3D scanning and rendering Cultural Heritage artifacts on a low budget

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1. ABSTRACT

The recent evolution of graphics technology has been impressive, and the management of very complex models is now possible on inexpensive platforms. Moreover, automatic scanning devices (often called 3D scanners) allow to build highly accurate models of real 3D objects in a cost- and time-effective manner. This paper discusses some issues in the use of this technology by taking into account a particular application context: the acquisition of Cultural Heritage artifacts. Specific needs of this domain are: a high accuracy, a lower cost of the scanning devices and an improved usability of the data produced. We will present the results of two projects, aimed at: the design of a low-cost scanner based on structured light; the design of a data simplification tool which enables complex dataset visualization on low cost computers.

1.1 Keywords

Cultural Heritage, 3D scanning, interactice graphics, virtual reality, geometry simplification.

2. INTRODUCTION

Cultural Heritage is one of the few fields where classical 3D modeling tools result inadequate to model the shape of the objects or artifacts of interest. This is both due to the shape complexity of most artifacts (e.g. sculptures) and also to the high accuracy requested. The 3D model in many cases should not only look visually similar to the real object, but should also be very accurate, from a geometrical point of view. This to allow a number of important uses, such as the construcion of 3D catalogues, the automatic reproduction of copies, the use of 3D models in the context of restoration plans, etc.

3D scanners give us the potential for a very precise reconstruction of the shape of a real object. This technology has been adopted in a number of recent projects in the framework of Cultural Heritage. Just to give some examples, we may cite the Digital Michelangelo Project of the Stanford University [1], the acquisition of the Michelangelo's Pieta' in Florence by the IBM T.J. Watson Laboratory [2], or the acquisition of a section of the Colosseum in Rome [3].

Scanning technology evolved in the last few years, but unfortunately not as fast as other electronic devices. One critical problem is the high cost of the scanning devices. A good scanner, able to produce data at the accuracy required by this class of application, costs more than 100K US$, and therefore some recent scanning projects required very high budgets [1]. This discourages the use of this technology in many Cultural Heritage institutions, especially in our national context.

Therefore, we investigated potential design for low cost and medium quality optical scanners. The design and prototipal construction of a new scanner based on consumer electronic technology was the result of this research line. Its architecture and features are described in Section 3.

A second very critical aspect in 3D scanning is the complexity of the triangle meshes produced. All scanners perform a regular sampling on the surface of the object, and return triangle meshes of complexity directly proportional to the scanner's sampling resolution and the object surface area. Producing huge meshes is therefore very easy. As an example, the size of the S. Mattew 3D model produced by the Digital Michelangelo Project is around 370M triangles. Meshes of this size are totally intractable even on high performance graphics workstations. The problem worsen if we consider that a common goal in the interactive graphics arena is to downsize sophisticated applications on PC platforms.

The management of very large datasets is a very active research area. A number of sophisticated technologies have been developed which allow to: simplify geometry maintainig geometric accuracy [4,5], even by preserving the eventual attribute contained (e.g. color or pictorial data) [6]; use Level Of Detail techniques to speedup rendering.

In the framework of this research mainstream, we have recently focused on a problem which arises while scanning large statues [1], but is completely general: how can we extend the simplification technology to manage dataset that do not fit the main memory of the usual computers? In other words, the question is how we could design an Out Of Core (OOC) mesh simplifier.

The last section reports the architecture of a new OOC simplifier, which is based on a hierarchical representation and adopts a simplification approach based on edge collapse [5].

Figure 1: The low cost scanner developed at CNR, based on structured light and consumer electronic technology.

3. AN INEXPENSIVE 3D SCANNER

Our scanner has been designed to fulfill the following goals:

- use only consumer technology, to ensure low prices and a very fast technological advance;
- sopport sufficient accuracy and resolution, i.e. situating midway between commercial low cost laser scanner and high quality ones;
- ensure easy operability and flexibility.

The scanner has been designed around two very common electronic devices:

- a video projector (preferably DLP technology), which is used to project structured light patterns on the object to be scanned;
- a digital still camera, used to acquire images of the object under structured lighting.

Both devices are driven by a software module running on a standard PC. This acquisition module produces a series of patterns (stripes at decrasing width, projected by the video projector) and drives the camera. Photos are taken, to acquire: images of the distorted patterns (from which the geometry is reconsructed), and images of the object under different illumination conditions (from which the illumination-invariant color, or “albedo”, of the object surface is reconstructed).

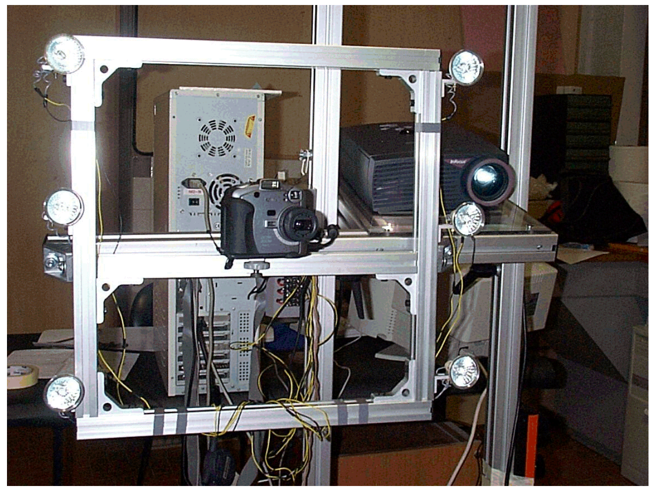

Figure 2: The scanner’s emitter and sensor units.

The global system, depicted in Figures 1 and 2, is able to produce:

- a range map of each selected surface portion, with sample density of 0.7mm;
- a color texture (aligned with the corresponding range map) which represents the pictorial detail present on the acquired surface section.

As usual in 3D scanning, complex objects are modeled via the acquisition of a set of partially overlapping range scans. Our proprietary software is used to register and merge all the range maps in a single triangulated mesh.

The scanner is currently in use at the Soprintendenza Archeologica Toscana, in the framework of the restoration of the Minerva, a bronze statue of the Museo Archeologico of Florence.

4. MANAGEMENT AND SIMPLIFICATION OF HUGE MESHES

Very large triangle meshes, i.e. meshes composed by millions of faces, are becoming common in many applications. Obviously, these complex meshes introduce severe overhead in transmission, rendering, processing and archival. Mesh simplification and LOD management are a rather mature technology that in many cases can efficiently reduce the above overhead. But only few available systems can manage meshes characterized by a huge size: RAM size is often a severe bottleneck.

We briefly introduce here a system which supports huge meshes management (including mesh editing, visualization, simplification and detail preservation) on PC-based platforms [7]. The system represents the data using a hierarchical data structure called Octree-based External Memory Mesh (OEMM), which allows to maintain the data on external memory, to load dynamically in main memory only selected sections and to preserve data consistency during local updates.

Our goal has been therefore to allow the management of huge meshes on a PC-based platform under the constraint of a limited memory size of the target architecture. None of the existing systems support this feature, even if we consider high-range graphics architectures. The hierarchical OEMM data structure is at the base of our mesh management and simplification system. The OEMM structure supports dynamic "on request" loading of portions of the current dataset from secondary memory, either for browsing or updating the geo-topological information. It is characterized by the global indexing supported on the whole mesh as well as by the dynamic re-indexing operated on each loaded mesh section. This data structure supports some classical operations: conversion from raw triangle-based mesh representation to OEMM, loading in main memory of selected sections, copy back on secondary memory of updated sections, etc. Other modules which can be build on top of the OEMM data structure are:

- a ***mesh editing*** library, that allows the user to perform simple editing actions (but crucial in a number of applications, like 3D scanning and rapid prototyping). These include: topological check of the mesh, detection of non-manifold components, detection of holes and automatic or user assisted hole-triangulation, elimination on request of complex vertices and faces, elimination on request of small components, etc.
- a ***mesh simplification*** library, which performs controlled simplification adopting the quadric error metric approach [5];
- a ***detail preserving*** library, which resamples bump- or rgb-texture to encode the high frequency detail lost during simplification, following the approach proposed in [6];
- a ***visualization*** module and GUI components.

Our system supports management and simplification of up to $O(10^9)$ triangles meshes. The time overhead due to the external memory management are affordable. Some examples of the simplified meshes produced are in Figures 3 and 4.

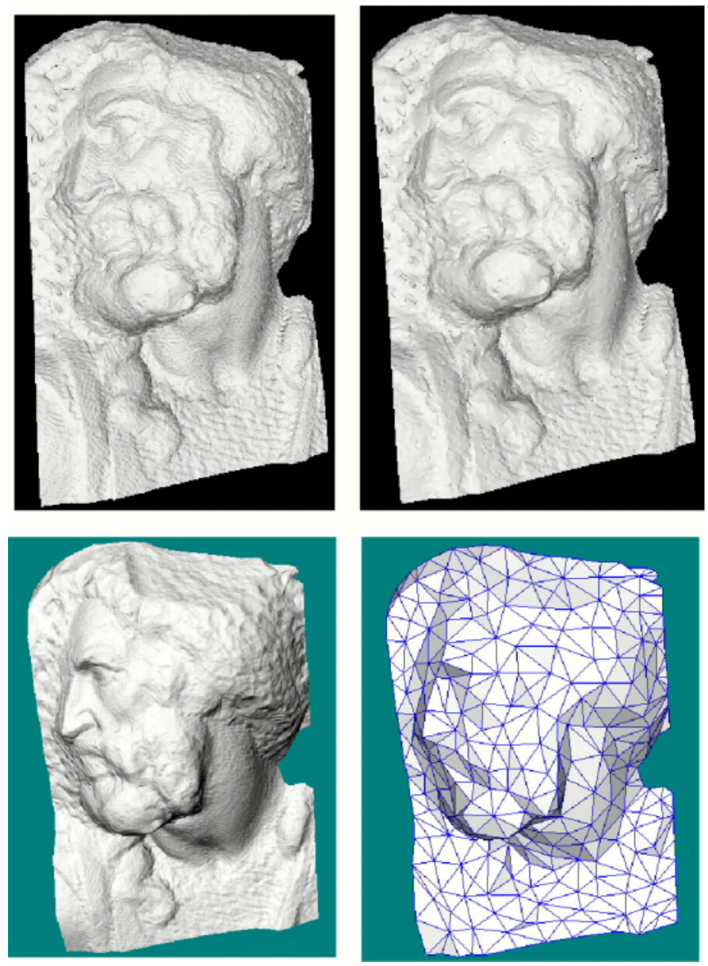

Figure 3: An image from the simplified Digital S. Mattew mesh: a portion of the high resolution mesh is up-left (4M triangles),a simplified intermediate LOD is up-right (48K tr.); a drastically simplified mesh (500 tr.) is shown bottom-right, with shape detail preserved by a resampled texture in bottom-left image.

The only other approach which supports out-of-core simplification of huge meshes is the out-of-core clustering solution proposed by Lindstrom [8]. This solution is very easy to implement and highly efficient in time. Unfortunately, it maintains most of the pitfalls of the clustering approach: the simplified mesh quality is lower than the quality of simplified meshes produced with the edge collapse approach, and simplification is not adaptive to surface shape. We have compared the results produced by OOC Clustering and our OEMM edge collapse simplifier on the same dataset (the Digital David), and the improvement of shape accuracy supported by our solution was significant.

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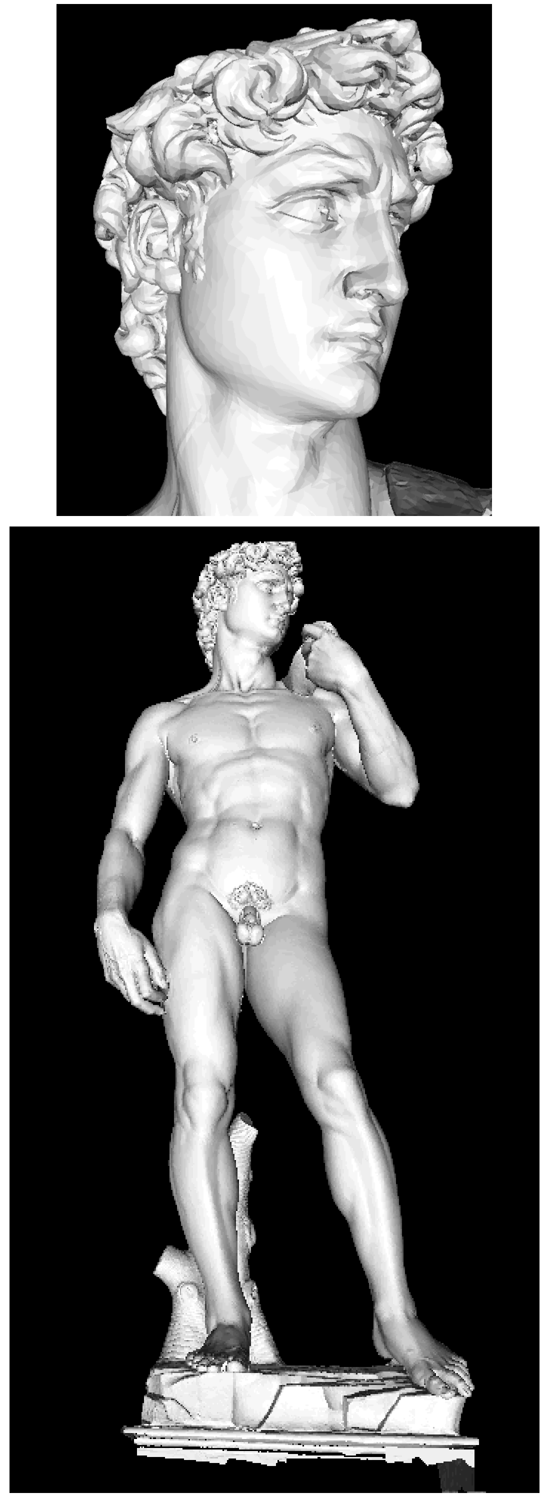

Figure 4: Images from a simplified Digital David mesh (only 215 K triangles).