

A 3D MODEL OF CASTLE LANDENBERG (CH) FROM COMBINED PHOTOGRAMMETRIC PROCESSING OF TERRESTRIAL AND UAV-BASED IMAGES

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ABSTRACT:

In this paper we demonstrate the workflow of 3D modelling and photorealistic texture mapping based on close range imagery acquired with a mini-UAV (Unmanned Aerial Vehicle) and in terrestrial mode. For generation of a highly accurate 3D model, a combined photogrammetric processing of these images was required. The conducted workflow consists of the following steps: project planning, flight planning, terrestrial and aerial image acquisition, camera calibration, control point measurement using GNSS (Global Navigation Satellite System), measurement of control and tie points in the images using the photogrammetric close range processing software Photomodeler 6, modelling and texturing of the object and visualization of the finalized model. Finally we achieved an excellent high resolution textured 3D-Model of the castle Landenberg with combining terrestrial- and UAV-Photogrammetry.

1. INTRODUCTION

1.1 Castle Landenberg, Sarnen

This paper is based on the result of a bachelor thesis at ETH Zurich. The aim was to achieve a digital, photorealistic textured 3D model of the castle Landenberg combining aerial and terrestrial images.

Sarnen is the capital of Obwalden in central Switzerland. The so called “Schützenhaus” is the town's landmark at an exposed position in the west of the village. The object is not only important for Sarnen, but also for the whole canton Obwalden, therefore the “Schützenhaus” is printed as the symbol of the canton in the Swiss passport (Figure 1). The “Schützenhaus” is a valuable relic of the medieval castle in Sarnen. Furthermore, the object was chosen because of the personal relation of one of the authors to Sarnen and to the object. The “Schützenhaus” is one of the two buildings which remain of the castle Landenberg. In the 13th century the castle Landenberg was built by Rudolf of Habsburg and at that time, it was the biggest in central Switzerland until the battles for freedom in 1291, where most parts of the castle were destroyed. From 1646 to 1998 the “Schützenhaus” was the meeting place of the Landsgemeinde (provincial assembly), until the public assembly was abolished in Obwalden 1998. Recently the castle is used for cultural and social events.

Due to the height of buildings it was not possible to accomplish a full stereo coverage of the whole building using only terrestrial images. UAV-based aerial images are a simple and fast way to achieve the needed stereo coverage.

For the data processing the following workflow was set up: Planning and image acquisition, camera calibration with iWitness, image pre-processing, image orientation and modelling using PhotoModeler (PhotoModeler 6), texture mapping and rendering using Blender (3D content creation suite, Blender 2.45), compare Figure 2.

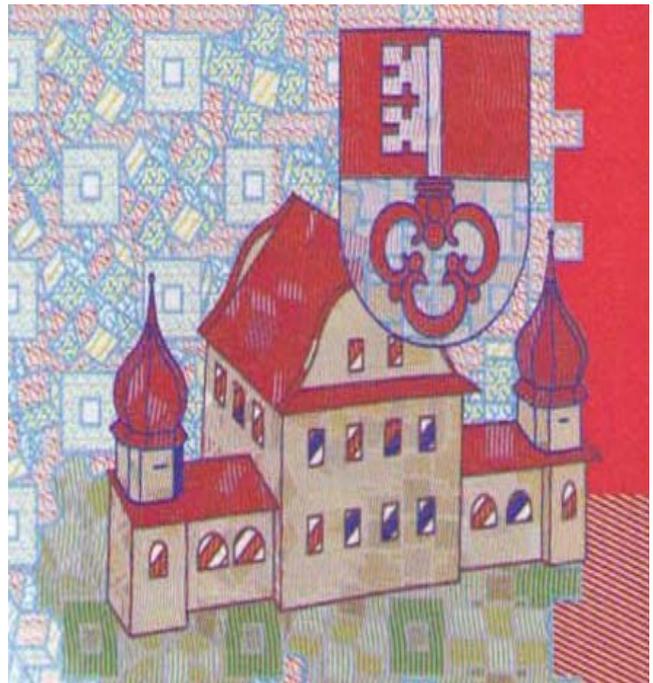


Figure 1: Zoom-in of page 13 of the Swiss Passport showing the Castle Landenberg.

visible. Furthermore, the autonomous system controls the position and can directly react on wind effects by correcting the position (Eisenbeiss, 2004).

2. WORKFLOW

2.2 Planning of the Terrestrial and Aerial Image acquisition

The combination of terrestrial and aerial imagery was chosen to achieve total image coverage of the object. Therefore, we acquired terrestrial photos from various stations situated around the building and aerial images positioned on a circle, with a radius of 25m around the centre of the building. The flying height was defined to 30m above ground. The centre of the building was defined in the Pixel Map 25 (swisstopo ©). The image acquisition points were defined on the circle with a distance of 25m from one point to the next, which corresponds to an azimuth between the points on the circle of 15°. Furthermore, the image acquisition from the helicopter was defined in a way that the camera was looking sideways with a zenith angle of 70° (see Figure 3).

Additionally, one image strip was acquired looking perpendicular to the front of the façade of the building. Figure 4 shows one example of an image taken from the front façade of the building.

Figure 2: Workflow for the data processing.

1.2 The mini UAV-system

The aerial images were recorded using the mini UAV-system, an autonomously operating model helicopter, of ETH Zurich. Our mini UAV-system is shown in Figure 3. The model helicopter is developed by the French company Survey-Copter, which is provided with an on-board navigation system (wePilot 1000) from weControl. The wePilot is equipped with a GPS (Global Positioning System), an INS (Inertial Navigation System), a magnetometer and barometer, which allows the mini UAV to perform attitude stabilization, position control and to navigate autonomously. The private company weControl GmbH is a spin-off of ETH Zurich that specialized in the development of miniature flight control systems for UAV-systems.



Figure 3: Mini-UAV of ETH Zurich (Surveycopter/weControl).

The mini UAV-system is controlled via a ground control station, the weGCS also provided by weControl. The mini UAV-system is capable to fly along a flight path pre-defined by waypoints. The key benefits of this mini UAV-system are the low costs for aerial image acquisition, fast realization of the image flight and instant quality control already in the field. The UAV is more stable and much more flexible in the air than a real helicopter. (weControl, 2008), (SurveyCopter, 2008)

The advantages of an UAV controlled with an autonomous operating control system vs. a remotely controlled helicopter are that the UAV flies exactly along the pre-defined route. Flying along an exact strip or even a circle with a remote controlled helicopter requires a lot of practice, while it is very difficult to navigate for the pilot, since the ideal path is not



Figure 4: Front view of Castle Landenberg. The image was acquired with our mini UAV-system.

The distance to the building was defined to 25m to the façade, while the helicopter should fly with a height of 5m above ground. The two planned model helicopter flights are shown in Figure 5.

For the image acquisition of the terrestrial images two main criteria were defined. Firstly, each point on the façade had to be visible in at least two images. Secondly, the distance of the terrestrial images to the castle was defined to 20 to 25 m, which allows a similar image scale as in the UAV-images. The image scale for all images was defined to ca. 1:3000, which corresponded to a resolution in object space of 1cm.



Figure 5: Flight Paths: Circle (left) and frontal stripe (Orthophoto: <http://www.gis.ow.ch/>, 2008).

2.3 Acquisition of Terrestrial and Aerial Images

Both, terrestrial and aerial images were acquired with a Nikon D2Xs 12 Megapixel still-video camera with a 18mm lens (Nikon AF NIKKOR 18 mm, 1:2.8 D).

Before image acquisition the auto focus was set to manual mode, while the focus was fixed to infinity. Afterwards, the focus was locked with a scotch tape to avoid unintended movements. The terrestrial images were taken from a tripod to avoid blurred images, since the light conditions did not always allow a short exposure time.

2.3.1 Terrestrial Images: Two sets of terrestrial images were taken. One image set was acquired at foggy weather, while the second set was acquired on a cloud free day. The images taken during sunshine have a huge difference in brightness. Due to the inhomogeneous intensity of the light it was difficult to find the optimal shutter speed. Additionally, in the images it was difficult to recognize details in the shadow areas.

The images taken with foggy weather were optimal for our purpose. As a result of the diffuse light no shadows occurred on the object and therefore the whole façade was distinguishable.

2.3.2 Aerial Images: Due to the fact that not all points of the object were visible from the ground, additional aerial images to the terrestrial images were essential for a full stereoscopic object coverage. The roof and the jutting could only be modelled by means of aerial images.

The geographic coordinates of the waypoints were calculated in MS Excel and imported in the weGCS ground control system. Before the real flight was accomplished, the flight was simulated on the computer using weGCS to verify the waypoints and the flight path. Therefore, an oriented pixel map was required. The flight path was then shown on the digital map in the flight control software viewer, which allowed a visual control of the waypoints. The helicopter was connected to the computer with a data cable and the simulation of the flight could be accomplished.

In the field the weGCS was connected to the UAV via a radio transmitter. For safety reasons the starts and landings were flown in manual remote controlled mode. As soon as the UAV was in the air, control was taken over by the weGCS navigation unit. A change from manual to autonomous operations and vice versa is fluently possible. The mission executor of the weGCS visualized the position of the aircraft together with navigation data such as speed and acceleration on the laptop. Missions could now be selected and executed. In this project, the circle and the stripe were stored and available for selection. The circle route was flown two times to ensure the acquisition of a

sufficient number of high quality images. The horizontal stripe from the front as well as the circle resulted in images of satisfactory quality. An example of an aerial image from the circle is shown in figure 6, while a zoom-in of this image is shown figure 7.

Finally, we can state, that for the terrestrial image acquisition a few number of hours were sufficient, while the helicopter was in total for data acquisition in the air only few minutes. However, for the helicopter flight also the preparation of the flight control station and the helicopter, before and after the flight has to be taken in account.

2.4 Camera Calibration in iWitness

In order to obtain accurate image measurements, the deployed camera had to be calibrated. For this purpose, we used the photogrammetric close range software iWitness.

iWitness is a low cost photogrammetric software which is easy to use. The software is designed for image-based accident reconstruction and forensic measurement. iWitness is capable of automatic camera calibration using special coded targets. One of the benefits using iWitness is that the object coordinates of the targets do not have to be known. Very important was that the targets were on different levels. After importing the images and an approximation for the focal length was entered, the software processed the calibration fully automatically. The results are shown in Table 1.

For the further work in Photomodeler the calibration parameters from iWitness were used. The estimated internal accuracy of referencing was 0.23 pixels, which iWitness classifies with the best rating; 'good'. The focal length and the values for the principal point coordinates X_p and Y_p did not diverge significantly from 18mm respectively zero for X_p and Y_p . The radial distortion parameters K_1 , K_2 and K_3 were very small so this was an acceptable result.

Parameter	Value
Focal length	18.544 mm
X_p	-0.084 mm
Y_p	-0.194 mm
K_1	3.247E-4
K_2	-8.243E-7
K_3	1.376E-9

Table 1: Results of the calibration in iWitness (where: X_p , Y_p = principle point coordinates, K_1 , K_2 , K_3 = radial distortion parameters).



Figure 6: Example of an aerial image from the circle route.



Figure 7: Zoom-in to the rectangle of figure 6.

2.5 Image Preprocessing

Before modelling, the first step was to select the images that were necessary to achieve a complete coverage of the façade. Due to the complex geometry of the building and the fact that the sight to some parts of the object was occluded because of trees, 19 terrestrial images were needed to ensure a precise and complete modelling of the façade.

From the 72 recorded aerial images 15 were selected from the circle and 3 from the linear stripe.

In order to avoid inaccuracies due to chromatic aberration we considered only the green channel for modelling. The green channel has two major advantages: it features the smallest aberration and the highest information density of the three RGB colour channels. We used Adobe Photoshop to extract the green channel and converted the images to greyscale images. The process was automated with a batch process.

2.6 Modelling with PhotoModeler 6

PhotoModeler version 6 is a photogrammetric software for image-based measurement and 3D modelling developed by Eos Systems Inc., particularly designed for the photogrammetric close range (Photomodeler, 2008).

After the interior orientation parameters of the camera obtained by the calibration and the images were imported into PhotoModeler, we could start measuring tie points in order to link and orient the images relatively. Thanks to the fact, that the aerial images were not acquired in nadir direction but inclined towards the building, the façade was visible on the aerial images. Therefore, the measurement of common tie points to connect the aerial with the terrestrial images could be accomplished efficiently.

The relative orientation was calculated with the bundle solution in a single block. The overall RMS was below one pixel which could be regarded as an acceptable result (see table 2). As soon as the relative orientation was fixed, we could start reconstructing the geometry of the building by defining points, curves and surface areas on the façade and the roof. It is crucial to keep in mind that an accurate measurement is essential for a realistic model.

Point Marking Residuals	
Overall RMS	0.992 pixels
Maximum RMS	3.843 pixels

Table 2: Results of the bundle orientation.

2.6.1 Modelling with NURBS curves

Modelling the rounded parts of the building with curves through tie points we obtained insufficient results in terms of geometric correctness and visualization quality as shown in figure 8. By modelling the rounded parts with NURBS (Non-Uniform Rational B-Splines), only two points were required to obtain a much smoother result like shown in figure 9.

2.7 Texture Mapping with Blender

As the wire frame geometry of a 3D landmark in most cases is rather simple, a high texture quality is required in order to simulate a more complex geometry (Schulze-Horsel, 2007). For a photo-realistic visualization of the 3D model, texture mapping was accomplished using Blender. The open source software based on Python can be used for modelling, texture mapping, 3D animation and rendering (Blender, 20008).

Due to trees and other plants covering the façade various images had to be rectified before they could be used for texture mapping. The disturbing objects, like plants were retouched using the stamp tool in Photoshop.

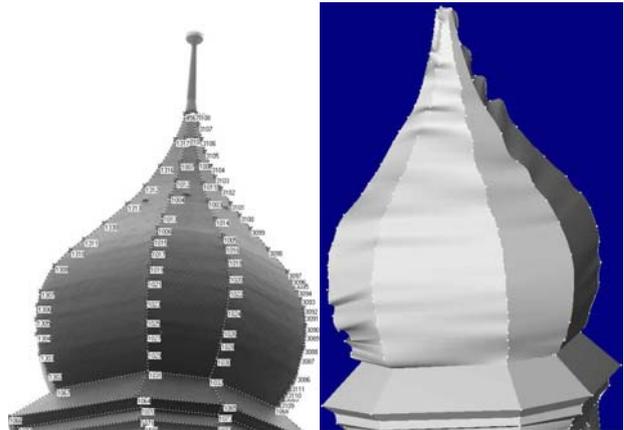


Figure 8: Modelling rounded parts with curves through tie points.

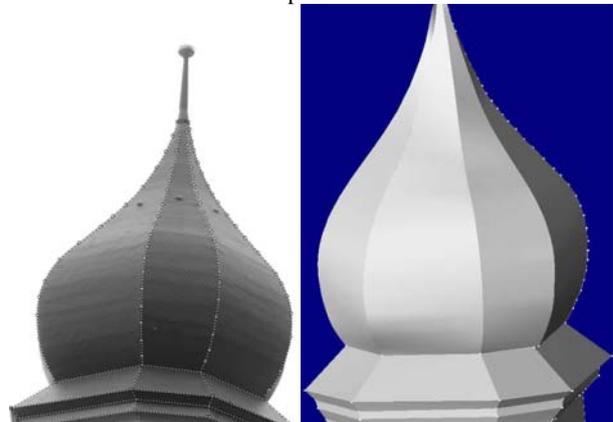


Figure 9: Modelling rounded parts with NURBS curves.

The 3D-Studio-file (3ds format) which was exported from PhotoModeler could be imported in Blender. For texture mapping, each triangle of the model was tied to the corresponding source image. Blender projects the source image subsets on the corresponding faces of the 3D model. In figure 10, the linking process between the source image (left) and the triangle in the model (right) is shown. In Blender this technique is denoted as "UV mapping".

The 3D model consists of a large number of meshes. Fitting all the triangles in the right position in the source image was a time-consuming work. Where triangles could not be fitted in the right position because of trees, the triangles were mapped on a similar looking position.

The high resolution of the texture maps on the façade and on the roof could only be accomplished because of the high resolution of the terrestrial and aerial images.

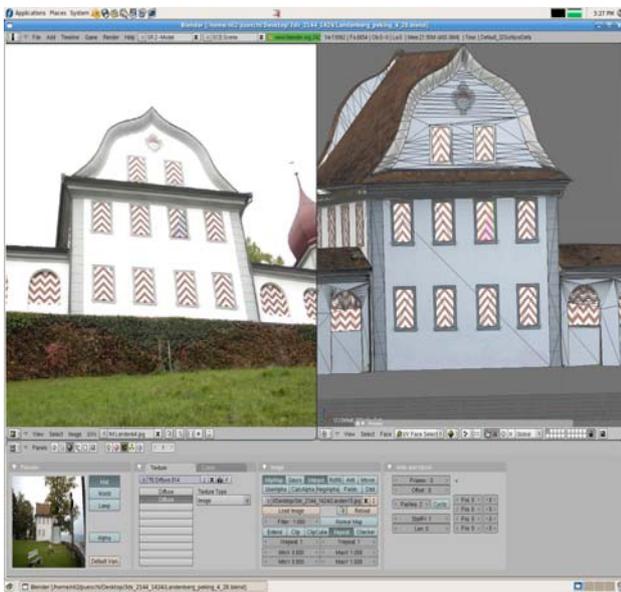


Figure 10: Texture mapping in Blender.

2.8 Absolute Orientation

For absolute orientation of the images, control points were measured in the field with a GNSS measurement system (GNSS System 1200, Leica Geosystems). For precise positioning the service swipos- GIS/GEO from the Federal Office of Topography, swisstopo, was used. Swipos is based on the automated GNSS network of Switzerland. If the System 1200 is linked to a mobile phone the data of these stations allow the use of a virtual reference station (swisstopo, 2008). A real time kinematic measurement in combination with a virtual reference station technique increases the accuracy and reliability. Due to this procedure, we achieved an accuracy of 2.5 cm in object space. This is an adequate result.

The control points were needed to register the finished model with an accurate position and orientation in the Swiss coordinate system. The final absolute orientation was accomplished after 3D modelling of the building because it was more comfortable to work in a local coordinate system during modelling and texturing.

3 RESULTS

Following the described workflow we were able to produce a geometrically accurate photo-realistically textured 3D model of Castle Landenberg. The overall RMS yielded by bundle adjustment is below 1 pixel, which can be regarded as an adequate result for manual measurements. After texture mapping with the terrestrial and aerial images with a footprint of approximately 1cm, the model of Castle Landenberg could be visualized with high quality.

The textured model was exported to VRML (Virtual Reality Modelling Language) format and can be viewed with any VRML viewer.

The generated model can now serve as a high quality digital representation of Castle Landenberg. On the one hand it is suitable for presentation and visualization purposes, e.g. to promote the site in terms of tourism, on the other hand it represents an important digital preservation of the castle which allows the user to perform measurements on the model or derive façade plans.

4 CONCLUSIONS

Thanks to the combination of terrestrial and aerial images a very good stereoscopic coverage of the object could be obtained. A precise measurement of the tie points was a crucial step to reconstruct an accurate 3D model. The facts that the aerial images were taken in oblique directions and that the façade was visible on both, the terrestrial and the aerial images, facilitated the combined processing. Compared to aerial images acquired from airplane or a real helicopter, aerial image acquisition by UAV features various advantages. Any camera can be mounted under the aforementioned UAV and therefore all required images can be taken with the same camera and with a similar footprint for the terrestrial and aerial images. Furthermore, the UAV only needs a few square metres for starting and landing and it can operate in areas where full size helicopters are too big to operate, e.g. near the ground at heights of up to 150 metres. UAVs are also more stable in the air and a campaign with a full size helicopter or plane is much more expensive (Zischinsky, 2000) Due to the fact, that UAVs are capable of operating in a lower altitude than full size aerial vehicles, a much higher image resolution can be realized.

Another approach would be to model the building with terrestrial laser scan data. Since laser scanners do not capture images, additional close-range and aerial images are necessary in order to produce a photo-realistically textured 3D model (Gonzo, 2007). Nevertheless, the required effort would be comparably high as for photogrammetric modelling.

Aerial images are important for modelling as well as for texture mapping. Therefore, the flexible and fast method of



Figure 11: Textured 3D model of Castle Landenberg in Blender.

image acquisition with UAVs lower the time and cost needed to realize a project. Due to the mentioned benefits of UAVs and the availability of a mini-UAV at ETH Zurich we decided to conduct the project with the mini-UAV.

Due to the fact that the modelling and texture mapping had to be done manually it was a time-consuming work to create such a detailed model of the complex building. The aerial images taken with the mini-UAV were important for modelling and texture mapping of the roof and other parts of the building which were not visible from ground.

As a conclusion from the work described in this paper, we can state that in the near future the application of mini UAVs for photogrammetric small and medium scale projects will increase significantly. By an increasing number of applications, it can be expected that mini UAVs will become more and more affordable in the future. With the increasing experience of the photogrammetric community, standard workflows will arise and the time effort will get even smaller.

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