of Interest

After exploring and analyzing the DEM, specific regions may be identified as displaced or containing incorrect height values. To correct this type of errors the user needs to select these regions of interest before performing some editing task on the terrain. Once selected, the values of the coordinates held by the regions of interest may be removed and interpolated, and/or smoothed using a specific filter.

A set of functionalities to manipulate the regions of interest is also needed. Furthermore, tools to delete defined regions of interest, to select inactive regions of interest, and to translate them to another position on the model should also be available to the user.
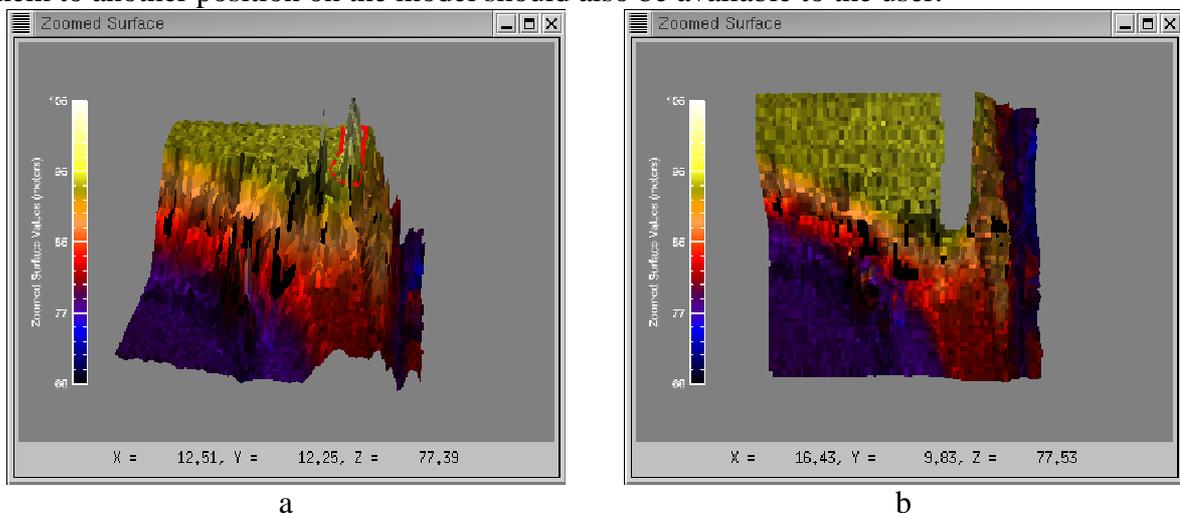

a   b

Figure 8: Definition of regions of interest and its editing. a) A region of interest is defined around an area; b) The region of interest is cut out from the surface.

Figure 8 presents the editing process of a region of interest. Initially the region has to be defined, which can be done by drawing a polygon around the area that should be edited. A selected area is illustrated in **Figure 8a**, surrounded by a red line which is higher than the rest of the terrain on the left side. This high area should be removed to make the terrain flat all the way to the start of the slope (right side of the terrain). **Figure 8b** shows the terrain after the removal of the height values held by the region of interest. The hole produced by the cutting process could now be interpolated and/or smoothed. It can also be observed that the region of interest that previously defined this area to be edited now has be deleted, once it is not anymore needed. On the other hand, another region of interest defined before has been left and can yet be used to edit the area held in it. The last region of interest drawn by the user is always the active one, so that previously defined ones become inactive when a new one is defined (Figure 8a).

5. Conclusions and Future Work

In this paper a methodology for supporting the correction of DEMs is proposed, in order to produce models with height values as accurate as possible. This correction is mainly related to the removal of dummy values and incorrect areas of the terrain, the smoothing of the terrain, and the definition of regions of interest on the surface to perform editing. The methodology is based on a virtual reality interface, where information is represented as 3D icons, and the visual analysis of the data is enhanced through the use of navigation strategies and exploration functionalities.

A further important contribution of this work is represented by its use of Taubin's smoothing algorithm with DEM data, instead of data such as polygonal meshes generated by surface reconstruction algorithms from 3D scanned data, for example. The shrinkage problem could be considerably alleviated.

In future work, other editing functionalities may be experimented, including the translation and scale of regions of interest defined on the terrain. In order to turn possible the simulation of real conditions of a specific terrain, a set of 3D objects should be available that could be used to populate the DEM. The definition of metaphor-based icons is needed to insert these tools into the 3D interface.

Finally, other experiences with Taubin's smoothing algorithm will be made, using weights associated to different values, determined by unit edge costs, in order to reduce the shrinkage effect.

6. Acknowledgements

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