

3D RECONSTRUCTION BY COMBINING TERRESTRIAL LASER SCANNER DATA AND PHOTOGRAMMETRIC IMAGES

Lina Han¹, Yanwen Chong², Yuanting Li³, Dieter Fritsch⁴

¹ State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, No.129 Luoyu Road, Wuchang District, Wuhan, Hubei Province, P.R.China, 430079

Email: hanlina@mail.com

² State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, No.129 Luoyu Road, Wuchang District, Wuhan, Hubei Province, P.R.China, 430079

Email: apollobest@126.com

³ Institute for Photogrammetry, University of Stuttgart, Geschwister-Scholl-Str. 24D, 70174 Stuttgart, Germany

Email: litelyt@gmail.com

⁴ Institute for Photogrammetry, University of Stuttgart, Geschwister-Scholl-Str. 24D, 70174 Stuttgart, Germany

Email: dieter.fritsch@ifp.uni-stuttgart.de

*Corresponding author: dieter.fritsch@ifp.uni-stuttgart.de

KEY WORDS: 3D reconstruction, point clouds, photogrammetric images, SURE software

ABSTRACT: 3D reconstruction of outdoors objects by means of terrestrial laser scanner (TLS) point clouds has been one of the most important and reliable technical methods. However, TLS point clouds have two main drawbacks. They don't have sufficient information about the object texture, and sometimes a complete perspective of the facades cannot be obtained due to irregular circumstances. Photogrammetric images contain the required texture and can be used to generate dense point clouds by further processing. Therefore, a flexible approach for getting 3D information from photogrammetric images is applied within this paper. Two steps are taken in this approach. Firstly, Structure from Motion reconstruction is used to derive orientations and sparse surface information. Secondly, with the resulting orientations and information, the SURE software, which has been developed by the Institute for Photogrammetry at the University of Stuttgart, is applied to obtain dense point clouds. Before 3D modeling, these two kinds of point clouds have to be brought into a common main reference system by means of a Helmert (seven-parameter) transformation and the ICP algorithm. Based on the processed point clouds, the Leica Cyclone software and Trimble's SketchUp can be used to produce geometric and texture-wrapped models. The textured models are shown and the quality of modeling and visualization is validated.

1. INTRODUCTION

For 3D model generation, terrestrial laser scanning and photogrammetry are two typical kinds of methods. Dense 3D point clouds of the surface of the object can be collected by the two methods which can be processed later to generate a CAD model.

Terrestrial Laser Scanning is a ground-based technique to measure the position and dimension of objects in the three dimensional space. This technique allows for reliable measurements and can get very dense point clouds of the object surface. Moreover, it is very accurate and of high speed, although the instrument is expensive. Thus it is very appropriate to do the 3D reconstruction by high definition surveying – in short HDS.

Photogrammetric point cloud generation is using close range and aerial imagery, which both have been using in this work. 3D point cloud generation can be performed by using stereo image pairs, called multi-view stereo. Therefore, the 3D coordinates of the points of an object can be determined by measurements made in two or more images taken from different positions. Image matching needs to be done to find the common points on each image. By using the collinearity equations a line of sight can be constructed from the camera location to the object point. Forward intersection can be done by the intersection of these rays that determines the 3D location of the point. Thus, the 3D point coordinates are obtained.

Fully textured 3D models are very important in digital preservation as reference scale models, and also can contribute to city plannings, road analysis, building maintenance, and to Building Information Models (BIM). But due to the complex environment of the urban area, there is still no optimal approach or procedure which is adequate for all cases. Although terrestrial laser scanning is very suitable for point cloud acquisition, it still can't get all data for the 3D reconstruction because of occlusions. Thus, 3D point cloud acquisition using both aerial photogrammetry and close range photogrammetry has been used to get the missing area and roof landscape.

2. TERRESTRIAL LASER SCANNING

The terrestrial laser scanner (TLS) emits a narrow laser beam that sweeps across a target object [1], such as a bridge or a building, gathering millions of closely spaced measurements (points with unique X,Y,Z values). The scanned data are collected and grouped to show the position and geometry of the objects in the three dimensional space. Modern 3D laser scanners are available from a number of manufactures, e.g. Faro, Leica, Riegl, Topcon, and others [3]. Since the area of interest of this work is focusing on the city center of Calw, a frequently visited city located 35km southwest of Stuttgart, Germany, the Leica HDS3000 has been chosen, because the laser beam emitted is eye-safe. It can get 1800 points per second and delivers large datasets including intensive maps scalar field and RGB. By the way, the city center of Calw has been chosen as Testbed for the EU 7. Framework Programme project “Four-dimensional Cultural Heritage World (4D CH World)”. Therefore, the results given below are used for research work in this project.

The scanner has a limited view, and according to the structure of the task area, it needs more than one station. Scan points are recorded and saved in a coordinate system which is related to the scanner, so different scans have different local coordinates. Therefore, it is necessary to determine the spatial relationship between the different scan stations, which is called scan registration. Moreover, the step from the scan coordinate system into the overall coordinate system is called *georeferencing* or just *transformation*. Reference objects and/or control points are needed for the registration process. Normally, three reference objects or control points are used to do the coordinate transformation. There are two common references: natural references (planes, slabs, pipes, corner points, etc.) and manually placed references (spheres, circular flat, checkerboard references, etc.). After registration, the final result can be shown, e.g. by the Cyclone software of Leica Geosystems.

After finishing the registration of each station, a complete point cloud of the block and the neighboring area with acceptable scanning accuracy and registration accuracy can be realized. But this point cloud is not yet sufficient to do the 3D modeling. The inner part of the block is missing since the roof can't be scanned by the terrestrial laser scanner. Furthermore, some areas of the block are missing due to the problem of occlusions. Occlusions are a problem which can always happen due to the irregular circumstance of the field work. Figure 1 demonstrates an example of the missing area of laser scanning results.

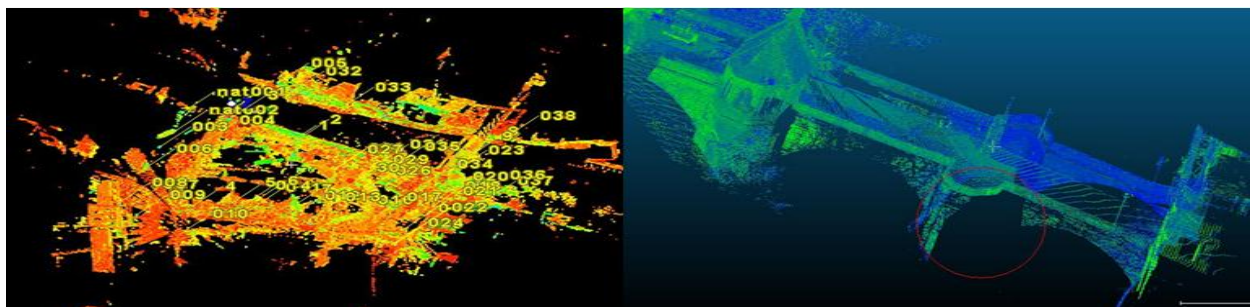


Figure 1. Missing area of the laser scan point cloud of the *Nikolaus Bridge*

Terrestrial laser scanning can deliver point clouds almost everywhere, as viewed from the station. But some areas are still missing because of occlusions. The missing part of the block is the roof which cannot be scanned by TLS. And also some limitations of the HDS3000 may cause some lack of data during the fieldwork. Therefore, other methods need to be combined to make up the drawback of the terrestrial laser scanner.

3. PHOTOGRAMMETRIC POINT CLOUD GENERATION

Photogrammetric point cloud generation is using close range and aerial imagery, which both have been using in this work. 3D point cloud generation can be performed by using single stereo image pairs and multi-view stereo. The 3D coordinates of the points on an object can be determined by measurements made in two or more images taken from different positions. Image matching needs to be done to find the common points on each image. By using the collinearity equations, a line of sight can be constructed from the camera location to the 3D object point [2]. In a first step, forward intersection can be completed by the intersection of these rays, that determines the three dimensional location of the point. Thus, a sparse 3D object point cloud can be obtained. In a second step, dense image matching is performed, to provide for each homologues pixel of the object the disparity in image space. The following forward intersection delivers a very dense point cloud of the object. By using photogrammetry the missing area of the building facade and the missing roof landscape in the terrestrial laser scanning point cloud can be made up. Afterwards, the

generated point clouds need to be brought into a common main reference system by means of a Helmert (seven-parameter) transformation and the ICP algorithm, before 3D modeling starts.

3.1 Close Range Photogrammetric Image Acquisition

Close range photogrammetry is performed by using photographs taken at a closer range, often less than 1,000 feet (about 300 meters) and is used for detailed three dimensional renderings and plotting of small-scale features and objects. By taking images in different positions with different orientations, the forward intersection can be done and the point cloud can be generated. For the missing area in terrestrial laser scanning, for example, laser scanning stations could not be set on the opposite side of the *Nagold* river, but it was no problem at all to take images from this location. Thus, close range photogrammetry could be used to make up the drawbacks of terrestrial laser scanning.

To start with close range photogrammetry, the images need to be taken first. For example, to document the well-known *Nikolaus* bridge, 12 images with different orientation and positions have been taken. The acquisition of digital images considers the desired coverage of the main façade, and should be taken in different positions and orientations to get stereo images. Figure 2 shows the pictures, which were taken by the Nikon camera 4288x2848pix CCD and 20mm focal length. The configuration of the images will affect the result of the 3D reconstruction, thus the places of taking images need to be well arranged, if possible. In order to find homologues features in the imagery the SIFT operator was used and VisualSfM delivered the orientations and positions of the images.



Figure 2. *Nikolaus* bridge images for close-range photogrammetry

3.2 Close Range Photogrammetric Image Data Processing

The close range images need to be processed first. 3D reconstruction needs the position and orientation of each image, which can be calculated by a bundle block adjustment. Scale-invariant feature transform (SIFT) is an algorithm to detect and describe local features in images. An important characteristic of these features is that the relative positions between them in the original scene shouldn't change from one image to another. After getting the common feature points by the SIFT operator, the bundle block adjustment can be carried out. This delivers the relative position and orientation of all images, and a sparse surface of the object is obtained. In this paper, Pairwise Feature Based Image Matching for GPU (SIFTGPU) and Multicore Bundle Adjustment (PBA) were used in the VisualSfM open-source software to obtain the sparse 3D reconstruction in model space. The RANSAC robustness estimation is used for filtering mismatches. After a first 3D reconstruction, the relative orientation and position can be obtained as given in figure 3 (left), and a sparse surface of the missing area can also be found.

Unfortunately, this sparse surface is not yet sufficient to do the 3D modeling. The processing steps of 3D modeling need a very dense point cloud of the surface. Here, the SURE software [5], which is developed by the Institute for Photogrammetry at the University of Stuttgart, is applied to obtain very dense point clouds. SURE is a software solution for multi-view stereo, which enables the derivation of dense point clouds from a given set of images and its orientations. Up to one 3D point per pixel is extracted, which enables a high resolution of details. Two kinds of data is needed to be input to the software: The images and their exterior orientation parameters. The following standards of image formats can be processed: JPEG, TIF and PNG. For the orientation and position information, the project file can be in .prj and Visual SFM file .nvm format. Within a first step, images are undistorted and pair-wise rectified. The second step select suitable image pairs and performs the dense stereo matching similar to the Semi-Global Matching (SGM) algorithm. Afterwards, a forward intersection of each stereo pixel can be done using the disparity image. The generated point clouds are in .las format and can be checked in the CloudCompare software. Figure

3(right) shows the point cloud which was generated by the SURE software.



Figure 3. 3D reconstruction via VisualSFM (left); Close-range photogrammetry point clouds (right)

3.2 Aerial Photogrammetry

Aerial photogrammetry is a technique for creating two dimensional (2D) or three dimensional (3D) models from aerial photographs, which are pictures of the Earth from a high altitude, usually from an airplane. For the missing area of the roof landscape, aerial photogrammetry has been used to generate the point clouds. The generated point clouds can not only be used in making up the missing area of the roof landscapes, but also in georeferencing process of all the point clouds. The aerial images are provided with georeferenced coordinates for the projection centers as well as their orientation angles – they were flown with a Ground Sampling Distance of 10cm. A total of six images have been used for this study.

With using the georeferenced EO parameters in the project file, dense image matching with the SURE software generated dense point clouds in the local Gauss-Kruger coordinate system. Within a first step images are undistorted and pair-wise rectified. In the second step, suitable image pairs are selected and matched using a dense stereo method similar to the Semi- Global Matching (SGM) algorithm. Using the disparity images a forward intersection of each pixel can be done. Thus, point clouds with 10cm interval can be generated, which are all directly georeferenced in Gauss-Kruger coordinates.

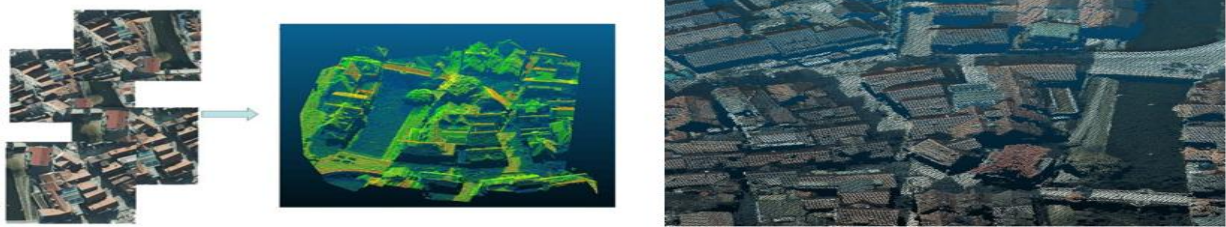


Figure 4. 3D reconstruction via aerial photogrammetry (left); Aerial photogrammetry point clouds (right)

3.3 Registration

After getting the point clouds of the missing areas, the point clouds from different resources need to be combined [4]. After reading the laser point cloud and photogrammetry point cloud at the same time in the CloudCompare open-source software, the position, orientation and scale are totally different, which means the data needs registration before using.

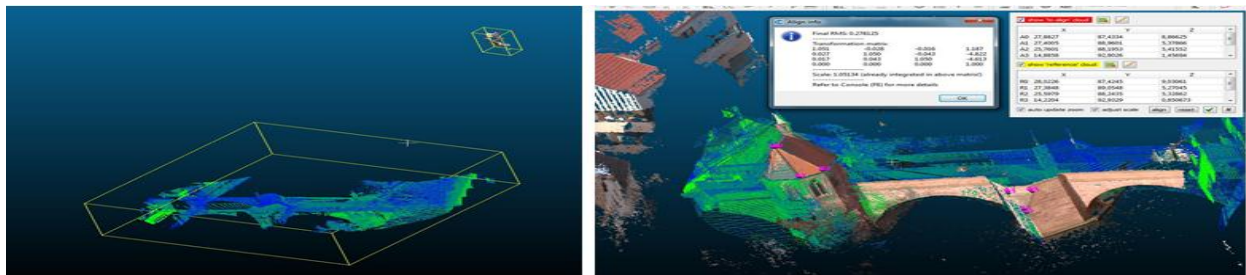


Figure 5. Laser and photogrammetry point clouds (left); Registration result via Helmert transformation (right)

A 3D Helmert transformation can also be called seven-parameters transformation, in which seven parameters need to be calculated including three translations $T=(t_x, t_y, t_z)$, three rotation angles α, β, γ as corresponding Euler angles and a scale factor λ . For each common point, three equations can be set. In order to calculate these parameters, more than seven equations need to be set which means for the Helmert transformation at least three common points are needed to define the unknown parameters. To combine the close range photogrammetry data and the laser data of the Nikolaus bridge together, six common points are chosen manually. For getting a better result, the common points need to be chosen very carefully and the positions of the points need to be well arranged. After getting a better result, the resulting RMS is 0.278m, which is not good enough, most probably caused by the manual selection of common points. Thus, some other method needs to be applied.

The ICP algorithm is chosen to get a better result. In the algorithm, one point cloud, the reference, or target, is kept fixed, while the other one, the source, is transformed to best match the reference. The ICP iteratively revises the transformation (translation and rotation) needed to minimize the distance from the source to the reference point cloud. It can combine two point clouds with similar shapes without needing common points – the only requirements are similar geometries and partial alignment of both point clouds; otherwise this algorithm can worsen the result. So the point clouds need to be well selected before registration. Figure 6 shows the result of an ICP registration without and with a corresponding area selected. Before and after the ICP registration the resulting RMS are 3.610m and 0.199m respectively.

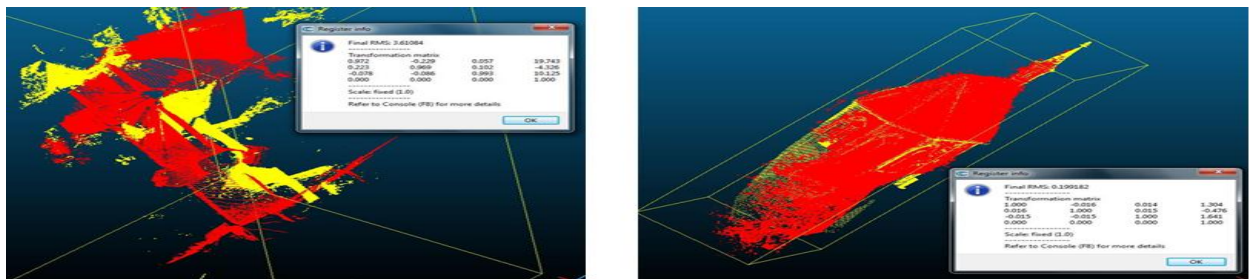


Figure 6. Without corresponding area selected (left); with corresponding area selected (right)

After repeated applications of the 3D Helmert transformation and the ICP algorithm, the final registration result of the bridge can be obtained by a combination of the close range photogrammetric point clouds and TLS point clouds. The resulting RMS is 0.08m, which has been improved considerably. Moreover, the missing area has been filled up. Furthermore, the same transformation steps can be applied for the registration of aerial photogrammetry point clouds. Since the aerial photogrammetry point cloud is georeferenced in Gauss-Krueger coordinates, it can be used as a georeference for the close-range photogrammetry point clouds and laser point clouds. After combining all the data together, a complete point cloud of the block has been generated to be used for the 3D modeling steps.

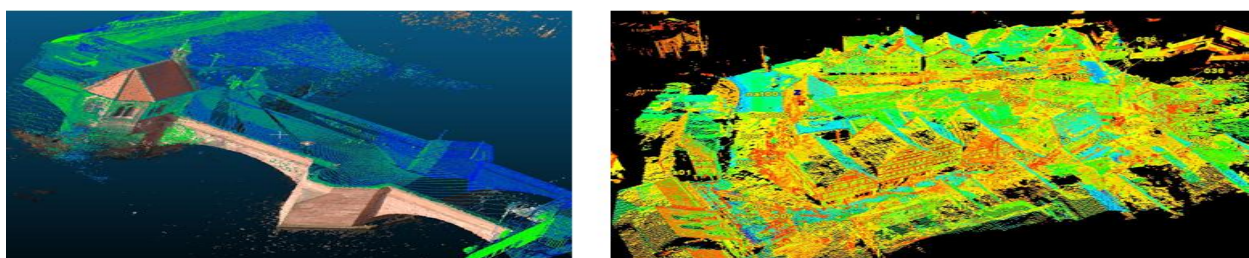


Figure 7. Final registration result of the Nikolaus bridge (left); Final registration result (right)

4. 3D MODELING

3D reconstruction can be done by using the Cyclone software of Leica Geosystems. In the 3D reconstruction procedure, CAD models need to be generated from the point clouds. The generated model will be combined with texture mapping for good visualization.

In the modeling phase, the basic modeling is done in Cyclone. Cyclone can generate planes, pipes, spheres, surfaces, and so on. In this step, both buildings and the terrain were generated. During the modeling, the geometry of the building should be considered since the shapes of the buildings are irregular. Simple objects provided by Cyclone need to be generated and combined together perfectly to fit the point cloud as good as possible, which means no gaps should appear in the generated model.

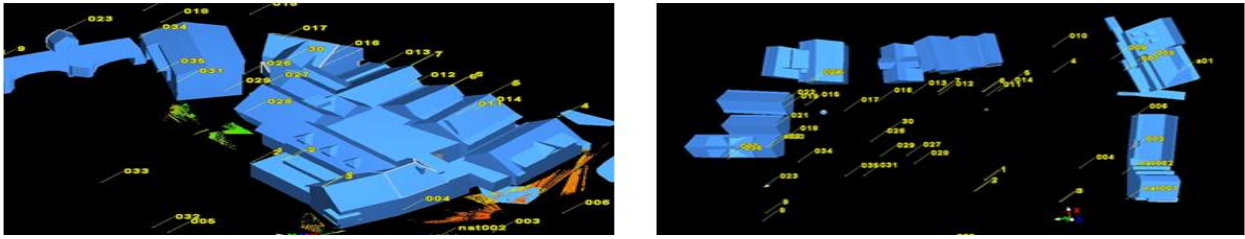


Figure 8. 3D reconstruction of two areas of Calw *Badstrasse*

Modeling in Cyclone can generate the basic geometry model, but it can only provide an approximation of the real shape. Still some details and important surface information is missing. This can be done in Trimble's SketchUp, and it can complete the surface color and other representation. For texturing, the photos with less distortion of the scanned area are necessary. For better photo quality, Photoshop was used to adjust photo color, and to cut out the suitable area. After having wrapped all the textures onto the model, the photorealistic model can be generated for visualization.

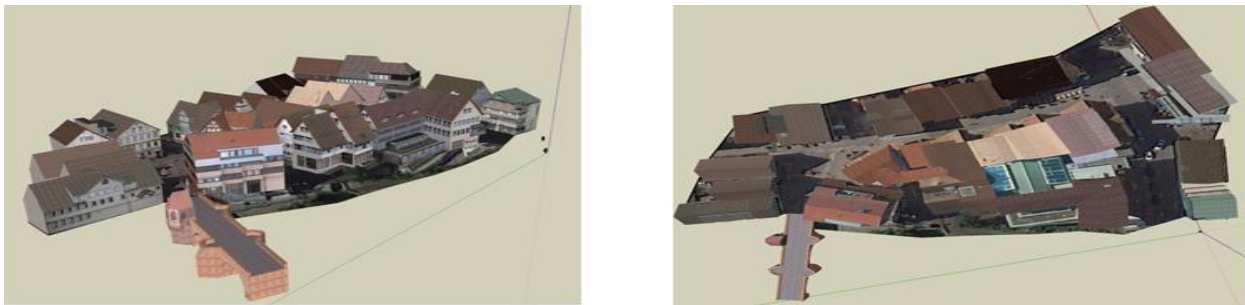


Figure 9. Generated 3D model of Calw *Badstrasse* after texture mapping

5. CONCLUSION

A 3D photorealistic model was created by means of HDS. Photogrammetry is a reliable method to make up for the drawbacks of HDS. Although due to the inconvenience and limitation of Terrestrial Laser Scanning, some information can't be obtained by TLS, in which case photogrammetry can almost make up for all the missing areas. TLS is a very stable and accurate for point cloud acquisition. Photogrammetry is a more flexible and a convenient way compared to TLS. By combining two methods together, complete point clouds of the block and neighboring areas can be delivered. But the quality of registration when combining TLS data and photogrammetry is very important. By using a Helmert transformation and the ICP algorithm, a result with a mean error of 0.08m could be obtained, which is sufficient for the work in progress. This quality can still be improved by using different methods under research.

Although the objectives of this paper have been accomplished and related research has been done, the 3D modeling reconstruction is still a very time consuming process. The procedures including 3D reconstructions by using the Cyclone software and photo processing for texture mapping take a lot of time. To conclude, more effective methods need to be developed to fit the growing demand of 3D modeling and texturing. Further research should also consider accuracy and efficiency improvements.

References

- [1] Heritage, G., Large, A., 2009. Laser Scanning for the Environmental Sciences. Wiley Blackwell Publishing Ltd.
- [2] Luhmann, T., Robson, S., Kyle, S., Harley, I., 2006. Close Range Photogrammetry: Principles, Techniques and Applications. Whittles Publishing.
- [3] Mechelke, K., Kersten, P., Lindstaedt, M., 2007. Comparative Investigations into the Accuracy Behaviour of the New Generation of Terrestrial Laser Scanning Systems. 8th Conference on Optical 3D Measurement Techniques, Zurich, July 9-12, Vol. I, pp. 319-327.
- [4] Moussa, W., Abdel-Wahab, M., Fritsch, D. 2012. An Automatic Procedure for Combining Digital Images and Laser Scanner Data. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXIX-B5, 2012, pp. 229-234.
- [5] Rothmel, M., Wenzel, K., Fritsch, D., Haala, N., 2012. SURE – Surface Reconstruction using Images. Pres. Paper, LC3D Workshop, Berlin.