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Evaluation of Digital Elevation Models Derived from Multi-Date Satellite Stereo Imagery for Urban Areas

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Abstract

High-resolution digital elevation models of urban areas can support humanitarian organisations in their work; especially the 3D reconstruction of buildings is desirable because it can be used for population estimation and damage analysis after crises and disaster events. In this paper, we test the quality of multi-date DEMs with 15 Pléiades images from Port-au-Prince, Haiti using the automatic stereo pipeline s2p. We focus on triplet combinations with images taken from different dates. This study investigates the meta-parameters satellite azimuth and incident angle to understand which recording geometry yields a good result in terms of completeness and accuracy. It is assumed that the closer the multi-date constellation gets to an in-orbit triplet, the better the quality of the DEM.

Keywords: satellite photogrammetry, digital elevation model, multi-date, matching quality indicator

1 Introduction

With the increasing availability of very high-resolution satellite imagery, such as from the Earth observation satellites Pléiades-1A&1B or the WorldView series, it has now become possible to create digital elevation models directly and fully automatically from stereo image pairs (de Franchis, Meinhardt-Llopis, Michel, Morel, & Facciolo, 2014; Gong & Fritsch, 2019; Krishna, Srinivasan, & Srivastava, 2008; Rupnik, Pierrot-Deseilligny, & Delorme, 2018). Thanks to this development, these data and their applications are also becoming interesting for actors outside the classical spectrum. Especially in the humanitarian field, automated derived elevation models yield a wide range of benefits. In this context, elevation models of urban areas are of particular interest, as they can be used for damage analyses of buildings or population estimates. To be able to act appropriately in crisis situations, quickly available data plays a decisive role. Often, however, high-quality in-orbit stereo image pairs are either not available in the archives, or have to be acquired in a time-consuming process (Krauß, D'Angelo, & Wendt, 2019). To address this shortcoming and reduce the reliance on in-orbit stereo pairs, several works have attempted to create DSMs from images with different acquisition times (multi-date), or combining images from different satellites (cross-sensor) (Facciolo, De Franchis, & Meinhardt-Llopis, 2017; Krauß et al., 2019; Ozcanli et al., 2015; Qin, 2019). While these works had access to a tremendous stock of images (up to 200 images per site), humanitarian organizations do not have the budget to acquire this number of images. For this reason, this study examines a Cost-effective approach by using only three images for the generation of a DEM. It addresses the question of which recording geometry yields the best results given that every chosen image in a triplet was taken at a different date. While other work has shown which parameter constitutes a good stereo pair, this study investigates the constellation of the satellite azimuth and the incident angles within a triplet. It can be assumed that the smaller the deviation of the three recording points from an optimal in-orbit tristereo recording, the better the quality of the calculated DEM. From a set of 15 images, all possible combinations are computed and the satellite azimuth and the incident angle are plotted. To generate the DEM, a multiview stereo method is used, which means that the images are first processed pairwise and then the resulting DEM are merged. Afterwards, the completeness and the accuracy of every fused DEM is computed by comparing it against a fusion of two in-orbit tristereo DEMs. This groundtruth data represents the best possible outcome obtained with optical data. Completeness is defined as a percentage of the valid cells. A cell is counted a valid if the vertical error is less than 1 meter with respect to the ground truth data. Accuracy is the root mean square error of all the calculated cells.

2 Related Works

The quality of the generated DEMs can vary significantly and depends on the respective recording parameters. Various works have shown which parameters result in a good stereo pair. On one hand, the convergence angle plays a decisive role. While Krauß et al. (2019) indicate an optimal angle between 5 and 15 degrees for Pléiades images, Facciolo et al. (2017) report an optimal angle of about 20 degrees for Worldview 3 images. On the other hand, it is obvious that the time difference between the two images is an important factor. The closer the images are to each other, the greater the likelihood that the images will be similar, and therefore more suitable for matching. As the time difference between the images increases, the urban structures on the ground will also have changed due to construction activity, making it difficult for the images to match. The same is true for seasonal influences such as vegetation periods or snow. Nevertheless, Facciolo et al. (2017) report that good results could also be achieved for images with the same DOY. Furthermore, Qin (2019) and Krauß et al. (2019) report that the angle difference also influences the quality. The larger this difference is, the worse is the completeness of the generated DEMs. In addition, sun elevation must be sufficiently large, so that no long shadows are formed, which are difficult to match (Krauß et al. 2019).

3 Data

The data used for this study consists of 15 panchromatic Pléiades acquisitions of Port-au-Prince, Haiti (Figure 1). The images cover an area of roughly 120 km² and were acquired between July 2013 and April 2015 with a ground sample distance (GSD) of 0.7 m. There are 3 triplets and 3 tuplets that were taken from the same orbit, respectively. To reduce computing power and save time, one test site has been chosen (Figure 2). The test site has a extent of 400 x 400 meters and is located in a flat terrain with relatively large and rectangular urban structures.

Figure 1: Data coverage in Google Earth

Figure 2: Footprint of the test site (07.2013)

Table1: Overview of available Pléiades images.

short name	acqu. date	satellite azimuth [°]	global incident angle [°]	sun elevation [°]
20130705_001	05.07.2013	234.66	8.43	70.8
20130705_002	05.07.2013	280.17	5.68	70.8
20130705_003	05.07.2013	328.24	8.11	70.8
20130706_001	06.07.2013	128.75	13.55	69.0
20130706_002	06.07.2013	73.34	13.78	68.7
20130706_003	06.07.2013	100.85	12.13	68.8
20141117_001	17.11.2014	243	18.96	50.1
20141117_002	17.11.2014	318.11	17.90	50.0
20141117_003	17.11.2014	274.26	14.90	50.0
20150429_00A	29.04.2015	238.1	6.43	71.9
20150429_00B	29.04.2015	300.62	6.13	71.9

As groundtruth, a composite of two tristereo Pléiades DEMs were taken. It was processed by the CATENA multi-stereo processing chain (Krauß et al., 2019) and consists of the same optical input data this study is using. This groundtruth DEM represents the best possible output of the existing data. By comparing the multi-date tristereo DEMs with the optimum, the deviation of the recording geometry from the optimal recording geometry can be measured.

4 Method

In the first step, the images and their RPC files were cropped to the extent of the test site using the opensource tool "RPC Cropper". The repository can be found on github (https://github.com/carlodef/rpc_cropper). However, the images cannot be cropped directly. Since this tool only accepts image coordinates as input, the geographical coordinates of the test site had to be converted into the image coordinates for each image. Afterwards, all possible combinations of three images are calculated. Since not all images overlap the test site, only 11 images are available for the area of interest. Combinations with images of the same date or only one day difference are not used when conducting the study. Only those combinations where the images were taken on different days are tested. This results 36 valid image combinations.

After these preparation steps, the DEMs can be generated with the fully automatic pipeline software s2p. It allows the processing of three-view stereo datasets by handling the stereo pairs independently and merging the resulting elevation models automatically. No further prior processing of the images is necessary. The only input required is the cropped images and their RPC file. A refinement of the semi-global matching (SGM) algorithm is used to match the images (Facciolo, Franchis, & Meinhardt, 2015). To solve the stereo image rectification problem of pushbroom cameras, s2p cuts the images into small tiles. For detailed information about how the s2p pipeline works, see (de Franchis et al., 2014). The resolution of the generated DEMs is 1 meter. Of the 36 image combinations, 26 resulted in an output. The remaining combinations yield an error, meaning no elevation model can be calculated.

Finally, the elevation models are aligned to the ground truth data. The co-registration is done with the Open-source tool "demcoreg" (https://github.com/dshean/demcoreg) which uses the algorithm outlined by Nuth & Kääb (2011). Since both heights are calculated using the ellipsoid WGS84 and have the same resolution, no prior vertical datum shift or resampling is necessary. Subsequently, a benchmark test of the generated DEMs takes place, carrying out a grid-based comparison of the DEM and the groundtruth dataset regarding completeness and accuracy.

5 Results

Figure 3 shows three generated multi-date DEMs. The images of the triplets span a period of 21 months. The quality of the DEMs varies quite strongly: while DEM A has a completeness of 29.8% and an RMSE of 2.95 meters, DEM C reaches only 14% and an RMSE of 81.53 meters. However, the visual observation as well as the RMSE value of DEM A indicate that significantly more pixels are useful to estimate houses and their heights for humanitarian operations. Figure 4 shows that with a threshold of 2 meters, already more than 40% completeness is achieved. In addition, it can be assumed that with a simple filling hole function this could be increased.

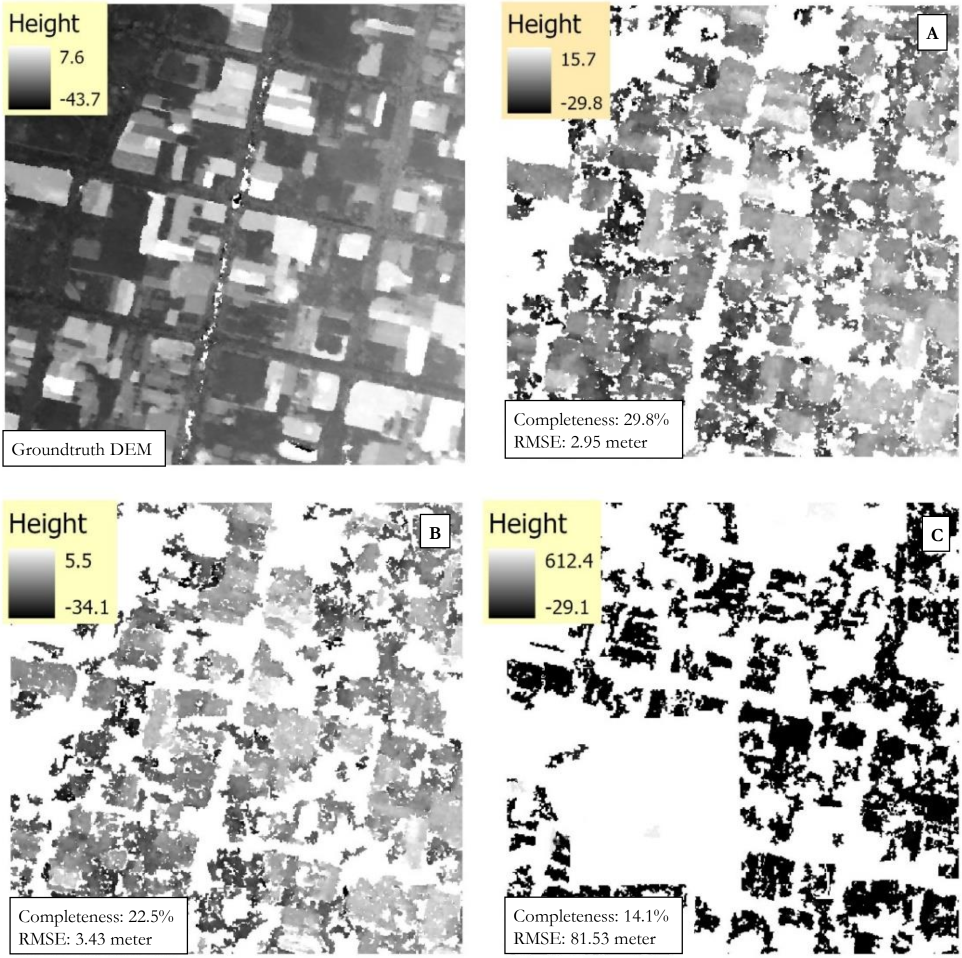

Figure 3: Comparison of three generated multi-date DEM's with ground truth data. Height values are in meter. Image combinations are: A) 20130705_003 - 2141117_003 – 20150429_00A, B) 20130705_002 – 20141117_002 – 20150429_00A, C) 20130705_001 – 20141117_001 – 20150429_00A

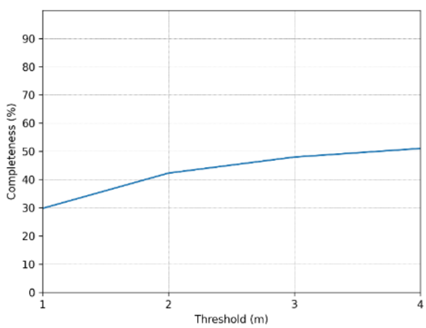

Figure 4: Completeness of DEM A with increasing threshold for valid pixels

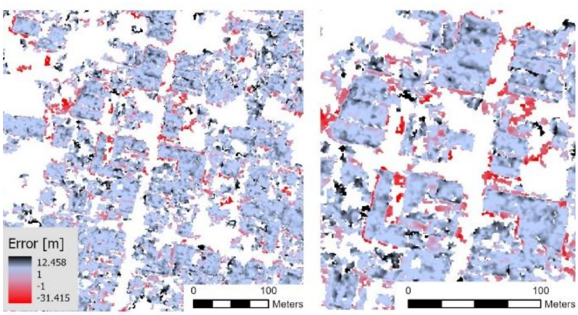

Figure 5: Error Image of DEM A with a zoom in on the right side. Stretched visualization (0.5% Clip)

The error image of DEM A (Figure 5) shows that smaller error values occur mainly within the roof surfaces. High error values, on the other hand, occur along building edges. Streets and spaces in between are hardly matched. Also single buildings are missing completely.

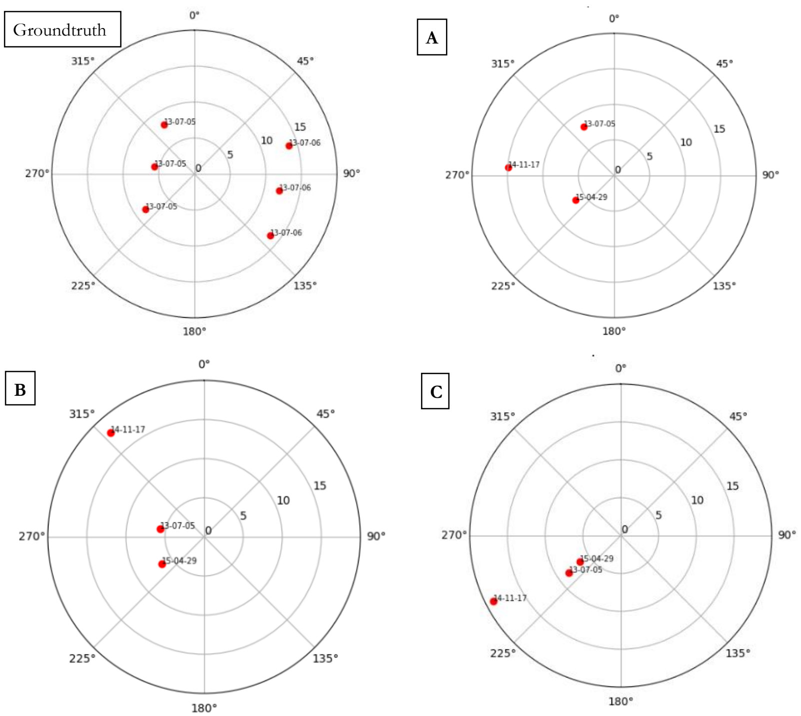

Figure 4: skyplot of the satellite constellation of the 3 DEMs and the ground trouth data. The satellite azimuth angle ranges from 0° to 360 ° and the incident angle from 0 ° to 20°. Note how the two triplets at ground truth are arranged on a line and look at the scene from two opposite sides, getting optimal coverage.

The different multi-date triplets on the skyplot illustrate that the images of an in-orbit triplet are on one line. To replicate this optimal constellation, one image from 29.04.2015 could be substituted in DEM A and DEM B, while the third image (14-11-17) does not fit. These two DEMs also show better completeness values than DEM C. In contrast, all images of DEM C have a very similar azimuth value, and thus, cannot represent the scene from different angles, leading to poor results.

For the best-achieved result, DEM A, the individual images have an incident angle of 8.1°(20130705_003), 14.9° (20141117_003) and 6.4° (20150429_00A). The time difference is 21 months. The recording positions are arranged so that the target was captured from the front, the centre, and the back. The convergence angle between each pair is within the ideal range of values recommended by Facciolo et al. (2017) and Krauß et al. (2019).

stereo pairs for DEM A	convergence angle
20130705_003-20141117_003	12.0°
20130705_003-20150429_00A	10.3°
20141117_003-20150429_00A	10.4°

6 Discussion and next steps

The achieved completeness values with a selection of only three images are low. Nevertheless, the best results are achieved when the recording geometry of the images simulate an in-orbit recording and capture the target from the front, the centre, and back. A drawback of the method is that the influence of the time difference cannot be determined, since all combinations have the same time span.

Due to the low completeness values, the next step is to check whether single stereo pairs provide better results than triplets. If this is the case, the question arises of how to merge the stereo pairs outside of s2p. One possibility is to take the median for each pixel. Another possibility would be to weight the DEMs using the Convergence Angle, the Coverage, or the Sun Elevation Difference and fill the NoData places of the best DEM with the information of the others.

Finally, it would be interesting to test the quality of the generated DEMs at sites with different urban characteristics to see if an industrial area with large rectangular buildings (harbour area) differs from small-structured cottage settlements on steep slopes (south of Port-au-Prince).

References

de Franchis, C., Meinhardt-Llopis, E., Michel, J., Morel, J.-M., & Facciolo, G. (2014). An automatic and modular stereo pipeline for pushbroom images. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *II–3*, 49–56. https://doi.org/10.5194/isprsannals-II-3-49-2014

Facciolo, G., De Franchis, C., & Meinhardt-Llopis, E. (2017). Automatic 3D Reconstruction from Multi-date Satellite Images. *2017 IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, 1542–1551. Honolulu, HI: IEEE. https://doi.org/10.1109/CVPRW.2017.198

Facciolo, G., Franchis, C. de, & Meinhardt, E. (2015). MGM: A Significantly More Global Matching for Stereovision. *Procedings of the British Machine Vision Conference 2015*, 90.1-90.12. Swansea: British Machine Vision Association. https://doi.org/10.5244/C.29.90

Gong, K., & Fritsch, D. (2019). DSM Generation from High Resolution Multi-View Stereo Satellite Imagery. *Photogrammetric Engineering & Remote Sensing*, *85*(5), 379–387. https://doi.org/10.14358/PERS.85.5.379

Krauß, T., D'Angelo, P., & Wendt, L. (2019). Cross-track satellite stereo for 3D modelling of urban areas. *European Journal of Remote Sensing*, *52*(sup2), 89–98. https://doi.org/10.1080/22797254.2018.1551069

Krishna, B. G., Srinivasan, T. P., & Srivastava, P. K. (2008). *Dem generation from high resolution multi-view data product*. 4.

Nuth, C., & Kääb, A. (2011). Co-registration and bias corrections of satellite elevation data sets for quantifying glacier thickness change. *The Cryosphere*, *5*(1), 271–290. https://doi.org/10.5194/tc-5-271-2011

Ozcanli, O. C., Dong, Y., Mundy, J. L., Webb, H., Hammoud, R., & Tom, V. (2015). A comparison of stereo and multiview 3-D reconstruction using cross-sensor satellite imagery. *2015 IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, 17–25. Boston, MA, USA: IEEE. https://doi.org/10.1109/CVPRW.2015.7301292

Qin, R. (2019). A Critical Analysis of Satellite Stereo Pairs for Digital Surface Model Generation and A Matching Quality Prediction Model. *ISPRS Journal of Photogrammetry and Remote Sensing*, *154*, 139–150. https://doi.org/10.1016/j.isprsjprs.2019.06.005

Rupnik, E., Pierrot-Deseilligny, M., & Delorme, A. (2018). 3D reconstruction from multi-view VHR-satellite images in MicMac. *ISPRS Journal of Photogrammetry and Remote Sensing*, *139*, 201–211. https://doi.org/10.1016/j.isprsjprs.2018.03.016