SYMBIOSIS OF UAS PHOTOGRAMMETRY AND TLS FOR SURVEYING AND 3D MODELING OF CULTURAL HERITAGE MONUMENTS - A CASE STUDY ABOUT THE CATHEDRAL OF ST. NICHOLAS IN THE CITY OF GREIFSWALD

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ABSTRACT: *In this contribution the possibility to combine terrestrial laser scanner (TLS) measurements and UAS photogrammetry for the detailed description and high quality surveying of a cultural monument will be illustrated by the example of the Cathedral of St. Nicholas in the city of Greifswald. Due to the different nature of UAS photogrammetry and TLS walls and windows as well as portions of roofs are captured with a different level of completeness and accuracy. The average deviations of the test areas on the overlap between the two measurement methods ranges from 0.015 m to 0.033 m with standard deviations of 0.025 m to 0.088 m.*

1. INTRODUCTION

The accuracy potential of UAS photogrammetry and terrestrial laserscanning (TLS) is similar, e.g. Naumann et al. 2013. Therefore a combination of both methods is a logical consequence. High-resolution surveying projects of buildings with UAS are very promising, as results from the cathedral at Magdeburg and the Leaning Tower in Bad Frankenhausen show, Hallermann, and Morgenthal, 2013. Bastonero et al., 2014 uses both methods sucessfully.

The Greifswald Cathedral of St. Nicholas which in parts dates back to the 13th century undergoes continuous maintenance. The goal of the survey is to obtain three-dimensional measurements of the building envelope as well as from the interior of the church. The point cloud and image data shall be used for the creation of floor plans, sections, elevation maps and image documentation.

Figure 1. Cathedral St. Nikolai in Greifswald, Germany (©Roland Rosner, Deutsche Stiftung Denkmalschutz)

The data will form the basis for damage assessment, structural design and the planning and redevelopment work. Thereby the accurate and high resolution 3D point clouds shall be managed in a common reference system.

The dimensions of the cathedral, and especially its tower with a height of about 97 m is impressive. The church is bound into an urban building ensemble of a medieval historic downtown area, which makes it difficult to survey the building with common terrestrial surveying techniques. The main restrictions are glancing intersections at high building parts and obstructions by other parts of the building. According to the a priori defined accuracy demands of the final 3D model (± 2.5 cm) TLS-generated 3D-information of the hull of the building are only possible for vertical walls up the height of the eaves of the nave of the church.

Figure 2. Photorealistic textured DSM of the cathedral and the surrounding buildings

The TLS generated 3D point cloud of the lower parts of the building was extended with UAS-photogrammetry for the higher parts of the building, including the tower. The overall model thus consists of different sub-models according to the respective measurement method.

The focus of the contribution will be on the data fusion of TLS and UAS to combine the advantages of both sources: the point cloud generated by UAS photogrammetry with a focus on the high elevated tower and the roofs of the complex and the point cloud made by terrestrial laser scanner techniques which focuses on the facades of the Church.

2. METHODS AND MATERIALS

2.1 Reference measurements with TLS and total station

The TLS point cloud of the upper parts of the cathedral were acquired with the phase difference Laser Scanner Photon 120 from FARO Europe. It has a range of 0.6 m to 120 m and a distance measuring accuracy of ± 0.002 m to 25 m. The TLS point clouds were linked together and also to the reference surveying network by tachymetrical surveyed targets. In preparation of the photogrammetric analysis of UAS image data 117 ground control points (GCP) were determined with a standard deviation of the 3D position of 0.013 m at the building complex using a total station, which has been stationed in relation to the same surveying reference network. They are used to increase accuracy and georeferencing of UAS image block. The use of a global coordinate system allows the continuous integration of data acquired with different techniques. The expenditure of time for the total station surveying of control points for the UAS photogrammetry is comparable with the measurement of tie points for the TLS. Often important, the time of flight of UAS is only a small part compared to the measuring time for the laser scanning.

2.2 UAS

Multi-rotor UAS, equipped with high-quality camera technology allow for automatic image flights at low altitudes along predefined paths. Besides being able to deliver live data for visual building inspection, UAS imagery are ideally suited for documentation and mapping purposes. Aerial surveys with strongly overlapping and highly redundant images, allow for an automatic determination of the surface structure via dense image matching techniques.

Figure 3. UAS MD4-1000 ready for take-off

The airborne survey was conducted with a UAS from Microdrones (MD4-1000). An Olympus PEN E- P2 camera with a fixed focal length of 17 mm and 12 MP is attached to the UAS. The autopilot of the UAS is able to acquire photos at a continuous rate or at predefined waypoints. in this case the UAS will stop, take the photo and proceed to the next waypoint. This approach is inefficient, therefore the continuous mode is selected.

2.3 Flight planning

During the aerial survey planning phase several issues have to be considered:

- A combination of nadir looking and vertical images reduces blind spots in complex roof structures
- High overlap rates (endlap /sidelap) and cross strips may also reduce blind spots in the point cloud
- Circular flights around a building require a continuous change in the orientation of the UAS and the camera. This is much more complicated than flying up and down the building, thus changing the horizontal position and the orientation of the UAS and the camera only between vertical "flight lines".
- The determination of the overlap around the tower is a little more different than for nadir looking flights.
- To avoid motion blur the exposure time should be no longer than 1/500.
- The distance to the object should be kept constant to maintain sharp images throughout the survey.
- Flying on a sunny day around a circular tower is not the best idea, because the strong illumination differences will cause additional problems. Furthermore the sun will cast unwanted shadows. Therefore surveys with overcast skies are the best.
- Around such a huge building shear winds may arise and a minimum safety distance of 15 - 20 m is strongly advisable.
- Flying in the city centre with a UAS always draws a lot of attention in the public. In order to maintain a maximum level of safety a clear and large enough starting and landing area should be marked with barrier tape.

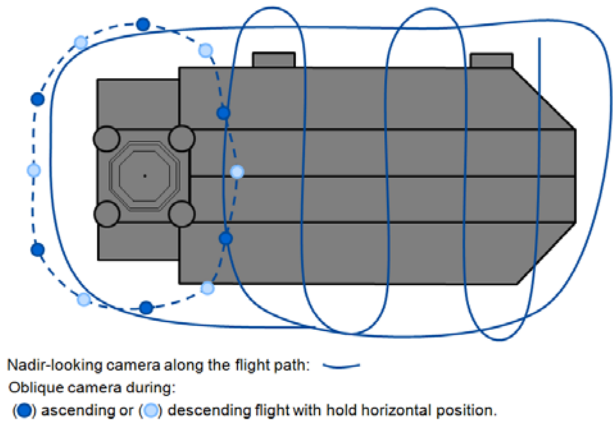

Figure 5. Flight plan of the church and the tower of the cathedral

The two UAS surveys took place in March 2014. The nave of the church was captured with parallel strips and additional oblique images around the church with a total of 348 images. The tower of the church was captured by 12 vertical strips with an angular distance of 30°. Due to a technical problem the camera looked unintentionally downwards during the descending strips, therefore only 6 vertical strips with some 550 images were used for further processing, figure 5.

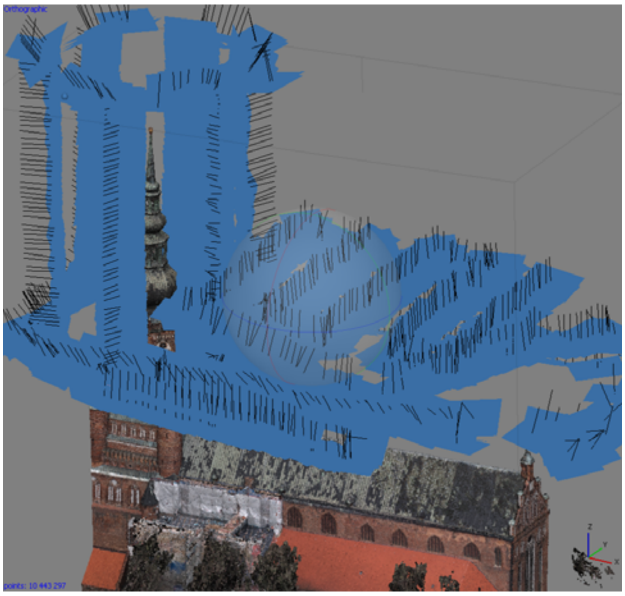

Figure 5. Photogrammetric block configuration of the cathedral

3. CONCLUSIONS AND OUTLOOK

The photogrammetric processing was done with two different software programs, AgiSoft Photo Professional (Agisoft LLC, Russia) and SURE (Institute for Photogrammetry, Stuttgart University, Germany), which produce both detailed 3D point clouds of strongly overlapping digital images by multi-image stereo mapping. The approach for these programs are pixel-wise correspondences between redundant image contents which are formed by automatic search algorithms. Then combinations of stereo image pairs are linked together and generates extremely dense surface models depending on the differentiation possibility of identical points in multiple stereo pairs.

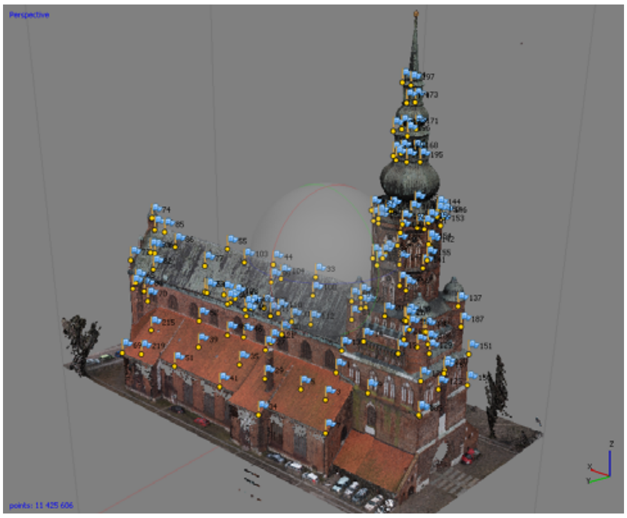

Figure 5. Distribution of the control and check points

First, the photogrammetric orientation of 923 images was calculated with Agisoft Photoscan. 117 points measured with the total station were used as ground control points on the one hand and on the other hand, for geo-referencing.orientation of the imagery was done with Agisoft Photoscan. Due to excessive use of processing resources a densification of the point cloud was performed with the software SURE. SURE also handles very large image blocks adapted to the size of the working memory. The orientations of the images and the distortion-free images computed with Photoscan were used as initial values for SURE. For each pixel, the 3D coordinates can be calculated from several stereo models based on an adapted SemiGlobal matching algorithm. With SURE filtering of point clouds were performed based on the estimated accuracy of each calculated point. Points with an estimated accuracy above 2 mm we filtered out, based on the redundancy of the resection calculation.

Since SURE delivered more conjunctions between images in areas with low contrast, so could a much more dense point cloud generated. These point clouds was thinned with LAStools by a factor of 10 and joined together to form a complete model of the tower of about 180 million points. This was especially helpful for the tower. Points with an estimated accuracy less than 2 cm were filtered out.

The point cloud generated with SURE provides a high quality especially for the brick-built facades of the towers, but also to the adjacent parts of the naves a very high point density with low noise. It thus corresponds approximately to the theoretical resolution corresponding to the sensor size and average camera distance.

In unfavourable textured or lit areas, e.g. dark niches and windows is the point cloud less dense and the noise increases. In the upper part of the tower comparatively frequent outliers and noise are noticeable. This is due to several factors:

- Strong signal depth (tower with side towers) and thus the extremely different base-distance relationships.
- Weaker transverse overlap in this area and the associated low image resolution, some less favourable cutting angle.
- Point allocation problems during the Semi Global Matching in transparent timber-framed structures of small facade structures and abrupt changes in surface contour (edges).
- Less favourable lighting conditions and textures, towards the tip of the tower increasingly smaller photo format filling, backlight and light reflections or relatively uniformly structured metallic roofing and cladding dome.

3.1 Verification of the accuracy

Representative test areas in the overlapping zone between TLS and UAS point cloud were used for accuracy comparisons. See figure 7 and 8 for details of the point clouds. Since the point clouds of UAS and TLS are based on the same coordinate system, an integration and comparison may performed easily.

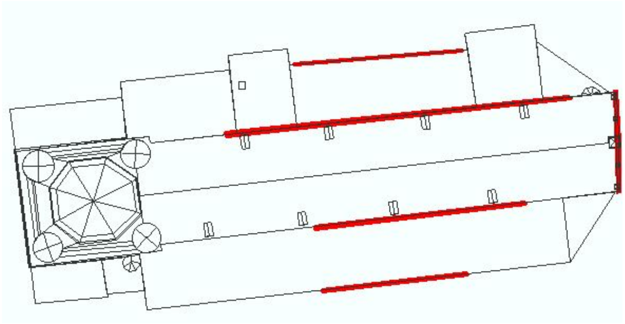

Figure 6. Location of the test areas (red) for determination of differences between the UAS DSM and TLS DSM

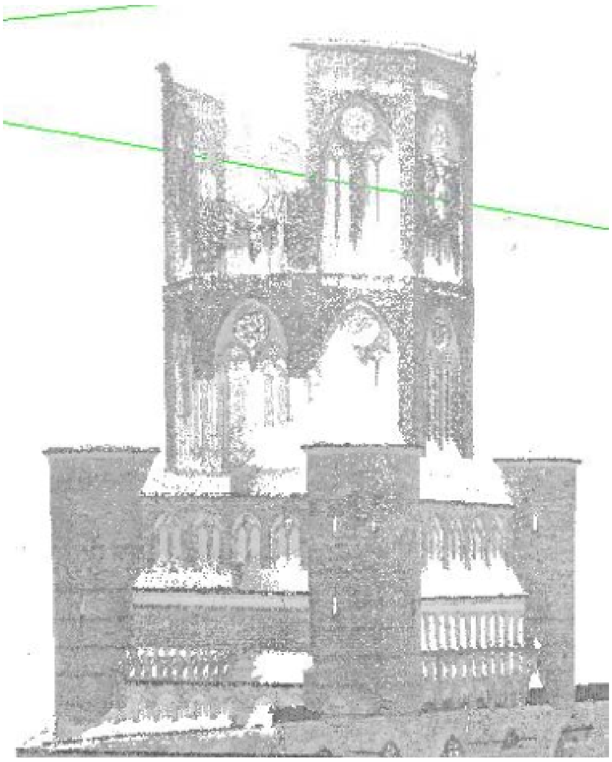

Figure 7. TLS-point cloud of the tower between 44 m to 60 m height (view from Southwest)

These areas were cut out from both point clouds and the point cloud. Differences compared to the TLS as reference method were determined using CloudCompare (OpenSource, Daniel Girardeau-Montaut). The test areas are located at different parts of the naves and have surface areas of 128-330 m², figure 6. The distance values were statistically analyzed (e.g. histogram, mean, standard deviation).

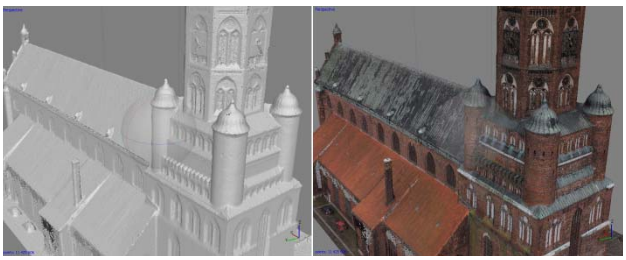

Figure 8. Model of the naves without and with fotorealistic texturing (AgiSoft, 11.5 Mio. Points)

Deviations greater than 30 cm were excluded as outliers from the comparisons. The average deviations of the surfaces in the test faces are in the range of 0.015 m to 0.033 m, and the standard deviations 0.025 m to 0.088 m respectively.

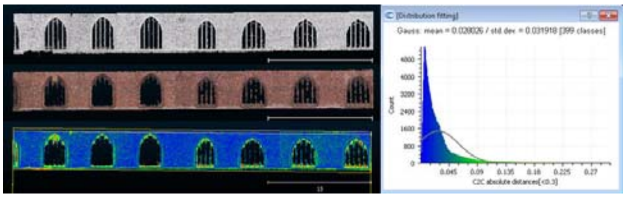

Figure 9. TLS DOM, UAS DSM and differences of distances between them as map and as histogram.

Within homogeneous surfaces (e.g. walls) the differences between the two point clouds are low and are within the range of few centimetres, e.g. figure 9 and 10..

Figure 11. Clips of both point clouds (TLS – yellow, UAS – red) in the lower to mid range of the tower facades.

Small structures and edges are better represented in the TLS point cloud as they appear smoothed in the UAS cloud. Large differences are mainly due to the lack of information in the other point cloud or in some cases by occasional outliers or incorrect measurements. for details see table 1.

Table 1. Summary of the UAS - TLS differences at four different test sites

Location of the test areas	Extent (Length x Height [m])	Area [m²]	Shortest distances: Medium / Sigma [m]
Nave Northface Groundfloor	25 x 8	202	0,015 ± 0,054
Nave Southface Groundfloor	32 x 4	128	0,030 ± 0,071
Middle Nave Northface Firstfloor	52 x 5	260	0,028 ± 0,032
Middle Nave Southface Firstfloor	33 x 4	132	0,033 ± 0,088
East Gable	15 x 22	330	0,024 ± 0,025

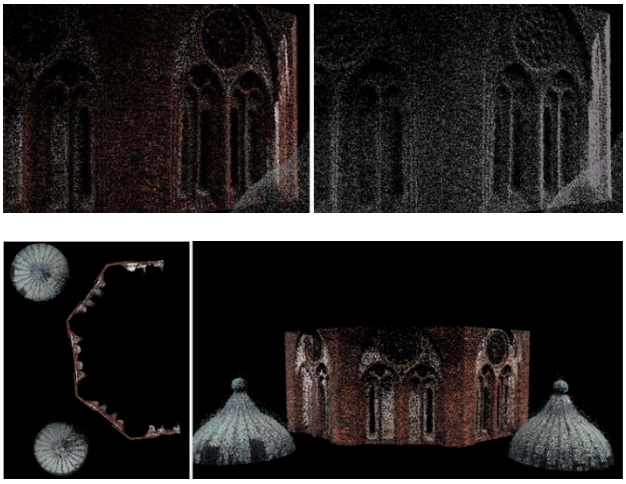

Figure 10. Detailed views of the SURE-point cloud of the tower (view from West)

4. CONCLUSIONS AND OUTLOOK

The quick visual inspection on demand without armor and lifts from the outside is a long held dream of architects and planners. For decisions on the reconstruction of the building, the images provide a valuable basis for assessing the current state.

Often the UAS photogrammetry will be the only workable and cost-effective measurement method for the 3D modelling of high buildings or rooftops, because all terrestrial methods lacks the perspective from above. With careful flight planning is expected that DSM can be generated almost completely.

The combination of TLS and UAS in this project is a logical consequence, because they complement each other in terms of overcoming problems of the other method. Only their combination allows a dense and accurate 3D model of the entire building and is favourable from an economic point of view. In the photogrammetry each object point must be to recognize exactly in multiple images. This is connected to misinterpretations when the texturing, lighting or cutting angle is insufficient. In contrast, the TLS as the angle and distance-based measurement method depends on the reflection properties of the measurement spots which are affected by the surface properties and the angle of incidence. The models of both methods have areas in which the respective method fails partially or is inaccurate.

For the UAS 3D-model the problem areas are at the lower building areas, from the ground to the eaves height of the aisles, while the TLS in contrast is more accurate, but has data gaps in the higher areas.

For architectural surveys with an accuracy Level III Eckstein (2004) requires an accuracy of 2.5 cm, which cannot be guaranteed for all areas with the applied UAS method.

The accuracy of comparisons against the TLS reference areas shows that for continuous surfaces, high accuracies were achieved with a standard deviation in the range a few cm and with low noise.

Abrupt transitions in the surface course cannot be accurately mapped because they are smoothed in the UAS point cloud. At these locations systematic differences of several centimeters to tens of centimetres may occur.

Greater accuracy could be achieved by improvements in image resolutions. For this purpose, a higher resolution camera or a lens with a longer focal length could used. Alternatively the distance between the object and the UAS could be reduced. Although the latter option has to be balanced with the increasing security risk.

5. AKNOWLEDGEMENTS

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