A Cost-Effective 3D Acquisition and Visualization Framework for Cultural Heritage

Hosameldin Osman Ahmed [1], Abdelhak Belhi [2,3] (✉), Taha Alfaqheri[1], Abdelaziz Bouras [2], Abdul H. Sadka[1], Sebti Foufou[4]

[1] Brunel University, London, United Kingdom
{hosameldin.ahmed2, taha.alfaqheri, abdul.sadka}@brunel.ac.uk
[2] CSE, Qatar University, Doha, Qatar
{abdelhak.belhi,houssem.gasmi,abdelaziz.bouras}@qu.edu.qa
[3] DISP Laboratory, University Lumière Lyon 2, Lyon, France
[4] Le2i Lab, University of Burgundy, Dijon, France
sfoufou@u-bourgogne.fr

Abstract.

Museums and cultural institutions, in general, are in a constant challenge of adding more value to their collections. The attractiveness of assets is practically tightly related to their value obeying the offer and demand law. New digital visualization technologies are found to give more excitements, especially to the younger generation as it is proven by multiple studies. Nowadays, museums around the world are currently trying to promote their collections through new multimedia and digital technologies such as 3D modeling, Virtual Reality (VR), Augmented Reality (AR), serious games, etc. However, the difficulty and the resources required to implement such technologies present a real challenge. Through this paper, we propose a 3D acquisition and visualization framework aiming mostly at increasing the value of cultural collections. This framework preserves cost-effectiveness and time constraints while still introducing new ways of visualization and interaction with high-quality 3D models of cultural objects.

Keywords: Cultural Heritage, Deep Learning, Artificial Intelligence, 3D Modelling, CEPROQHA Project, 3D Interaction, Motion controller.

1 Introduction

Art and culture are the essence of humanity as they pack a lot of historical information that cannot be found elsewhere. Cultural artifacts are distinguished by their variety, shape, type, and value. Hence, the preservation of cultural heritage is an important process to curate and maintain these assets along with their provenance information for current and future generations. However, the physical preservation of these assets is a tedious and delicate process that requires a lot of time, resources and needs to be undertaken by highly skilled professional curators. As a cost-effective and reliable way for art and culture preservation, digital technologies offer additional ways to preserve and further give more value and excitement around cultural heritage [1-3]. A lot of effort was undertaken to provide Information Technology (IT) solutions in the cultural domain. Some of the existing applications are geared towards digital preservation and the documentation of collections to ease the management and retrieval of assets. Other applications focus mainly on the end-user experience with innovative ways to increase the value and attractiveness of assets using latest data acquisition and visualization technologies such as 3D, VR, AR and other immersive technologies to enable new ways of content consumption in the domain of cultural heritage.

In this paper, we mostly focus on technologies related to 3D imaging acquisition, visualization and content consumption focusing on a specific use case related to interaction with museum objects. A high-value cultural asset is often put in a glass box, under a certain type of lighting conditions and with limited interaction. This traditional exhibition scheme seems not to attract younger people and is often reported to be "boring". Several 3D visualizations and interaction frameworks exist in this context, but their generalization is costly. The 3D modeling of assets takes a considerable amount of effort and requires the use of expensive hardware. Through this paper, we aim at tackling this challenge of 3D content acquisition, adaptation, and visualization using consumer-level hardware offering a more cost-effective yet attractive framework to allow 3D visualization and interaction with high-value museum assets. In this framework, first, a Digital Single Lens Reflex (DSLR) camera, lighting setup and a basic turntable are used for the 3D content acquisition. Then, our framework uses photogrammetry as the main technology to model 3D cultural objects. Some optimizations are introduced to this process where artificial intelligence techniques such as super-resolution and motion interpolation are used to generate high-resolution input images for the photogrammetry process. Finally, for the interaction with the created 3D cultural objects, a leap motion controller is used to capture end-user hand motion, this motion is then translated into controls that are used to interact in real-time with the generated 3D model allowing 360° rotation, movements, and zoom actions with the asset [4].

The rest of this paper is organized as follows. In section two, we present the works related to the 3D acquisition, visualization and interaction with cultural heritage assets. In section three, we present the methodology and the implementation steps of our framework focusing mostly on data acquisition, data preprocessing, photogrammetry and motion interaction. Section four concludes the paper and outlines some perspectives of future work.

2 Related work

The digitization of cultural heritage plays an important role in long-term preservation as it is more reliable and less difficult to implement and maintain assets in a digital form. As an added challenge, museums and heritage institutions want to promote their collections using new digital content consumption techniques especially to attract visitors and to give more value to their collections. In this regard, a lot of work has been undertaken for the design and implementation of 3D acquisition and visualization technologies for cultural heritage serving a wide range of use cases. In this work, our primary focus is for application dedicated to exhibitions in addition to end-users and not for professional applications as the system requirements for later are usually strict about quality and do not necessarily focus on cost-effectiveness and interaction which are the main drivers behind our study.

Most of the 3D acquisition techniques fall into two main categories: laser scanning and photogrammetry. For cultural heritage, several works [5-9] have addressed this challenge. Of these techniques, laser scanning seems to attract more wealthy institutions that aim at achieving the best possible quality. Thus, the applications of laser scanning for cultural heritage are mostly for extremely valuable assets. The most iconic scanner used in this context is the CultLab3D developed in Germany [6] where costs per scan are around 1000 USD. Other solutions such as shape from a stereo, shape from motion, shape from shading and shape from silhouette are used as cost-effective alternatives [10]. Our focus in this paper goes to two of these methods: Shape from motion and shape from a silhouette. These two methods are reported to give average results in terms of quality when used in an uncontrolled environment while still achieving the best cost-effectiveness.

For end-user interaction, many approaches that implement the concept of virtual museums have been proposed. These solutions try to reconstruct an immersive museum visit experience by modeling museum architecture as well as assets [11]. Other approaches use virtual reality headsets and motions controller to provide a more immersive experience for end-users [12].

3 Methodology

In this section, we present the design and implementation details of our cost-effective cultural 3D acquisition, pre-processing, visualization and interaction framework. As shown in **Fig. 1**, the proposed framework consists of five main stages, these include data acquisition, preprocessing, photogrammetry, 3D model adaptation, and motion-based 3D visualization. The following subsections discuss these stages in more detail.

3.1 Data acquisition

The data acquisition stage is crucial for our framework as high-quality images are required for the process of photogrammetry in order to generate good 3D models of the assets. The registration accuracy of the object geometry depends on the object texture and size.

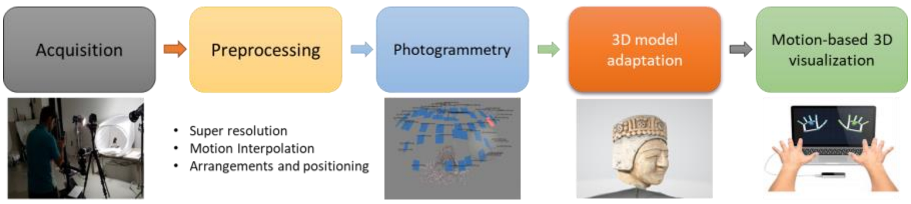

Fig. 1. From data acquisition to display and interaction

The capturing equipment includes lighting photographer stands, lighting box, measuring distance device, and semi-professional 2D camera. **Fig. 2** shows the data acquisition setup for data registration. To get good quality capturing results, all the capturing equipment is installed and configured in the best possible way.

In the camera setup, the camera is positioned into three different angles. The angle degree of the camera position is set to (45°) as depicted in **Fig. 3**. More details on the pre-processing step are presented in section (3.2). The captured data set includes 13 assets with different surface materials and sizes using the same capturing conditions.

Fig. 2. Capturing setup in Museum of Islamic arts/ media digital lab in Qatar

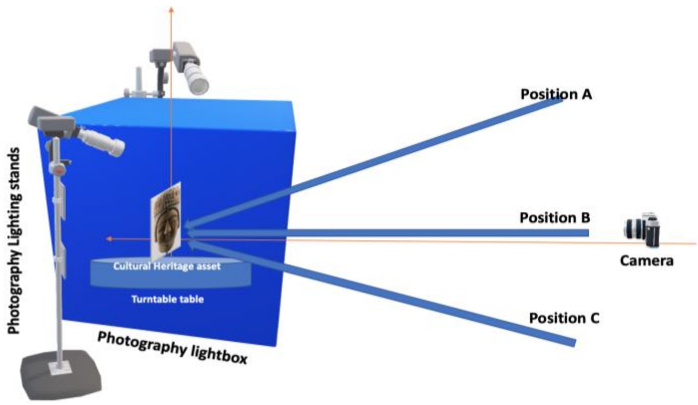

Fig. 3. Camera position setup

3.2 Data preprocessing

After performing the data acquisition using the setup presented in the previous section, a preprocessing step is required in order to filter, enhance the quality and organize the captured visual content to be used for the 3D model generation. Photogrammetry has the main advantage of not requiring expensive 3D scanning hardware as it only works on single 2D images captured using a 360° shooting setup. However, if one or some of the captured pictures do not meet the strict quality, positioning and environmental parameters required, the whole 3D modeling process will most likely fail.

As a result, to preserve cost-effectiveness while still having good quality results, we use super-resolution and motion interpolation as software-based solutions to enhance the quality of the acquired image and generate more frames for the photogrammetry process as shown in **Fig. 4**.

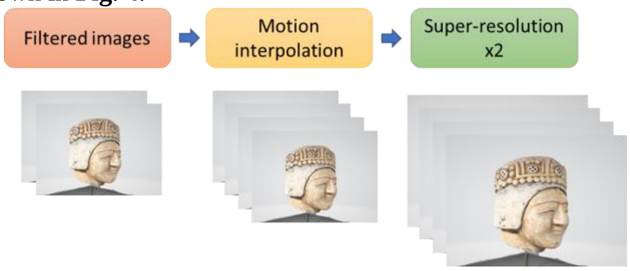

Fig. 4. Data preprocessing stages

3.3 Photogrammetry and 3D model adaptation

Photogrammetry is a technique for generating 3-dimensional shapes through the analysis, measurements, and interpretations from a group of images acquired using a set of strict guidelines.

For our framework, we compared two of the most used tools for photogrammetry in the context of cultural heritage: Autodesk Recap Photo (**Fig. 5**) and AgiSoft PhotoScan (**Fig. 6**). Both performed almost similarly but using our setup, Autodesk recap photo yielded consistent results.

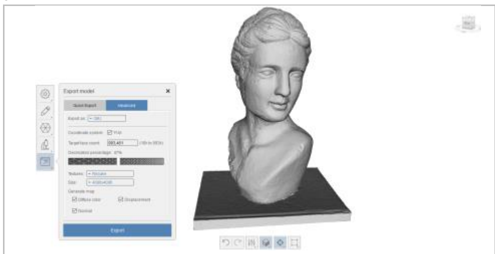

Fig. 5. Photogrammetry using Autodesk Recap Photo

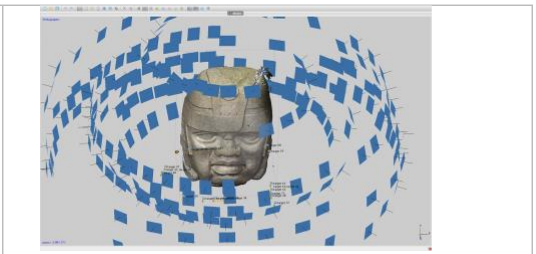

Fig. 6. Photogrammetry using AgiSoft PhotoScan

Once preprocessed, the images are put into the Recap photo software, the 3D model is then generated using the Autodesk Cloud service. After that, the 3D models are tweaked using the provided tools and exported to either OBJ or FBX formats.

3.4 3D visualization and interaction

The 3D models created using our proposed framework can be utilized as virtually reinstated forms of the original Cultural Heritage (CH) assets to be presented in virtual museums and for further advancement of historical research and education. For the presentation of these 3D models, we utilized Unity 5.6 software in our framework for visualization and interaction of the produced models. Recently, there has been an increased interest in Virtual Reality (VR) techniques for various applications due to the developments in the field of VR. An important example of these applications is the virtual museum installation. Hence, to facilitate human interaction to the virtual reality of the acquired 3D models, we have used the LEAP motion controller (see **Fig. 7**) that can provide an informative representation of hands and fingers motion. The device has two infrared cameras that work to track the user's hands. The device was designed to allow integration with a wide range of platforms without too much hassle for developers as it is shipped with a high-level API that simplifies application development. Using this setup, one can interact with the acquired 3D model of the CH assets.

Fig. 7. Leap Motion Controller (https://developer.leapmotion.com/)

It is now well established from a variety of studies, that recent human-computer interaction (HCI) techniques are based on computational vision owing to its capability to track and recognize human gestures typically. Commonly, these techniques employ images taken from a camera or a stereo pair of cameras to determine the hand pattern at each time instant [13, 14].

In our proposed framework we have developed a visualization and interaction system that can help researchers and museum visitors to interact with the created 3D objects more simply and practically. Our system consists of a laptop, Leap motion controller, Unity 3D software and C# programming language. The 3D object visualization comprises preprocessing object data by assigning different attributes through inspector and C# to control the location, rotation, scale of the 3D object in Euclidean X/Y/Z space, adding collider, i.e., boundary, to the simulated 3D, control how the model is displayed via mesh render, creating and applying material to the model that contains the texture information. The leap motion controller is used to track the motion of bare hands to allow natural interactions with a 3D object in a controlled area. The Leap Motion controller includes three infrared emitters and two infrared cameras that can be used to track the image of the hand. Then, based on this tracking the controller extract information and transmit it to the laptop to be used by the unity 3D software for the interaction with the targeted object. In our system, the extracted information is used to present virtual hands that can be used to interact with the object including, turning, moving, grasping, zooming, pushing forward and backward.

To test our system, ten users used the Leap Motion controller to interact with a 3D head model using virtual hands presented in 3-dimensional virtual space as can be seen in **Fig. 8**. The test results indicate that the users found the practice positive and that it was easy for them to interact with the targeted 3D object. **Fig. 8** also displays screenshots from various interaction types with a 3D head model.

Fig. 8. A user using the proposed visualization and interaction system

4 Conclusion

In this paper, we presented the design and implementation details of a framework dedicated to the acquisition, processing, 3D model generation, 3D model visualization and human interaction of digitized 3D models of cultural heritage. The framework was mainly designed to address cost-effectiveness concerns as well as to minimize the time required to digitize and generate 3D models of cultural heritage objects. Preliminary results show that the framework achieves good quality results due to the use of artificial intelligence techniques to perform super-resolution and motion interpolation on the acquired data before the generation of 3D models using photogrammetry. In future work, we aim at improving its quality and usability and conduct further testing and result validation for more types of assets.

Acknowledgement

This publication was made possible by NPRP grant 9-181-1-036 from the Qatar National Research Fund (a member of Qatar Foundation). The statements made herein are solely the responsibility of the authors (www.ceproqha.qa).

The authors would also like to thank Mr. Marc Pelletreau, the MIA Multimedia team, the Art Curators and the management staff of the Museum of Islamic art, Doha Qatar for their help and contribution in the data acquisition.

References

1. Belhi, A., Bouras, A., Alfaqheri, T., Aondoakaa, A.S., Sadka, A.H.: Investigating 3D holoscopic visual content upsampling using super-resolution for cultural heritage digitization. Signal Processing: Image Communication 75, 188-198 (2019)

2. Belhi, A., Gasmi, H., Bouras, A., Alfaqheri, T., Aondoakaa, A.S., Sadka, A.H., Foufou, S.: Machine Learning and Digital Heritage: The CEPROQHA Project Perspective. In: Fourth International Congress on Information and Communication Technology, pp. 363-374. Springer, (2018)
3. Belhi, A., Bouras, A., Foufou, S.: Towards a hierarchical multitask classification framework for cultural heritage. In: 2018 IEEE/ACS 15th International Conference on Computer Systems and Applications (AICCSA), pp. 1-7. IEEE, (2018)
4. Belhi, A., Bouras, A., Foufou, S.: Digitization and preservation of cultural heritage: The CEPROQHA approach. In: Software, Knowledge, Information Management and Applications (SKIMA), 2017 11th International Conference on, pp. 1-7. IEEE, (Year)
5. Scopigno, R., Callieri, M., Cignoni, P., Corsini, M., Dellepiane, M., Ponchio, F., Ranzuglia, G.: 3D models for cultural heritage: beyond plain visualization. Computer 48-55 (2011)
6. Singh, G.: CultLab3D: digitizing cultural heritage. IEEE Computer Graphics and Applications 34, 4-5 (2014)
7. Pavlidis, G., Koutsoudis, A., Arnaoutoglou, F., Tsioukas, V., Chamzas, C.: Methods for 3D digitization of cultural heritage. Journal of cultural heritage 8, 93-98 (2007)
8. Stanco, F., Battiato, S., Gallo, G.: Digital imaging for cultural heritage preservation: Analysis, restoration, and reconstruction of ancient artworks. CRC Press (2011)
9. Belhi, A., Foufou, S., Bouras, A., Sadka, A.H.: Digitization and Preservation of Cultural Heritage Products. In: IFIP International Conference on Product Lifecycle Management, pp. 241-253. Springer, (2017)
10. Gomes, L., Bellon, O.R.P., Silva, L.: 3D reconstruction methods for digital preservation of cultural heritage: A survey. Pattern Recognition Letters 50, 3-14 (2014)
11. Bastanlar, Y., Grammalidis, N., Zabulis, X., Yilmaz, E., Yardimci, Y., Triantafyllidis, G.: 3D reconstruction for a cultural heritage virtual tour system. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Beijing 37, 1023-1028 (2008)
12. Gonizzi Barsanti, S., Caruso, G., Micoli, L., Covarrubias Rodriguez, M., Guidi, G.: 3D visualization of cultural heritage artefacts with virtual reality devices. In: 25th International CIPA Symposium 2015, pp. 165-172. Copernicus Gesellschaft mbH, (2015)
13. Manresa, C., Varona, J., Mas, R., Perales, F.J.: Hand tracking and gesture recognition for human-computer interaction. ELCVIA Electronic Letters on Computer Vision and Image Analysis 5, 96-104 (2005)
14. Weichert, F., Bachmann, D., Rudak, B., Fisseler, D.: Analysis of the accuracy and robustness of the leap motion controller. Sensors 13, 6380-6393 (2013)