

MULTI - RESOLUTION 3D MODEL BY LASER DATA

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ABSTRACT:

In the last decade, the new technology of laser scanning has improved the architectural and archaeological survey. This instrument measures millions and millions of points in a short time. But the more interesting and above all more difficult goal is, up till now, the data processing. Using several procedures and testing some softwares it is possible to generate a 3D mesh with different resolution. It is useful when the single parts of the architectonic object present a variety of aspects. The triangles of the mesh can be decimated referring to planar surfaces without many details. On the contrary it will be necessary to refine the parts regarding decorations, bas-reliefs, statues and so on. This kind of procedures generates a 3D mesh easier to manage in the realization of a virtual reality scenario. Furthermore the textures applied at the same resolution too, allow to reconstruct the object faithfully and to explore it on the net on-line. The application regards a recent survey of the façade of the Ancona Dome by Mensi GS100 Laser Scanning.

1. INTRODUCTION

Techniques for 3D digitising and modelling the cultural heritage objects have been rapidly advancing over the past few years. The ability to capture details, the degree of automation, and the geometric accuracy vary widely from one approach to another and recently it is very improved.

The process of creating 3D model from real scenes has well-known steps: data collection, data registration, and data modelling (geometry, texture and lighting). There are many variations within each step depending on the used sensor and the data collection procedure. Approaches that skip the geometric modelling step, such as image-based rendering, are popular for applications that require only visualization or some walkthrough. However, only 3D textured model allows unrestricted walkthrough and close inspection of the details.

Due to the surface meshes produced at increasing complexity in many applications, interest in efficient simplification algorithms and procedure and multi-resolution representation is very high. An enhanced simplification approach together with a simple multi-resolution surface generation are presented here. Moreover, we show that with a small increase in memory, which is needed to store the multi-resolution data representation, we are able to extract any level of detail representation from the simplification results in an extremely efficient way.

Surface simplification is a very hot topic in visualization, for several applications. In fact, huge surface meshes are produced in a number of fields: volume visualization, where isosurfaces composed by millions of facets can be extracted on high resolution volume datasets; virtual reality, where very complex models are built to cope with the complexity of real environments, e.g. to support high quality walkthrough in virtual worlds; automatic modelling, where technologies for the automatic acquisition of the shape of 3D objects are emerging (e.g. 3D range scanners), and the high precision infers very complex meshes (in order of hundreds of thousands of facets); free form surface modelling, where optimised polyhedral approximations of parametric surfaces produced highly detailed meshes (El-Hakim, 2001).

We show that mesh optimisation can be effectively used in at least two applications: surface reconstruction from unorganised points, and mesh simplification (the reduction of the number of

vertices, in an initially dense mesh of triangles).

Substantial results have been reported in the last few years, aimed at reducing surface complexity while assuring a good shape approximation.

2. STEPS FOR CLOSE RANGE DATA SCANNER PROCESSING

In order to realize a 3D multi-resolution representation we used a number of 3D modelling and mesh optimisation procedures.

Numerous papers have dealt with this issue, but one problem remains to be addressed i.e. the availability of commercial tools for both 3D modelling and high-resolution texture mapping onto dense 3D models. Very few solutions exist on the market addressing this issue. We report an effective approach based on commercial software to the problem of high-resolution photo-realistic texture mapping onto the 3D multi-resolution model generated from range scanner maps.

Active sensors such as laser scanners have the advantage of automatically acquiring dense 3D points organized for automatic modelling. For relatively simple objects, structures or environments, most existing methods are capable of successfully creating 3D models, varying degree of automation, level of details, effort, cost and accuracy.

We outlined different procedures for reconstructing a surface from a set of unorganised data points. Each project tries to optimise some part or all of the modelling phases.

The goal of phase one was to filter the data acquired in differential way. After than to improve the fit and to reduce the number of faces a mesh optimisation was applied. Finally, to obtain a good visualization, the problem of the filling of the holes and the smoothing of the model was solved. Here we summarize some of the steps for the reconstruction of a complete fully textured model. The different resolution models were also created after compressing the polygons to appropriate spatial resolutions.

We always take into account the obtained results for every step and the memory amount of the saved file.

We experimented some techniques implemented in the commercially available softwares. To illustrate the proposed modelling method, we made a survey of the façade of Ancona's Cathedral by a new Mensi GS100 Laser Scanning.



Figure 1. All points acquired by Mensi GS100 laser scanning

3. REDUCING CLOUD POINT DATA BY FILTERING

The reduction of the cloud points before the Delaunay triangulation becomes necessary to process quickly the data and to reduce the file of 3D meshes in terms of kilobyte.

Several softwares apply different procedures to filter the range maps. It is possible to use a percentage value and the result is detailed and functional if performed by steps.

Infact, the selection of a small percentage reduction value tries to preserve the general form of the object and erases the points uniformly.

Another procedure uses a tolerance value for the data filtering. In practice a 3D grid is built with this tolerance value as the dimension of the cube. Of all the points inside every cube one only is leaved (Figure 2)

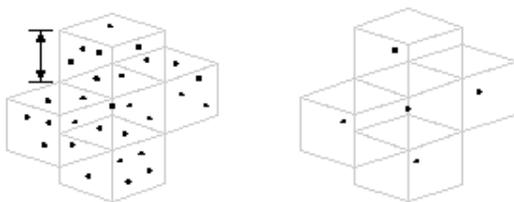


Figure 2. A criterion for data filtering

The reduction of the number of points can be obtained during the loading data phase, by an arbitrary exclusion, reading only the coordinates of some of them (for example 1 point every 3). Furthermore to work at different resolutions starting from the original data and to compare the various filtering steps, it is possible, in some softwares, to create some layers.

To test these procedures at first we selected a small surveyed area: the left part of the eardrum of the façade of the Church.

The applied methodology decreases mostly the points of the regular elements of the eardrum unchanging the number of points of the descriptive areas (for example the decorative elements) (Figure 3).

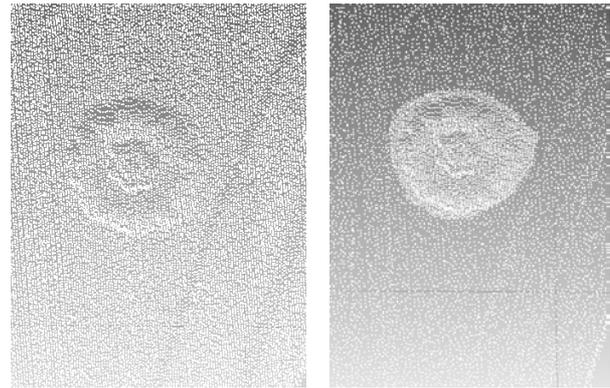


Figure 3. The original data and the filtered ones at different resolution

Finally all points of the façade, except every detailed part, have been filtered with the tolerance of 1 mm while the data concerning the portal, the most complex element, have been treated with a tolerance of 0.5 mm. The only elements not reduced have been the data of the windows, the central arcade and the friezes in the eardrum.

A first filtering made on the smooth façade only (blue elements in figure 4) reduces the 3.536.069 original points to 88.134 ones.

At the second step made on the portal (green elements in figure 4), excluding the most meaningful details, reduces the 3.205.838 original data to 274.563 ones. The red elements are unchanged.

Finally we reduced the initially loaded points from 7.080.979 to 701.769.

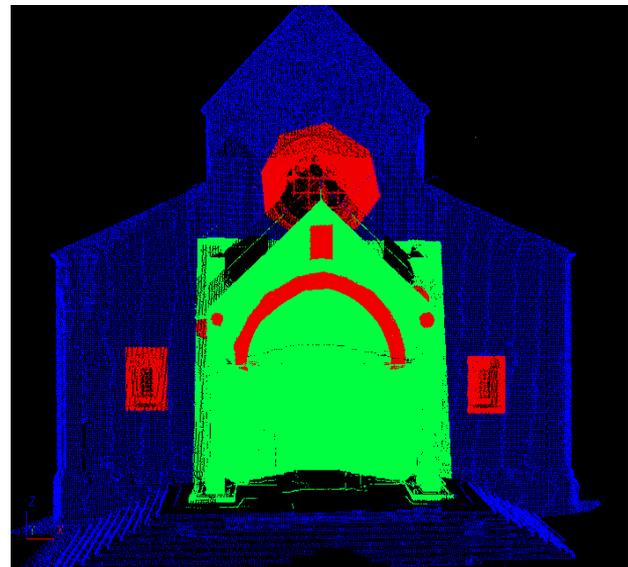


Figure 4. The multi-resolution filtering on the whole data set

Using the previously filtering we observed the aspect of 3D meshes generated by Delaunay triangulation on the data at different resolution. As it is shown in Figures 5, the created meshes have much more asperity in the filtered part and greater detail in the high resolution areas.

Another remarks is that in the filtered data many holes show up inside the generated three-dimensional model. Therefore we write now about filling of holes.

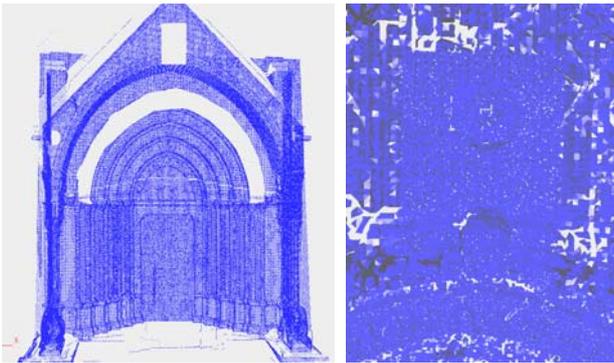


Figure 5. The 3D meshes generated using the filtered data

4. MESH SIMPLIFICATION AND SMOOTHING MODEL

Another possibility to simplify the 3D representation is the mesh optimisation. Given an irregular dataset the term simplification refers to the problem of building an approximate representation with a smaller size, built by choosing a set of vertices and a new triangulation that covers the same domain. Surface/mesh simplification can be driven by two different objectives: producing a more compact mesh which is sufficiently similar in terms of visual appearance, or to produce a model which satisfies a given accuracy. In the first case the main goal is to reduce visualization time. In the second case, special emphasis is given to data quality and representation accuracy. This is often the case for scientific visualization applications, where the user requires measurable and reliable data quality. Our goal was to test and to try different mesh simplification procedures and methods in the framework of scientific visualization applications, with a special commitment to the quality of the obtained mesh (considering both the geometry and the real aspect of the object) and in the same time to allow a speed rendering (De Floriani et al., 1995).

Intuitively, a mesh is a piecewise linear surface, consisting of triangular faces pasted together along their edges.

The mesh optimisation problem can be roughly stated as follows: given a collection of data points X in R^3 and an initial triangular mesh M_0 near the data, find a mesh M of the same topological type as M_0 that fits the data well and has a small number of vertices.

The method is known as mesh simplification or decimation. At first it was documented by Schroeder et al. in 1992. Mesh simplification is defined as “the problem of reducing the number of faces in a mesh while minimally perturbing the shape”.

In general, any level of reduction can be obtained with most of the approaches listed below.

- *Mesh decimation*: based on multiple filtering passes. This approach analyses locally the geometry and topology of the mesh and removes vertices that pass a minimal distance or curvature angle criterion (Schroeder et al., 1992). New decimation solutions which support global error control have been recently proposed.
- *Mesh optimisation*: in a similar way to the previous one, mesh optimisation is achieved by evaluating an energy function over the mesh, and minimizing such a function either by removing/moving vertices or collapsing/swapping edges (Hoppe et al., 1993). An enhanced version, progressive meshes was recently proposed to provide multi-resolution management, mesh compression, and selective refinements (Hoppe, 1996).

- *Multi-resolution analysis*: the approach uses re-meshing, re-sampling to build a multi-resolution representation of the surface (Rossignac et al., 1993), from which any approximated representation can be extracted (Eckbert et al., 1997).

A general comparison of the above approaches is not easy, because efficiency depends largely on the geometrical and topological structure of the mesh and on the results required. For example, the presence of sharp edges or solid angles would be managed better by a decimation approach, while on smooth surfaces mesh optimisation would give better results. On the other hand, the good results in the precision and conciseness of the output mesh given by mesh optimisation technique are counterbalanced by substantial processing times.

A simple decimation algorithm is implemented in some commercial softwares. This is the procedure: multiple passes are made over all vertices in the mesh. During a pass, each vertex is a candidate for removal and, if it meets the specified decimation criteria, the vertex and all triangles that use the vertex are deleted. The resulting hole in the mesh is patched by forming a local triangulation. The vertex removal process repeats, with possible adjustment of the decimation criteria, until some termination condition is met. Usually the termination criterion is specified as a percent reduction of the original mesh (or equivalent), or as some maximum decimation value. It is possible to use a decimation criterion based on vertex distance to plane or vertex distance to edge. Drawing a plan between the vertices of edge and the middle vertices the algorithm measures the distances between the middle vertices and the plan. If the distance between the middle vertex and the plan is smaller of the threshold, the algorithm considers them non necessary vertices and eliminates them (Figure 6).

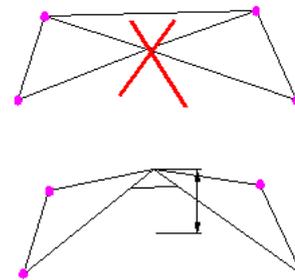


Figure 6. A decimation criterion

An example of this procedure is shown in the figures 7 and 8. At first we have the phase of mesh reconstruction using all the dataset, it has a storage of 1026 Kb. In the second step using this mesh as a starting point, mesh optimisation produces the meshes in figure 8, where the first has a file dimension of 780 Kb and the second of 560 Kb.

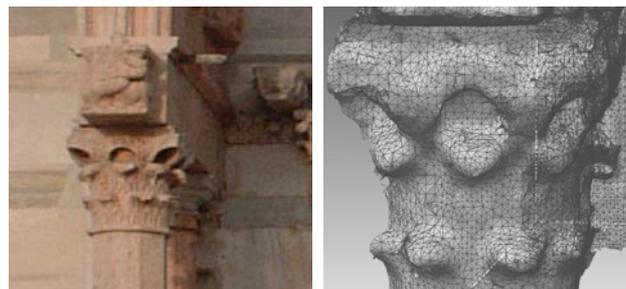


Figure 7. The image of the surveyed object and the original triangulated data (608.660 mesh faces)

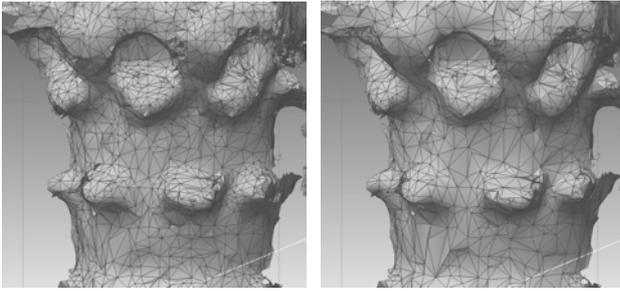


Fig. 8 A mesh simplification example: the simplified starting mesh (45.645 mesh faces) is on the left and the simplified one again (30.429 mesh faces) is on the right

At the present there is no common way to measure the error. In fact, many simplification approaches do not return measures of the introduced approximation error while simplifying the mesh. For example, given the complexity reduction factor set by the user, some methods try to optimise the shape of the simplified mesh, but they give no measure on the introduced error. Other approaches let the user define the maximal error that can be introduced in a single simplification step, but return no global error estimate or bound. Some other recent methods adopt a global estimate error or simply ensure the introduced error to be under a given bound (Ciampalini et al., 1997). But the field of surface simplification still lacks a formal and universally acknowledge definition of error, which should involve shape approximation and hopefully preservation of feature elements and mesh attributes.

5. FILLING THE HOLES AND SMOOTHING THE MODEL

The model generated through the simplification of the cloud of points, shows some discontinuity of the mesh in form of empty spaces (holes). The area takes into account in this case is a part of the portal represented by the statue of the lion with a column. Some softwares solve this problem through the filling algorithm. In the triangulated meshes the holes can be closed perfectly by an automatically procedure.

It is possible also to calculation the areas of the holes and then to close them automatically in respect to the maximum extension of the select perimeter. It can repeat iteratively the steps of the procedure (Figure 9).

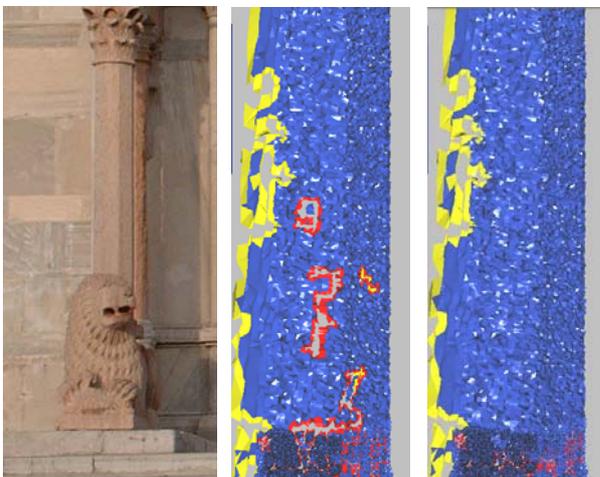


Figure 9 Some examples of surface reconstruction and filling of holes

Another algorithm closes the plain holes. A hole is defined plain when the neighbour triangles are closed from a plan. This kind of hole can automatically be filled and the additional triangles are included in the mesh.

On the contrary the holes present in the surface which are artefacts of the data, as self-shadowing prevented some regions of the surface from being scanned, can manually be filled.

In many softwares the comparison is possible between the original data and the obtained mesh to evaluate the filling procedure (Figure 10).

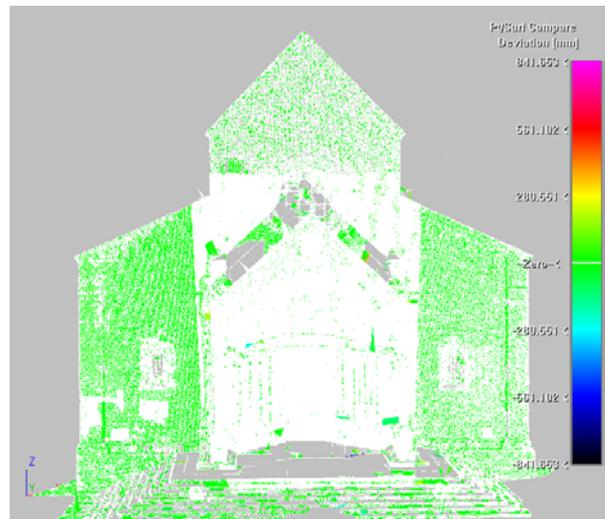
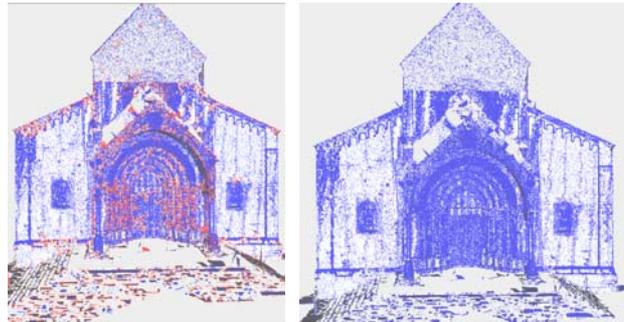


Figure 10. The original mesh, the filled one and the evaluation representation

Another procedure for generating a good representation of the 3D mesh is the smoothing. The smoothing is a procedure that is used for the improvement of the quality of the triangulated meshes and for the regularizing of the 3D surface. This step on one side improves the definition of the object but from the other one increases much more the file memory in terms of kilobyte. There are different algorithm to realize the smoothing model: the *Median Filter Smoothing*, the *Edge Swapping Smoothing* and the *Regularization Smoothing*. The first one moves the vertices of the meshes in accord with a filter automatically planned by the software. Any triangle is added to the topology of the surface so that the original aspect is preserved. However, using more times this filter is underlined a narrowing in the processed area. On the contrary in the Edge Swapping Smoothing the angles are divided in two triangles and they come iteratively changed according to the applied smoothing. The vertex position of the meshes doesn't change, the triangles are modified but their number is preserved. The last method of smoothing is the Regularization Smoothing: the algorithm moves the vertices of the meshes looking for the approximation to equilateral aspect. Also in this case some triangles are added

to the topology of the surface but this one doesn't change. In detail the figure 11 shows the obtained results: the 3D model is defined and the discontinuities are smaller. In conclusion it can be observed that the increase in percentage of the file storage is between 1% - 2% with respect to the original file but we have obtained the qualitative improvement of the final three-dimensional model.

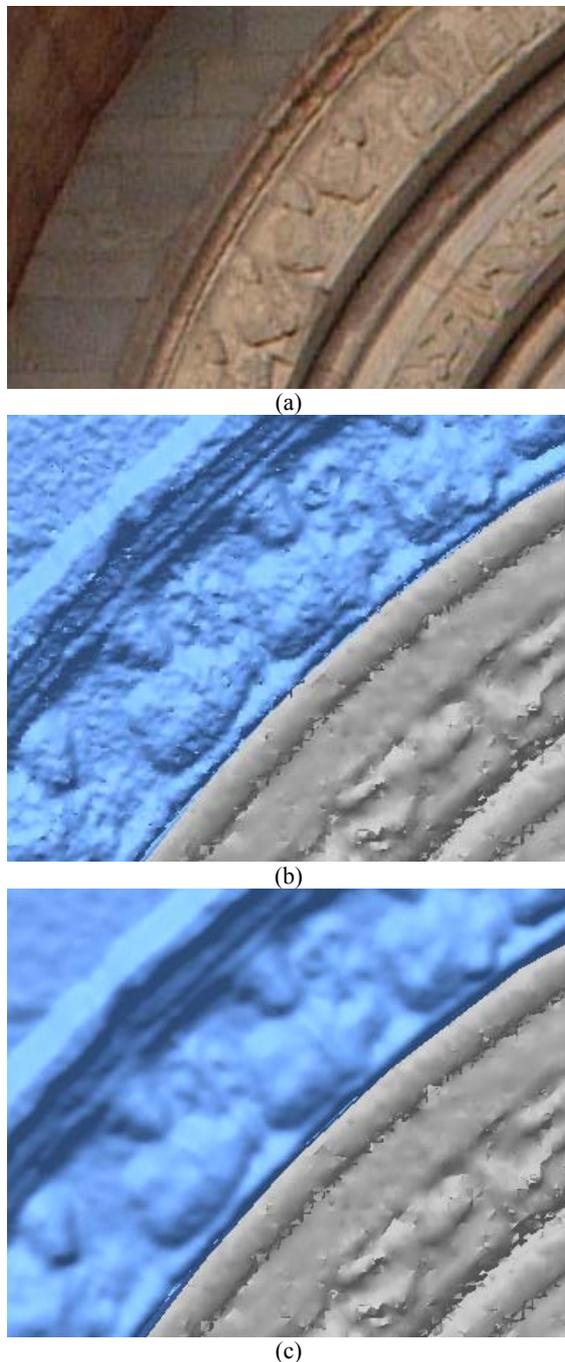


Figure 11. An example of smoothing model: (a) the decorative elements of the portal, (b) the triangulated meshes, (c) the smoothing model

Now the 3D models created after every steps are ready to be merged and compared for the final 3D representation and exported in CAD to generate a virtual textured model (Figure 12). The whole 3D model has 2.223.065 mesh faces and a data storage of 35 Mb.

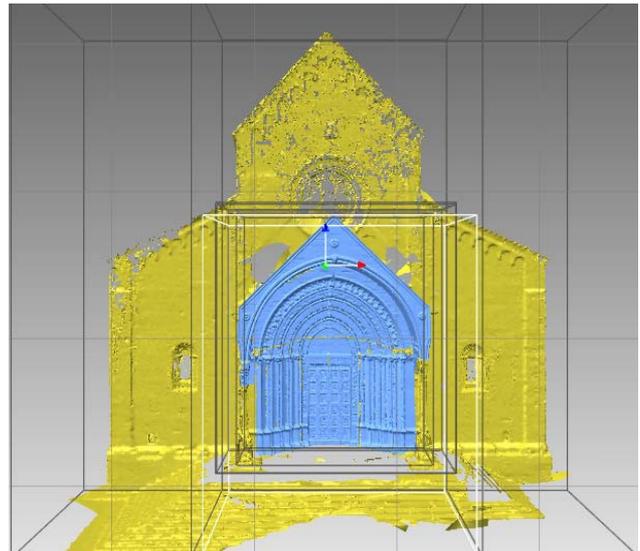


Figure 12. The meshes merged at different resolution

6. A MULTI-RESOLUTION VIRTUAL REPRESENTATION

The capacity to create, display, manipulate, archive and share a digital representation of the shape and appearance of an existing object, finds a most challenging class of applications in high-resolution recording of heritage-related objects and sites. Once the object or site has been “virtualised”, one can use immersive technologies to study or to promote a cultural site using a virtual 3D visit (El-Hakim et al., 1998). However, beyond photo-realistic rendering, a 3D model contains a wealth of information that can be analysed and enhanced. Features that are small or only visible from a distance can be interactively examined, thus, allowing the study of fine details such as tool marks or surface texture.

Multi-resolution representation, a data structure which allows the compact representation of a number of representations, has different levels of detail, proportionally to the data size (e.g. the number of faces in a surface). So the mesh simplification is widely used in a number of leading edge applications (e.g. virtual reality, VRML, etc.)

Geometric modelling is essential to recreate realistic models of sites that have a lot of surface details difficult to model. Sensors and techniques for 3D modelling of small and medium size single objects, for example to the size of a human, have reached an advanced stage so that these models can be created accurately and fully automatically. However, the situation is different for more complex large objects and environments or sites. Although there is no clear definition, a complex environment may consist of multiple objects of different types and may require a large number of images or scans to completely reconstruct in 3D. The success of those systems increase with the use of multiple sensors and the availability of CAD models (Beraldin et al., 2002).

Texture mapping is also an efficient way to achieve realism with only a low resolution, faster to render, geometric model. Recently, techniques that map real-scene images onto the geometric model, also known as Image Perspective Techniques (IPT) have gained a lot of interest. Though, some commercial 3D systems supply a colour texture in registration with the 3D image unfortunately with very limited visual image quality. Sometimes there is the possibility to apply the textures of the materials received by the incorporated digital camera to the laser scanner system (Figure 13).

It is better when high-resolution colour images can be precisely mapped onto the geometric model.

The proposed methodology is very flexible and suitable for non-experts. It uses commercially available software which combine the re-projection of the 3D points found in the un-textured model file (e.g. VRML format) onto the texture images to give the complete realistic – looking and geometrically correct 3D textured model. 2D images created from digital cameras can be mapped onto the 3D model. These 2D images can be taken specifically for texturing purposes or obtained by other means, e.g., tourist photos, postcard, infrared or ultraviolet images, or even historical photos.

The model is first manually segmented (in the 3D modelling software) into mutually exclusive regions. Each region is mapped onto a region (entirely comprised) that is a subset of one of the 2D images (Figure 14).

Reducing the complexity of surface meshes is therefore a must to guarantee interactivity in rendering or, in some cases, to make possible the rendering itself. In fact, such large meshes often go over the sustainable storage/graphics performance of the current mid-level graphics subsystems.

In spite of the constant increase in processing speed, the performances required by interactive graphics applications in many cases much higher than those guaranteed by current technology.



Figure 13. The pseudo texture model of the portal



Figure 14. The multi-resolution textured representation

CONCLUSIONS

Virtual and virtualised environments offer the possibility to expand our abilities in planning, creating and experiencing new surroundings, e.g. virtual tourism on sites that have been closed to the general public or sites not popular as somebody may want. The resulting visual simulation aims at an exact representation of the real world allowing for photo-realistic rendering, telepresence, and intuitive information queries. People have been trying to improve the sense of realism by using models generated by sensors. If the goal is the generation of photo-realistic images for visualization, then purely image-based rendering techniques offer a general solution. However, if the goal is also to analyse the work, to preserve and share a record of their geometry and appearance, then explicit shape information must be acquired and stored in an adequate representation that also includes some forms of appearance modelling.

A high degree of realism can be attained by those techniques and the context in which the artefacts were discovered or were used can be recreated.

REFERENCES

- Beraldin J. A., Picard M., El-Hakim S. F., Godin G., Latouche C., Valzano V., Bandiera A., 2002. Exploring a bizantine crypt through a high-resolution texture mapped 3D model: combining range data and photogrammetry. In *Proceedings of the Intern. Workshop on Scanning for Cultural Heritage Recording – Complementing or Replacing Photogrammetry*, Corfù, Greece.
- Ciampalini A., Cignoni P., Montani C., Scopigno R., 1997. Multiresolution Decimation based on Global Error. In *The Visual Computer*, Springer International, 13(5).
- De Floriani L., Puppo E., 1995. Hierarchical triangulation for multiresolution surface description. In *ACM Trans. on Graphics*, 14 (4).
- El-Hakim S. F., Brenner C., Roth G., 1998. A multi-sensor approach to creating accurate virtual environments. *ISPRS Journal for Photogrammetry and Remote Sensing*, 53(6).
- El-Hakim S. F., 2001. 3D modelling of complex environments. In *SPIE Proceeding , Electronic Imaging*, Vol. 4309. Videometrics and Optical Methods for 3D Shape Measurement VII, San José, CA.
- Heckbert P., Garland M., 1997. Survey of surface simplification algorithms. Technical report, Carnegie Mellon University – Dept. of Computer Science.
- Hoppe H., DeRose T., Duchamp T., McDonald J., Stuetzle W., 1993. Mesh optimization. In *ACM Computer Graphics Proceedings Annual Conference Series (SIGGRAPH '93)*, 1993.
- Hoppe H., 1996. Progressive meshes. In *ACM Computer Graphics Proceedings Annual Conference Series (SIGGRAPH '96)*, 1996
- Rossignac J., Borrel P., 1993. Multi-resolution 3D approximation for rendering complex scenes. In B. Falcidieno and T.L. Kunii, editors, *Geometric Modeling in Computer Graphics*, Springer Verlag.
- Schroeder W. J., Zarge J. A., Lorensen W.E., 1992. Decimation of triangle meshes. In Edwin E. Catmull, editor, *ACM Computer Graphics (SIGGRAPH '92 Proceedings)* volume 26, July 1992.