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Journal of Cultural Heritage
Journal of Cultural Heritage 11 (2010) 1–9

Original article

A practical approach to making accurate 3D layouts of interesting cultural heritage sites through digital models

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Received 30 July 2008; accepted 9 February 2009
Available online 13 November 2009

Abstract

On many occasions, the graphic information handled by people working in the cultural heritage sector is still bidimensional. Layouts showing elevations and cross sections are the most widespread tools. However, there is an increased need for carefully detailing the complexity of valuable sites with an improved accuracy. This implies the measuring and handling of three-dimensional data, using both commercial and turn-key hardware and software solutions. Taking the usual traditional process as a reference, in the present paper a new effective methodology for carrying out computer assisted delineation of layouts from cultural heritage sites, using 3D digital models, is described. The proposed procedure has been tested in five intervention projects on representative churches within the "Merindad de Aguilar de Campoo" medieval area, in the north of Spain.[1] This area has the largest collection of Romanesque art in the world, and is currently under European Heritage Site and World Heritage Site declaration process by the UNESCO.

Keywords: 3D laser scanning; Laser surveying; Color measurement; Digital model; Texture mapping; Feature extraction

1. Research aims

The present work is aimed at defining a novel methodology for obtaining digital models and subsequent layouts required for guiding the architectonic interventions in interesting cultural heritage sites, with improved accuracy and reliability and reduced time with respect to the traditional process. Thus, the quality of the work and the competitiveness of the companies carrying it out will significantly increase.

To this end, an applied research approach is proposed which combines and enhances state-of-the-art computational algorithms, for managing the great deal of geometric and color data provided by recent laser scanning devices. Hence, useful digital models of complex shaped objects will be readily obtained, thereby favoring the cataloguing and diffusion of the original sites, as well as the conservation and restoration work.

The proposed approach has been implemented through a set of practical tools for handling colored triangle meshes, which give support to the automatic and manual delineation by means of the said digital models. These tools have been made compatible with the well-known AutoCad software package, which is the most widespread standard in architectonic delineation.

2. Introduction

Photogrammetry has been extensively used for obtaining three-dimensional digital models from valuable sites from a set of photographs [1]. However, in general terms, it is worth pointing out that this technique is primarily oriented to solving well-defined shapes (such as cones, cylinders or plane polygons). Complex shapes are preferably acquired using modern laser scanners.

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[1] Santiago church, at Cezura (Palencia); Sta. Mª. la Real church, at Valberzoso (Palencia); Sta. Cecilia hermitage, at Vallespinoso de Aguilar (Palencia); Ntra. Sra. de la Asunción church, at S. Martín del Rojo (Burgos); and S. Miguel Arcángel church, at S. Miguel de Cornezuelo (Burgos) (2005–2007). To learn more, please visit http://www.romaniconorte.org/en/portada/.

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doi:10.1016/j.culher.2009.02.007

Laser scanners can sometimes be an alternative and are always a complement to photogrammetry techniques, as stated in [2,3]. Often, the best suited devices to Architecture and Heritage applications are those based on the "time-of-flight" technology used by common laser distance meters and total stations. The target surface is automatically scanned to the desired resolution by the measuring laser, so that the geometric coordinates (X, Y, Z) of every point travelled across by the laser beam are obtained with respect to the scanner location [4]. Acquisition speed over 1500 points a second are usual for pure time-of-flight devices, this speed being significantly increased when using phase-shift technology (but leading to larger noise levels).[2] Thus, a point cloud is obtained to a desired spatial density. Moreover, the color coordinates (R, G, B) of each measured point can also be obtained by projecting its geometric coordinates onto a color imaging device attached to the scanner (either internally or externally), following the perspective projection model [5].

The resulting point cloud can be processed to build a polygonal model consisting of a triangle mesh that faithfully describes the measured surface in shape and dimensions. Color can also be incorporated to the geometric model, but often leading to a description of limited consistency because the measured color values are determined by the geometric resolution, the imaging parameters (iris, shutter, focus) and the lighting conditions, which can vary largely during the scanning process (specially when working outdoors) [6,7].

A better color description can be obtained by using an independent digital camera with high-quality optics and high-resolution sensor. The control of all the imaging parameters must be possible in order to avoid any undesired variation of these parameters during image acquisition. A number of images can be taken from a set of viewpoints, under preselected imaging parameters, and the obtained pictures can be mapped, i.e. superposed onto the triangle mesh, thus giving an appearance of great realism to the model [8,9].

The geometric models, along with the color information (from either the color coordinates of the measured points, or the said image superposition onto the triangle mesh), allow three-dimensional digital models to be generated which are highly useful in the cataloguing, preservation, restoration and diffusion of the cultural heritage, as shown in [10,11]. In addition, these models will serve as a basis for obtaining the layouts required for site surveying.

In the present paper, a methodology, software tools and results on the delineation of layouts in three dimensions from geometric and color data obtained using laser scanners are described as an advantageous alternative to more conventional methods still in use. Particular stress is put on automating the delineation process as much as possible.

3. Methodology

Frequently, fast and economic surveying does not entail the use of photogrammetric techniques. Alternatively, the traditional solution consists in obtaining the individual coordinates of a number of control points that are considered of interest according to the criteria of skilled people. This procedure represents a considerable effort in field-work, since several work weeks are required for referencing a few hundred points. Moreover, it is hardly applicable to the sculpted details often present in sites of cultural interest [12]. In order to reduce the required number of points, a set of complementary photographs are usually taken from frontal viewpoints. Then, in a second phase back in the office, the perspective of these images is corrected in the computer, and the points measured are joined together properly and fitted into guidelines. Accordingly, a template to carry out the delineation process to centimeter-range accuracy is obtained.

Laser scanners provide thousands of times more information than this traditional approach, and field-work time drops dramatically, as has been demonstrated through the digitization of five sites of cultural interest by CARTIF.[1] Raw 3D data obtained upon time-of-flight technology is often noisy, so scanner manufacturers often supply firmware options for setting measuring thresholds so that the collection of bad data at long range is prevented. Our tests on the most popular scanners available on the market in 2006 enabled us to find that this filter can be turned off in most models, so all returned laser pulses can be kept even though the data are inaccurate. In the present work, a LEICA HDS-3000 was selected. Data filtering is always applied in this model, leading to reliable point clouds. This choice was later reinforced by the study of Adami et al. [13], where the suitability of different laser scanners for cultural heritage applications is specifically discussed. In addition, millimeter-range accuracy within a measuring range of dozens of meters is attained and, in agreement with [14], basic aspects related to the use of conventional measuring equipment are kept: physical contact to the target object is not required, adaptation to the local orography is allowed and georeferencing is possible.

Manual delineation of layouts can be envisaged on the obtained point clouds, using common CAD applications enhanced with specific plug-ins for the handling of large numbers of points. Our analysis of two representative programs, KUBIT PointCloud[3] and LEICA CloudWorx has enabled us to conclude that they have some basic drawbacks:

- handling the huge data amount required for precise documentation is not easy;
- clearly differentiating the features to be drawn becomes hard when point density is huge;
- large-scale automation of the delineating process is not possible.

Meshed models represent a suitable alternative to point clouds. In particular, triangular meshes are the simplest case from the mathematical point of view and also involve the smallest computational processing effort [15]. For this reason, they

[2] http://laser.jadaproductions.net/.

[3] This software is a standard for displaying and handling millions of 3D points in the AutoCad environment.