3D Reconstruction applied to Virtual Heritage and Cultural Conservation

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ABSTRACT
There is increasing interest in creating 3D photo-realistic computer models of monuments or heritage buildings, both indoors and outdoors. Our approach to 3D Reconstruction is to use automated distance measurements together with photographs. Two technologies are used: i) a combined laser - digital camera sensor for data acquisition and ii) mobility for resolving spatial occlusions. After a few scanning operations it is possible to create complete 3D textured models of the building or monument "as-built". The models are visually appealing, Internet compatible and geometrically and dimensionally accurate. The paper describes the main steps in building complete 3D models. Results include the models of the "Cour d'Honneur" and "Salon Delacroix" at the French National Assembly (Palais Bourbon), Paris, and the "Sala dello Scrutinio" at the Doges' Palace, Venice.

KEYWORDS: 3D Reconstruction, 3D Modelling, Virtual Heritage.

INTRODUCTION

It is part of human nature to build realistic representations of the real world. The objectives may be the desire to document information for future generations or to have training material in specific matters. In a world of constant change, there is an increasing interest to use new technologies to create realistic models of monuments, heritage buildings and historic city centres. The objectives are various including accurate documentation, dissemination and use of the material to the entertainment industry (e.g., games, films).

It can be said that an effective representation is the one that best provides "*the feeling of being there*". To achieve this, it is important to provide spatial awareness. The user should not be a passive spectator but rather an actor totally immersed and interacting with the represented world. In recent years, 3D Reconstruction technologies evolved dramatically in generating the 3D representation of real objects, buildings and environments. Progresses in Virtual Reality technologies (e.g., computing power, graphics software, head mounted displays, position sensors) allow for powerful computer interfaces enabling the real-time perception of relative distances and spatial relationships.There are basically two ways of creating the 3D model of a building. The first involves the use of a CAD tool to design the monument into the computer. This approach involves a large amount of manual work, i.e., measuring the correct distances and angles in the real world to have a dimensionally correct model. An alternative approach is the automated generation of a dimensionally correct 3D model, based on the reality "as-

built".
Our approach is to combine distance measurements with photographs. Distances are measured using a laser range scanner, and photographs taken with a digital camera. All system components are commercial.
Figure 1 shows a tripod based 3D acquisition system. It makes a complete 340° by 80° scan with an angular resolution of 0.19° in about two minutes

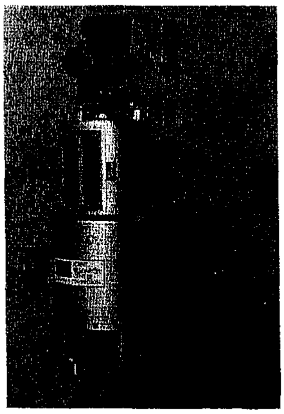


Figure 1: Portable, tripod based 3D Acquisition system with laser range scanner and digital camera.

3D RECONSTRUCTION
In order to create a complete model of a scene it is necessary to overcome single view occlusions (e.g., objects hiding others). This is achieved by scanning the environment from different viewpoints. The software integrates the different datasets (Figure 3) into a single triangulated model [1]. The triangulation is multi-resolution, in the sense that the density of triangles increases with local spatial detail. As such, there are less triangles in planar surfaces and more, smaller triangles where spatial detail is to be preserved

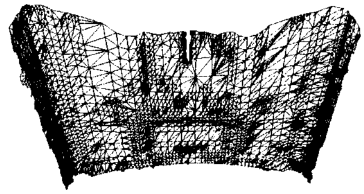
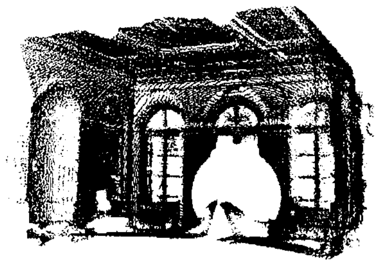
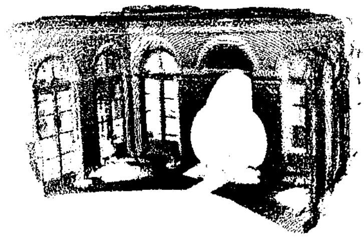


Figure 2: Multi-Resolution triangulation [Salon Delacroix, Palais Bourbon, France]



(a) Cloud of points - view 1



(b) Cloud of points - view 2

(c) Combined cloud of points

Figure 3: Integration of two 3D datasets acquired at different capture points [Salon Delacroix, Palais Bourbon, France]

To achieve visually realistic models, digital photographs are used to "paint" the 3D representation of the scanned areas. Each triangle in the model is "painted" with the corresponding area from one or multiple photos [2]. Since pictures may be taken at different spatial resolutions (i.e., zooming factors), it is possible to have different levels of photographic detail. A Z-buffering technique is used to avoid projection mistakes due to occlusions.

To have a complete texture map several images are normally required. As such, a fundamental aspect is colour blending, i.e., the procedure to smoothen out the colour transitions between the different images. Figure is the result of the automated blending of seven images in the model of the Bornholm round church in the Baltic Sea. Coloured lines delimit the parts used in each image.

Figure 4: Final texture image obtained from blending of seven digital images [Bornholm round church, Denmark].

FEATURES OF 3D RECONSTRUCTED MODELS

The final 3D models have the following characteristics:

Internet compatible - models are coded into VRML (Virtual Reality Modelling Language) and can thus be viewed with any Internet browser irrespectively of the computing platform or operating system. VRML is a 3D standard for the Internet and MPEG4 communications.

Visually appealing - This derives from the fact that the models are textured with real photos from the scene.

Geometrically and dimensionally accurate - Existing laser scanners acquire 3D points with an accuracy of about 2cm over a distance of more than 100m.

Provide a realistic feeling of "being of there" – The VRML format allows the setting of predefined viewpoints without compromising user's interactivity. It is thus possible to navigate interactively through or around the model and be aware of the existing spatial relationships, as if one is exploring the real environment.

Application specific tools and interfaces - Java scripts/applets can be easily written for easier navigation or for more specific tasks, e.g., measurement of the real dimensions (see Figure 5), surfaces or volumes.

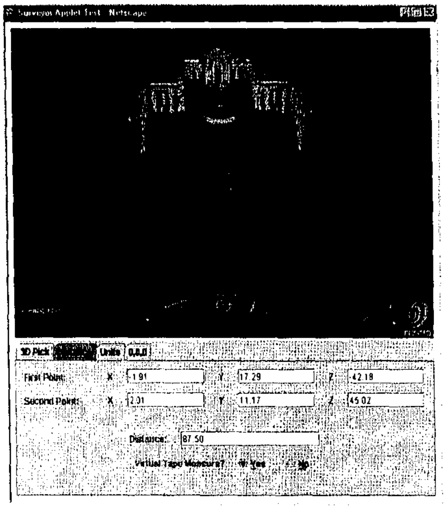


Figure 5: The Surveyor's Java applet provides the distance (in meters) between two interactively selected 3D points [Cour d'Honneur, Palais Bourbon, Paris].

Framework for advanced Human Computer Interface - The 3D models can also be linked to other images/document using hyperlinks. 3D models are thus used as 3D maps. By clicking in a "hot" area, other data can be retrieved (e.g., by clicking on a 3D object, a window with details and close-ups may open). Hyperlinks make navigation more realistic, e.g., the user enters a new room by clicking on a door The insertion of real-time, on-line data is also possible, e.g., live images from a camera can be displayed on a screen inside the model.

Multiple Level of Detail - It is possible to insert or integrate previously acquired detailed models into the overall model (e.g., a highly detailed model of a bas-relief can be inserted in the model of a monument), allowing therefore the easy creation of virtual and dynamic exhibition spaces or museums.

Model size adapted to application - It is possible to adapt the model size to existing transmission or storage requirements by decimating the 3D-triangle mesh and/or re-coding the photographic images.

Contextual Information – Current computing and graphics technology do not allow for large, detailed 3D reconstructed models of a monument including its background. A solution is to use accurate 3D models for the relevant parts and to use panoramic images for distant background scenery providing a realistic spatial context as shown in Figure .

By incorporating panoramas into 3D detailed models there is the opportunity to convey visual quality when at the capture points and spatial quality when moving though the surroundings, usually from one capture point to another. Panoramas are built from still colour images acquired using a digital camera and are also used to texture map the 3D model extracted from the range data.

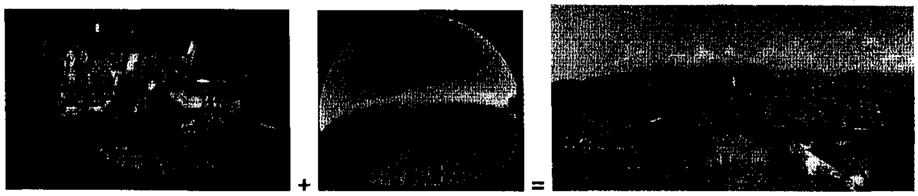


Figure 6: Combination of the background VRML panorama with the 3D model.

SELECTED EXAMPLES

Figure 7: Six snapshots from the 3D model of the Delacroix room, Palais Bourbon, Paris.

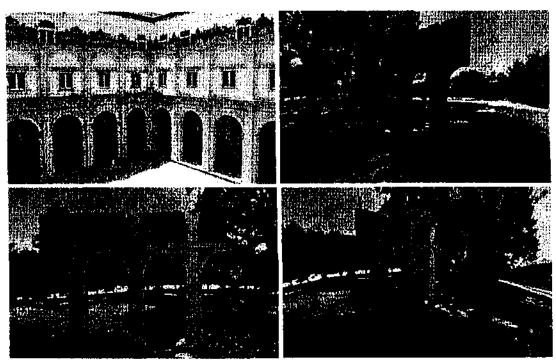


Figure 8: Cloister of the São Vicente de Fora monastery, Lisbon, and snapshots of the 3D model of the JRC replica.

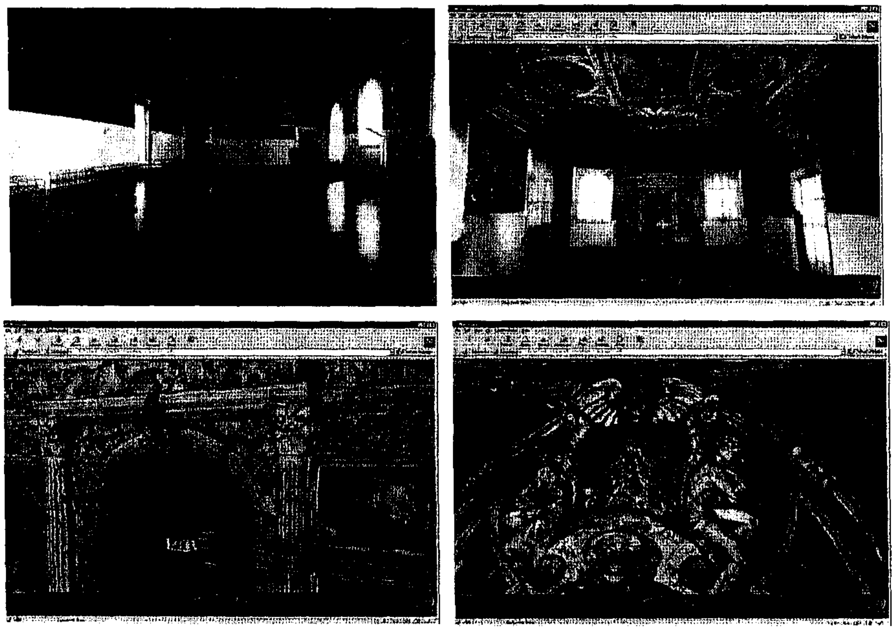


Figure 9: VRML model of the "Sala dello Scrutinio", Doges' Palace, Venice, BBC Tomorrow's World, Nov. 2000.

Figure 10: Four snapshots of the 3D Reconstructed model of an Italian farmhouse over Lago Maggiore, Italy.

DISCUSSION AND CURRENT WORK

The paper illustrated a new automated technique for the 3D Reconstruction of monuments "as-built". The main advantage is that it takes reality as the base of modelling.

A main aspect of this technique is that a single acquisition session can produce all sorts of models each one targeted to different applications. Indeed, it is possible to have the high-quality master model, including fine spatial and visual detail (and normally of large dimension), for high quality documentation or scholar applications, and low-size, lower quality model targeted for Internet applications where download times are important. Intermediate quality models are easily derived from the initial one.

It is believed that 3D reeonstruction is of particular use in cultural heritage both for indoor and outdoor applications. A few examples were presented. The same technique together with the design of clever Java scripts/applets can be used in archaeology or architectural studies, whenever there is the need to quantify distances and orientations between relevant features. The fact that laser sensors are used for distance measurement makes the data dimensionally and geometrically correct. As an example, the implications of Stonehenge (UK) in astronomy could have been easily found had a geometric and dimensionally correct model existed. 3D models in archaeology can be most beneficial for documenting the findings in different strata, as well as to provide 3D time (and depth) continuity to the objects found. Animations and other forms of data presentation can be easily built. 3D models can also help assembling objects from individual parts.

Our current work concentrates in two aspects: i) increase the visual and dimensional quality of the models; ii) extract structural representations for seismic analysis of heritage buildings and monuments.

A further area of development is the seamless combination of the 3D models with real-time, on-line data originated from the real world. This association of modelled (and yet realistic) data with on-line data helps building powerful Human-Computer Interfaces (HCI). As an example, it is thus possible to visit the ruins of a medieval castle and see in 3D how the castle looked like in ancient times.

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