SV3DVISION: 3D RECONSTRUCTION AND VISUALIZATION FROM A SINGLE VIEW

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ABSTRACT:

Nowadays, there is a huge proliferation of software based on traditional image-based 3D reconstruction methods which use multiple images to extract 3D models. However, sometimes it is not possible to obtain such images, mainly when damaged or destroyed buildings need to be documented and only single photographs or paintings exist or even when working with multiple images, parts of the scene appear in only one image due to occlusions or lack of features to match between images. This paper presents the sv3DVision software, a tool developed for the 3D reconstruction and visualization from a single view which integrates approaches of Photogrammetry, Computer Vision and Computer Graphics.

1. INTRODUCTION

In the knowledge and new technologies society in which we live, it could seem unreasonable to research in the development of methods for 3D reconstruction from a single view when the big proliferation of digital cameras and computers allow to take and process multiple images respectively. Nevertheless, the value of single images seems to re-emphasize its diverse applications for Cultural Heritage documentation, when damaged or destroyed buildings need to be documented and only single photographs or paintings exist or even when working with multiple images, parts of the scene appear in only one image due to occlusions or lack of features to match between images.

From a single view, it is possible to extract substantial information about the original object and even to reconstruct the 3D model. One of the most critical steps in this process concerns to identify with a high precision and reliability the structural elements belonging to an oblique image. Particularly, in architectural environments vanishing points constitute the framework that support the whole process, since provide independent geometric constraints which can be exploited in several ways: from the camera self-calibration and a dimensional analysis of the object, to its own 3D reconstruction. Nevertheless, achieve a balance between quality and reality is a difficult goal to overcome, mainly taking into account that 3D reconstruction from a single view is a task that presents an intrinsic complexity derived from its bad proposal 'ill-posed problem' which increases with the scale. In this sense, the key pass through developing multidisciplinary approaches that exploit the synergies with other disciplines in order to provide an ideal research frame. Up to now, Photogrammetry, Computer Vision and Computer Graphics are the main disciplines that participate in this synergic context providing different approaches: from camera self-calibration and 3D reconstruction, to the interactive and dynamic 3D visualization on Internet.

sv3DVision is a software developed for the 3D reconstruction and visualization from a single view which can be portrayed by the following features:

- It constitutes a considerable change with respect to the classical photogrammetric software based on stereoscopic vision.

- It supposes a contribution in a multidisciplinary context, destined to the synergic integration of methodologies and tools of others disciplines such as: Photogrammetry, Computer Vision and Computer Graphics.

- It establishes an own methodology for the 3D reconstruction from a single view combining several scientific approaches.

- It represents a multidisciplinary tool for the popularization and dissemination of the Architectural Cultural Heritage, as well as its utilization in research and education.

The paper presents the following structure: the second section gives an overview about the 3D reconstruction methods from a single view as well as the main tools developed up to now; the third section analyses the sv3DVision software based on its main features; a final section is devoted to put across the main conclusions and future perspectives.

2. OVERVIEW OF THE 3D RECONSTRUCTION TECHNIQES FROM A SINGLE VIEW´

To our knowledge there are several papers which address the problem of 3D reconstruction from a single view: (Debevec, 1996) is the first person who develops a reconstruction system from single images, exploiting user-selected edge features to build a model from 3D primitives and then verifies its accuracy by projecting the model back into the original image; (Parodi&Piccioli, 1996) investigate the reconstruction of 3D models from line drawing (on a single image) assuming geometrical constraints provided by the location of vanishing points; (Liebowitz et. al., 1999) propose a two-pass reconstruction method applied to planar facades. In a first step, the visible facades are individually reconstructed by rectification. The second step proceeds in an incremental fashion, that is to say, the facades are positioned in turn;

(Heuvel, 1998) describes a method for reconstructing polyhedral object models from a single view. The method uses measurements of image lines, object information as well as topology and geometric constraints (parallelism, perpendicularity); (Criminisi et. al., 1999) presents a technique that makes use of the following assumptions: three orthogonal sets of parallel lines, four known points on ground plane and one height in the scene; (Remondino, 2003) develops a method for 3D reconstruction of human skeleton using a single view. In this approach the author uses a scaled orthographic projection and some additional constraints in order to simplify the relations between the 3D object coordinates and the 2D image measurements; (El-Hakim, 2000) presents a flexible and accurate method which can be used by a wider variety of sites and structures. The approach does not need models of the object nor known internal camera calibration. Neither use vanishing lines or vanishing points. In this sense, several types of constraints based on topological relations and basic primitives are established; (Sturm et. al., 1999) develops a similar approach based on three types of constraints: coplanarity of points, perpendicularity of directions or planes and parallelism of directions or planes. Nevertheless, in this case the author uses the vanishing points as complementary geometrical elements in 3D reconstruction.

In contrast to 3D reconstruction from multiple images, there is not a big variety of software packages available for the 3D reconstruction from a single image. Nevertheless we can remark the following: 3D Builder, primarily designed for processing multiple images, but can work with a single image (3D Builder, 1999). It allows the use of parallelism and perpendicularity of objects edges. PhotoModeler, also designed initially for the 3D reconstruction from multiples images, but can supports reconstruction from a single image based on a manual identification of features by the user supported with geometrical constraints (PhotoModeler, 1999). Relatively new are the packages Canoma (Canoma, 1999) and ImageModeler (ImageModeler, 1999) which are based on the principles developed by Debevec (Debevec, 1996). Particularly, Canoma works with so-called primitives supported by geometrical constraints (parallelism and perpendicularity) while ImageModeler works with multiple images, although allow a dimensional analysis exploiting the geometrical constraints from a single view. Finally, a non-commercial packages for 3D reconstruction from a single image that use the same principles as 3D Builder is SolidFit (SolidFit, 1999). In the same line, the software Photo3D (Photo3D, 2000) allows to create a 3D model using the background photo image as a reference and the camera calibration. Again, geometric constraints are used to create the model.

One general disadvantage of the software presented above is that they generally act as 'black boxes' and do not supply detailed information on the accuracy of the resulting model. Furthermore, statistical testing or robust estimators for blunder detection is not very advanced.

In this sense, the software that we have developed, sv3DVision, presents a hybrid character, since combines several of the approaches commented above. On the one hand, exploiting the vanishing points geometry of an oblique image and on the other hand applying the geometrical constraints common in man-made structures such as architectural buildings. Regarding to the reconstruction step, the method developed in sv3DVision keeps certain resemblance with the approach developed by (Liebowitz et. al., 1999), since obtains rectified images based on vanishing points and camera internal parameters.

Finally, with relation to the disadvantages commented above, sv3DVision is a software designed for educational and research purposes that integrates a didactic simulation interface that allow to create and analyze different simulated models in order to understand the whole process. On the other hand, sv3DVision incorporates several robust and statistical techniques in order to guarantee reliability in the automatization of the process.

3. THE SV3DVISION SOFTWARE

sv3DVision is a software package that presents a triple structure generated under three different interfaces (Figure 1): Simulation, Reality and 3D Visualization, which allow to work with simulated perspective models or real images in order to obtain a 3D reconstruction and visualization from a single view.

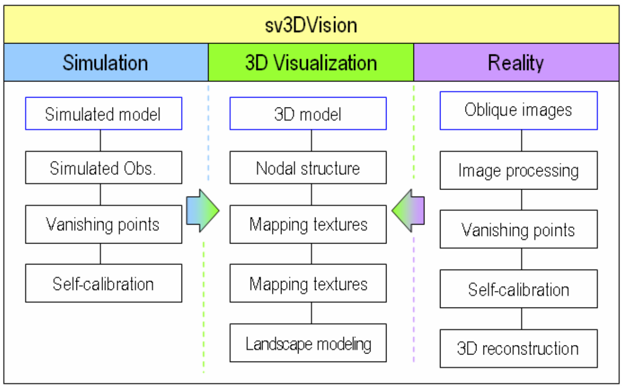

Figure 1. Triple structure in *sv3DVision*

3.1 Simulation interface

Through the Simulation interface (Figure 2), the user can control whatever type of geometric or statistical parameter in the generation of a simulated model. The graphic and dynamic simulation of the perspective model is achieved based on the modification of camera parameters (internal and external) and the colinearity condition. In this way, the Simulator developed performs as a checkup platform, where the different input parameters such as: vanishing lines, accidental errors, gross errors and even the own radial lens distortion, can be setup in order to analyze the accuracy and reliability of the algorithms before being extrapolated to real situations (images).

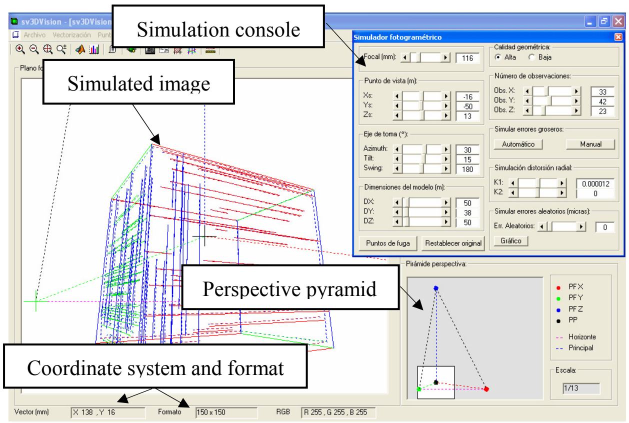

Figure 2. Simulation interface in sv3DVision

The simulation console (Figure 3) enables to control the following parameters:

- Camera geometrical parameters, corresponding to the internal and external parameters.
- Object simulated parameters, corresponding to the three orthogonal dimension (length, depth and height), as well as the datum definition.
- Quality geometrical parameters, corresponding to the maximum and minimum size of observations, segments inclination, as well as gross and an accidental errors ratio.
- Radial lens distortion parameters, corresponding to the value of the coefficients K_1 and K_2.

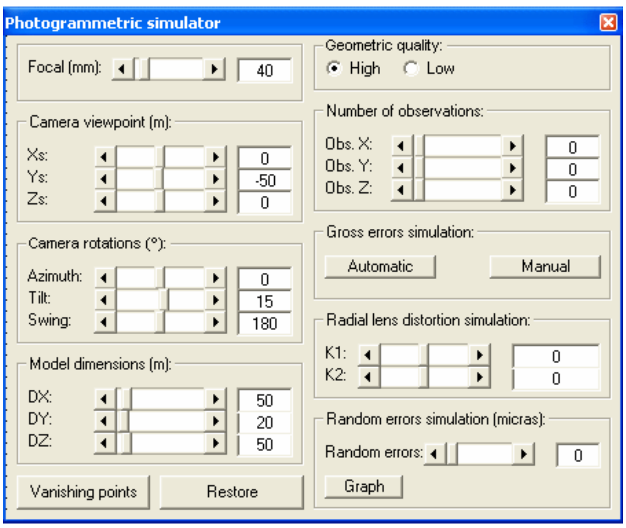

Figure 3. Simulation console in sv3DVision

A complete description of this simulation interface and its performance is given in [Aguilera et. al., 2004].

3.2 Reality interface

Through the Reality interface the user can work with real oblique images belong to architectural buildings, in order to obtain a 3D reconstruction from a single view.

Next, it will be described the most relevant features of sv3DVision corresponding to the Reality interface.

Digital processor. One of the most critical steps in 3D reconstruction from a single view resides in detecting with high accuracy and reliability the structural elements belonging to an oblique image. This is not an easy task, taking into account that usually images contains noise due to the own acquisition process as well as the radial lens distortion. So, although a huge proliferation of image processing algorithms exist currently, hierarchical and hybrid approaches will be required in order to guarantee quality. Unfortunately, it does not exist an universal method for automatic vectorization, so it will the own requirements of each case which will define and adapt the algorithm. In this way, (Heuvel, 1999) applies a line-growing algorithm so-called Burns detector (Burns et al., 1986) for vanishing lines extraction; (Tuytelaars et. al., 1998) create a parameter space based on Hough transform (Hough 1962) to detect vanishing lines automatically; more recently (Liebowitz et. al, 1999), (Almansa et. al 2003) and (Remondino, 2003) apply Canny filter (Canny 1984) for the same purpose.

With relation to the methods remarked above, sv3DVision incorporates an original approach for processing oblique images. An automatic vectorization algorithm has been developed which presents a hierarchical structure that starts with the basic task of filtering and ends with the detection of basic primitives through segmentation and clustering approaches. Particularly, in a first level, a preliminary extraction of edges supported by Canny filter is performed. In a second level, basic primitives are obtained through a labelling process supported by colinearity condition. This step provides also an estimation of the radial lens distortion parameters. Finally, in a third level, the lines are clustered with respect to the three main vanishing points direction supported by a RANSAC (Fischler&Bolles, 1981) algorithm.

Figure 4 illustrates the result of clustering process for three vanishing points.

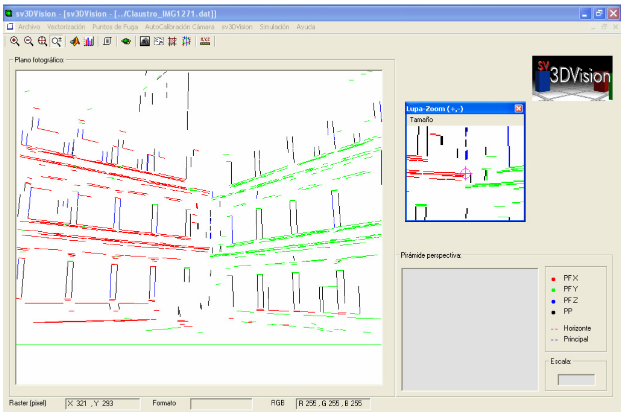

Figure 4. Clustering lines in sv3DVision

Vanishing points calculator. sv3DVision allows to combine several proven methods for vanishing points detection together with robust and statistical techniques (Figure 5).

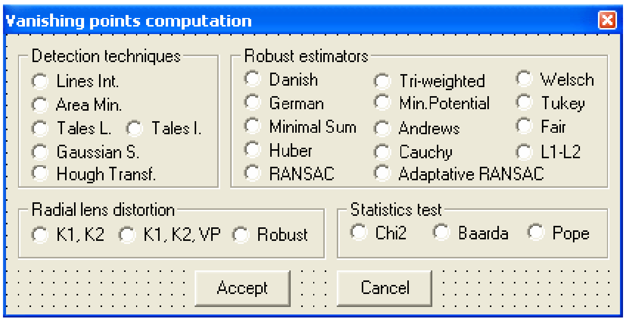

Figure 5. Methods and techniques for vanishing points detection in sv3DVision

A large selection of methods have been developed: from the easiest approaches such as: intersection of lines and triangle area minimization methods, to the most successful methods supported by Hough transform and Gaussian sphere. In regard to statistical tests, every one is based on a hypothesis contrast supported by several statistical parameters. Particularly, Chi-Squared Test allows to obtain a global balance about the model adequacy, while Baarda (Baarda, 1968) and Pope (Pope, 1976) Test allow to detect automatically possible outliers corresponding with wrong vanishing lines through an iterative technique that analyzes the standardized residual with respect to a established threshold. This threshold well-known as 'statistical cutoff or critical value' is determined based on a specific statistical distribution: Gaussian and T-Student distributions are applied for Baarda and Pope Tests respectively. Finally, with relation to robust estimators, a double classification can be considered: M-estimators which apply a specific weight function in an iterative re-weighted least square process (Domingo, 2000), and RANSAC robust estimators which combine the traditional (Fischler&Bolles, 1981) and adaptative (Harley&Zisserman, 2000) approaches, incorporating a specific adaptation to each vanishing point technique.

Camera self-calibrator. Single image calibration is a fundamental task starting in the Photogrammetry Community and more recently in Computer Vision. In fact, both share several approaches with different purposes: while Photogrammetry tries to guarantee accuracy and reliability, Computer Vision is more concerned about the automatization and rapidity in camera calibration. In this way, approaches exploiting the presence of vanishing points have been reported in Photogrammetry (Bräuer&Voss, 2001), (Heuvel, 2001) and (Grammatikopoulos et. al. 2003), as well as in Computer Vision (Caprile&Torre, 1990), (Liebowitz et. al., 1999), (Cipolla et. al., 1999) and (Sturm, 1999). In the context of Photogrammetry the general approach established is based on the use of three orthogonal vanishing points and some constraints among lines. Alternatively, in the context of Computer Vision, several approaches are supported by the computation and decomposition of the absolute conic from three vanishing points or the rotation matrix.

The self-calibration method performs by sv3DVision presents a hybrid character that combines approaches related to Photogrammetry and Computer Vision. On the one hand, applying tools belonging to the image processing and geometric constraints of the object in order to estimate the radial lens distortion parameters, and on the other hand exploiting the geometry of structural elements, mainly vanishing points based on the orthocentre method (Williamson, 2004), in order to compute the geometric camera parameters.

Therefore, sv3DVision allows to calibrate unknown or semi-unknown cameras taking into account the following assumptions: (*i*) the single image contains three vanishing points; (*ii*) the length (in 3D space) of one line segment in the image is known; (*iii*) the own geometry of the object provides the necessary constraints not being necessary to use calibration targets. In this sense, sv3DVision performs the camera self-calibration following a triple process: Firstly, internal camera parameters (principal point, focal length and radial lens distortion) are estimated automatically. Secondly, camera orientation is computed directly based on the correspondence between the vanishing points and the three main object directions. Then, camera pose is estimated based on some priori object information together with a geometric constraint.

More details about this calibration method are given in [Aguilera 2005].

Oblique image rectifier. sv3DVision allows to rectify oblique images without using control points, once the vanishing points and internal camera parameters have been computed. In this sense, given an oblique image corresponding to a 3D object, the goal is to obtain a metric rectification of each plane that composes the object. This is equivalent to obtaining an image of a specific plane of the object where the camera's image plane and the object plane are parallel. Nevertheless, the own complexity of the scene which presents several planes with different depths carries that a partial rectification corresponding with each fundamental plane has to be performed. In this way, the user will have to define manually each one of the structural planes of the object and assign the corresponding geometrical constraint (Figure 6).

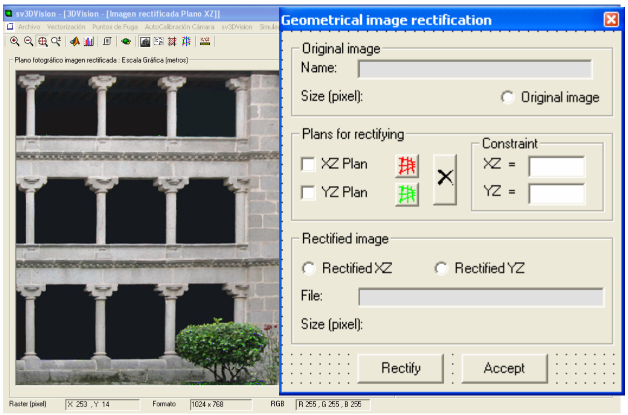

Figure 6. Rectification in sv3DVision

Particularly, the approach developed in sv3DVision is based on the projective transformation and in its decomposition using the Singular Value Decomposition (SVD) method (Golub&Reisch, 1971). As is well known, the map between an object plane and its corresponding image plane is a projective transformation. Habitually, this map can be determined from the correspondence of four (or more) points with known position. However, it is not necessary to determine the entire projective transformation in order to obtain a metric rectification (Liebowitz et. al. 1999); the plane rotation, translation and uniform scaling which are part of the projective transformation map, and account for four degrees of freedom, are irrelevant to the rectification. Thus, the idea is to determine only four of the eight parameters of the projective transform, exploiting geometric relation on the object plane such as parallelism and orthogonality. These geometric relations maintain correspondences in the image plane with the vanishing points and infinite vanishing line. Concretely, the infinite vanishing line determined by the union of two or more vanishing points, represents the image of the line at infinity of the object plane and allow passing from projective to affine geometry and the opposite. Thus, this line has two degrees of freedom which encode all the pure distortion of the plane. This interchange between transformations based on a decomposition of the projective transformation is carried out applying a SVD approach supported by several Gives rotations (Golub&Reisch, 1971), which allow to introduce zeros in the projection matrix selectively.

Dimensional analyzer. sv3DVision allows to analyze the different dimensions of the object based on coordinates, distances and areas, as well as contrasting the corresponding associated deviations in order to estimate the accuracy of the reconstructed 3D model (Figure 7). Particularly, sv3DVision incorporates procedures supported by colinearity condition and geometric constraints (coplanarity and parallelism) (Heuvel, 1998) that allow to obtain dimensions of whatever part of the object measuring directly over the oblique image. Obviously, the camera calibration parameters must be known.

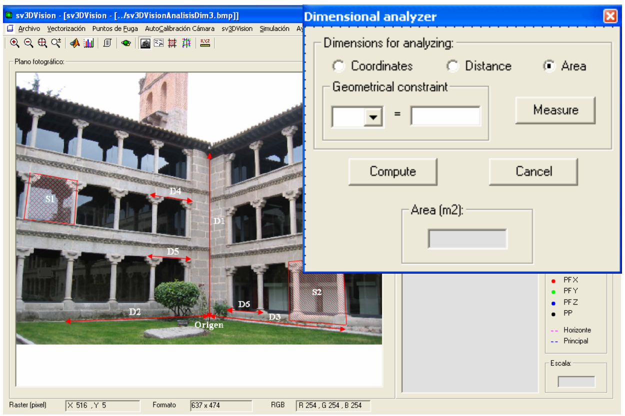

Figure 7. Dimensional analyzer in sv3DVision

An interesting approach to obtain whatever dimension related with the object from single images is developed in the ImageModeler software (ImageModeler, 2000).

3.3 3D Visualization interface

sv3DVision and its 3D Visualization interface (Figure 8) fulfils the following requirements and features:

Requirements

Flexibility: the 3D Visualization interface allows its utilization in an independent and flexible way, so we can work directly with VRML files in order to create, edit and visualize 3D models and scenes.

Extensibility: the 3D Visualization interface provides the possibility to develop new tools in order to improve the program.

Scalability: the 3D Visualization interface allows the combination of different 3D models together with real or artificial landscapes, in order to generate and extend complex scenes.

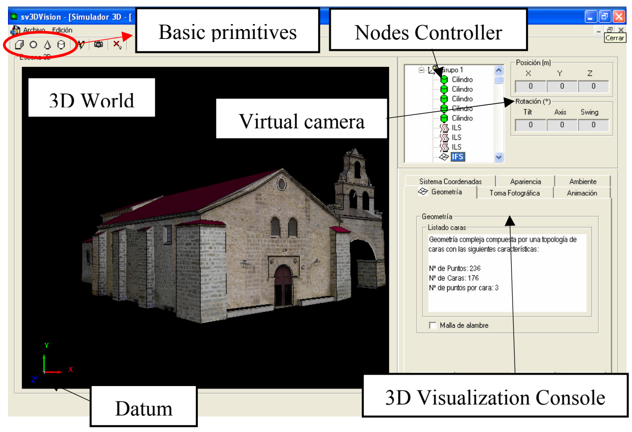

Figure 8. 3D Visualization interface in *sv3DVision*

Features

Obtain a 3D interactive visualization of the reconstructed model. The 3D Visualization interface provides an automatic transformation of the reconstructed 3D model into a topological structure (points, lines and surfaces) sorted hierarchically in a nodes network similar to VRML (Aguilera et. al., 2004).

Nodes Controller and 3D Visualization Console. The Nodes Controller and the 3D Visualization Console allow an integral control over the 3D model and the scene. In this way, whatever operation of creation, editing or deletion over the model or scene, will be performed selecting the element over the Nodes Controller and introducing the corresponding value in the Visualization Console (Figure 9).

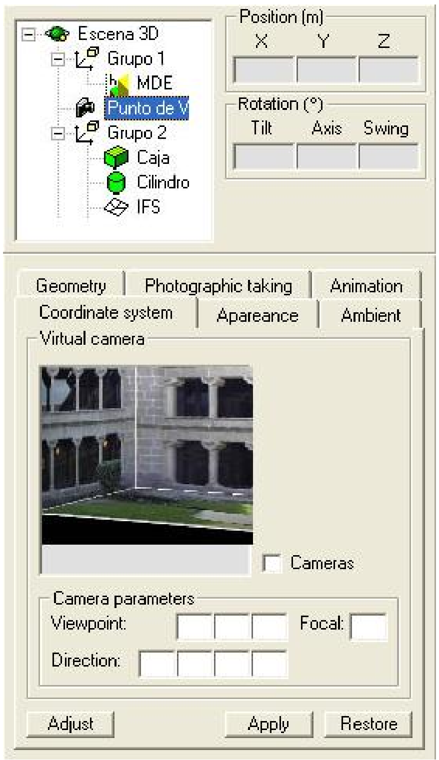

Figure 9. Nodes Controller and 3D Visualization Console in sv3DVision

Define global and local coordinate systems. The 3D Visualization interface enables the definition of multiples coordinate systems that allow whatever spatial action: rotation, scale factor and translation over the model (local system) or scene 3D (global system).

Create and edit different types of geometries. The 3D Visualization interface allows to create, edit and visualize different types of geometries: from simple geometries (basic primitives) to complex geometries supported by the topology of points, lines and faces. Furthermore, the 3D Visualization interface allows three different levels of representation: (*i*) Wire-frame representation, which represents the geometry exclusively; (*ii*) Surface representation, which represents the faces that integrate the object; (*iii*) Solid representation, which represents the faces that integrate the object together with its texture.

Scene modeling. The 3D Visualization interface allows to create and edit different environments: from artificial landscapes based on cylindrical or spherical illuminated panoramas which represent the remainder of the landscapes and far objects, to the automatic generation of real environments through Digital Elevation Models (DEM) with orthorectified textures (Aguilera et. al. 2005). The final integration of the 3D Model with the artificial or real scene will provide an increase in the level of realism (Figure 10).

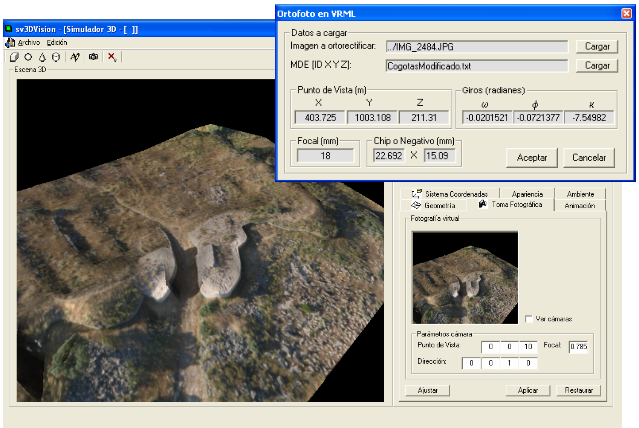

Figure 10. DEM and orthophoto generation in sv3DVision

Materials and orthorectified texture mapping. Materials defined by their colours and radiometric properties (opaqueness, transparency, diffusion, reflection and emission), are mapped through a uniform and continuous renderization supported internally by VRML. Unfortunately, the photo-texture mapping cannot follow the same approach and a previous correction (rectification) will be required in order to obtain a realistic result. In this sense, an adaptation of 'Anchor Points Method' (Kraus, 1993) to VRML has been developed, allowing a orthorectified texture mapping between the 3D geometry and the image.

Virtual camera. The 3D Visualization interface allows the introduction of view points into the scene and the manipulation of the different camera parameters in order to visualize the object from whatever imaginable perspective. In this sense, the virtual photograph can be saved and used for different analysis and operations. Furthermore, a simple algorithm supported by a Proximitysensor node enables to obtain the camera pose in real time and thus the possibility to create animated flights.

4. CONCLUSIONS AND FUTURE PERSPECTIVES

The development of the software sv3DVision represents a clear contribution in a multidisciplinary context, destined to the synergic integration of different methodologies and tools, in the 3D reconstruction from a single view.

On the other hand, the average results and deviations obtained in the 3D reconstruction from a single view by sv3DVision (5-10 cm), lead to the conclusion that sv3DVision is a program that accomplishes partial and modelled reconstructions of the object or scene, not being suitable for performing structural analysis of buildings.

Regarding future perspectives, the own synergy between disciplines provides several riveting ideas: In the context of Photogrammetry, new algorithms and methods could be developed to work with multiple images in order to document and reconstruct complex scenarios with multiples vanishing points; In the context of Computer Vision, sv3DVision could be extended to robotic applications (guidance of robots or mobile platforms), adapting its algorithms to real time applications; In the Computer Graphics context, to develop an immersive virtual reality system that provides an Augmented Reality frame, maintaining a correspondence between the changes in the rendered scene (dynamic textures) and the perceptions of the user.

Finally, to perform a comparative study between the different software developed for 3D reconstruction from a single view and sv3DVision, it would be another interesting proposal to the future.

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