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Original article

Minimizing the adverse effects of bias and low repeatability precision in photogrammetry software through statistical analysis

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While photogrammetry is widely implemented in fields such as archaeology and cultural heritage, the accuracy of this method has yet to be fully addressed. It is imperative that digital photogrammetry models depicting sites of cultural heritage have accurate dimensions to avoid misunderstandings and incorrect analysis. This paper outlines a new method for minimizing the adverse effects of bias and low repeatability precision in photogrammetry software. Specifically, this paper quantitatively addresses the effects of systematic error during scaling of digital photogrammetry models as well as the random error due to a repeatability issue inherent to photogrammetry software. The method was developed using statistical analysis and robust uncertainty calculations and validated through multiple case studies.

1. Introduction

Documentation of heritage structures is an integral part of understanding how to best monitor [1,2], conserve [3,4], and learn from them. There are different means of documenting structures, such as sketches, photographs, virtual tours [5], and three-dimensional (3D) digital models. The process of building 3D models can be carried out by many methods; this paper, in particular, will focus on photogrammetry which generates a digital, 3D model [6]. This can be done by using a non-invasive approach called structure from motion (SfM), a technique which estimates 3D structures from 2D image sequences. While this method has been widely implemented on archaeological projects [7–12], application of SfM software in photogrammetry may cause an inaccurate model which can, in turn, lead to inaccurate conclusions about a site. Remondino et al., 2012 reported discrepancies of up to a meter between measurements taken directly from the structure and those determined by the photogrammetry models [13]. Conversely, Verdiani and Braghiroli, 2012 reported their models had discrepancies of only 5 mm using the same software (Agisoft Photoscan [14]) on a similar structure [15]. The large difference in these results suggests that sometimes there are factors at play that prevent the model from being as accurate as the software is capable.

The accuracy of a photogrammetry-generated digital model can depend on many different factors, as depicted in Fig. 1, including the particular structure's features being modeled, lighting conditions, the camera used, and experience of the operator. These factors influence the quality of the photographs that are needed to create the model. Moreover, the software may also generate different models from the same set of photographs, i.e., if the exact same set of photographs was used two times in the software, the two resulting models will have dimensions that are different from each other, and might differ significantly from the dimensions of the structure being documented [13]. The difference between the model and the structure being modeled depends on the scaling factor that associates distances between points in the model to those on a structure. While this fact is known, how great an effect this has on the resulting models has not yet been fully quantitatively explored. Additionally, the difference among photogrammetry models can depend on the repeatability precision of the software. Further research into what affects the accuracy of a photogrammetry model (i.e. scaling length, repeatability precision,) is necessary.

Articulating the need for accurate analysis of photogrammetry models and software, Green et al., 2014 states that SfM needs to demonstrate reliable accuracy for it to be taken seriously as a measurement tool [16]. Sapirstein, 2016 made great strides towards assessing the accuracy of the models in its discussion of the benefits of using coded targets for photogrammetry and the necessity of a common error reporting terminology [17]. Additionally, working to ensure the accuracy of photogrammetry models, Koutsoudis et al., 2013 [18] and Koutsoudis et al., 2014 [19] comprehensively

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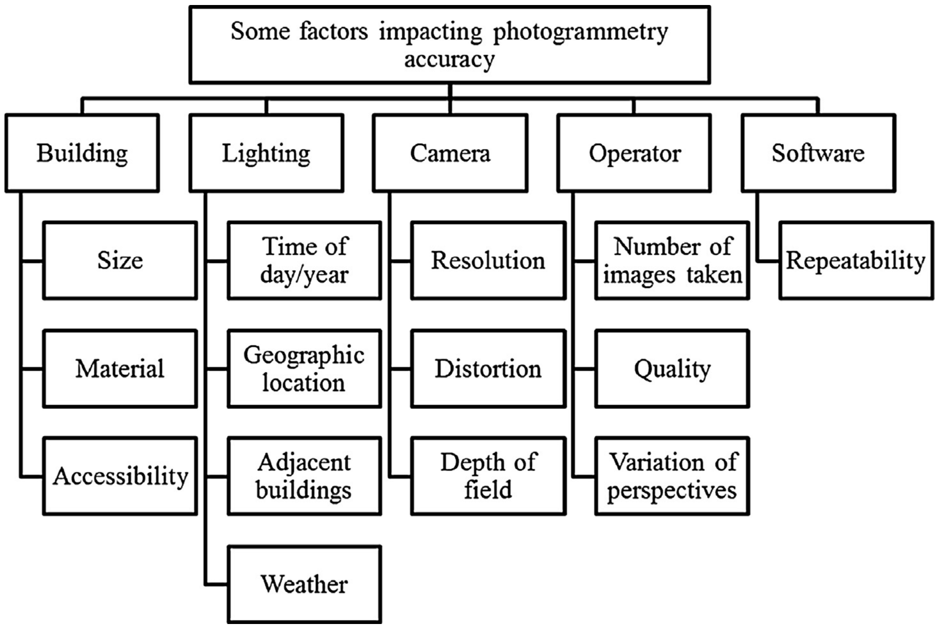

Fig. 1. A non-exhaustive list of factors that affect the success of a photogrammetry model.

evaluated the accuracy of photogrammetry approaches by comparing them to the results of 3D laser scanning. These papers outline and discuss new methods for quantitatively assessing the accuracy of photogrammetry software. While the current literature illustrates that there is an interest in methods that can improve the accuracy associated with photogrammetry models, notably, there is a gap in the field when quantitatively assessing bias and repeatability precision. This paper explores the effects of bias and repeatability precision of photogrammetry software, which has yet to be fully quantitatively explored, and outlines a method for minimizing their adverse effects through statistical analysis.

2. Overview of photogrammetry models

A user can make a photogrammetry model of a structure by taking images of it and “stitching” them together with photogrammetry software. These images should be taken in lighting where there are minimal shadows and it is recommended that the images taken overlap by at least 60% to create a 3D model without “holes” in it [14]. These images can then be imported to a photogrammetry program such as Agisoft Photoscan [14] or Python Photogrammetry Toolbox [20]. Each of these programs generates a point cloud or a 3D set of data points that represent the external surface of the structure. From here a user can generate a mesh, connections between vertices of the point cloud that create polyhedral objects, or textured model, a 3D model with high detail and color information. A user should take several measurements of the structure’s geometrical features (line segments between two characteristic points) to scale the 3D photogrammetry model after processing to the real size. A user can input a measured length between two specified points on the model, and this enables the software to scale the model to the appropriate size. By having a model whose size reflects the dimensions found on a physical structure or site, any length along the structure or site can be determined from the model. This can be done by “measuring” the distance between the points of the model that corresponds to the length of interest on the structure.

As mentioned in the introductory section, photogrammetry software suffers a repeatability issue where the same set of images can be run twice in the same software, with the resulting models being discernibly different. As an example, Fig. 2 displays a snapshot of two different models of a 16-meter brick façade generated using Agisoft Photoscan photogrammetry software [14]. The models are made of 101 images taken using a Nikon D90 (resolution of 4288 × 2848). Photos were taken both orthogonal to the façade as well as from varying, non-orthogonal, viewpoints. The effective overlap of the images, or the mean number of projections of each point in the point cloud, is 8.43. This means that each point in the point cloud is visible or matched in an average of 8.43 photographs. While the models in Fig. 2 were created from the same images in the same software, they are dissimilar, one is distorted and one is not, illustrating the low repeatability precision of the software.

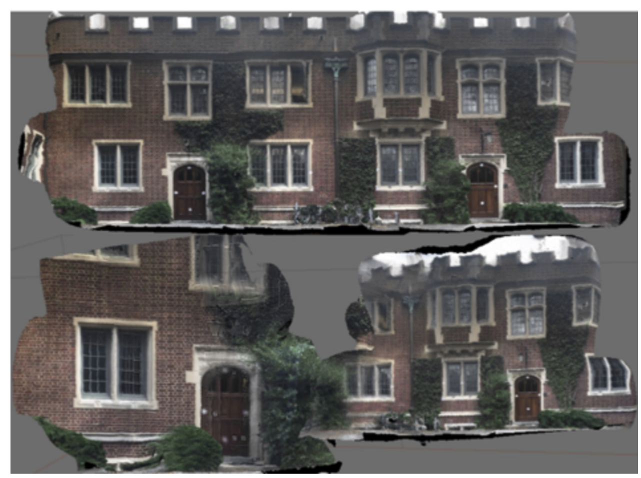

Fig. 2. Two models of the facade were generated from the same set of photographs in the same program, illustrating low repeatability of the software.

Since the differences between models are not always as obvious as shown in Fig. 2, this poses a challenge to assessing the accuracy of models generated with this technique. A model can appear to be undistorted and yet have dimensions that do not correspond to the site it is based on. A method is proposed here that should be integrated into existing workflows for the creation of photogrammetry models. This method minimizes the adverse effects of bias and low repeatability precision of photogrammetry software and will increase the accuracy of the resulting photogrammetry models.

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