LASER SCANNING FOR SHAPE MEASUREMENTS

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KEY WORDS: 3D scanning, laser-based scanning, shape measurement, digital 3D models.

ABSTRACT

3D digital models have a variety of applications such as the realization of 3D catalogues and virtual museum, fast prototyping, restoration and architectural supporting and monitoring. This paper reports the preliminary results of a project regarding the development and the use of new technologies in the Cultural Heritage (CH) field.
3D graphics starts with the *modeling* stage, that is the realization of a digital representation of the object of interest. Classic 3D modeling tools are often inadequate to model the shapes in Cultural Heritage applications because of the shape complexity of most art works (e.g. sculptures and architectural mouldings) or the high accuracy required. 3D scanning techniques are sufficiently accurate to provide high fidelity reproduction of the shape of an object. These techniques have been adopted in a number of recent Cultural Heritage projects: the Digital Michelangelo Project of the Stanford University (Levoy et al., 2000), the acquisition of Michelangelo's Pietà in Florence by the IBM T.J. Watson Laboratory (Rushmeier et al., 1998), and the acquisition of a section of the Coliseum in Rome by an Italian research team (Gaiani et al., 2000).
Laser scanning is probably the most versatile non-contact method for 3D measurements. Its main advantages are low cost, small size, high resolution and real-time response. In this paper we present a laser scanner system for Cultural Heritage applications and we also discuss the experience we get, the problems encountered during the development of our project and further possible applications of such 3D techniques in the restoration field.

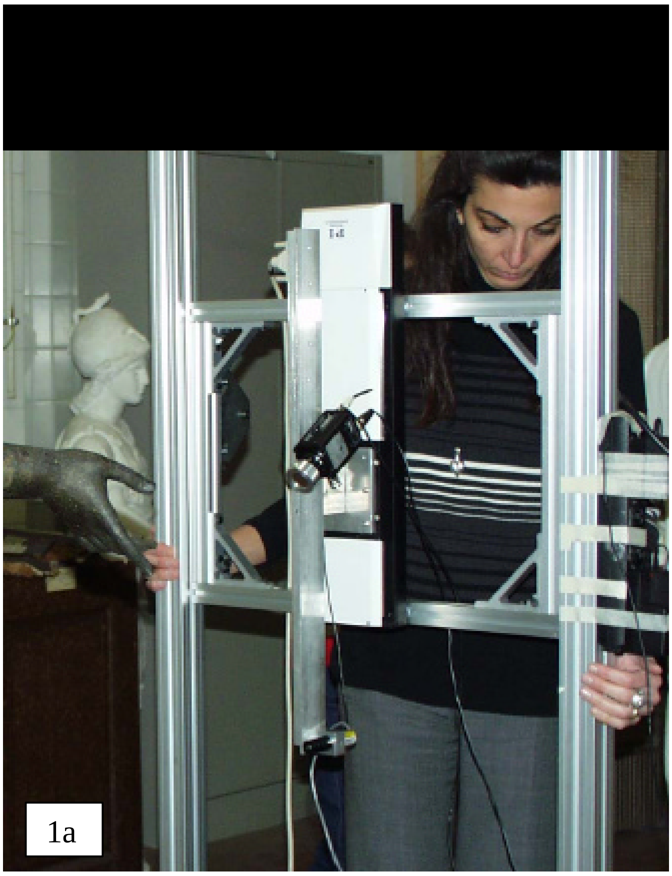
INTRODUCTION

3D scanning technology evolved in the last few years, but the high cost of 3D scanning devices hampers the use of this technology in many Cultural Heritage institutions. Another reason that restrains the introduction of 3D scanning technology in the CH field is the limited diffusion of knowledge about its potentialities. Moreover, there are only few applications able to manage 3D complex models, thus showing the full capabilities of such data.
The main goal of our work is to further develop and assess 3D scanning and graphic technologies, with a particular focus on the restoration of CH art works. The second goal is to train a multidisciplinary team of experts in restoration, archaeology, architecture, optics and computer science to discuss and hopefully design new tools useful for restoration. The final goal is not only to produce "nice 3D images", but to design useful tools for the restorers.

THE LASER SCANNER

A laser scanner for Cultural Heritage applications has been realized at the Istituto Nazionale di Ottica (INOA) in Florence. Among the active non-contact devices for 3D measurements, laser scanner is probably the most versatile one. Its main advantages are great set-up simplicity, small size, high resolution and real–time response.
The working principle is based on the optical triangulation: a light source illuminates an object and an image of this light spot is then formed, by means of a lens, on the surface of a linear light sensitive sensor. By measuring the location of the light spot image the distance of the object from the instrument can be determined, provided the baseline and the angles are known (Levoy et al., 2000).
The source employed is a laser diode (Lasiris Inc., $\lambda = 670$ nm, $P = 30$ mW) with a 60° prism head to project a light line and the sensor is a CCD camera (Jaj Corp., 1300 × 1030 squared pixel 6.7μm wide, S/N > 56 dB). These two devices

are mounted on a motorized stage to allow the scanning of statues or architectural mouldings, and the whole system is computer controlled. The experimental set-up is shown in Figure 1a. In its typical configuration, the laser sheet is horizontal (parallel to the floor), but to facilitate scanning horizontal crevices and extruded parts, the system can be oriented anyhow (Figure 1b). The gantry consists of two vertical trusses (2 meter long) on which the motorized stage can vertically translate and rotate around an axis perpendicular to them.
The system has been tested on reference surfaces and corrections for lens distortion were made. The accuracy of location of the image spot, and hence the instrument accuracy, is degraded by laser speckle (Baribeau et al., 1991). The resulting quota resolution is 50 μm and the absolute error is less than 0.3 mm, with a stand-off distance of 0.5 m and a scanned area of about 30×30 cm^2.



1b

Figure 1: Experimental set-up of the prototype of laser scanner realized at INOA (Florence).
Instrument configuration 1a) in vertical arrangement for frontal shot; 1b) tilted to reach shaded areas.

A software, realized at INOA, manages both the control (translation stage) and the acquisition systems (grabber and CCD camera). The output is a sequence of profiles gathered in meshes of binary data.
With the above system configuration the digitalization of the shape of a plaster head (30 cm height) has been realized (see Figure 2). Twelve meshes have been acquired for a complete reconstruction of the whole head (Figure 3).

Figure 2: Plaster head with the superposition of the red laser line.

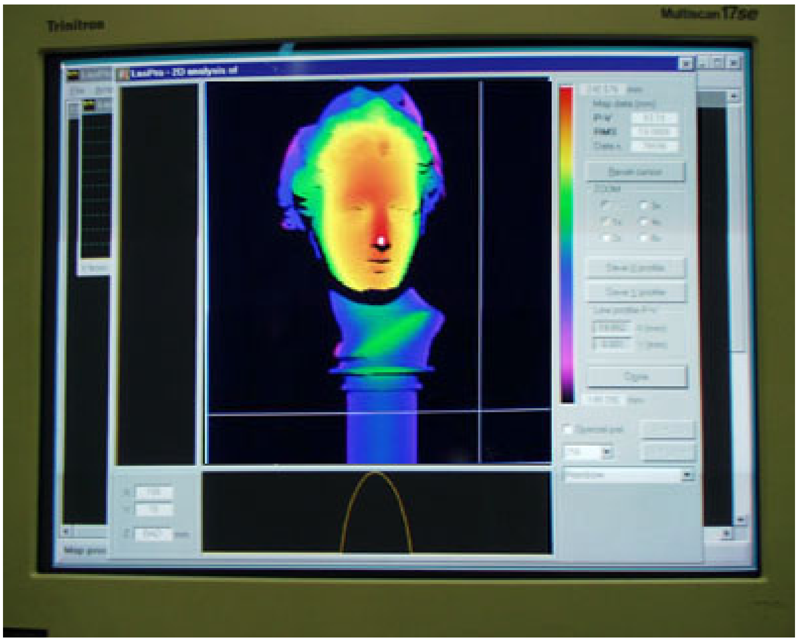


Figure 3: Pseudo-color preview of a single mesh.

The following processing consists of aligning and merging the scans taken from different gantry positions.

THE 3D SCANNING SOFTWARE TOOLS

The pipeline of phases of any 3D scanning session is rather complex, involving many steps: **acquisition planning** (where we decide how many range maps have to be shot to acquire in a complete manner the surface of the object); **scanning** the artifact; **aligning** the range maps (all the range maps have to be aligned to lie in the same space); range map **merging** (to build a single, non redundant mesh out of the many, partially overlapping range maps); mesh **editing** (to improve the quality of the reconstructed mesh); mesh **simplification** (to reduce the often huge complexity of the model obtained); finally, mesh **conversion** (to export the mesh produced to the data representation scheme used by the application/system of interest).

A comprehensive tutorial of the techniques proposed in literature and most frequently used in applications has been recently proposed (Bernardini et al., 2000).

Some of us (CNUCE – I.E.I. CNR) have designed a suite of software tools that manages most of these phases:

MeshAlign: the module allows the registration of multiple range maps, which by definition represent the distance of the surface sampled points from the sensor location. All range maps coordinates are therefore given relative to the current sensor location, and different locations are needed to get a complete coverage of the object surface. This means that all these range maps have to be transformed into a unique reference space, such that sections of the range maps that correspond to the same surface zone will be geometrically overlapped. The registration module follows the approach proposed by K. Pulli (Pulli, 1999), which is improved by the adoption of a multiple level of detail representation of the range maps that allows improving the performance and the accuracy of the process. An image of the interface of the MeshAlign module is in Figure 4.

MeshMerge: the module allows the reconstruction of a single 3D mesh out of a set of registered range maps. It adopts a new approach (Rocchini et al., 2000), which is characterized by a lower space complexity and improved accuracy with respect to the current alternative volumetric reconstruction approaches (Curless et al., 1996).

Mesh Edit: the module allows performing simple editing actions on the mesh, to improve its quality (e.g. to fill small holes, to remove non-manifold components of dangling edges/faces, to apply smoothing filters, etc).

MeshSimplify: the module supports the simplification of the (huge) meshes produced by 3D scanning devices, by removing in a controlled manner mesh vertices. The simplification follows the edge collapse approach (Garland et al., 1997) and has been implemented in an *out-of-core* fashion to allow the management of meshes that could be larger than the core memory of the computer used (Cignoni et al., 2001).

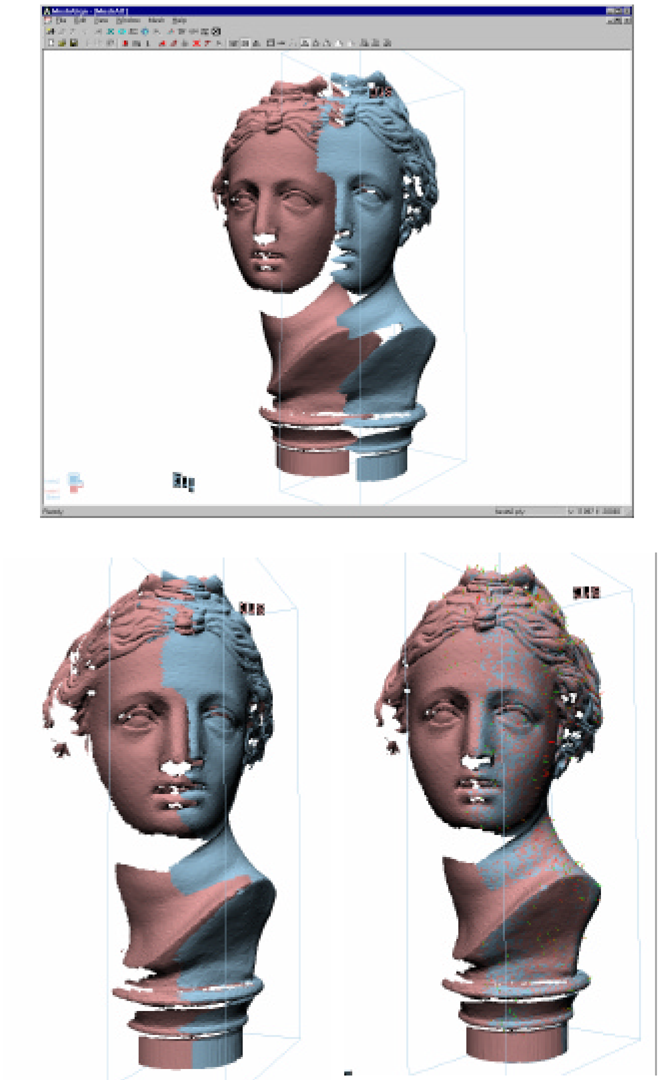


Figure 4: The MeshAlign tool: the system GUI is on the top, with two range maps loaded (and rendered at low resolution); on the bottom, the result of aligning these range maps: (left) approximate manual registration and (right) automatic fine registration.

These suite of tools are described in more details in paper n. 2 ("A suite of tools for the management of 3D scanned data", C. Rocchini, P. Cignoni, C. Monani, P. Pingi, R. Scopigno).

PRELIMINARY RESULTS

As it is usual in 3D scanning, complex objects are modelled via the acquisition of a set of partially overlapping range scans. The plaster head has been laser scanned and 12 meshes were taken to cover the whole surface. To overcome the problem of shaded areas the system has been translated and rotated. A single mesh was composed by 1121 profiles with 1000 points each, with a sampling accuracy of 0.25 mm.
Our proprietary software has been used to register and merge all the range maps in a single triangulated mesh. The alignment of this set of range maps took approximately half a day. A complete digital model of the plaster head has been produced, and is shown in Figure 5. The 3D mesh has been reconstructed from the range maps using MeshMerge and selecting an inter-voxel distance of 0.20 mm. The mesh reconstructed is rather big: around 450K triangular faces. To improve usability, this mesh was simplified using our external memory simplifier, MeshSimplify. The results presented in Figure 5 are simplified models representing the whole plaster head.

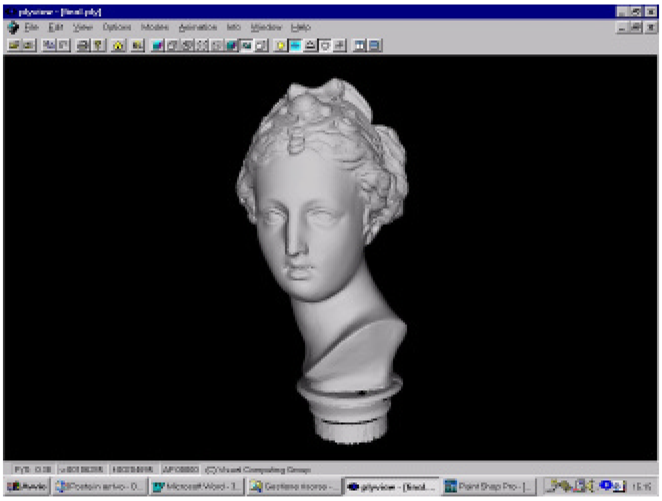


Figure 5: Final three-dimensional mesh obtained by merging twelve range maps.

CONCLUSIONS

In this paper a prototype of high resolution laser scanner has been presented, along with the software tools for a high quality digital representation of 3D objects. The system has been calibrated with a resulting quota resolution of 50 μm, and has been tested by measuring a plaster head 30 cm height. We have planned an upgrade of the instrument to work at a larger scale, that is to say for shooting big statues and architectural details.
A multidisciplinary team has been formed to approach the problems, validate the technologies chosen and interpret the experimental results.
The realization of very precise instruments and digital models allows a number of new applications such as the restoration planning, documentation and reproduction. Tools can be designed to simulate the planned modifications to the **appearance** and **shape** before acting on the real object. The possibility of evaluating in a virtual manner the different final appearance, before actually performing actions which cannot be withdrawn, would be a very valuable tool, useful both for rehearsal purposes or for showing the forecasted results to the (often a non-expert) person in charge of the decision concerning the restoration or its funding. Taking trace of all the actions operated on the object (by performing annotations on the 3D mesh and assigning attributes to selected mesh components, in a manner similar to what can be done with a time-varying GIS for terrain dataset); map and cross-correlate different results of non-destructive analysis on top of the 3D geometry (e.g. photographs, X-ray, thermographs, etc.), providing better capabilities for results analysis and interpretation. Finally, the reproduction of missing parts via the use of rapid prototyping techniques can be extremely valuable for all those art works that are so endangered that a standard casting procedure results not-feasible.

AKNOLEDGMENTS

We wish to thank Dr Marinella Greco for photo-reporting during measurements.

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