Fusion of laser scanning and photogrammetric data for the documentation and VR visualization of an archaeological tomb complex

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SUMMARY

In this paper, we investigate the complementary use of data acquired using terrestrial laser scanning (TLS) and photogrammetry for a cluster of rock tombs in Sheikh Abd el-Qurna, Western Thebes. We focus on two tombs where the combination of the two methods helps to solve particular challenges. In the first case, the complete geometry of a narrow vertical shaft could only be reconstructed by stitching together models obtained originally from the separate use of both techniques. In the other case, the geometry was derived from the TLS data, while RGB information was captured photogrammetrically. This allowed better handling of the poor illumination inside the tomb than by using the camera integrated in the scanner.

We demonstrate the potential of combining the data derived from the two methods to generate a high-resolution model with respect to geometry and texture. To combine the data, the photogrammetric model has to be scaled and aligned to the TLS model. We achieve this by extracting distinctive points in both models and determining their correspondences across the models. The scale is then computed, as the mean ratio of the Euclidean distances between sets of corresponding point pairs in the individual models. Corresponding points are also used to estimate the parameters of the congruency transformation, which aligns the two models coarsely. The fine alignment is carried out by applying the iterative closest point algorithm (ICP).

For the first scenario, a photogrammetric model obtained from 98 images was used to fill the gaps that could not be acquired using TLS due to the geometry of the shaft. For the second scenario, a point cloud derived from about 80 scans was merged with a 3D model reconstructed from roughly 7000 images with 30 megapixels each. The photogrammetric model was computed on a high performance computer using Agisoft Photoscan. After scaling and aligning, the two models were merged resulting in a colored high-resolution 3D model. The mentioned processing steps (scaling and alignment) are equal for both scenarios.

To visualize the tomb complex on consumer grade computers with photorealistic quality, the high-resolution model and the textures from the images are translated to physically based rendering (PBR) calibrated surfaces. PBR enables rendering of the model with simplified geometry keeping the full visual information. As all images were equally illuminated, there are

no shadows in the images and the resulting model contains automatically an albedo texture that can be used in the PBR process. The result is a 3D model and its corresponding shaders that can be viewed e.g. using virtual reality glasses connected to a standard computer.

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1. INTRODUCTION

Powerful tools for the 3D reconstruction of manmade objects or of landscapes as digital models have become available over the last few years. On the one hand, laser scanners like the Faro Focus or the Leica BLK360 are easy to use and enable terrestrial laser scanning (TLS) with comparably low up-front investment. On the other hand, advances in photogrammetric image processing resulted in fully automated processing chains implemented in software packages like e.g. Agisoft PhotoScan or Pix4D. They do not require a deep knowledge in photogrammetry for reality capture resulting in a colored 3D point cloud. However, there are still application cases where expert knowledge is needed to obtain point clouds and models of sufficient quality. Such an application case is presented and discussed herein.

Current laser scanners often feature an RGB camera and are thus capable of acquiring both point clouds for 3D representation and high-resolution images. However, apart from significant increase in data acquisition times usually associated with imaging using the internal cameras, the internal cameras are also limited in terms of performance under difficult conditions. Usually, they do not allow choosing individual settings like exposure time or aperture for the single image. This leads to unbalanced exposures when scanning outdoors or in other locations with strongly varying light conditions. A possible way to overcome this problem is to acquire the color information separately from the geometry by using a high-quality camera, e.g. an SLR, in addition to the scanner, and to combine the data in post-processing, see e.g. Lambers et al. (2007). This may also allow obtaining a 3D model with high geometric and texture quality in a more economical way than carrying out the measurements using only one of the techniques, see Friedli and Theiler (2014).

In this paper, we focus on two application cases, where the combination of the two methods helps to solve particular challenges for the 3D reconstruction of ancient rock-cut tombs, located at the hillside of Sheikh Abd el-Qurna in Western Thebes. The data were acquired and processed within the interdisciplinary project *Life Histories of Theban Tombs*[1] led by the Department of Ancient Civilizations of the University of Basel.

The first case is the main burial shaft in the courtyard of tomb TT84. The top-most part of this narrow and approximately 10 m high shaft could not be mapped using the scanner because of obstruction by lower parts of the shaft. However, it was possible to cover the missing parts by images obtained using a camera mounted on a telescope bar. Thus, the top part of the shaft was

[1] Funded by SNSF (grant number: 162967) and outlined at https://lhtt.philhist.unibas.ch/sheikh-abd-el-qurna/.

reconstructed photogrammetrically and the combination with the TLS model yielded a complete model. In total, 8 scans and 98 pictures were used to create the final model.

Figure 1: Tomb TT84 - image of the 3D model of the terrain and the shaft (background, left), and a picture of the top inside of the shaft (right).

The second case represents the reconstruction of the funerary chapel TT95A. In this case, the geometry was acquired using TLS, while the color information for documentation and rendering was captured photogrammetrically. The motivation for using both technologies was the poor illumination inside the funerary chapel. Extensive equipment and effort would have been required to illuminate the chapel well and without strong shadows for the imaging with the camera integrated into the scanner. The related effort including additional time needed for on-site preparations was considered prohibitive. It was also assumed, that the radiometric quality of the photogrammetric model would be superior to the one obtained using the integrated camera of the scanner, as each image could be acquired with the same illumination using synchronized flash equipment, which is not available for the scanner.

Figure 2: Photo of the first pillar hall measuring roughly 18 x 9 m2 (left) and map (right) of the entire funerary chapel TT95A; scan positions marked in the map (Source: M. Kacicnik and G. Heindl, S. Stucky, LHTT).

2. WORKFLOW

2.1 TLS

The scans were acquired using a Faro Focus3D S120 and a Faro Focus3D X330. Although both laser scanners feature RGB cameras, no color information was acquired during the scans for the reasons described above. It was also decided to omit artificial targets but rather register the scans using features within the point clouds. This saved time during data acquisition as well as during processing, as no artificial targets had to be removed from the point clouds after registration in order to provide a clean model. The distance between adjacent scan positions was roughly 2 m on average. Greater distances would have caused troubles with occlusions due to the rough surfaces or insufficient overlap due to the narrow spaces. The particularly short distances between the scanner and the surfaces, along with the high number of scans and the high overlap allowed to acquire the single scans with low resolution; it was set to 12 mm at 10 m which still resulted in a model with a resolution better than 5 mm as the distances were typically much less than 10 m.

The raw scan data were imported into Geomagic Control[2]. First, clutter points (people, unwanted objects, etc.) were manually removed from the individual point clouds. The point clouds then had to be coarsely registered. This was carried out by manually selecting $n \geq 3$ corresponding points in the overlapping point clouds and having the software estimate the parameters of the congruency transformation. This coarse registration was globally refined using the iterative closest point (ICP) algorithm (Chen and Medioni 1991; Besl and McKay 1992). Finally, the registered point clouds were merged into a single point cloud and uniformly down-sampled to a manageable point cloud resolution (1 cm used herein). For the example of the funerary chapel, this means a reduction from 950 Mio to 38 Mio points.

[2] https://www.3dsystems.com/software/geomagic-control-x

2.2 Photogrammetry

The photos were acquired using a Nikon D810 with 35 mm lens under equal illumination conditions and without any shadows by using a professional photoflash equipment. The colors were adjusted in post-processing using a color calibration bar. This resulted in a set of photos featuring virtually true colors and being free of shadows. To ensure that there are enough photos of sufficient quality, sets of photos where already processed on site with low density using Agisoft PhotoScan. So, additional photos could be taken exactly where needed in order to avoid holes in the photogrammetric model.

The color-adjusted photos were imported as JPEGs into Agisoft PhotoScan. No lens correction was applied beforehand. After the import, we inspected the loaded images and removed the redundant images manually. As no camera calibration was carried out in the field, a self-calibration using the Brown's distortion model was done in PhotoScan. The camera parameters are estimated during the image alignment process, which yields a sparse cloud that consists of the found matches. The alignment was done without creating camera groups or junks; so, all pictures were processed in a single bundle block set adjustment. In order to speed up the alignment process of this large set of photos, the pair preselection option was used. The keypoints were limited to 40’000 points and tie points were filtered to a maximum of 4000 points. Existing conspicuous outliers were removed manually after this process. In a next step, we generated a dense point cloud to match the density of the TLS scans. This dense cloud was then used for the fusion with the TLS data, which is described in the next section.

2.3 Data merging

In order to combine the photogrammetric and TLS point clouds, they have to be equally scaled and co-registered. Intrinsically, the scale of the photogrammetric point cloud is arbitrary whereas the TLS point cloud is true to scale due to the metric distance measurements that are used for the computation of the 3D coordinates. Naturally, the preferred choice would be to scale the photogrammetric point cloud and make it true to scale. However, in order to facilitate the direct usage of the estimated external camera parameters for texture mapping in Photoscan (explained later in this section), we scale the TLS point cloud such that it corresponds to the scale of the photogrammetric one.

We propose a data-driven approach consisting of three steps for estimation of the scale factor and transformation parameters. In the first step, we estimate the coarse scale factor from distances between points, which can be identified in both models with sufficient accuracy. If the point-clouds cover exactly the same space (i.e. they have 100% overlap) this can be achieved automatically by computing the ratio of the distances between the two most distant points in both point clouds. In the particular case of TT95A, we computed the convex hull of the individual point clouds and searched for the most distant points just within the set of vertices of this convex hull. In comparison to the brute-force approach (computing the distances between all pairs of points in the point cloud), this greatly reduces the time and memory complexity of the first step. In the second step, after coarsely scaling the TLS point cloud, we estimate the transformation parameters coarsely aligning the TLS point cloud to the photogrammetric one based on the extraction and matching of keypoints (see e.g. Tombari et al. (2013)), i.e. points that are distinctive and presumably easy to extract (e.g. corners). Because the keypoint extraction and matching algorithms are not scale invariant, it is important to perform the coarse scaling beforehand. Herein we use the point cloud library implementation of the Harris3D keypoint extraction algorithm (Rusu and Cousins 2011), which is an extension of the well-known Harris2D keypoint extraction algorithm (Harris and Stephens 1988) and uses normal vectors instead of image gradients, in combination with the keypoint-based 4-points congruent set geometrical constraint matching algorithm proposed by Theiler and Schindler (2012). Finally, after coarsely aligning the point clouds, we perform the simultaneous refinement of the scale factor and transformation parameter estimation using the extended version of the ICP, which also enables scale factor estimation and was proposed in Zinßer et al. (2005)[3]. Thus obtaining the transformation parameters, which can be directly applied to align the TLS mesh model with the photogrammetric model, which was the initial goal of this scaling and registration step.

The aligned TLS model is then imported in Photoscan for texture mapping. Due to the registration of the TLS model to the photogrammetric one, the mesh is in the correct location with respect to the aligned images, and the texture from the images can be directly projected onto the mesh. PhotoScan offers different mapping options that determine how the object texture is packed in the texture atlas. Here the generic mapping was chosen, as it is recommended by Agisoft for objects with arbitrary geometry.[4] The other options aim at ball-like objects or the generation of orthophotos. As this texturing process is computational costly, therefore, to avoid failure due to RAM limitations, the texture was not exported into one single file but into several smaller patches. This allowed exporting each patch (20 used herein) with the default resolution of 4096 x 4096 pixels and still storing the texture of the complete model with a higher resolution.

3. APPLICATION 1

In the first application example, we indicate the possible gain of complementing the data of both acquisition technologies by combining the derived point clouds to obtain a full 3D model of a vertical burial shaft. In this application, the overlap of the point clouds is small (approximately 15% of the larger (TLS) point cloud), which means that the coarse scale factor has to be estimated by manually measuring corresponding distances in both models and computing the mean value of their quotient. This derived point clouds represent a challenging example for the data driven estimation of the coarse registration as the geometry of the shaft consists predominantly of flat surfaces without notable features. Furthermore, the

[3] The CloudCompare implementation of the aforementioned algorithm is used herein. http://www.cloudcompare.org/

[4] Agisoft Photoscan Manual 1.4

corresponding corner points, which are considered as representative keypoints, are not visible in both point clouds. Nevertheless, a sufficient number of keypoints was successfully matched using the algorithm proposed herein. Correspondences were then used to estimate the transformation matrix, which enables combination of both point clouds as depicted in figures 3 and 4.

Figure 3: Point clouds of the narrow vertical shaft. *Left*: TLS point cloud, *Middle*: photogrammetric point cloud, *Right*: point clouds combined using the proposed algorithm. For clarity we only show the top part of the shaft and as a negative, i.e. looking at the empty space represented by the point cloud (the shaft seems to be a column).

Even though that the distances for the coarse scale factor were carefully selected, the third step of the algorithm indicated an error of the coarse scale factor estimation of approximately 2%, hence confirming the importance of the refinement step of the scale factor estimation.

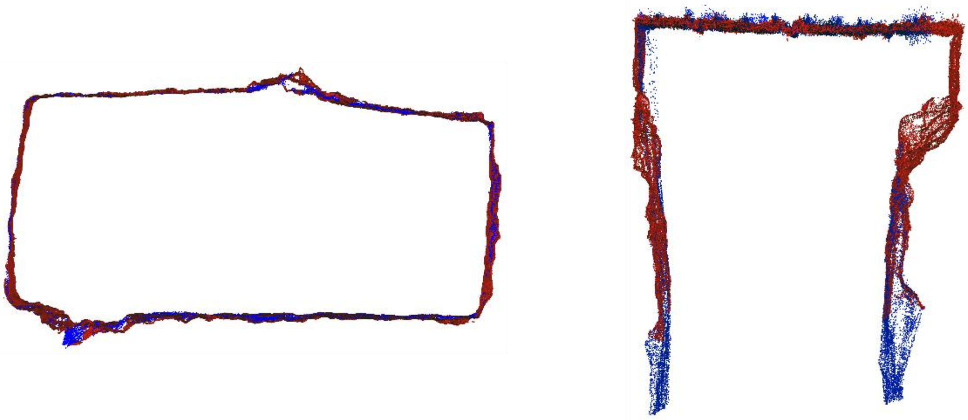

Figure 4: Figure showing the result of the merged point clouds in a horizontal cross section (left) and a vertical cross section (right). It is clearly visible that the scaling and registrations worked, as there are no big discrepancies. It can also be seen that the photogrammetric model (red dots) covered a good part of the overhanging top part, which was not visible with the scanner.

4. APPLICATION 2

As mentioned in section 1, with the second example we demonstrate the potential of the separate acquisition of the geometry and color information with TLS and photogrammetry. For this example, where we have a closed object that was fully reconstructed with both techniques, the proposed workflow could be applied and no manual registration or scaling was required. The funerary chapel TT95A with its clear shape and the fact, that both models covered the same object, enabled the detection of enough keypoints for a reliable scaling and registration process. Figure 5 shows that the registration of the two models worked as the RMSE is below 1 cm.

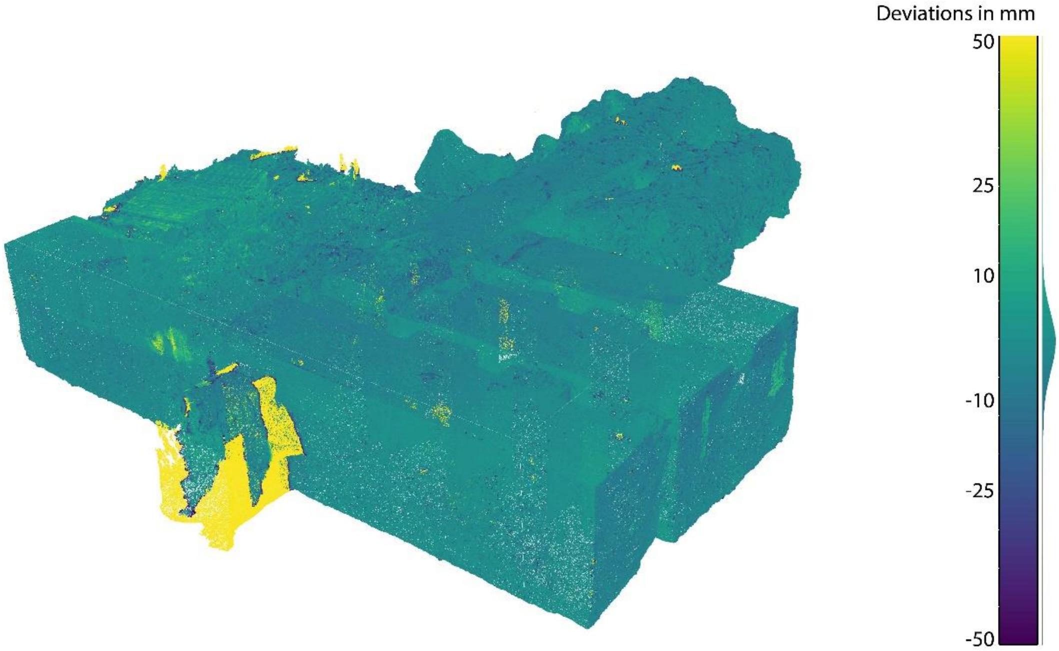

Figure 5: Result of the registration of the photogrammetric and TLS model. The mean distance between the two models was below 1 cm and the larger deviations occur around the entrance and the cracks, where the photogrammetric model has some holes and the scanner was able to scan deeper into the cracks.

The final model from PhotoScan has a high resolution with respect to geometry and texture as shown in figure 6c. From the illustrations a) and b) it can be seen, that a part of the lower burial chamber accessible through a shaft in the 1st pillared hall is missing in the photogrammetric model and that the entrance is not fully reconstructed in the TLS model. As the texture is applied to the mesh, i.e. here to the TLS model, the entrance stays partially reconstructed and for the lower burial chamber, where the image information is missing, a standard texture was applied.

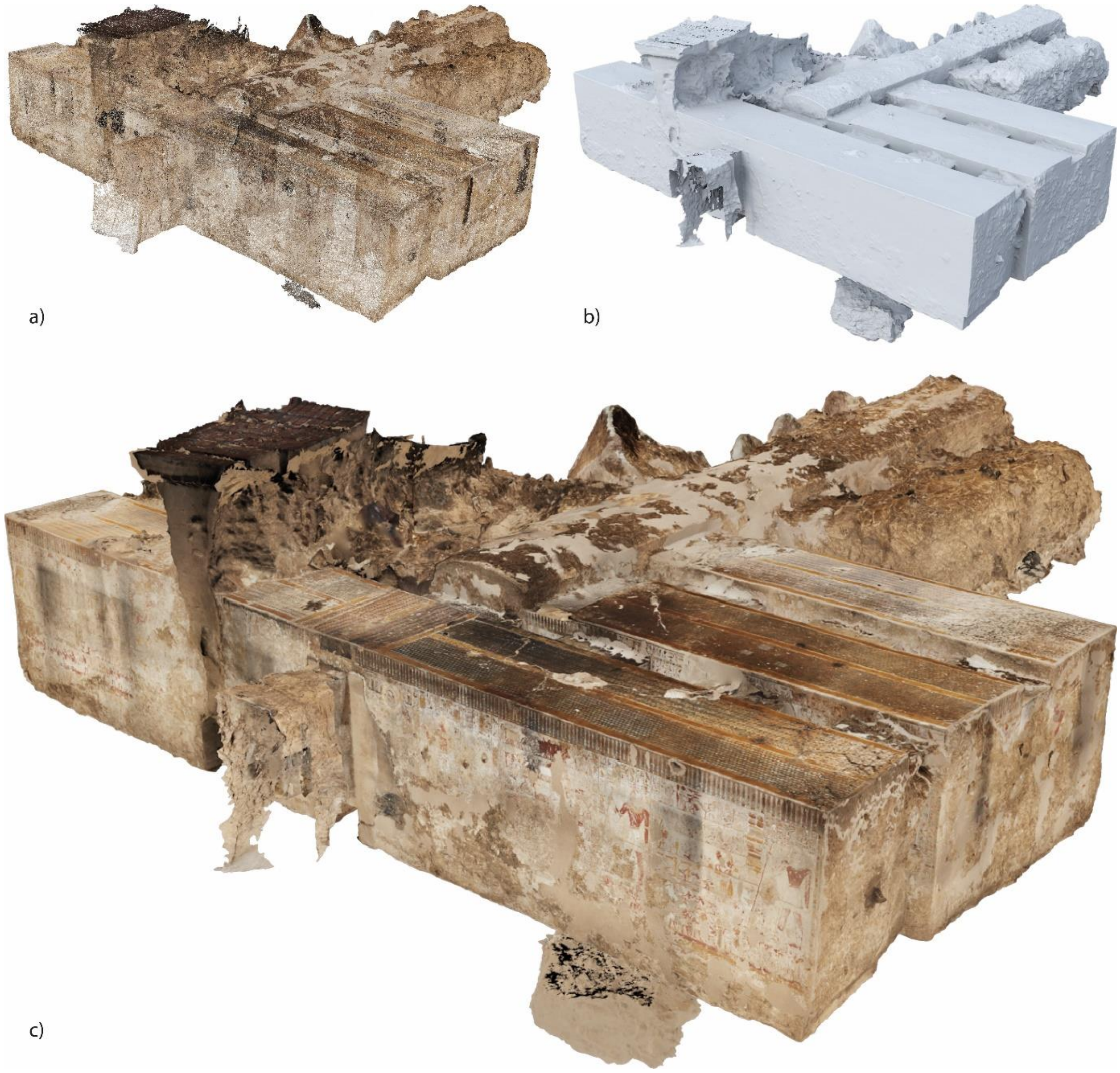

Figure 6: Illustrations of the merged models of the funerary chapel TT95A. Figure a) represents the photogrammetric point cloud, figure b) the mesh derived from the laser scans, and figure c) the combined model. For the parts where no pictures were available, a standard texture was applied.

For the visualization of complex geometry in 3D computer graphics software or game engines for real time visualization, the data needs to be optimized in order to reduce the calculation effort. This is achieved by reducing the resolution of the geometry, i.e. the number of faces. The loss of geometric details is compensated with height maps. These height maps are generated from the high-resolution geometry and then transferred to the model with a lower geometric resolution. Height maps are raster images that are used to store surface values like the surface elevation. In our case, we use bump maps to simulate the shadows of a highly detailed geometry on a geometry with low resolution when rendered. This process makes it possible to show the scanned data via 2D maps in real time with high resolution. In the shown example in figure 7, we used Geomagic to visualize the difference between using bump maps from the high-resolution model and without (figures 7b and 7c). As it can be seen from figures 7a and 7c the difference between the models is hardly visible anymore, even though, the model in 7a consist of 25 Mio faces and the model in 7c of only 22'000 faces. This proves that applying bump maps allow reducing the geometric resolution without a loss of visual details for rendering applications.

Figure 7: Examples of the rendered ~~,~~ models with different geometric resolution and with the application of the bump map. Figure c) shows a low-density mesh with approx. 22'000 faces where the bump map from the mesh with 25 Mio faces depicted in a) was applied. Figure b) shows the rendering of the low-density mesh without the bump map. The difference is clearly visible when compared to the model with the bump map in figure a).

5. CONCLUSION

In this work, we show the possibility of complementing/combining the point clouds obtained using TLS and photogrammetry. Not only is it possible to complement the acquisition techniques in order to derive a full geometry of complex structures as shown in the first application case but also they can be combined, e.g. combining the geometric information of the TLS with radiometric information of the photogrammetric point cloud and thus exploiting their respective advantages. In order to combine the point clouds they have to be expressed in a common reference frame. Herein, we propose a data driven approach for registration of the point clouds, taking the intrinsically arbitrary scale and orientation of the photogrammetric point clouds into consideration. We also show the applicability of the proposed method on two application cases.

Furthermore, we address the challenge of the large data size of the derived models for visualization purposes. By reducing the geometric complexity of the models using bump maps, we successfully reduce the data size while at the same time preserving most of the visual information. This paves the way for using the large data models in real-time applications or visualization in the virtual reality environment.

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REFERENCES

Besl P, McKay N (1992) A Method for Registration of 3-D Shapes. IEEE Trans. Pattern Anal. Mach. Intell. 14:239–256.

Chen Y, Medioni G (1991) Object modeling by registration of multiple range images. Proceedings 1991 IEEE Int Conf Robot Autom 2724–2729.

Friedli E, Theiler PW (2014) Documentation of Remote Archaeological Sites – a Comparison Between Long Range Laser Scanning and Uav – Based Photogrammetry. In: FIG Congress 2014. Kuala Lumpur, Malaysia, pp 1–15.

Harris C, Stephens M (1988) A Combined Corner and Edge Detector. Procedings Alvey Vis Conf 1988 23.1-23.6.

Lambers K, Eisenbeiss H, Sauerbier M, et al (2007) Combining photogrammetry and laser scanning for the recording and modelling of the Late Intermediate Period site of Pinchango Alto, Palpa, Peru. J Archaeol Sci 34:1702–1712.

Rusu RB, Cousins S (2011) 3D is here: point cloud library. IEEE Int Conf Robot Autom 1–4.

Theiler PW, Schindler K (2012) Automatic Registration of Terrestrial Laser Scanner Point Clouds Using Natural Planar Surfaces. ISPRS Ann Photogramm Remote Sens Spat Inf Sci I:173–178.

Tombari F, Salti S, Di Stefano L (2013) Performance evaluation of 3D keypoint detectors. Int J Comput Vis 102:198–220.

Zinßer T, Schmidt J, Niemann H (2005) Point set registration with integrated scale estimation. Int Conf Pattern Recognit Imaging Process 116–119.

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