Journal of Physics: Conference Series

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To cite this article: C. Daffara *et al* 2022 *J. Phys.: Conf. Ser.* **2204** 012077

Focus-stacking system for 3D acquisition of sculptures and archaeological manufacts

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Abstract. In this paper we present the basic features of the Shape from Focus techniques and discuss the potentiality of its application in the 3D imaging of small sculptures and archaeological manufacts. A scanning system for optimizing the image stack acquisition in laboratory was assembled, while 3D reconstruction was done in ImageJ.

1. Introduction

Born in the industrial field for production and quality control, the 3D measurement of an object gained great importance in many fields, from robotics to anthropometry and reverse engineering [1, 2]. In particular, optical systems are widely applied because of their non-invasive nature and high accuracy. The rapid evolution of hardware and software tools (CAD modeling, image processing) and the "digital revolution" have led to the spread of increasingly powerful and versatile techniques [3, 4, 5, 6, 7].

Many of these techniques can also give important contributions in the Cultural Heritage field [8], from the typical applications in artwork diagnostics [9] up to the recent 3D printing of artworks, also used for inclusive tactile fruition [10].

In this paper we propose the Shape from Focus (SFF) technique as a tool for 3D imaging of small sculptures and archaeological manufacts. SFF has great versatility, when adapted to cultural heritage applications it exhibits peculiar features and potentialities.

Figure 1 shows a sketch of the optical setup to perform SFF at a macroscopic scale and a photograph of the system working in the OpDATeCH (Optical Devices and Advanced Techniques for Cultural Heritage) Lab of the University of Verona (Italy).

The optical unit, a CMOS camera, is centered on the region of interest and mounted on a motorized vertical slit, the motor is controlled via a PC. Once acquired the 2D stack, the 3D shape is reconstructed in the image processing platform ImageJ.

In the following, after a brief description of the background and acquisition technique, preliminary results on cultural heritage objects at the macro-scale (tens of centimeters) are given.

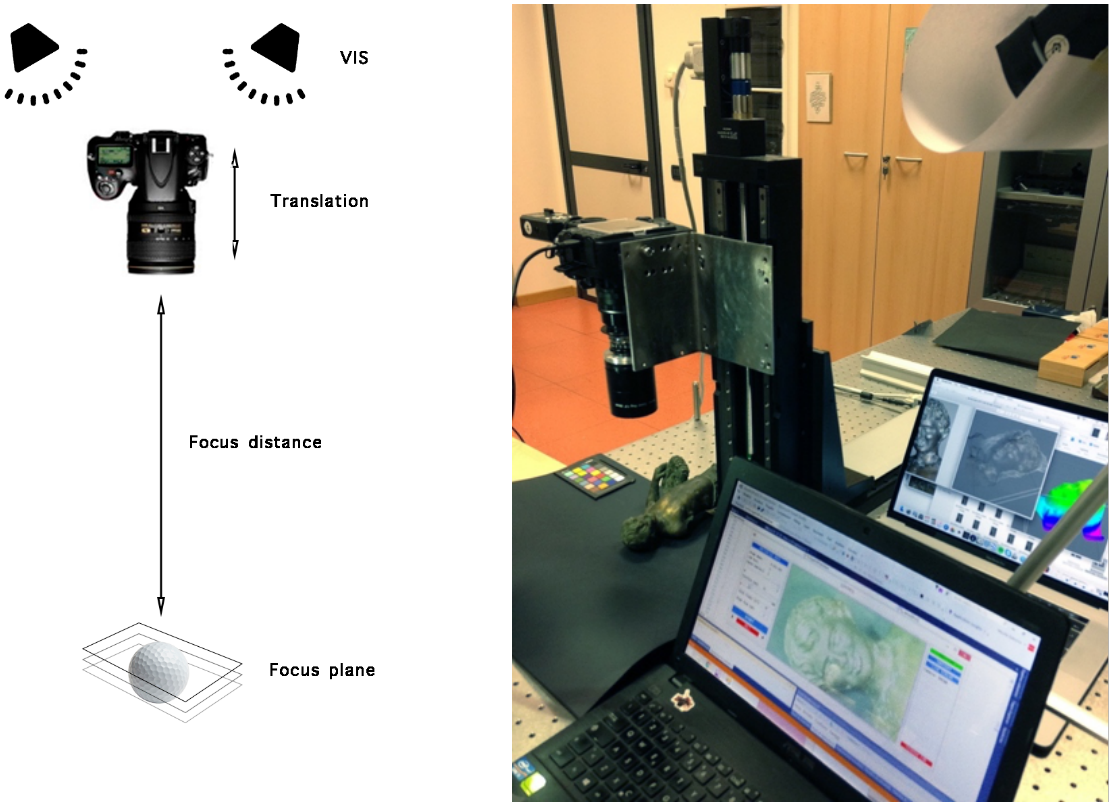

Figure 1. SFF experimental setup: sketch (left) and system during the measurement (right).

2. Basic principles

Shape from Focus was early introduced [11] as a method to obtain shape information from rough surfaces. SFF is a widely used technique, especially at microscopic level while applications at macroscopic level are relatively recent [12]. To the best of our knowledge, there have been very few applications in cultural heritage, once again generally at the microscopic level [13, 14]. Basically, SFF produces 3D maps based on a stack of 2D images, obtained by varying the camera-object distance. Changing this distance with a constant step while keeping aperture and focal length fixed, assures constant magnification [11]. Conversely, the sequence of images can be exploited to obtain a fully focused image, as shown in literature [15].

As can be seen in Figure 2, a focus plane “slicing” the object is defined by the sensor-optics configuration and easy modelled in optical geometry approach. Surface elements are focused when lying on this plane, which position is known with respect to the initial reference; moving the elements along the optical axis causes defocusing. The depth distance (then surface height Z) can be associated to the surface element position XY, locally in the image frame, after application of a best focus algorithm to the image stack. Different operators are used to evaluate the sharpness of the pixel in a neighbourhood [16].

3. Test methodology and experimental results

A feature of SFF is the possibility to choose the optical unit from the commercially available cameras. In this work, SFF on artworks was validated using the setup of Figure 1 and a Nikon camera with a full-frame 36 megapixel CMOS sensor. The camera was equipped with an 80mm Nikon lens. The depth of field was set to 2 mm. The camera was mounted on a motorized precision position system with micrometric accuracy, triggering the shots. Figure 3 shows an

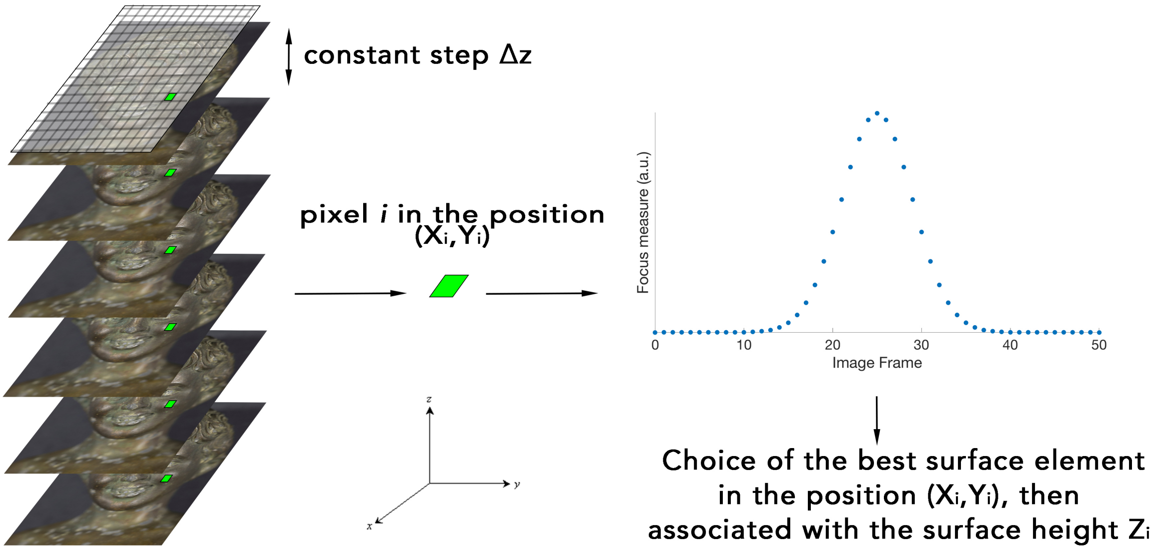

Figure 2. Sketch of the SFF basic principles.

excerpt of the image stack. The test object was a small-sized (scale of ten centimeters) metal sculpture, partially visible in Figure 1, right. The basic idea of SFF can be appreciated: only some regions are in focus.

Figure 3. Different images from the image stack. Only the information of the regions in focus are used for the 3D reconstruction.

An example of the final reconstruction is given in Figure 4.

In order to test the reliability of the proposed technique, we acquired the shape of the object with a high precision laser depth sensor mounted on the same motorized precision position system. We employed a line-of-sight profilometry setup [17] in order to construct the same kind of surface modeling (some time called 2.5D) representing a ground truth dataset. An interferometric probe based on conoscopic holography was used to measure the surface heights

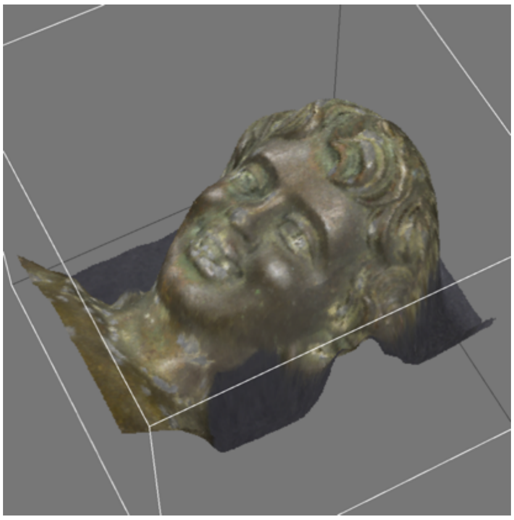

Figure 4. Final 3D reconstruction by SFF with the texture.

with an accuracy down to the micrometer. The probe was equipped with 200mm focal lens, allowing to acquire a depth range of 125 mm at a standoff distance of 200 mm. The motorized position system allowed to create a high precision spatial grid of heights measurement from which the surface can be reconstructed. Here, the step of the grid was set at 50 µm. Figure 5 shows the comparison between the two 3D reconstruction.

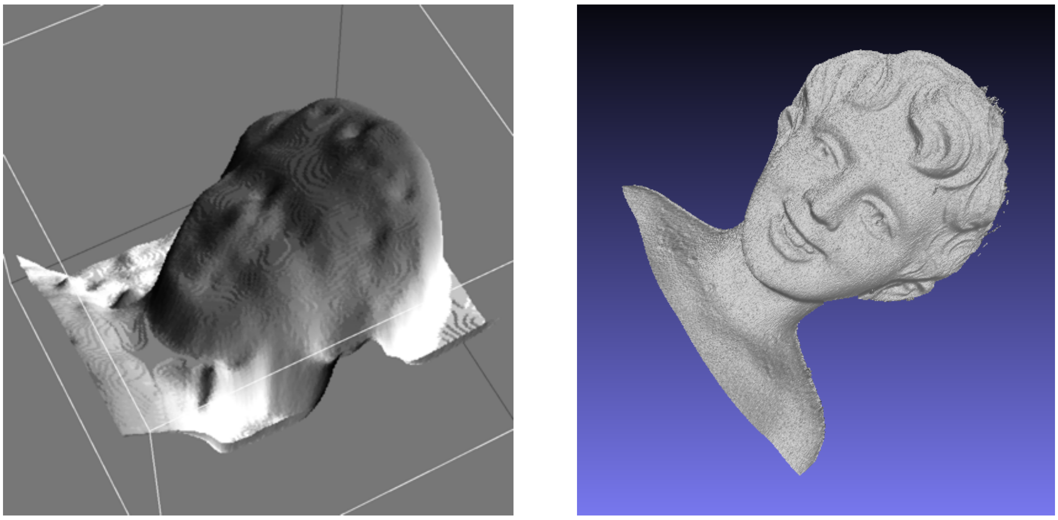

Figure 5. 3D shape reconstructed by SFF from raw data (Z) the without the texture and visualized with ImageJ (left). 3D ground truth micrometric reconstruction by the line-of-sight profilometer and visualized with MeshLab (right).

In the case of the SFF the lateral resolution (in the XY plane) is determined by the pixel size at the object plane and the reconstruction algorithm, while the the height (Z) resolution is given by the depth of field of the optical system with a positioning accuracy ensured by the stages. As reported above, the optical profilometer allows to reach a micrometer accuracy in the Z dimension provided the time-consuming measurement (in the order of hours). On the other hand, the proposed SFF method allows a fast reconstruction (order of minutes) of the shape on the condition of a lower resolution but with the advantage to visualize also the texture.

4. Conclusions

In this paper we proposed the use of the Shape from Focus (SFF) technique for 3D imaging of cultural heritage objects. Some experimental results demonstrate the feasibility of the proposal. SFF has the advantage of being monocular and collinear, thus no shadowing effects (induced by rough surfaces) can occur. Furthermore, the technique can be adapted to many different situations because of the very wide choice in cameras and lenses. Commercial DSLR, calibrated DSLR, industrial cameras and so on can be used as optical units. A clear shortcoming is that the depth resolution is low, compared to established techniques such as profilometry by conoscopic holography. However, these better performing techniques may exhibit problems in out-of-laboratory conditions and their cost is usually very high. Therefore, SFF can be an interesting solution for field use if its inherent resolution is suitable for the selected application.

5. Acknowledgments

The authors thank Vittorio Barra, formerly at University of Verona, for the scientific photography.

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