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Non-contact reverse engineering modeling for additive manufacturing of down scaled cultural artefacts

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Abstract

In recent years, reverse engineering has achieved a relevant role in the cultural heritage field. The availability of 3D digital models of artefacts opens the door to a new era of cultural heritage: virtual museum creation, artefact cataloguing, conservation, planning and simulation of restoration, monitoring of artefacts subjected to environmental degradation, virtual reconstruction of damaged or missing parts, reproduction of replicas, etc. In this paper, two different non-contact reverse engineering scanning systems were utilized for 3D data acquisition of a cultural heritage artefact. The digital data acquisition and processing procedures of the scanned geometry have been illustrated and compared to evaluate the performance of both systems in terms of data acquisition time, processing time, reconstruction precision and final model quality. Finally, additive manufacturing technologies were applied to reconstruct a down scaled copy of the artefact.

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Keywords: Reverse engineering; cultural heritage; laser scanning; photogrammetry; additive manufacturing

1. Introduction

In the industrial field, reverse engineering (RE) is the most popular method utilized for the creation of a 3D digital model of an existing physical object via diverse 3D scanning technologies (e.g. coordinate measuring machines, laser scanners, structured light digitizers, etc.) [1].

Nowadays, the different issues related to the preservation and enhancement of cultural heritage have attributed a key role to the RE technology. In 2016-17, over €100 million for research and innovation in the field of cultural heritage have been made available under the EU's research funding programme Horizon 2020 [2]. This increase in funding recognises cultural heritage as an investment opportunity where research and innovation can make a difference.

RE technologies allow to obtain high precision models of artefacts, both digital and physical, preserving the integrity and avoiding the risk of possible damages as they are based on not-in-contact acquisition techniques [3, 4].

The employment of RE methods for cultural heritage can be developed for several purposes such as the use of innovative multimedia applications in which the 3D objects are placed in their original environment such as virtual museum, or the realization of faithful 3D copies through additive manufacturing processes, and even more important for the inspection and monitoring of the environmental degradation over time of the artefacts.

In the last decades, numerous papers and projects have illustrated and successfully demonstrated the enormous potential of the RE technologies applied to the cultural heritage field [5-7].

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In 1997, the 3D digital images of the 'Madonna col Bambino' of Giovanni Pisano and of two bas-relieves of Donatello at the 'Cappella degli Scrovegni' in Padova were realized by the National Research Council of Canada and the University of Padova [8].

One of the first world wide famous application of the RE technology for cultural heritage is dated in 1999, when a laser scanner with a working volume of 3 m (width) by 7.5 m (height) was utilized to scan Michelangelo's David on its pedestal [9]. In 2003, the digital reconstruction of the great Buddha statue in Bamiyan, Afghanistan, was obtained using different types of images [10].

In last years, a new technology based on the use of unmanned aerial vehicles (UAV) was employed for outdoor applications such as the Ying County Wooden Pagoda, the Banqiao Mosque in China [11] and the Cathedral of Santiago de Compostela in Spain [12].

Generally, the methodological process applied in the field of conservation and enhancement of cultural heritage consists of three stages: acquisition of the artefact geometry with the use of RE technologies; visualization and improvement of the acquired digital model; possible use of additive manufacturing (AM) technologies to reproduce the physical model of the artefact [13].

In this paper, two different non-contact RE scanning methodologies, respectively based on a portable measuring arm (PMA) with laser scanner and a digital close range photogrammetry (DCRP) system, were utilized for the 3D data acquisition of a cultural heritage artefact consisting of a VI century sculptured column of large and complex geometry. The acquisition procedure and the following digital processing of the acquired geometry are illustrated and compared in order to evaluate the performance of both systems in terms of acquisition and post-processing time, point clouds and polygonal models quality, and precision. As final phase, the RE modelling for additive manufacturing of down scaled cultural artefact was developed and applied to the artefact under study.

2. Case study

The cultural heritage artefacts under study are located at the Basilica of San Giovanni Maggiore, Naples. The Basilica of San Giovanni Maggiore, after a long period of neglect, was subjected to a long and difficult restoration, of about thirty years duration, and reopened only in January 2012. Since then it has been managed by the Foundation of the Association of Engineers in Naples to host conventions, concerts, exhibitions and cultural events in general. The Basilica has a Latin cross plan with three naves and a transept with two chapels on the sides.

The most interesting element of the Basilica is certainly the early Christian apse, situated behind the XVIII century baroque altar by Domenico Antonio Vaccaro. The apse, dating back to the VI century, has a semi-circular shape with four arches, supported by pillars, that looked out on an ambulatory in continuation of the aisles. During the recent restauration work, the apse was deprived of its XVII century wooden choir that covered two finely inlaid monolithic marble columns with square section. The columns configuration reveals they are of Roman making of the II century, first built for a Roman temple in that location and later utilized in the VI century for the newly constructed early Christian Basilica of San Giovanni Maggiore (Fig. 1).

Each square section monolithic marble column presents two lateral faces, in view, finely inlaid with rich decoration, whereas the other two lateral faces, largely hidden to view, have smooth surfaces with no decoration.

The two monolithic columns of 51 cm x 55 cm x 500 cm size were chosen as large cultural heritage artefacts with complex geometry to be modeled, the reasons being:

- The ancient marble columns are of exceptional historical, artistic and architectural value.
- The columns' lateral faces in view are very rich in detail and decoration.
- The recent restoration of the Basilica did not involve activities on these columns which are currently still waiting for conservative consolidation.

In this paper, the left column (red arrow in Fig. 1) located behind the apse was considered for RE modeling with reference to its two highly decorated lateral faces.

3. RE non-contact systems for 3D data acquisition

Two diverse RE non-contact scanning methodologies, respectively based on a portable measuring arm (PMA) with a laser scanner and a digital close range photogrammetry (DCRP) system, were employed for 3D digital data acquisition of the left column (Fig. 2) [7, 14].

3.1. Portable measuring arm with laser scanner

The portable measuring arm (PMA) is a high-end laser scanning platform consisting of a Romer Absolute Arm 7525 SE (Hexagon Metrology) anthropomorphic arm with seven rotational axes and a high-precision external laser scanner CMS 108 (Fig. 2a, 2b). The tubular segments of the arm, made of carbon fibre reinforced plastic, ensure maximum stability and minimum weight. The arm has an ergonomic pistol grip to enable the manual measurement of 3D points at any orientation within the arm's spherical reach (2.5 m), with a volumetric precision of ±0.058 mm and a repeatability of ±0.027 mm. The CMS 108 external laser scanner mounted on the arm allows to collect up to 30.000 points per second with a precision (2σ) of 20 μm.

Fig. 1. Monolithic marble columns (II century) in the early Christian apse (VI century) located behind the baroque altar (XVIII century).