Ž. SANTOŠI, M. ŠOKAC, D. KOROLIJA-CRKVENJAKOV, B. KOSEC, M. SOKOVIĆ, I. BUDAK
ISSN 0543-5846
METABK 54(4) 695-698 (2015)
UDC – UDK 669.35.6:739.5.712.7:620.18=111

RECONSTRUCTION OF 3D MODELS OF CAST SCULPTURES USING CLOSE-RANGE PHOTOGRAMMETRY

Received – Primljeno: 2014-09-28
Accepted – Prihvaćeno: 2015-02-25
Preliminary Note – Prethodno priopćenje

This paper presents the possibilities of application of close-range photogrammetry, based on the Structure-from-Motion (SfM) approach, in 3D model's reconstruction of bronze cast sculptures. Special attention was dedicated to the analysis of image processing strategy, and its impact on the 3D model reconstruction quality. For the purpose of analysis a bust of Nikola Tesla, placed in front of the Faculty of Technical Sciences University of Novi Sad was used. Experimental results indicate that the strategy employing multi-group photo processing provides substantial reductions in processing time while providing satisfactory results in 3D reconstruction.

Key words: bronze cast sculptures, close-range photogrammetry, 3D model reconstruction

INTRODUCTION

Since the appearance of first systems, some 25 years ago, 3D digitization has seen intensive development. Novel methods for 3D digitization are more accurate, precise and faster, allowing the sampling of larger quantities of data while shortening the time required for data acquisition. At the same time, the area of their potential application keeps getting wider, regarding the characteristics of materials which can be digitized, as well as the complexity of geometry. However, none of the existing methods offer universal, high-quality 3D digitization regardless of materials and geometric forms. In other words, each method has its area of application within which the method performs best [1].

Digital photogrammetry is among the more recent methods which opened the way to wider application of 3D digitization. Current directions of investigation include photogrammetry based on coded markers [2, 3], which is becoming increasingly present in industry [2]. The latest investigations in this field are focused on close-range photogrammetry, based on SfM (Structure from Motion) approach [4]. This type of photogrammetry is based on triangulation, i.e., the measurement of coordinates of unique points on two recorded images in order to establish the position of a point in space relative to the referential coordinate system [1, 5].

This paper deals with the application of SfM-based close-range photogrammetry on the reconstruction of a 3D model of an art sculpture, cast in bronze. Special attention was devoted to analysis of the strategy of reconstruction and its impact on the quality of the resulting 3D polygonal model. The results can be used for further development and application of this method.

Ž. Santoši, M. Šokac, I. Budak, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia. D. Korolija-Crkvenjakov, Gallery of Matica Srpska, Novi Sad, Serbia. B. Kosec, Faculty of Natural Sciences and Engineering, University of Ljubljana, Ljubljana, Slovenia. M. Soković, Faculty of Mechanical Engineering, University of Ljubljana, Ljubljana, Slovenia.

MATERIALS AND METHODS

Fundamental prerequisite for successful 3D digitization by close-range photogrammetry is the generation of quality photo images [5]. Image resolution is a crucial quality factor. Higher resolution means smaller object areas covered by a single pixel. Beside image resolution, directly connected with the image quality is the size of physical object being digitized and its relative distance from the camera. Moreover, high-quality photo images require good photographing conditions [3], lighting conditions being the top priority. Although daylight is best for lighting purposes, it is generally avoided due to problems with shaded side of the physical object. With this in mind, artificial lighting sources are commonly used, whereas several lighting sources alleviate the problem of shaded surfaces.

During reconstruction of a 3D model using SfM-based approach to close-range photogrammetry, object coordinates are established by triangulation without the need for coded markers [4]. This requires that the surface of the physical object has a unique texture which allows determination of a given point in space [2]. Generally, metal objects have highly reflective surfaces and are not suitable for 3D digitization using optical methods. Bronze busts are manufactured by wax casting. As art forms, busts are used to commemorate famous and merit able persons and are usually placed in open spaces, being subjected to various atmospheric influences (rain, sunshine, snow, etc). After a certain period, under the influence of oxidation, the surface begins to develop a thin oxide layer [6]. The greenish colour of copper oxide creates a characteristic texture which allows the application of surface-from-feature approach to close-range photogrammetry.

Beside the texture, it is also important to select an appropriate photographing strategy. Strategies vary depending on the object, however, it is of utmost importance to generate photo-images of all surfaces which require reconstruction. General strategy demands that the photo-images be taken so as to allow partial superposition, where the areas of primary interest require more photographs. Three-dimensional objects such as the busts, require full-circle photographing at various altitudes, while maintaining that the imagined normal line projected through the image center, also passes through the center of the photographed object [5].

3D models generated by photogrammetry are "dimensionless", in the sense that real object dimensions cannot be recovered from the photo image [7]. However, as these models are determined in parametric way with the preserved dimension proportions, the problem of "dimensionless" is solved by placing calibration poles with markers of well-known length within the area of interest. The alternative is to use some previously measured features on the very object. The dimensional accuracy of the reconstructed polygonal 3D model directly depends on the method used for scale determination. Error resulting from inadequate definition of scale belongs to systematic errors. There are numerous factors which affect the quality of the reconstructed 3D model (photo-image resolution, object surface texture, lighting, etc). This investigation focused on the influence of photographing and image processing strategy. The basic photogrammetric strategy is to take evenly distributed photographs around the object of interest.

The strategy of grouping, analysed in this investigation, is based on the following principle: a series of photos are taken using a small increment of angle, followed by another series of photos taken with a much larger incremental angle. In order to reconstruct a complete volumetric object, at least three groups of photographs are required, which form an equilateral triangle. As the number of photographs taken from the corners of regular polygons increases, so does the total effective image overlap, which results in a more accurate object reconstruction. From the theoretical aspect, higher number of images means higher quality of a reconstructed polygonal 3D model.

For the purpose of analysis, of the effects of strategy selection on the final quality of the reconstructed polygonal 3D model, a bust of Nikola Tesla, placed in front of the Faculty of Technical Sciences building in Novi Sad was used. The bust was made of bronze which has developed a layer of oxide over time, thus becoming suitable for 3D reconstruction by SfM-based close-range photogrammetry.

Acquisition of photo images was performed using a prosumer-class camera Canon Powershot S5 IS, which belongs to the category of super-zoom digital photo cameras. The camera's main features are: CCD sensor of 5,75 x 4,32 mm; maximum picture resolution of 3 264 x 2 448 pixels; compact lens.

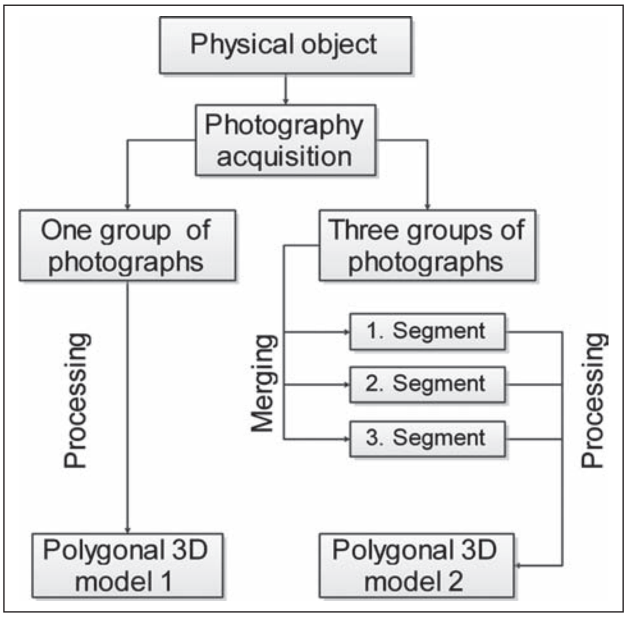

Figure 1 General workflow of experiment using two different strategies

To allow elimination of multi-coloured background and enhance contrast to allow easier pre-processing of photographs, a white screen was set up behind the object of interest. All photographs were taken in daylight conditions during afternoon, without the flash. The camera was set to auto mode, meaning that the aperture, shutter speed and ISO sensitivity were automatically selected based on conditions at the time of photographing. A total of 30 photographs were taken in highest resolution supported by the camera. The experiment included generation of two 3D models based on the same set of photo images, but with different strategies applied (Figure 1).

Agisoft PhotoScan software was used for pre- and post-processing. During reconstruction, focus was placed on the frontal and lateral sides of the bust (Figure 2).

The processing of images takes place in several phases, which require definition of input parameters.

Figure 2 The bust of Nikola Tesla with some of the photographing positions

Figure 3 Dense point cloud 411 830 points

Figure 4 3D polygonal model 1

Figure 5 Polygonal 3D model 1 with texture

Figure 6 3D polygonal model 2, obtained from the three groups of photographs

For both experimental strategies following four parameters were used: 1. image alignment - high level, 2. dense point cloud generation - medium quality, 3. polygonal model generation - with interpolation, and 4. texture generation – average.

RESULTS AND DISCUSSION

The output results of the first phase of photo image processing are a low-density point cloud and the positions used to take photographs from. In the next phase (Figure 3) point cloud density was increased to be compatible with one of five quality categories- from sparse to dense. Similarly to results presented in [8], the differences in quality and accuracy between medium and high levels were almost unnoticeable, while the time reduction was significant. Dense point cloud is the basis for the creation of the polygonal 3D model (Figure 4). Within the last phase, it was possible to map a texture onto the polygonal model, since the texture had been previously sampled from the photo images (Figure 5). Reconstruction of Nikola Tesla bust was successfully completed in both cases. The process of photo acquisition took something over 10 minutes.

The strategy which involved a single group of 30 photographs with 3 264 x 2 448 pix resolution, resulted in 46 065 points in a sparse point cloud (Figure 2), while the approximation of medium quality resulted in a dense point cloud with 411 830 points (Figure 3). Total reconstruction took more than 60 minutes. The effective photo overlap index was 4,4.

In the case of the second strategy, there were three groups of photographs which covered the frontal and two lateral sides of the bust. Each of the three groups of photographs was subjected to following procedure: 1. image alignment, and 2, dense point cloud generation. Due to the number of photo images within each group - which was smaller than the total number of images used in the first strategy - the processing was faster. Once the dense point clouds were generated, photo groups (chunks) were aligned and integrated. The dense point cloud integrated in this manner, contained much more points compared to the corresponding point cloud obtained by the first strategy. An overview of the processing is presented in Table 1.

Table 1 **Overview of the processing of the three groups of photo images**

	Segment 1	Segment 2	Segment 3
Number of photos	7	8	8
Sparse point cloud	16 921	15 391	19 898
Dense point cloud	210 592	238 749	251 242
Effective overlap	3,31	3,40	3,49
Time / min:sec	03:54	04:25	04:26

The resulting, integrated point cloud, ready for polygon meshing contained a total of 695 589 points. Total reconstruction time was 15 minutes. Rather than high dimensional accuracy of casts, art sculptures (busts) prioritize aesthetic judgment [9]. Visual comparison between the 3D model obtained by a single group of photo images (Figure 4) and the 3D model obtained by alternative strategy employing three groups of photo images (Figure 6), reveals some problems in the reconstruction of fingers pressed against the face.

The problems are due to insufficient number of photographs covering that particular area. Using CAD software which supports work with polygonal 3D models, the problems with polygonal mesh can be efficiently remedied, thus yielding the required polygonal 3D model. Table 2 reviews characteristics of applied strategies.

Considering that both strategies yield approximately even output quality, based on the results from Table 2 it

Table 2 **Strategy overview**

	One group of photographs	Three groups of photographs
Time of processing	More than 60 min	Approx. 15 min
Low PC configuration	No	Yes
Number of photographs	30	23

is evident that the strategy with multiple groups of photographs can be given advantage.

CONCLUSIONS

The results presented in this paper indicate the potential of SfM-based close-range photogrammetry for the reconstruction of cast art sculptures. Moreover, it has been established experimentally that the strategy employing multi-group photo processing provides substantial reductions in processing time while providing satisfactory results in 3D reconstruction even on computer hardware of average performance.

Based on previous discussion, it can be concluded that SfM-based close-range photogrammetry represents a promising method for 3D reconstruction of bronze sculptures. Its potential areas of application include digitization of molds based on preparatory models, generation of 3D documentation of cultural heritage, as well as restoration of damaged sculptures, digital protection of art heritage and creation of virtual museum/ gallery shows.

REFERENCES

[1] I. Budak, Đ. Vukelić, D. Bračun, J. Hodolič, M. Soković, Sensors 12 (2012) 1, 1100-1126.
[2] T. Luhmann, ISPRS Journal of Photogrammetry and Remote Sensing 65 (2010) 6, 558-569.
[3] M. A. Aguilar, F. J. Aguilar, F. Agüera, F. Carvajal, Biosystems Engineering 90 (2005) 4, 397-407.
[4] M. J. Westoby, J. Brasington, N. F. Glasser, M. J. Hambrey, J. M. Reynolds, Geomorphology 179 (2012), 300-314.
[5] A. Bernardini, G. Fangi, Proceedings, XXI International CIPA Symposium, A. Georgopoulos (ed.), vol. 1, CIPA 2007 Organizing Committee, Athens, 2007, pp. 129-134.
[6] F. Gallese, G. Laguzzi, L. Luvidi, V. Ferrari, S. Takacs, G. Venturi Pagani Cesa, Corrosion Science 50 (2008) 4, 954-961.
[7] V. Stojaković, Facta universitatis - series: Architecture and Civil Engineering 6 (2008) 1, 113-125.
[8] I. Budak, B. Kosec, M. Soković, Journal of Achievements in Materials and Manufacturing Engineering 54 (2012) 2, 233-241.
[9] M. Atalay, Percipi, (2007) 1, 44-52.

Note: The responsible for English language is Ognjan Lužanin, Faculty of Technical Sciences, Novi Sad, Serbia