

PHOTOGRAMMETRICAL DOCUMENTATION OF THE BRONZE EQUESTRIAN STATUE OF JAN ZIZKA IN THE FORM OF THE ACCURATE 3D MODEL OF THE BRONZE PLATE JOINTS

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Abstract:

The monumental bronze equestrian statue of Jan Zizka on Vitkov Hill in town Prague (Czech Republic) is one of the largest statues in the world – nowadays it is on the third place after statues Don Juan de Oñate (USA) and Viktor Emanuell II.(Italy) . It's about 9 meters high, together with the pedestal it measures 22 meters. It weights 16,5 tons. The design and construction of this monumental statue was finalised in 1942, but the realisation was possible after Second World War from political reason; it was mounted on its pedestal in 1950. A decision about restoring of this monument after investigation of conservators has been done in 2009. Detailed documentation and reconnaissance of statue was planned as a first step of all restoration activity. The statue was measured with two different documentation techniques: laser scanning and photogrammetry. One dataset is a high density point cloud obtained from precise terrestrial laser scanner Leica HDS, the second is a set of hundreds of high resolution calibrated images from digital camera Canon 5D Mark II. Before image acquisition, the statue was covered with small 5 mm circle targets (aprox. 1.500 pieces) that served as a tie points and 50 geodetic reflexive targets used as a control points. The control points were measured with total station and the measuring was processed as a network adjustment using least squares method.

This paper will describe the photogrammetrical processing of the images and the method of creating the accurate 3D model of the bronze plate joints. Both dataset (images and triangular network obtained from the point cloud) were too enormous for processing in a standard photogrammetrical software (we use software Photomodeler) and for this reason it was necessary to develop a special software (in Matlab language), which combines the data from the laser scanning and results of photogrammetry processing in software Photomodeler.

1. INTRODUCTION

The monumental bronze equestrian statue of Jan Zizka on Vitkov Hill in town Prague (Czech Republic) is one of the largest statues in the world – nowadays it is on the third place after statues Don Juan de Oñate (USA) and Viktor Emanuell II.(Italy) . It's about 9 meters high, together with the pedestal it measures 22 meters. It weights 16,5 tons. The design and construction of this monumental statue was finalised in 1942, but the realisation was possible after Second World War from political reason; it was mounted on its pedestal in 1950. A decision about restoring of this monument after investigation of conservators has been done in 2009. Detailed documentation and reconnaissance of statue was planned as a first step of all restoration activity. The statue was measured with two different documentation techniques: laser scanning and photogrammetry. The aim of the project was to create the precise 3D virtual model with texture, before the start of restoring works.

2. METHODOLOGY

Due to the complicated shape of the statue with many occlusions and high space depth differences, the photogrammetrical method of multi-image intersection and bundle adjustment processing was chosen. This method requires the set of images captured around the statue from different positions in order to have all measured points visible on at least two images captured from different locations. The statue is seated on a high pedestal, that is even level up on the extensible front part of the first floor of the monument (see Figure 1). For this reason, the images could not be captured directly from the ground. Crane traveling around the statue is very limited and not all the needed views from proper distance could be reached. Therefore it was decided to acquire the images from very close range after the scaffolding for conservators has been built up. A crane was also used, but these images served only for visualisation purposes, and not for the photogrammetrical modeling. The stereo-photogrammetry method was not used, because the ratio of high space depth differences of the statue to the camera location was high. Furthermore, it would be impossible to measure the ground control points (GCP) for each stereo-pair.



Figure 1: Complex view on statue from a crane.

3. GROUND CONTROL POINTS AND TIE POINTS

Before image capturing, the statue was covered with tie points and GCP paper targets. From the scaffolding it was possible to attach on the bronze statue approximately 1 400 self-adhesive black and white 5 mm round shaped targets, that served as a tie points. The external orientation of cameras was then accomplished with a high precision and much more faster, than manual finding naturally signalized features. Such a features would be difficult to identify because the ultra-wide lens with a high perspective image distortion was used. The paper targets were easily identified even in a long distance from the camera station, which leads to a higher cohesion of the model geometry (see Figure 2). The tie point targets were attached mainly in the location of connection of neighbouring bronze plates and used for modeling the skeleton model of the statue. The measured GCP targets (aprox. 50), coming into the bundle adjustment, were attached uniformly around the bronze sheathing of the statue. The square shaped GCP targets made from the self-adhesive reflex plastic have printed black cross and the circle, that is diagonally divided with black and white colour. In the centre, there is a 5 mm punched hole, used for more precise target placing on the statue surface. Before placing each GCP target, the small 5 mm cross was gently punched to the bronze surface for the case that the target would fall off and would be needed to replace. The geodetical measuring of the GCP was done by company MDP Geo with total station. The measuring was realised in local system from several positions around the statue on the ground and processed as a network adjustment using least squares method with standard deviation 5 mm. The measuring was problematic, due to the very steep observations and the scaffolding around the statue.

4. IMAGE ACQUISITION

Several images were captured from the crane, aprox. 10–20 meters far-away from the statue, but the main part of the dataset was acquired from the scaffolding in distance aprox. 1–3 meters, without use of a tripod. Every image was captured three times with a different exposure. No flash or other type of artificial lighting was used. Overall, 3×570 (3 different exposures) images were acquired! Absolute majority of the images were taken with ultra-wide lens (16 mm), smaller part with 35 mm focal length. Focusing was mainly manually fixed, in some cases automatic focusing was used. The images were captured in full format Canon *.CR2 (raw).

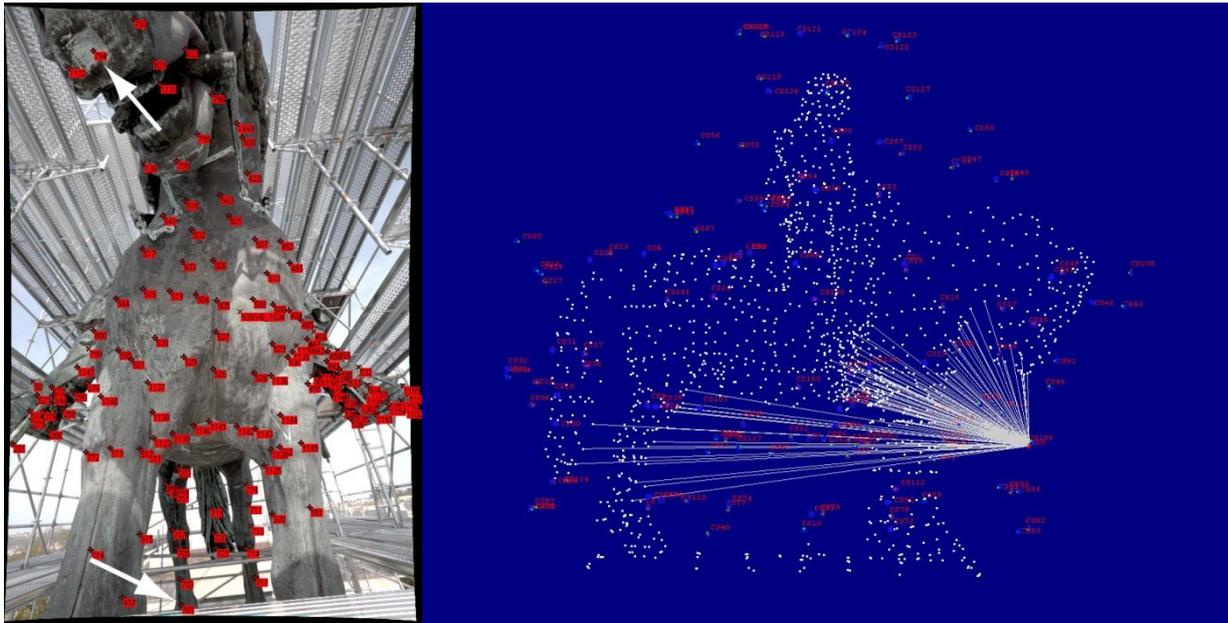


Figure 2: The white arrows on the left image point to the two tie points. Their distance is approximately 7 m. Right image shows all the rays of this camera station.

5. CAMERA CALIBRATION

For image acquisition, there was used digital camera Canon EOS 5D Mark II, 35 mm full-frame with Canon EF 16–35 mm F2.8L II USM lens. The use of an ultra-wide lens required a very precise calibration, for which several software (SW) solutions was used (SW Dcraw, Photomodeler v6 and self-made software in Matlab language). The parameters of the focal length, principal point, distortion (radial and decentric) and chromatic aberration were calibrated in dependence on used focal length (16 mm and 35 mm) and also on the focusing distance (56 cm, 69 cm, 94 cm, 163 cm, infinity). Overall, $2 \times 5 \times 3$ (RGB channels) = 30! independent calibrations were calculated. The information about the focusing distance parameter (exif.SubjectDistance) was loaded from the exif information stored in the raw image. However, this exif parameter is not visible directly in original Canon raw format *.CR2 and therefore all the images had to be converted to another raw format Adobe *.DNG and loaded here. The planar calibration field for SW Photomodeler, extended with four points in space, was captured from 16 different positions. The images were firstly converted to the original Bayer RRGB scheme with SW Dcraw and than separated into a three independent grayscale images (RGB) with the quarter of the original resolution. Than the calibration process was made in SW Photomodeler independently for each channel and the resulting parameters were saved to the common input file for next computing in SW Matlab. Next, the parameters were balanced in order to have the one common focal length for all channels and also in order to take advantage of the whole image format after distortion repair (similar to idealization process in SW Photomodeler – however, this SW do not compute chromatic aberration). Finally, there are 10 calibration protocols (for two focal length and 5 focus distances) that were used for image optimization (idealization) of the photogrammetric images in SW Matlab.

6. IMAGE PRE-PROCESSING

Because the depth of field of the used ultra-wide lens is very large, the absolute majority of the images were captured with manual focus set to 1 m (94 cm, according to exif information). Small set of images were captured with automatic focusing function. The exact information about the focusing distance was loaded from the exif information stored in the raw image and proper calibration protocol for removing distortion and chromatic aberration was then used. The images were firstly converted to the original Bayer RGGB scheme with SW Dcraw. This full resolution grayscale images were in next step optimized in SW Matlab for distortion and chromatic aberration and than debayerized back to the standard RGB output format. The processing of one image of the size aprox. 21 Mpx on a power PC workstation last for about 2 minutes. The whole photogrammetric dataset conversion was computed in several tens of hours!

number of all captured images (3 stands for 3 exposures)	3×570
number of images used in project	131
number of all marked points	8 075
number of all computed tie points	1 353
number of GCP used in project	35
maximum tie points on one image	165
minimum tie points on one image	15
average number of tie points in one image	62
Overall RMS without GCP	1.6 px
Overall RMS with GCP (stddev. 5 mm)	1.6 px
Overall RMS with GCP (fixed)	2.0 px
number of sub-pixel marked points	6 037
number of non sub-pixel marked points	2 038

Table 1: Project statistic.

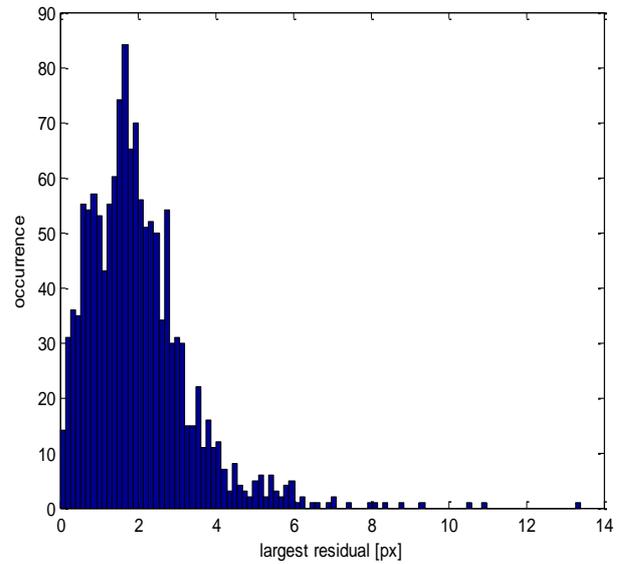


Figure 3: Histogram of the tie points largest residuals.

7. EXTERNAL ORIENTATION IN SW PHOTOMODELER V6

The creation of the virtual model of the statue was realised in photogrammetrical SW Photomodeler v6. The total number of 131 most proper images was subsequently selected for processing. The rest of the images can be added in the future for detailed modeling of the particular part of the statue. On each image, there were manually marked tie points and GCP and referenced with the relevant points in the other images. In SW Photomodeler, it is possible to use the automatic function for circle shaped target point marking, but this function is not robust enough to reliably find targets located far-away from the camera station or deformed by perspective projection. Several tests with different parameter settings of this function proved, that manual marking is more reliable and faster. The process of manual checking and relocating missed targets would be very time consuming. In next step, the GCP coordinates in local system were referenced with relevant points in the project. The external orientation of cameras and Cartesian coordinates of all referenced points in 3-dimensional space and local system of GCP was computed with bundle adjustment method, using least mean square (LSM) condition. The processing of large dataset of a high resolution images and tie points was performing without any problem. The Photomodeler SW was very stable.

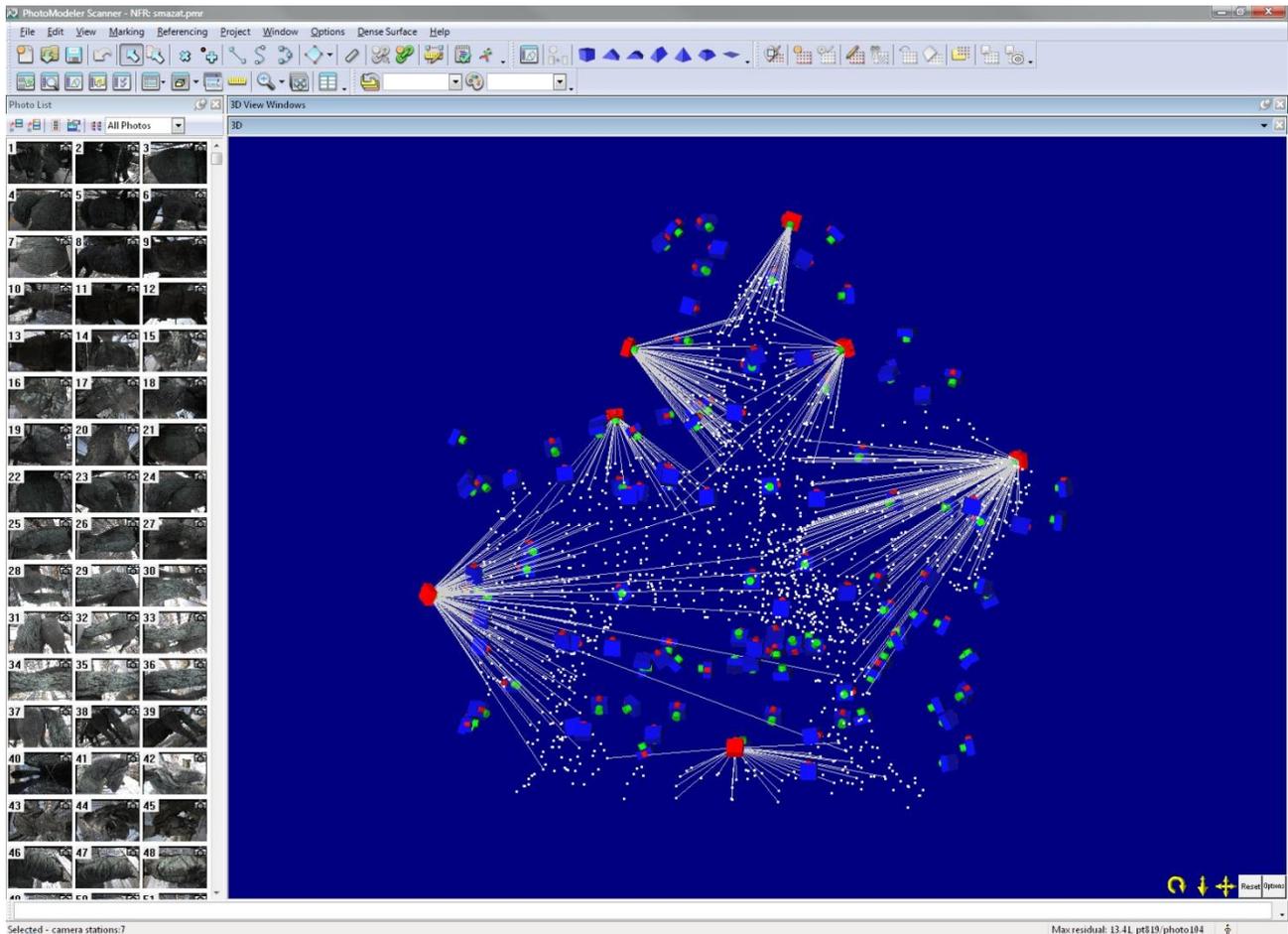


Figure 4: Overview of the project in SW Photomodeler.

8. PRECISION OF THE MODEL AND COMPARISON WITH LASER SCANNING

We were very interested what will be the overall precision of the project based on the ultra-wide lens and if the geometry of the model would not be deformed in the case that no GCP will be used. The results were very interesting. Overall RMS without using GCP was 1.6 px. Comparison of geodetical measured GCP with relevant points exported from SW Photomodeler was done in SW Alltran using identity transformation. Standard deviation (stddev.) of full vector after transformation was 9.3 mm, stddev. in coordinates was 5.4 mm. Stddev of GCP after geodetic network adjustment was 5 mm and so it is not possible to decide if the utilization of GCP in the project was needed. For completeness, the stddev. of the calibration was 0.4 px which is only the quarter of the Overall RMS of the project. The error of the point marking on the image was set in SW Photomodeler to 1 px (for sub-pixel and also non sub-pixel marking). For utilization of the GCP into the project it is important to set the stddev. of the GCP. This setting seems problematic in SW Photomodeler and evidently has no effect. Stddev. of the GCP was set to 5 mm but overall RMS has not changed (1.6 px was reported). No change in overall RMS was repeated with setting stddev. to 1 mm. The project has not changed till the GCP were set to fixed (GCP are than considered as absolute precise and the project has to match their values). Overall RMS was than 2.0 px. The influence of the different stddev. of the GCP was also tested by setting different point marking error (10 px and 100 px), but without success. Overall RMS has not changed. This results in question, wheater the project is more precise with utilization of the fixed GCP (overall RMS 2.0 px) or without them (overall RMS 1.6 px). The project was also compared with the model that was acquired by laser scanning (LS) and transformed in SW Geomagic Studio v10 using ICP (iterative closest point) method. The transformation was realised to the set of tie points (1350) exported from SW Photomodeler (from the project without GCP). It was not possible to get the coordinates of relevant GCP targets from the laser scan model, because the scanning was made long time before the scaffolding has been build and the GCP targets were not attached yet. Therefore, the transformation is slightly influenced on behalf the model from SW Photomodeler without GCP. The function 3D compare in SW Geomagic was

used for the comparison. The stddev. between the LS model and tie points was 7 mm. The comparison between LS model and selected tie points relevant to GCP results in stddev. 6 mm. The stddev. between the LS model and GCP was 5 mm. Spatial accuracy of the input LS model was 6 mm. Based on these results, it is not possible to decide, which measuring method is more precise. It is also important to mention, that some parts of the statue could change its position due to the vibrations (e. g. the horse tail was moving several centimeters while attaching the point targets).

9. VECTORISATION – SKELETON MODEL

The creation of the virtual skeleton model was very problematic. Many of the bronze plate joints were invisible for human eye and also for camera even with the high resolution. Therefore, we had to inspect the statue from very close view and draw by hand the location of the joints into the printed images. Also from laser scanning it was not possible to extract the joint locations. Due to the ultra-wide lens, it was also very problematic to find enough image points – rays with sufficient geometry in order to compute the 3D Cartesian coordinates of the points representing the plate joints. We decided to try the new method for deriving the 3D points from photogrammetry and laser scanning. The procedure is as follows: We manually marked the proper points representing the plate joints on images in software Photomodeler. Inasmuch the exterior orientation parameters for each image is known, it is than possible to project the relevant ray into the model from laser scanning, previously transformed to the coordinate system of Photomodeler. The ray intersecting the model constitutes the Cartesian coordinates of the demanded point. The theory is very simple, but the realisation was very problematic. In software Photomodeler, there is possibility to load the triangulated model and do the above described procedure. In real, it is not possible to load the high resolution 3D polygonal model into the large project with thousands of points and work with it. The software is unfortunately written for much lower data-sets. For these reasons we decided to develop software in Matlab language capable of do such a work. The program does not have the graphical interface, instead we used the software Photomodeler for marking the points and than transfer the image coordinates into the matlab program. The exterior orientation taken from software Photomodeler was the second input. The third data set was the high resolution polygonal model from laser scanning. These data-sets are enough to compute the desired plate joints. The algorithm is very simple. It computes the ray of each point and than the intersection with the model. For the intersection, the algorithm has to know which particular triangle is in the ray direction. This makes the code very slow, because the algorithm has to test each triangle. There is a many ways how to speed up the process. We used the technique common in programming computer games. The key idea is to transform the data set into the multi-level octree voxel data structure. In this structure, each voxel contain certain amount of triangles. Instead of searching all triangles, the algorithm computes first the intersected voxels and than test much smaller part of the triangles in those voxels. The hierarchical approach also speed up the process very much. Therefore, it was possible to derive the requested plate joints in reasonable time.

10. TEXTURING MODEL FROM LASER SCANNING

One of the aim of the project was to use the photogrammetrical images for texturing the LS model, which can be imported in decimated version into SW Photomodeler. This processing was not realised successfully, because the function for texturing the model is not sophisticated enough to balance the different exposure of images. The final model was unusable. For this reason, the model was not printed on 3D Zcorp printer yet and additional texturing methods has to be tried.

11. ACKNOWLEDGEMENT

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Figure 5: Final vectorised model.

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