

APPLICATION OF PHOTOGRAMMETRY FOR DIGITIZING INFORMATION ABOUT CULTURAL HERITAGE IN THE FORM OF DISPLAY HOLOGRAMS

E. V. Rabosh*, N. S. Balbekin, A. V. Mezhenin, N. V. Petrov

ITMO University, St. Petersburg, 197101, Russia

Commission II, WG II/8

KEY WORDS: Photogrammetry, Digitizing, Display holography, Cultural heritage, Analog-digital conversion, 3D reconstruction.

ABSTRACT:

The aim of this article is to demonstrate the possibility of using photogrammetry as a method for documenting and digitizing data reconstructed from a display hologram. We discuss the importance of the task of digitizing information from holograms and the search for its solution, which will allow display holography to gain new distribution. Textured point clouds were obtained for the object and for its image reconstructed from the display reflective type hologram using monochromatic radiation. The requirements for the experimental setup for the digitization of the reconstructed from hologram object wavefront, as well as for the number of photographs for the hologram capturing are formulated and explained. The calculated three-dimensional models of the object and the reconstructed object wavefront were compared according to the Pearson correlation criterion. The achieved correlation value is 0.903. The results of comparison of two 3D models in the estimation of the standard deviation are given.

1. INTRODUCTION

The accelerating development of science and technology makes it possible not only to fully understand the world around us, but also to reliably preserve the knowledge and artifacts of ancient times. With the improvement of computer technology and digital optical imaging systems, methods for digitizing and storing information receive a new impetus in their development: light-sensitive CMOS matrices reach resolutions up to 150 MP (Kemper and Kemper, 2020; Sukhavasi et al., 2021), the latest laser scanners such as Light Identification Detection and Ranging (LIDAR) were made to ensure security workflow and efficient monitoring of the atmosphere, cloud storage today allows a person to store terabytes of data (Spillner et al., 2013) without using their own solid state drives. At the same time, the volume and performance are growing, and, accordingly, the frequency of use of solid-state drives. All these mentioned tools and technologies are used in a wide range of areas, this is the reason for the ever-increasing demand for systems with the ability or potential to store big data. These areas include, first of all, image processing, the gaming industry, web applications, virtual reality, streaming services, tools for complex calculations (Gama et al., 2019; Kaur et al., 2018; Mekuria et al., 2018; Puig et al., 2020), and the museum industry. As for the latter area, it is already well known that many museums around the world use interactive installations (Vaz et al., 2017), conduct online tours, and implement augmented reality (Ch'ng et al., 2019) and neural network technology to collect and store (Doulamis and Varvarigou, 2012; Lis-Gutiérrez et al., 2019; Muthanna et al., 2018) large amounts of museum content in digital format. The transfer of analog information to digital format is carried out through the use of techniques such as laser scanning (Galushkin et al., 2019), photogrammetry (Mccarthy, 2014). The latest technology is actively used, in addition to museum exhibits (Ballarin et al., 2020), in the field of restoration of memorial

buildings (Pavlidis et al., 2006) and complexes, archaeological sites (Vlachos et al., 2019). Moreover, photogrammetry is more common for solving such problems since it is simpler and less expensive than laser scanning (Gerbino et al., 2004). Popularization of the cultural and historical heritage and knowledge that has been accumulated by mankind throughout its existence in a new format is carried out by integrating digital technologies into many areas of human activity, in particular, in the museum industry. All this contributes to attracting audiences of different ages and fields of activity and brings museums to a new level of development.

Until now, the museum, as a cultural center, remains a massive repository of especially valuable objects (Agostino and Arnaboldi, 2021; Latham and Simmons, 2019; Ward, 2020), which means that strict requirements are imposed on the process of archival preservation of exhibits (Belhi et al., 2019). Unfortunately, modern digital storage media are not yet very suitable for archival storage of large amounts of data. For comparison, the service life, and the number of rewriting data on hard drives are limited: up to 5-10 years and up to 1000 times, respectively (Lin and Emami, 2018; Narayanan et al., 2016). Cloud storage, in turn, cannot be a completely resilient system due to unauthorized access attempts (Balakrishnan et al., 2021; Shamshirband et al., 2020) and malicious activities. In contrast to digital instruments and their characteristics, we take as an example optical holography, namely the method of both registration a wavefront reflected by an object and reconstruction and preservation information in the form of analog reflection-type holograms.

Analog holography is a well-known method for storing large amounts of data (Collier et al., 1973), which has found its application in the field of optical information processing, optical instrumentation, interferometry, non-destructive testing of

* Corresponding author.

E-mail address: rabosh.ev7@gmail.com (E. Rabosh)

products, and the manufacture of optical clones. In this study, we further omit the concept of *analog holography* and talk about *display holography* as one of the sections of analog holography. Display holography has found its niche in the museum field. The rapid development of display holography began when, in the late 60s. of the last century, John Asmus was one of the first to suggest recording volumetric display holograms of museum exhibits in order to demonstrate holograms outside the location of the object itself (Asmus et al., 2016). However, display holography does not have a large-scale application today since analog data carriers are being replaced by digital ones. Also in the museum industry, there is a trend towards the presentation of information in digital format and the need for appropriate information transformation technologies. These technologies should provide a detailed conversion of information about the shape of the surface, about the relief, the color of the object, and all this into a digital image of the object. To some extent, this is a creative process that requires interdisciplinary knowledge and skills. Many of the digital technologies cannot provide an image that is identical to the object itself. However, as regards display holography, the production of volume holograms is realized on light-sensitive high-resolution materials (Bruder et al., 2017; Gentet et al., 2017), the information capacity of which exceeds the capacity of most existing media. When recording holograms, the transmission of the smallest details of an object with high resolution is achieved, since the resolution of holographic photosensitive media exceeds the resolution of matrix photodetectors by 1–2 orders of magnitude. With all these advantages of display holography and holographic materials, there is a serious disadvantage. This disadvantage is associated with the lack of methods for digitizing information from holograms for the tasks of precision quantitative analysis and data processing by digital means. As a consequence, it is precisely this shortcoming that holds back today's development of display holography.

In this study, we report the application of photogrammetry as a method for digitizing an object wavefront. Progress in this area will contribute not only to the widespread use of display holography, but also to the development of new areas of application of photogrammetry.

2. OBJECT OF STUDY

On the example of a 7.7 cm high ceramic vase (Figure 1), we can analyze the possibilities and numerical results of the proposed combination of display holography and photogrammetry techniques. The object is decorated on both sides with a pattern, fragments of which are used in this study. The object is static, and the material of the vase is ideal for recording a reflection type hologram. Therefore, on the basis of the created model, which is the digital twin of the object, it is possible to analyze the quality of the output data obtained by the photogrammetry method.

3. METHODS AND INSTRUMENTS

3.1 Hologram recording

The hologram of the object was recorded according to the scheme of Yu. N. Denisyuk, a Soviet and Russian physicist who discovered to the world a method for recording three-dimensional images of an object wave front reflected from an object, according to the scheme in colliding beams (Denisyuk, 1972; Denisyuk and Sukhanov, 1970), (Figure 2).



Figure 1. The photograph of object Vase.

A diode-pumped solid-state laser was used as a radiation source (DPSS-laser) with wavelength $\lambda = 640$ nm. Monochromatic high-resolution photographic plates for holography (PPH-03M plates 102×127 mm manufactured by LLC TD “Slavich” (PPH-03M, n.d.)) were used as a photosensitive material. PPH-03M is a thick halide-silver composition designed for recording counter directional reflective type of holograms sensitized to radiation in the red region of the visible frequency range of the electromagnetic spectrum.

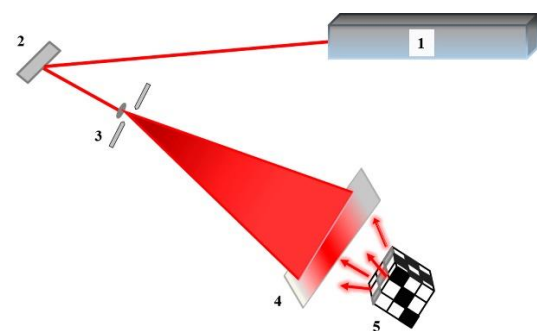


Figure 2. The schematic diagram of the recording of display holograms by the method of Yu. N. Denisyuk: 1 - laser, 2 - mirror, 3 - pinhole microlens system, 4 - photosensitive plate, 5 - object.

3.2 Digitizing process

The object and the object hologram were shot with a Canon EOS 1100D camera with a central shutter with the following characteristics: CMOS-matrix 4272×2848 pixels, lens focal length 35 mm. Figure 3 shows the photogrammetry scheme of the object, top view. The object was placed on a motorized rotation stage, the camera was set at a distance of 25 cm from the object. 40 photographs of the object were obtained with a translator rotation step of 19.75°.

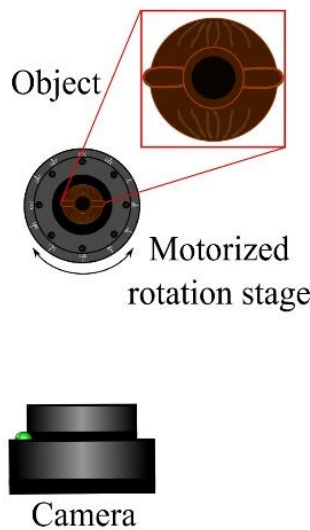


Figure 3. The setup of object digitization, top view.

In the case of a hologram, the photogrammetric installation is complicated by the fact that in order to accurately restore the object image without visible distortions and deformations on the hologram, it is necessary to install and fix the light source above the hologram at an angle equal to the angle of incidence of the laser radiation when recording the hologram (see Figure 2). When photographing, this limitation can contribute by adding flare to photographs. This problem has a solution, but we do not consider it in this paper.

The structure, consisting of a hologram and a light source, is stationary, and the camera moves relative to it, taking photographs in several planes (Figure 4 and 5) along the azimuthal angle. The main task of hologram photogrammetry is to obtain the maximum possible number of photographs of the recovered information from the hologram. For this object, we received 40 photographs without distortion.

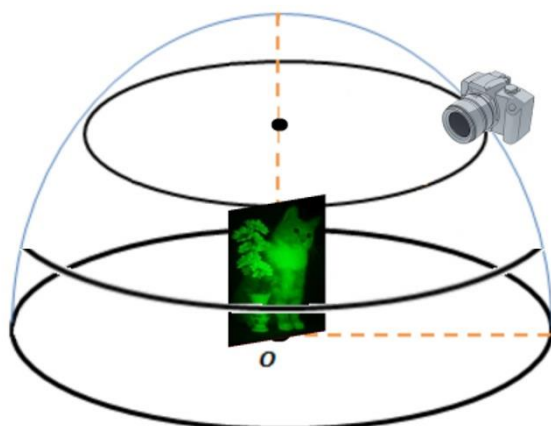


Figure 4. The schematic image of hologram photogrammetry from two levels of camera height.

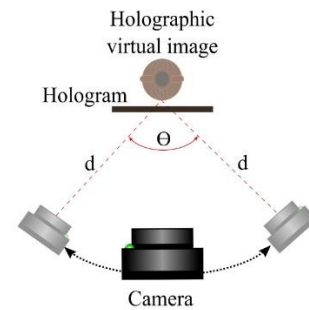


Figure 5. The setup of hologram digitization, top view.

3.3 3D Modeling

The construction and processing of three-dimensional models were conducted using the Agisoft Metashape software package. The 3D model is built in four stages (Figure 6 and 7):

- 1) Here, the program aligns all the photograph needed to build. The program also determines the focal length, orientation, and position of the images relative to the object. As a result of the first stage, a sparse cloud is built, which includes the maximum of the found common points of the future model, based on the positions of the cameras and images (Figure 6.1).
- 2) A dense point cloud is built, which is the main frame of the 3D model. The depth map for each of the images is also determined here (Figure 6.2).
- 3) A three-dimensional polygonal model is built that repeats the shape of the object itself. This is achieved by building the generation of polygons, from which, when these triangles are combined, the surface of the model is formed (Figure 6.3).
- 4) Finally, texturing of the model is performed (Figure 6.4).

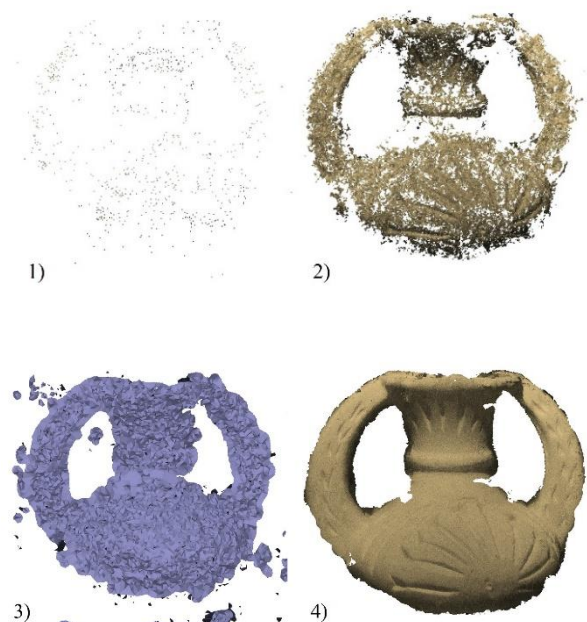


Figure 6. Stages of building the model from hologram: point cloud (1), dense point cloud (2), solid polygonal model (3), and textured model (4).



Figure 7. Image of one of the views of the 3D model of the object.

4. RESULTS

The analysis of the obtained 3D-models (Fig. 8 and 9) was based on comparison the surface profiles fragments. To do this, the same area on the three-dimensional object was selected for both models. This fragment is a set of recesses created during the manufacture of the vase. For fragments from the object and hologram models, 9 images were obtained for each model with the same rotation of the models. The resulting images are two intensity arrays that can be compared numerically.

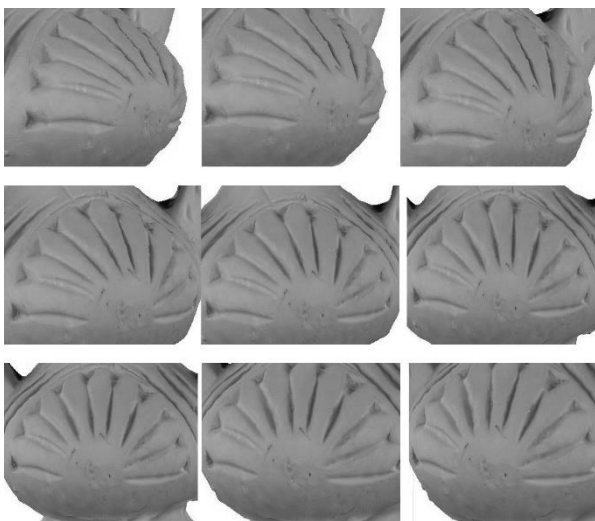


Figure 8. Images of the cut fragment from the object model.

Figure 10 (f) shows the plotted graphs of two surface profiles with similar structures.

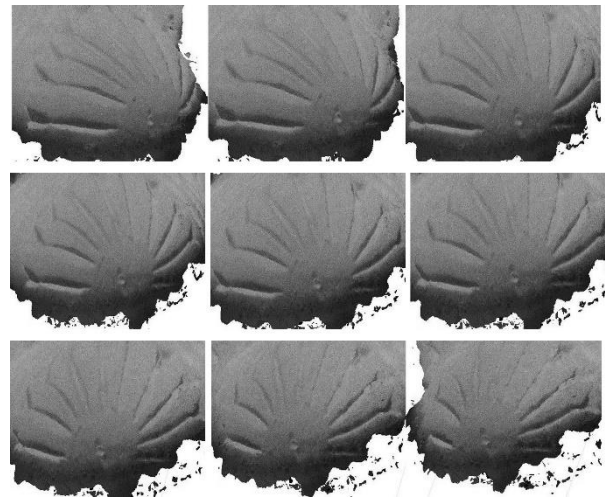


Figure 9. Images of the cut fragment from the hologram model.

The obtained cross-sections of 3D and 3Dh models surfaces were compared according to the Pearson correlation criterion:

$$r = \frac{\sum_{i=1}^N (z_q z_p)}{N}, \quad (1)$$

where $z_q = (q_i - \bar{q}) \left(\frac{1}{N} \sum_{i=1}^N (q_i - \bar{q})^2 \right)^{-\frac{1}{2}}$, and $z_p = (p_i - \bar{p}) \left(\frac{1}{N} \sum_{i=1}^N (p_i - \bar{p})^2 \right)^{-\frac{1}{2}}$, q_i and p_i are i -th elements of array Q (black line on Figure 10 (f)) and array P (red line on Figure 10 (f)), correspondingly, \bar{q} and \bar{p} are the mean values. The correlation coefficient value ($r = 0.903$) indicates very high consistency of three-dimensional models, since the Chaddock Scale r is $0.900 < 0.903 < 0.999$. Thus, the result obtained shows the possibility of using photogrammetry as a method of digitizing information recorded on a hologram for the purpose of further research.

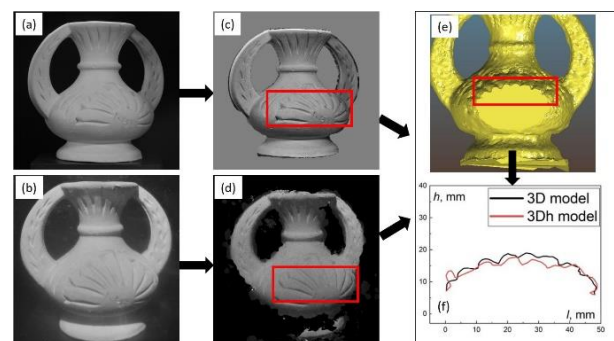


Figure 10. Photographs of the object (a) and its image, reconstructed from the reflective type of hologram (b). Front views of 3D (c) and the 3Dh (d) models. The highlighted in red areas of front views (c) and (d) show the fragments along which the surface profiles were plotted. Relief area of object for constructing cross-sections (e), and surface profile plot for both 3D and 3Dh models (f).

Next, using CloudCompare soft, we compared the polygonal mesh of the object (reference model) with the polygonal mesh of the reconstructed object front model, created from a series of photographs from the object's hologram. Model matching is

carried out automatically: the program recognizes identical points in a three-dimensional coordinate system, along which two objects under study are superimposed (Figure 11). After superimposing two clouds, CloudCompare program automatically calculates the average of the discrepancy between objects. The results of the first experiments comparing the polygonal meshes of the object and the reconstructed object front showed a high degree of correlation between the models (Fig. 12 and 13, where green indicates an exact match). The RMS value for the isolated fragments was 0.1711.

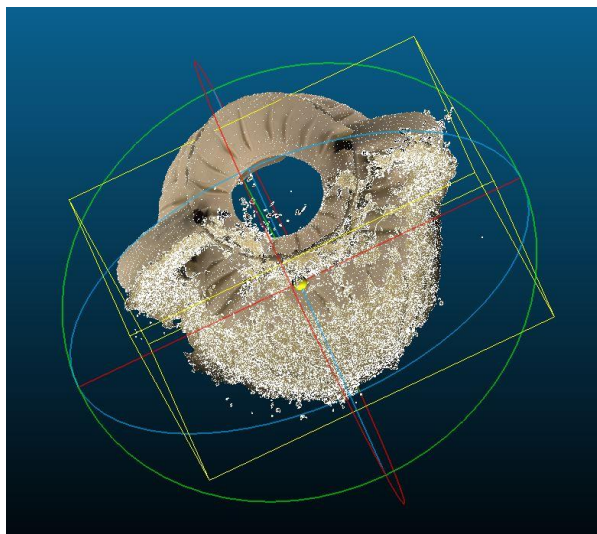


Figure 11. The stage of combining the reconstructed front model with respect to the object model (textured model).

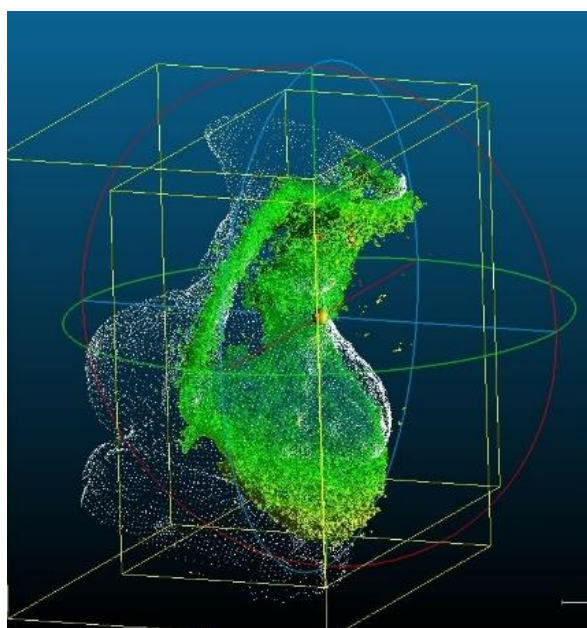


Figure 12. View of merged models after alignment.

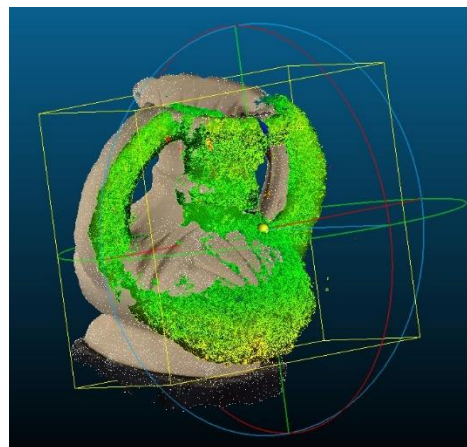


Figure 13. View of the merged models after texture mapping and calculation of standard deviation.

We also obtained a normal distribution (Gaussian distribution) (Figure 14) after aligning the models and calculating the standard deviation, which demonstrates the high identity of our model obtained from a series of photographs of the object front reconstructed from the hologram, relative to the reference model of the object itself.

The obtained RMS value indicates the need for a series of experiments in the future with different illumination of the hologram. Since, as we described earlier, glare (zero diffraction order) is possible in the case of photographing a hologram, this leads to a decrease in the number of photographs. As a consequence, we have a cloud of points, the number of which is much less than that of the point cloud of the reference model. This makes it difficult to match clouds and/or polygon meshes and subsequently calculate the deviation.

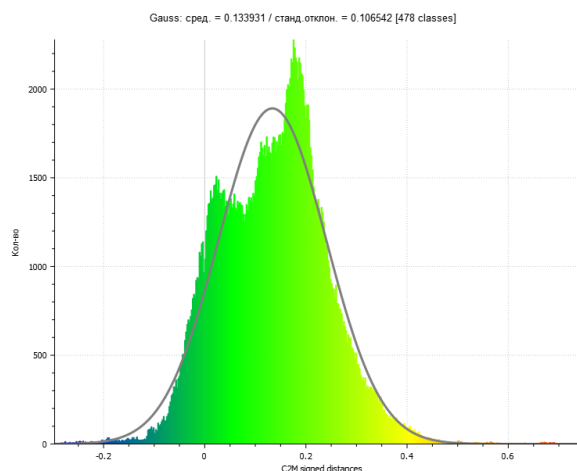


Figure 14. Gaussian distribution plot obtained by analyzing the quality of photogrammetry results.

5. CONCLUSION

In this article, we have demonstrated the results of an experimental study based on a combination of display holography and photogrammetry methods. The method of photogrammetry of information recovered from holograms turned out to be a convenient and promising method for documenting and digitizing data. During this study, several methods were tested for comparing the results of photogrammetry. The combination yielded important results, allowing further exploration of a new field for both photogrammetry and holography. It turned out that the choice of light source significantly affects the resulting photo data, which means that in the next study this should be given more attention. The next stages of our research will be an in-depth analysis of the obtained digitized results using photogrammetry using MeshLab and Cloud Compare. The main advantage of these programs is a better understanding of the algorithms that are used in the field of data photogrammetry.

Further research in this direction will reduce the RMS discrepancy to 0.05 and less. To do this, we will refine the methodology for obtaining more high-quality photographs of the restored front.

REFERENCES

- Agostino, D., Arnaboldi, M., 2021. From preservation to entertainment: Accounting for the transformation of participation in Italian state museums. *Account. Hist.* 26, 102–122. <https://doi.org/10.1177/1032373220934893>
- Asmus, J.F., Guattari, G., Lazzarini, L., Musumeci, G., Wuerker, R.F., 2016. HOLOGRAPHY IN THE CONSERVATION OF STATUARY 3630. <https://doi.org/10.1179/sic.1973.005>
- Balakrishnan, N., Rajendran, A., Pelusi, D., Ponnusamy, V., 2021. Deep Belief Network enhanced intrusion detection system to prevent security breach in the Internet of Things. *Internet of Things (Netherlands)* 14, 100112. <https://doi.org/10.1016/j.iot.2019.100112>
- Ballarin, M., Balletti, C., Vernier, P., Heritage, C., 2020. REPLICAS IN CULTURAL HERITAGE : 3D PRINTING AND THE MUSEUM EXPERIENCE XLII, 4–7.
- Belhi, A., Bouras, A., Foufou, S., 2019. Towards a Hierarchical Multitask Classification Framework for Cultural Heritage. *Proc. IEEE/ACS Int. Conf. Comput. Syst. Appl. AICCSA 2018-November*, 1–7. <https://doi.org/10.1109/AICCSA.2018.8612815>
- Bruder, F.K., Fäcke, T., Rölle, T., 2017. The chemistry and physics of Bayfol® HX film holographic photopolymer. *Polymers (Basel)* 9. <https://doi.org/10.3390/polym9100472>
- Ch'ng, E., Cai, S., Leow, F.T., Zhang, T.E., 2019. Adoption and use of emerging cultural technologies in China's museums. *J. Cult. Herit.* 37, 170–180. <https://doi.org/10.1016/j.culher.2018.11.016>
- Collier, R. J., Burckhardt, C. B., Lin, L. H., 1973. Optical Holography, (1971). Transmission T (TE) ETTI Mirror Cursor Marker Spectrum M, 200.
- Denisyuk, 1972. Contact us My IOPscience On the gyrogroups of Hungar This article has been downloaded from IOPscience . Please scroll down to see the full text article . View the table of contents for this issue , or go to the journal homepage for more Download details : 1095, 24–26. <https://doi.org/10.1070/RM2012v067n04ABEH004804>
- Denisyuk, Y.N., Sukhanov, V.I., 1970. Hologram recorded in a three-dimensional medium as the most perfect form of image. *Sov. Phys. - Uspekhi* 13, 414–415. <https://doi.org/10.1070/PU1970v013n03ABEH004268>
- Doulamis, A., Varvarigou, T., 2012. Image analysis for artistic style identification. *Emerg. Technol. Non-Destructive Test.* V 71–76. <https://doi.org/10.1201/b11837-14>
- Galushkin, A.A., Gonobobleva, S.L., Parfenov, V.A., Zhuravlev, A.A., 2019. Application of 3D Scanning for Documentation and Creation of Physical Copies of Estampages. *Restaurator* 40, 1–14. <https://doi.org/10.1515/res-2018-0010>
- Gama, E.S., Immich, R., Bittencourt, L.F., 2019. Towards a multi-Tier fog/cloud architecture for video streaming. *Proc. - 11th IEEE/ACM Int. Conf. Util. Cloud Comput. Companion, UCC Companion 2018* 13–14. <https://doi.org/10.1109/UCC-Companion.2018.00022>
- Gentet, P., Gentet, Y., Lee, S., 2017. Ultimate 04 the New Reference for Ultra-Realistic Color Holography.
- Gerbino, S., Martorelli, M., Renno, F., Speranza, D., 2004. Cheap photogrammetry versus expensive reserve engineering techniques in 3D model asquisition and shape reconstruction. *Int. Des. Conf. - Des.* 2004 6.
- Kaur, R., Chana, I., Bhattacharya, J., 2018. Data deduplication techniques for efficient cloud storage management: a systematic review. *J. Supercomput.* 74, 2035–2085. <https://doi.org/10.1007/s11227-017-2210-8>
- Kemper, H., Kemper, G., 2020. Sensor fusion, GIS and AI technologies for disaster management. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. - ISPRS Arch.* 43, 1677–1683. <https://doi.org/10.5194/isprs-archives-XLIII-B3-2020-1677-2020>
- Latham, K.F., Simmons, J.E., 2019. Whither museum studies? *J. Educ. Libr. Inf. Sci.* 60, 102–117. <https://doi.org/10.3138/jelis.2018-0050>
- Lin, X., Emami, T.I.M., 2018. Fail-Slow at Scale : Evidence of Hardware Performance. *ACM Trans. Storage* 14, 23:1-26.
- Lis-Gutiérrez, J.P., Zerda Sarmiento, Á., Viloria, A., 2019. Intellectual Property in Colombian Museums: An Application of Machine Learning, in: *Intelligence Science and Big Data Engineering. Big Data and Machine Learning*. Springer International Publishing, pp. 289–301. https://doi.org/10.1007/978-3-030-36204-1_24
- Mccarthy, J., 2014. Multi-image photogrammetry as a practical tool for cultural heritage survey and community engagement. *J. Archaeol. Sci.* 43, 175–185. <https://doi.org/10.1016/j.jas.2014.01.010>

Mekuria, R., Kylili, C., Wagenaar, A., Griffioen, D., 2018. Performance assessment and improvement of the video streaming backend with cloud storage and On-the-Fly format conversion. Proc. 23th ACM Work. Pack. Video, PV 2018 31–36. <https://doi.org/10.1145/3210424.3210433>

Muthanna, A., Ateya, A.A., Amelyanovich, A., Shpakov, M., Darya, P., Makolkina, M., 2018. AR Enabled System for Cultural Heritage Monitoring and Preservation, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). Springer International Publishing. https://doi.org/10.1007/978-3-030-01168-0_50

Narayanan, I., Wang, D., Jeon, M., Sharma, B., Caulfield, L., Sivasubramaniam, A., Cutler, B., Liu, J., Khessib, B., Vaid, K., 2016. SSD Failures in Datacenters. Perform. Eval. Rev. 44, 407–408. <https://doi.org/10.1145/2896377.2901489>

Pavlidis, G., Koutsoudis, A., Arnaoutoglou, F., Tsioukas, V., Chamzas, C., 2006. Methods for 3D digitization of Cultural Heritage.

Puig, A., Rodríguez, I., Arcos, J.L., Rodríguez-Aguilar, J.A., Cebrián, S., Bogdanovych, A., Morera, N., Palomo, A., Piqué, R., 2020. Lessons learned from supplementing archaeological museum exhibitions with virtual reality. Virtual Real. 24, 343–358. <https://doi.org/10.1007/s10055-019-00391-z>

Shamshirband, S., Fathi, M., Chronopoulos, A.T., Montieri, A., Palumbo, F., Pescapè, A., 2020. Computational intelligence intrusion detection techniques in mobile cloud computing environments: Review, taxonomy, and open research issues. J. Inf. Secur. Appl. 55. <https://doi.org/10.1016/j.jisa.2020.102582>

Spillner, J., Müller, J., Schill, A., 2013. Creating optimal cloud storage systems. Futur. Gener. Comput. Syst. 29, 1062–1072. <https://doi.org/10.1016/j.future.2012.06.004>

Sukhavasi, Susrutha Babu, Sukhavasi, Suparshya Babu, Elleithy, K., Abuzneid, S., Elleithy, A., 2021. Cmos image sensors in surveillance system applications. Sensors (Switzerland) 21, 1–52. <https://doi.org/10.3390/s21020488>

Vaz, R.I.F., Fernandes, P.O., Veiga, A.C.R., 2017. Interactive Technologies in Museums i, 30–53. <https://doi.org/10.4018/978-1-5225-2927-9.ch002>

Vlachos, M., Mathelier, R., Agrafiotis, P., Skarlatos, D., Photogrammetry, U., Photoscan, A., 2019. SOFTWARE COMPARISON FOR UNDERWATER ARCHAEOLOGICAL XLII, 1–5.

Ward, A.L., 2020. A Plan for Progress, Preservation, and Presentation at the Safety Harbor Museum and Cultural Center.

PPH-03M, n.d. <http://www.tdslavich.ru/content/plastinki-fotograficheskie/>. 10 January 2022