

Performance Evaluations of 3D Web-Services and Open-Source software for digital modeling of archaeological finds

Mauro Lo Brutto, Paola Meli

The Structure From Motion (SFM) algorithms derived from Computer Vision community make image-based techniques a competitive and user friendly approach to obtain 3D information of real objects. These algorithms have been implemented in many 3D web-services and open-source software to develop free instruments for the reconstruction of very detailed 3D digital models. Their use is becoming very common above all in archaeological studies but their potentiality for metric application has not been tested at all. The aim of the work is to investigate the quality and the accuracy of 3D models obtained through 3D web-services and SFM open-source software. Different tests have been performed using some 3D web-services (Autodesk 123D Catch, ARC3D, My3Dscanner) and one freeware software (VisualSFM). The 3D models have been compared to reference models obtained by photogrammetric and laser scanning techniques. The work has showed that in some situations these instruments could substitute photogrammetric and laser scanning techniques.

1. Introduction

The survey techniques which allow to obtain 3D information of real objects can be divided into two main categories: range-based techniques that use active sensors and image-based techniques that are based on passive sensors (Remondino & El-Hakim, 2006). The former include the measurement techniques that use systems such as laser scanners, structured light systems or range-imaging camera, while the latter include systems based on photogrammetric or computer vision techniques. The choice of the technique to use depends on the budget, on the time available, on the operating conditions, on the complexity and on the features of the objects and on the operators experience (Remondino, 2011). In particular the scientific research has been increasingly moving towards the study of no time consuming and low cost solutions to perform surveys that allow to obtain complete, metrically and qualitatively accurate 3D reconstructions. The image-based techniques are becoming the main protagonists in this field of research due to the development of algorithms derived from computer vision such as the Structure from Motion (SFM) approach. Indeed this strategy allows to orient a very huge number of images without any knowledge of the camera parameters and network geometry and to obtain a sparse 3D point cloud (Szeliski, 2010). The SFM process is divided into three phases: automatic features detection and extraction, identification and elimination of outliers and false matches through the use of robust estimates and finally computation of internal and external images orientation parameters through bundle adjustment (Nguyen, *et al.*, 2012; Remondino *et al.*, 2012). The sparse point cloud calculated by the SFM algorithms can be refined through the application of dense stereo matching algorithms, to create a more detailed point cloud and the 3D model of the object.

Recently the SFM procedure and the dense image matching algorithms have been developed in several open-source and freeware software (Blunder and PMVS, VisualSFM, Mic Mac, Apero, etc ...), in some commercial software (Agisoft Photoscan, PhotoModeler Scanner, 3DF Zephyr) and finally in web applications defined 3D web-services (ARC3D, Autodesk123Dcatch, Cubify, My3Dscanner etc...) (Vergauwen & Van Gool, 2006). The use of these techniques has



Dataset	Description	Dimensions [cm]	Number of images	Camera type	Resolution [pixel]	Dist. camera-object [m]	GSD [mm]
1	Sculptural artwork	30 x 45 x 30	85	Kodak Easyshare C315	2576 x 1932	0.75	0.28
2	Arula	33 x 33 x 15	8	Canon EOS-1Ds Mark II	4992 x 3328	1.00	0.15
3	Fountain of the Dolphins	490 x 540 x 260	11	Canon D60	3072 x 2028	7.00	3.10

Table 1 - Main characteristics of the datasets.

had a gradual and constant increase to get 3D information mostly in archaeological field both during excavation operations and for finds documentation (Callieri, 2011; Moulon & Bezzi, 2011; Plets *et al.*, 2012; De Reuet *et al.*, 2013). These tools are not developed to be used for metric surveys but mainly for 3D visualization. For this reason the studies for their reliability and for the accuracy of the final products are increasing significantly. Several studies have investigated their possible use instead of traditional photogrammetry and laser scanning techniques (Fratu De Balestrini & Guerra, 2010; Doneus *et al.*, 2011; Lo Brutto & Meli, 2012; Skarlatos & Kiparissi, 2012; Di Paola *et al.*, 2013; Inzerillo & Santagati, 2013).

The work aims to verify the metric reliability of the 3D reconstruction of small and medium size objects obtained by SFM and dense matching approach using some 3D web-services (Autodesk 123D Catch, ARC3D, My3Dscanner) and the freeware software VisualSFM. The main objective is to investigate the performance of these applications in relation to the quality and metric accuracy of the final products and to assess whether these new tools can be a valid alternative to laser scanning and traditional photogrammetric techniques for some applications in Archaeology.

2. Methodology

The CV tools used are Autodesk 123D Catch (<http://www.123dapp.com/catch>), ARC3D (<http://homes.esat.kuleuven.be/~visit3d/web-service/v2/index.php>), My3Dscanner (<http://www.my3dscanner.com/index.php>), three of the 3D web-services available online for free during the carrying out of this work, and the freeware software VisualSFM (<http://ccwu.me/vsfm/>). For the performance evaluation some datasets were used; the datasets are different for type of object, size, type of camera, camera network, number of images, resolutions (Table 1).

The work was divided into three phases: images acquisition and processing of the datasets, exporting, scaling, alignment of 3D models obtained with the 3D web services and the open-source software, comparison with the reference 3D models.

The images were processed with the various 3D web-services following the procedures provided by these services (images upload, remote computing of the images orientation and of the 3D model, download the model as points cloud or as mesh); the data processing with VisualSfm was performed with the hardware resources of the our Geomatics laboratory.

The models were scaled using different approaches with respect to the available features in the used tools. The 3D models obtained with Autodesk 123D Catch and VisualSfm were scaled using known distances measured collimating points directly on the images through the management platform of the 3D web-service in the first case and through the freeware software Sfm_Georef (James & Robson, 2012; http://www.lancaster.ac.uk/staff/jamesm/software/sfm_georef.htm) in the second case; with ARC3D and My3Dscanner the 3D models were





Figure 2 - Camera network of the Dataset 1.

scaled with the open-source software MeshLab (<http://meshlab.sourceforge.net/>) through the inclusion of a scale ratio estimated by measuring one or more known distances directly on point clouds or polygonal models.

The reference 3D models were obtained by laser scanning or by the processing of the same images used for the tests by commercial close-range photogrammetry software.

All the models were put in the same reference system using the ICP algorithms.

Different methodologies were carried out for metric comparisons among the models used as reference and the test models. The type of metric comparisons performed were chosen according to the characteristics of the objects:

- three-dimensional comparison between surfaces through the creation of a map that identifies the distance in three dimensions;
- comparison between 2D profiles.

3. Data acquisition and data processing

3.1 Dataset 1: Sculptural artwork

A sculptural element that represents a head with two faces was the first object test. This sculpture is situated at the “Enchanted Castle” in Sciacca. The “Enchanted Castle” is located on a country large area in the western part of the city of Sciacca, near Agrigento on the southwestern coast of Sicily (Italy). In this area, the sculptor Filippo Bentivegna has created among olive and almond trees sculptures of heads carved into the rocks or on tree trunks. These sculptures are so strange and particular that this place should be an obligatory destination for tourists staying in Sciacca. The dataset was composed of two strips taken from a distance of about 75 cm from the sculpture (Figure 2). The two strips were taken putting the camera at different heights and rotating around the sculpture in order to get images with different viewpoints of the head: the first strip, constituted of 43 images, was taken putting the camera in front of the head, while the second, composed of 42 images, was taken putting the camera on the top of the sculpture (Figure 3).

The reference model was created through photogrammetric techniques using the software Photomodeler Scanner 2013 performing the classic photogrammetric workflow (camera calibration, image orientation, calculation of point clouds and 3D model). The photogrammetric orientation provided a RMS of about 0.48 pixels in the image coordinates and of about 0.62 mm in the object coordinates. In order to scale the photogrammetric model four calibrated bars of 300 mm (respectively indicated with a number from one to four) were placed at the four sides of the head. Two bars, respectively, the 1 and 3 positioned in correspondence of the two faces, have actually been used for the operation of scaling, while the other two have been used as check





Figure 3 – Some images of the Dataset 1.

Bars	The deviations values on the lengths of the bars [mm]		
	2	3	4
Photomodeler Scanner	0.17	-	0.05
Autodesk 123D Catch	0.46	0.70	0.60
Arc3D	-	-	-
My3DScanner	-0.20	-0.60	0.20
VisualSFM	-0.09	-	0.80

Table 4 - Deviations on the lengths of the bars not used for scaling.

	Number of points	Number of triangles	Gaps [%]
Photomodeler Scanner	957.072	1.918.178	-
Autodesk 123D Catch	228.454	456.306	1
Arc3D	1.721.166	3.364.809	28
My3DScanner	425.747	773.109	8
VisualSFM	311.612	618.657	12

Table 5 - Number of points, of triangles and percentages of the gaps for the Dataset 1.

providing residuals of 0.17 mm and of 0.05 mm respectively. The 3D model was calculated with a step of 1.5 mm, using 20 stereopairs.

The models calculated with the 3D web-services and VisualSFM have been converted into an exchange format and managed with Geomagic and CloudCompare software (<http://www.danielgm.net/cc/>) to perform metric comparisons. The calibrated bars not used to scale the 3D models were measured and used as check; the residuals values for almost all the models were below the millimeter thus highlighting that the models seem to have been scaled properly (Table 4). This check was not performed for the model generated with ARC3D since three of the four bars were reconstructed only partially.

A first analysis was carried out evaluating the number of calculated 3D points, the resulting number of triangles and the percentage of gaps of the respective polygonal surfaces. This analysis shows that there is not always an effective relationship between the number of calculated points and the 3D reconstruction quality of the object. For example, the 3D model obtained with ARC3D was the one that has shown the most significant gaps, although it is constituted by the largest number of points and triangles (Table 5).

In order to facilitate graphic representation of the comparisons with the reference model the 3D models were represented in the two main sides called “Face A” and “Face B” (Figure 6). The 3D maps resulting from the 3D comparisons with the reference model have shown that in general the distribution of the deviations was quite satisfactory in all models since the deviations were for the most part contained in the range of ± 2 mm, with the exception of the model obtained with ARC3D (Figure 7). Furthermore the areas with higher deviation values were undercut areas as the portions around the eyes, the tip of the nose and low parts or the areas in contact with the floor.



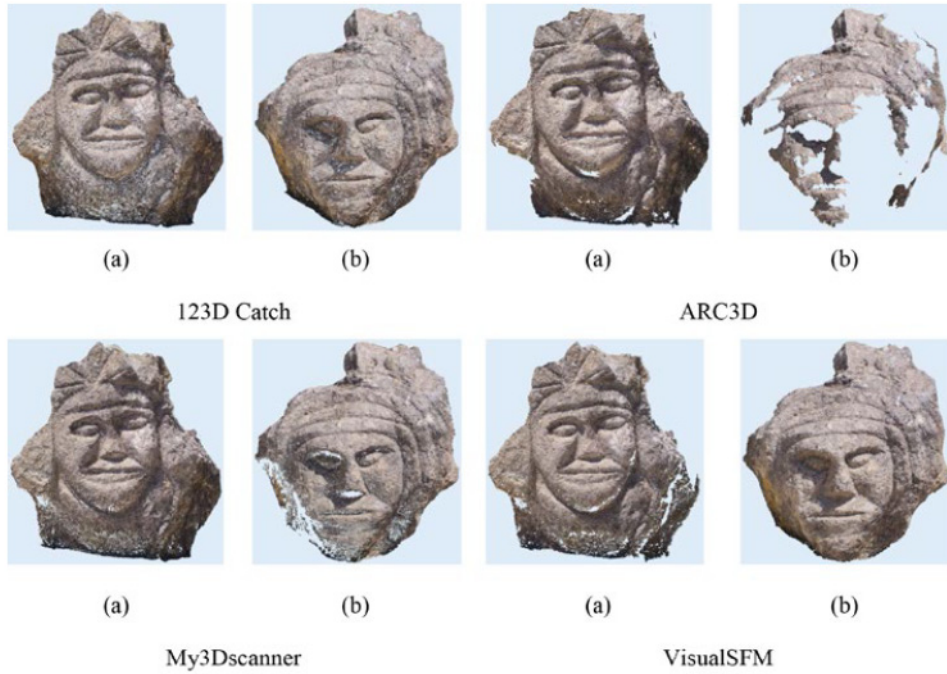


Figure 6 - Points clouds generated with 123D Catch, ARC3D, My3DScanner and VisualSFM (a) "Face A", (b) "Face B".

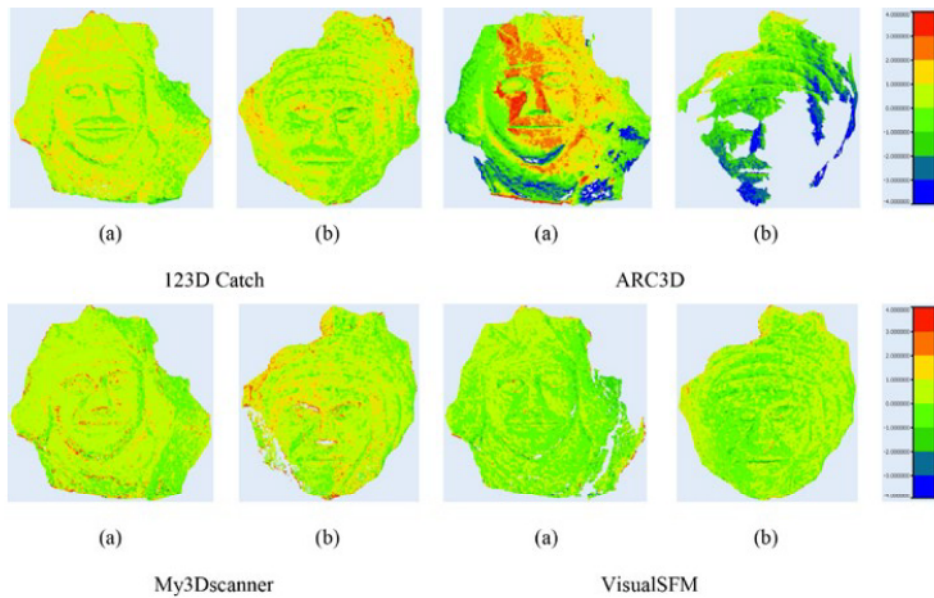


Figure 7 - Maps of the 3D comparisons with the reference model of the two faces- "Face A", (b) "Face B".



	<i>Mean [mm]</i>	<i>Standard Dev. [mm]</i>
Autodesk 123D Catch	0.46	0.70
Arc3D	0.56	1.38
My3DScanner	0.15	0.66
VisualSFM	0.00	0.55

Table 8 - Statistical values of the 3D comparisons of the Dataset 1.

The worst result was obtained with ARC3D indeed the 3D reconstruction was partial and the obtained deviations were higher than all other models with an odd distribution of the deviations especially in “Face B” where most of the values are negative. The mean and the standard deviation of the residuals have shown that the best accuracy was obtained from the VisualSfm 3D model (Table 8). Moreover the mean values obtained with the 3D web-services were always all positive and also quite significant (0.46 mm for 123D Catch and 0.56 mm for ARC3D). This condition would indicate the presence of a systematic error whose cause is difficult to identify (images orientation problems, errors of the scaling operations or alignment problems between the 3D models). However the values of standard deviation were below the millimeter in all resulting models, except for ARC3D, and then within tolerances for graphic representation of a scale of 1:2.

3.2 Dataset 2: The Arula of the Temple of Victory

The second dataset was an archaeological object that represents one of the most important finds of the collection preserved in the Archaeological Museum of Himera (near Palermo, on the northwestern coast of Sicily - Italy). The object test is an *Arula*, dating back to 480 BC, that represents a winged old man that carries the lifeless body of a young man probably a representation of the myth of Daedalus and Icarus.

The test was performed only at the surface of the low relief. The dataset was composed of 8 convergent images taken from a distance of about 1 meter (Figures 9 -10).

The reference model was obtained by laser scanning technique, using the triangulating laser scanner Minolta Vivid 9i. The scan, consisting of 26 mesh, was resampled to obtain a surface with a uniform step of 0.50 mm.

The points clouds generated with the investigated tools have a low percentage of gaps; in particular, also in this case the points cloud generated by ARC3D has the highest percentage of gaps although it is constituted of a number of points and triangles significantly higher than all the points clouds generated by the other 3D web-service (Figure 11 – Table 12).

A calibrated bar of about 170 mm, placed on the base of the *Arula*, was used to scale the models. The maps resulting from the 3D comparisons with the reference model have shown that the largest values of residuals were for the most part in correspondence of the edges of the *Arula* (Figure 13). The mean of the residuals was below the tenth of a millimeter while the standard deviation was below the millimeter (Table 14). The standard deviations were lower than the sampling step of the point cloud resulting from the laser scanning (0.50 mm) and were within tolerance for graphic representations of the scale of 1:2.

Finally further comparisons were performed by extrapolating two sections from the 3D models (Figure 15) and comparing the respective deviations with the same sections extracted from the laser scanner model (Figure 16). The AA section has shown greater deviation values present in





Figure 9 - Camera network of the Dataset 2.



Figure 10 - Some images of the Dataset 2.



Figure 11 - Points clouds of the Dataset 2.

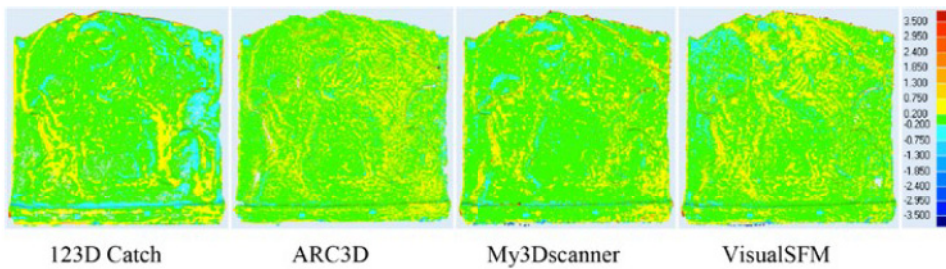


Figure 13 - Maps of the 3D comparisons with the reference model.



	Number of points	Number of triangles	Gaps [%]
Laser scanner	65.308	127.277	-
Autodesk 123D Catch	101.666	210.507	1
Arc3D	2.218.318	4.345.869	2
My3DScanner	102.700	212.947	1
VisualSFM	222.959	461.854	0

Table 12 - Number of points, of triangles and percentages of the gaps for the Dataset 2.

	Mean [mm]	Standard Dev. [mm]
Autodesk 123D Catch	0.05	0.33
Arc3D	0.03	0.32
My3DScanner	0.03	0.29
VisualSFM	0.00	0.28

Table 14 - Statistical values of the 3D comparisons of the Dataset 2.



Figure 15 - Section scheme.

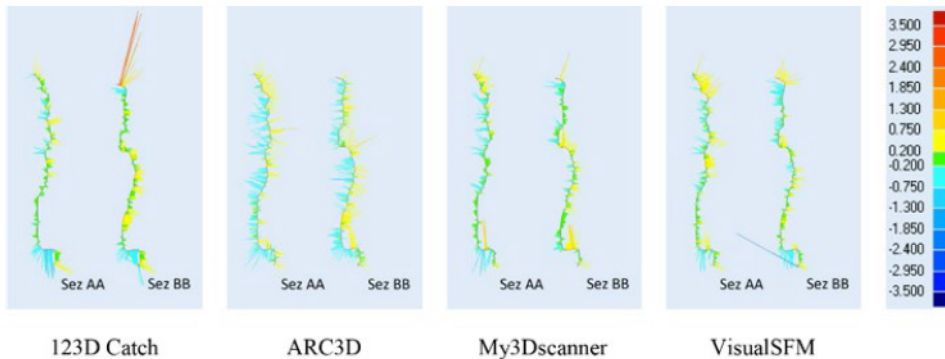


Fig. 16 - 2D comparisons between the sections extracted from the calculated 3D models and the reference model.

the protruding areas and in correspondence with changes of curvature; the section extracted from ARC3D model has displayed the greatest deviations. The BB section has shown the greatest deviation values at the edges of the *Arula*. In particular the section resulting from the comparison with 123D Catch has had odd values in the edge areas of the top part and a prevalence of positive values especially in the central part of the section; also in this case the section resulting from the comparison with ARC3D has displayed greater deviation values uniformly distributed in the entire section.



	<i>Number of points</i>	<i>Number of triangles</i>	<i>Gaps [%]</i>
Laser scanner	3.072.144	6.154.966	-
Autodesk 123D Catch	145.190	277.887	9
My3DScanner	204.471	391.387	16
VisualSFM	187.211	360.121	23

Table 20 - Number of points, of triangles and percentages of the gaps for the Dataset 3.

	<i>Mean [mm]</i>	<i>Standard Dev. [mm]</i>
Autodesk 123D Catch	0.51	14.07
My3DScanner	-0.55	9.06
VisualSFM	0.66	9.35

Table 22 - Statistical values of the 3D comparisons of the Dataset 3.

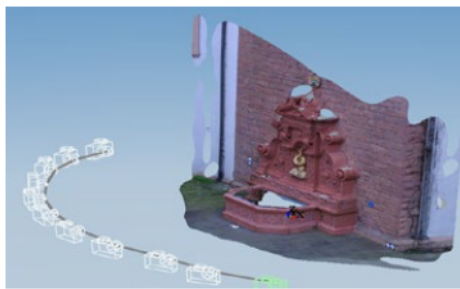


Figure 17 - Camera network of the Dataset 3.



Figure 18 - Some images of the Dataset 3.

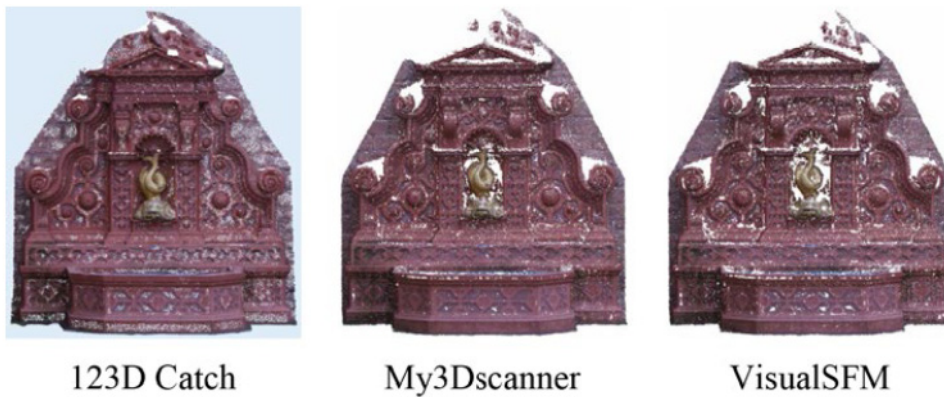


Figure 19 - Points clouds of the Dataset 3.

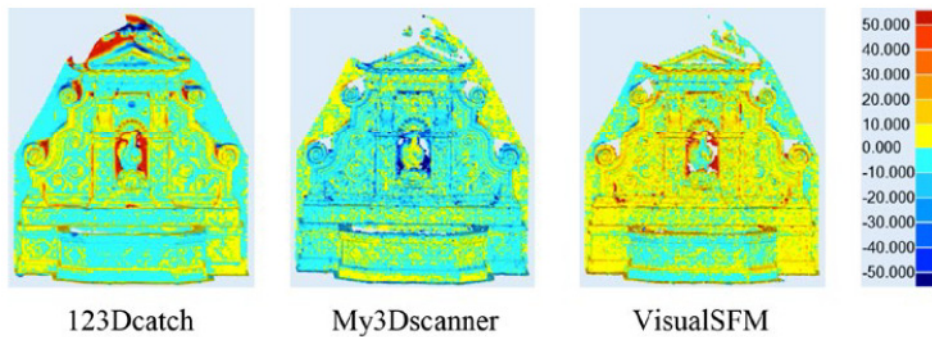


Figure 21- Maps of the 3D comparisons with the laser scanner model.



3.3 Dataset 3: The Fountain of the Dolphins

The object of the third test was the dataset called “Fountain-P11” available on the website <http://cvlabwww.epfl.ch/data/multiview/denseMVS.html> for metric checks concerning dense multi-view stereo matching (Strecha *et al.* 2008). The dataset was constituted of 11 convergent images of the Fountain of the Dolphins (Figures 17-18). This fountain is situated in the courtyard of the castle of the town of Ettligen in Baden-Württemberg, Germany. The comparisons were carried out using as reference a model obtained through laser scanning available on the same website.

The images were processed with 123Dcatch, My3Dscanner and VisualSFM; ARC3D was not considered in the evaluation since it created a model quite incomplete.

As can be seen from the generated point clouds (Figure 19) and from the number of points and triangles of the 3D reconstructions of each tools (Table 20) the points cloud of 123D Catch has had fewer percentage of gaps (9%) than the point clouds obtained by the other instruments although the number of points and triangles was lower.

Maps resulting from the 3D comparisons of all three datasets has shown that the larger deviations were present in areas not visible from the photos such as the central recess or undercuts areas and the recessed portions of the spirals (Figure 21).

The mean and the standard deviation were all below the centimeters except for the value of the standard deviation obtained with 123D Catch (14.07 mm). The worst result was obtained with 123D Catch while the best result was achieved with My3Dscanner. The values of standard deviation were of the order of centimeters allowing graphic representation of a scale of 1:50 (Table 22).

4. Comments and conclusion

The work represents a test of the potentialities of the image-based techniques using 3D web-services and open-source softwares to generate 3D models of real objects of small and medium dimensions.

The first and the second testes allow to state that for objects of small and medium size it is possible to obtain good results in terms of both quality and metric accuracy of 3D reconstructions. The obtained standard deviation allows the extraction of graphic representations from a scale of 1:2. Therefore for some applications and for this type of objects the considered tools could be a valid alternative to traditional photogrammetry and laser scanning techniques. The last test demonstrates that the 3D reconstruction is more problematic for medium size objects and especially for objects of great complexity. The obtained standard deviation values are within the tolerances for the extraction of drawings at a scale of 1:50; this metric accuracy is acceptable for many applications in the survey of cultural heritage but definitely not adequate for an accurate metric survey of the fountain used as a case study. For medium size objects the approach does not seem comparable in metric terms with the “classics” photogrammetric or laser scanning surveys yet.

The instruments investigated have a considerable potentiality for metric uses but it is necessary to consider some problems due to the impossibility of operator intervention to facilitate the success of the automatic process and due to the difficulty to verify the metric accuracy of the final products without reference data. Furthermore, it is important to pay particular attention to the images acquisition phase and to the camera network geometry that should be suitable for dense image-matching and chosen in relation of the characteristics of the object in order to obtain 3D reconstructions complete and without deformation. Finally, it is important to note that the performance of this instruments can be very different despite this applications are based on the same operating principles. For example all tests conducted for this work with ARC3D have proved the instability of this 3D web-service in terms of both processing capability and metric accuracy.

Authors

- Mauro Lo Brutto: Dept. of Civil, Environmental, Aerospace and Materials Engineering (DICAM), University of Palermo, Italy. mauro.lobrutto@unipa.it
- Paola Meli: Dept. of Civil, Environmental, Aerospace and Materials Engineering (DICAM), University of Palermo, Italy. paola.meli@unipa.it



References

- Callieri M., Dell'Unto N., Dellepiane M., Scopigno R., Soderberg B., Larsson L., 2011, Documentation and interpretation of an archeological excavation: an experience with dense stereo reconstruction tools, The 12th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST.
- De Reu J., Plets G., Verhoeven G., De Smedt P., Bats M., Cherretté B., De Maeyer W., Deconynck J., Herremans D., Laloo P., Van Meirvenne M., De Clercq W., 2013, Towards a three-dimensional cost-effective registration of the archaeological heritage, *Journal of Archaeological Science* 40, 1108-1121.
- Di Paola F., Inzerillo L., Santagati C., 2013, Image-based modeling techniques for architectural heritage 3D digitalization: limits and potentialities, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XL-5/W2, 2013, 555-560.
- Doneus M., Verhoeven G., Fera M., Briese Ch., Kucera M., Neubauer W., 2011, From deposit to point cloud – a study of low-cost computer vision approaches for the straightforward documentation of archaeological excavations, *Geoinformatics CTU FCE*, 6, 81-88.
- Fratus De Balestrini E., Guerra F., 2010, New instruments for survey: on line softwares for 3D reconstruction from images. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science*, Vol. XXXVIII-5/W16, 545-552.
- Inzerillo L., Santagati C., 2013, 123D Catch: efficiency, accuracy, constraints and limitations in architectural heritage field, *International Journal of Heritage in the Digital Era*, Multi Science Publishing, Volume 2, Number 2, 263-290.
- James M. R., Robson S., 2012, Straightforward reconstruction of 3D surfaces and topography with a camera: accuracy and geoscience application, *Journal of Geophysical Research*, Volume 117, F03017,
- Lo Brutto M., Meli P., 2012, Computer Vision tools for 3D modelling in Archaeology, *International Journal of Heritage in the Digital Era*, Multi Science Publishing, Volume 1, Supplement 1, 1-6.
- Moulon P., Bezzi A., 2011, PythonPhotogrammetry Toolbox: a free solution for three-dimensional documentation, *Proceedings of VI Workshop ArcheoFOSS*, Napoli, Italy, Juno 9-10, 2011, 12 pp..
- Nguyen H. M., Wünsche B., Delmas P., 2012, 3D Models from the Black Box: Investigating the Current State of Image-Based Modeling. *Proc. of the 20th International Conference on Computer Graphics, Visualization and Computer Vision (WSCG 2012)*, Pilsen, Czech Republic, June 25–28, 2012, 10 pp.
- Plets G., Gheyle W., Verhoeven G., De Reu J., Bourgeois J., Verhegge J., Stichelbaut B., 2012, Three-dimensional recording of archaeological remains in the Altai Mountains, *Antiquity* 86 (333), 884–897.
- Remondino F., 2011, Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning, *Remote Sensing*, 2011, 3, 1104-1138.
- Remondino F., Del Pizzo S., Kersten T., Troisi S., 2012, Low-Cost and Open-Source Solutions for Automated Image Orientation – A Critical Overview, *Proc. EuroMed 2012 Conference*, M. Ioannides et al. (Eds.), LNCS 7616, Springer, Heidelberg, 40-54.
- Remondino, F., El-Hakim S., 2006, Image-based 3D modelling: a review. *The Photogrammetric Record*, 21(115), 269-291.
- Skarlatos D., Kiparissi S., 2012, Comparison of laser scanning, photogrammetry and SFM-MVS pipeline applied in structures and artificial surfaces. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume I-3, 299-304.
- Strecha C., Von Hansen W., Van Gool L., Fua P., Thoennessen U., 2008, On Benchmarking Camera Calibration and Multi-View Stereo for High Resolution Imagery, *Proc. IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, 8 pp.
- Vergauwen, M., Van Gool, L., 2006, Web-based 3D reconstruction service, *Machine Vision and Application*, 17, 411-426.
- Szeliski R., 2010, *Computer Vision: Algorithms and Applications*. Springer,

