ASPECTS OF THE DSM PRODUCTION WITH HIGH RESOLUTION IMAGES

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ABSTRACT:

This paper deals with the production of digital surface models (DSM) from high resolution images. The paper explains why the quality of the dense DSM depends on the quality of input data and data compilation. The INPHO GmbH software MATCH-T DSM has been redesigned to produce very dense DSM data. The most important improvement was the introduction of sequential multi-image matching. The point extraction is no longer based on static models, but on computation units. Each computation unit in MATCH-T DSM chooses the best suited image pairs. Each image pair delivers a point cloud, the combined point clouds are filtered by a robust analysis. The precision and the completeness of the MATCH-T DSM from high resolution images is analyzed in two case studies.

RESUME:

Cet article a pour sujet la production de modèles numériques de surface (MNS) à partir d'images aériennes à haute résolution. L'article montre pourquoi la qualité du MNS dense dépend fortement de la qualité des données d'entrée et du mode d'acquisition. Le logiciel MATCH-T DSM développé par INPHO GmbH a été reconçu pour pouvoir produire des MNS très denses. Pour ce faire, une méthode d'autocorrélation séquentielle a été développée. L'extraction n'est plus effectuée par une compilation de modèles stéréoscopiques statiques ; pour chaque unité d'extraction, MATCH-T DSM choisit les paires d'images les plus appropriées ; chaque paire d'images fournit un nuage de points qui sont ensuite filtrés à l'aide d'une analyse statistique robuste. La précision et la complétude du MNS extrait avec MATCH-T DSM sont évaluées dans deux études.

1. INTRODUCTION

Matching algorithms are seeing a renaissance. The cause of this resurgence is the increasing demand of accurate and low price DSMs. The new matching generation can hardly be compared to the last one. Because the current technologies offer much more computing power and the introduction of digital cameras has revolutionized the traditional photogrammetric project scale and overlap. This article introduces requirements for the production of very dense DSMs from high resolution images. In this paper high resolution images are aerial images with a resolution higher 20 cm. The article presents changes to the matching technologies to achieve high quality results for these new challenges, and analyses of the quality of the DSM, introduced with the new MATCH-T DSM software.

2. INPUT AND DATA COMPILATION

The quality of a dense DSM depends on the quality of input data and data compilation. The input data are images, orientations and camera calibration data. Additionally, results will be influenced by the stability of the hardware and flight planning. Since MATCH-T DSM can correlate with sub-pixel accuracy, it is essential to use a digital metric camera with reliable stability and precision.

2.1 Overlap

The traditional photogrammetric workflow is based on 60% forward and 30% side overlap. This standard overlap creates occlusion areas and reduces the redundancy of image information. Overlaps of 60/60 or 80/30 allow just enough redundancy for the DSM extraction as 4 images cover any open area. Only very high overlap configurations like 80/60 or 90/70 reduce significantly the occlusion areas in wooded or city areas.

Most of the new digital large frame cameras have a non-square format, hence the viewing angles along the line of flight and across the line of flight differ. The longer side which has the larger angle of view exhibits more occlusions than the short side. Thus the camera should be mounted in a way that the smaller side of the sensor is perpendicular to the flight direction.

The high overlap allows a higher probability of successful matches, as the features are very similar. On the other hand the base line is smaller so the height accuracy is lower. That means that the extraction needs both: Models with high overlap in order to minimise the occlusion areas, and models with large base lines to get better height accuracy. Hence the DSM quality has two facets height precision and completeness.

2.2 Direct georeferencing

Direct georeferencing has become more and more popular in the last decade. Direct georeferencing is mainly used for orthophoto production. With high resolution images an aerotriangulation is still mandatory because the sub-pixel precision potential of the high resolution images cannot be achieve with direct georeferencing [Cramer 2005]. Without this accuracy, the DSM extraction performance is reduced.

2.3 Grid correction

Insito calibration is more and more done to minimise the effects of the sensor instability. For lower precision photogrammetric production the insito camera calibration is not mandatory, as the achieved correction is within sub pixel range. For high accurate matching with high overlapping images this correction reduces the noise of the point cloud because remaining image errors caused by the sensor instability are better compensated [Cramer 2007]. Usually, the benefits of the self calibration are mostly visible at the model border and corners.

2.4 Ground sampling distance

As the large frame and push broom digital cameras have a fixed focal length the only way to modify the GSD is to change the flying height but this also changes the perspective of the images. Therefore high resolution digital image capture is traditionally flown at low heights, but here the amount of occluded areas rises quickly.

Of course a strong overlap of 80% reduces the amount of excluded areas. Nevertheless, because of the perspective changes, the image features are less similar than if it were captured from a higher altitude. This reduces the matching accuracy and augments the risk of miss matching. In general it can be said that DSM extraction from high resolution images is more complicated than DSM extraction from middle resolution digital imageries. The situation may change with the introduction of digital cameras with a smaller angle of view.

3. DSM EXTRACTION METHOD

INPHO's automatic DTM derivation tool MATCH-T DSM has been redesigned to produce very dense DSM data. The most important improvement was the introduction of the sequential multi-image matching and a new robust algorithm for point filtering.

3.1 Short review of the MATCH-T method

The automatic DTM generation approach in MATCH-T is mainly characterised by the feature-based matching technique being hierarchically applied in image pyramids and a robust surface reconstruction with finite elements.

For DTM extraction the measured 3D points, together with curvature and torsion constraints are introduced as observations. The weights for the curvature and torsions observations both regularize and smooth the DTM.

A complete description of the MATCH-T design can be found in Krzystek, P. and Ackermann, F., 1995.

3.2 Introduction to the MATCH-T DSM method

The key idea of the MATCH-T DSM method is the automatic measurement of an extremely large number of irregularly distributed surface points. Robust statistics can successfully eliminate gross error to reduce the noise of the point cloud, as long as most of those points represent the surface and outliers caused by mismatches or displacement in the scene deviate from the majority of "good" points in a statistical sense.

3.3 Sequential Multi-Matching

In order to increase the amount of 3D points, the point extraction is no longer based on static models, but on computation units. Each computation unit in MATCH-T DSM chooses the best suited image pairs. Each image pair delivers a point cloud. The combined point clouds are filtered by a robust analysis. INPHO calls this extraction method sequential multi-matching.

3.4 From FBM to LSM

The previous MATCH-T versions used feature based matching for the auto-correlation, where sub-pixel precision is up to one third of a pixel. In order to improve the matching precision, LSM can be optionally selected in the new MATCH-T DSM version. The improvement in height accuracy of the raster is about 20%, but computation time increases by a factor of two, thus LSM is optional. The user can decide himself if the 20% accuracy improvement is worth spending that extra time.

3.5 Model Selection

The selection of the best suited image pairs is based on the analysis of the DSM slope. The algorithm chooses images that have the best viewing angle of the matching unit. The algorithm allows a limitation of the number of models which are used for the DSM extraction in one matching unit. Indeed with high overlapping images, the amount of image pair combinations increases quickly by $\frac{1}{2}*(n-1)(n)$ with n the number of images.
As a significant parameter, the model azimuth direction has been selected. The point extraction is made in 6 main directions. If one model delivers not enough 3D points then MATCH-T DSM selects the next best suited model for this azimuth.

It is possible that some matching units do not have any texture. For this reason, MATCH-T DSM analyses the quantity of extracted 3D points and recognizes if the image area has poor or no texture. Hence, MATCH-T DSM tries up to 20 models combinations per matching unit.

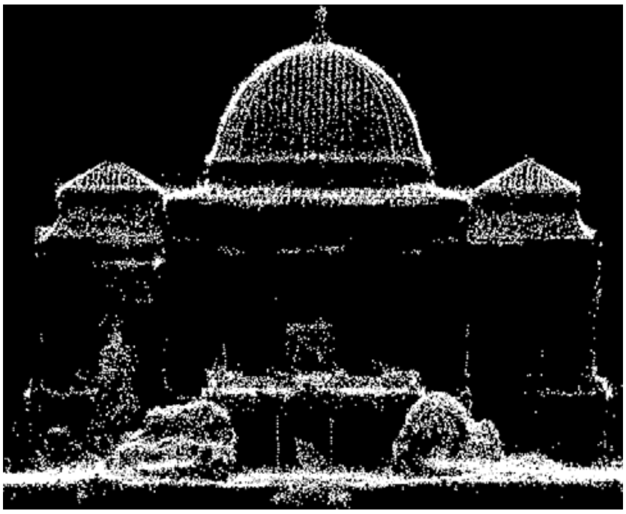

Figure 1. True 3D filtered MATCH-T DSM point cloud from aerial images

3.6 True 3D Filtering

Filtering must be used to eliminate mismatched points. Such filtering is a classification in correctly matched points. Often, the filtering is performed using an interpolation of the terrain surface because the end product is a DTM. Thus MATCH-T has used a finite element interpolation in order to filter the point cloud. This interpolation describes a 2.5D surface. The finite element filtering has to choose one Z value for one X,Y coordinate pair. It is well suited for DTM extraction but the real world is 3D. This method cannot be used to extract 3D Surface Models (3DSM): the extracted point cloud of MATCH-T DSM delivers a true 3D representation (figure 1.).

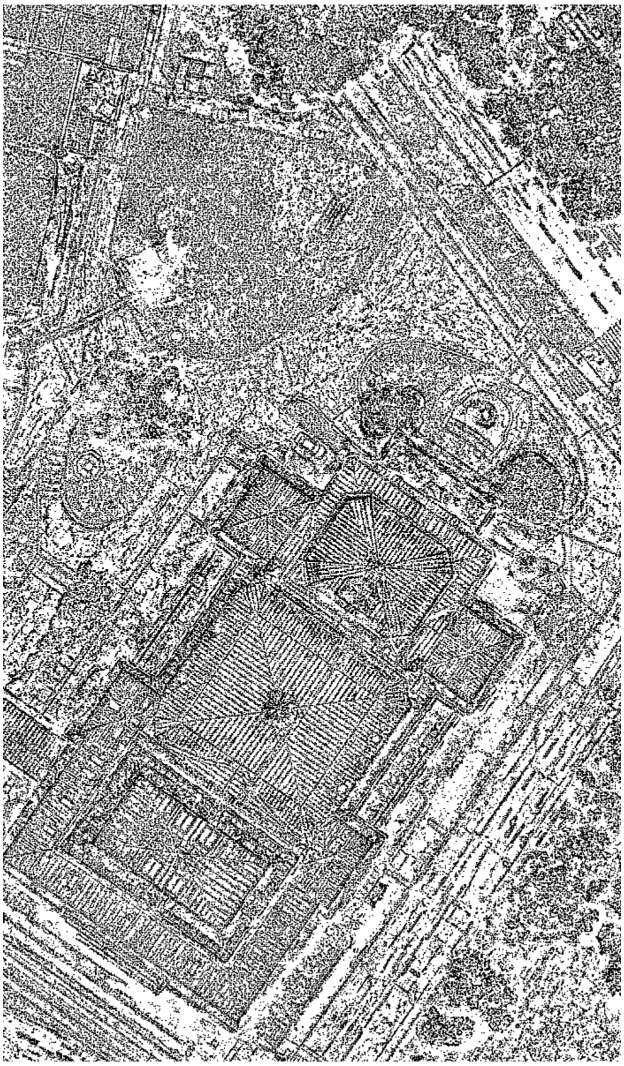

Figure 2. Filtered MATCH-T DSM point cloud distribution

The new filtering algorithm of MATCH-T DSM works in 3D and can select more than one Z for one X,Y coordinate pair. A statistical analysis recognizes points with high redundancy and then selects those with the best accuracy. The filtering realizes both a noise and data reduction without loss of information.

3.7 Point distribution

Figure 2 illustrates the 3D point distribution. One can recognize that the distribution is similar to an image that has been processed with an edge detection operator. Indeed, as MATCH-T DSM uses the Förstner operator to extract points, this point distribution is as expected.

After the point filtering the distribution is more regular but areas with poor textures are still easy to recognize.

4. CASE STUDIES

INPHO has made two case studies using different digital camera geometries and different GSDs. The goals have been to determine the accuracy, the completeness and the reliability of the MATCH-T 3DSM point cloud. In each case, the analysis has been made with high resolution images, the image orientation parameters have been determined by aerotriangulation.

4.1 Case Study 1: 80/30 compare to 80/60 Overlap

This case study compares the quality of DSMs extracted from two project configurations using the same imagery. The project with 80/30 overlap has been derived from the 80/60 project by omitting each second strip.

The information about the project can be found in the table 1.

Type of terrain	Urban
Camera	Ultra CAMD
GSD	7cm
Spectral characteristics	Panchromatic image
DSM representation	3D point cloud
Number of Control points on the ground	287
Number of Control points off ground	341

Table 1. Input information of case study 1

The result summarized in the table 2 shows clearly the benefit of the higher side overlap. The amount of extracted points is twice, the final point density is almost 50% higher. With a completeness of 93% the DSM covers effectively the complete surface. Only poor textured areas are not covered. The precision is significantly better and the mean Z offset is considerably reduced. Thanks to the high resolution images, the point density is very high. Such a point density for photogrammetric products is unconventional and opens new fields of research and applications.

Overlap	80/30	80/60
Number of extracted points	264 538 105	554 846 130
Number of points after the filtering	13 828 673	19268617
Density	11,93 pts/m²	16,62 pts/m²
Completeness of a 50 cm Raster	85,6%	92,9%
Percent of validated points	97%	97%
Standard deviation of control points	12,5cm	10cm
Mean Z shift	-6,5 cm	-2,2 cm

Table 2. Summary of the results of case study 1

4.2 Case Study 2: MATCH-T DSM from ADS40 compared to ALS 50 First Pulse point cloud

This case study estimates the accuracy of the MATCH-T DSM point cloud from a reference surface. This surface model was generated from the LIDAR first pulse point cloud using the software SCOP++. The information about the project can be found in the table 3.

From the filtered MATCH-T DSM point cloud a reduced point cloud was obtained. For each point a height difference to the interpolated LIDAR surface is computed, from those differences the accuracy of the MATCH-T DSM point cloud has been estimated.

Sensor	ADS 40	ALS 50
GSD	15 cm	
Orientation	Adjusted	Adjusted
Spectral characteristics	Forwards and Backward panchromatic Nadir Green channel	
DSM representation	Point cloud	Point cloud from First Pulse
Point density	4 pts/m²	2 pts/m²

Table 3. Input information of case study 1

LIDAR data are used as reference because at this image scale the accuracy of the interpolated surface from the LIDAR points is higher than the MATCH-T DSM point cloud. The result can be found in the table 4.

Surface type	Textured Roof surfaces	Flat Terrain
Number of MATCH-T DSM checked points	26782	57850
Percent of validated points	96,3%	99,8%
Standard deviation of validated points	26,4 cm	19,0 cm
Mean Z shift	- 25,6 cm	- 6 cm

Table 4. Summary of the results of case study 2

As it can be expected the MATCH-T DSM point cloud is more accurate on the flat terrain than on the roof surfaces. But height differences on sloped surfaces like roofs do not directly correspond to the residual error, which is measured perpendicular to the sloped surface. Furthermore MATCH-T DSM delivers a point cloud that contains approximately twice as many points as the comparable LIDAR flight. Thus some deviations in the comparison between LIDAR and MATCH-T DSM result from small structures like chimneys and jutties which are not always completely represented in the LIDAR point cloud or the MATCH-T DSM.

The high percentage of accepted points shows that the MATCH-T DSM point cloud is very well filtered. The few gross errors can be eliminated through a second filtering process.

The achieved mean accuracy corresponds to a matching accuracy better than half of a pixel. Then, the accuracy of the MATCH-T DSM point cloud is well suited for automatic building generation or high precision DTM production from high resolution images.

5. CONCLUSION

This paper has shown that MATCH-T DSM delivers a highly reliable and highly accurate result. The point cloud extracted with MATCH-T DSM from high resolution images delivers a better 3D representation than a traditional raster. The point cloud extracted with MATCH-T DSM is well suited for building extraction, high accurate DTM production and object recognition. The studies show that MATCH-T DSM is competitive to LIDAR for large surface DSM production especially if coupled with high resolution orthophoto production. One can consider MATCH-T DSM as a passive point scanner, the measurement speed only depending on office computing resources.

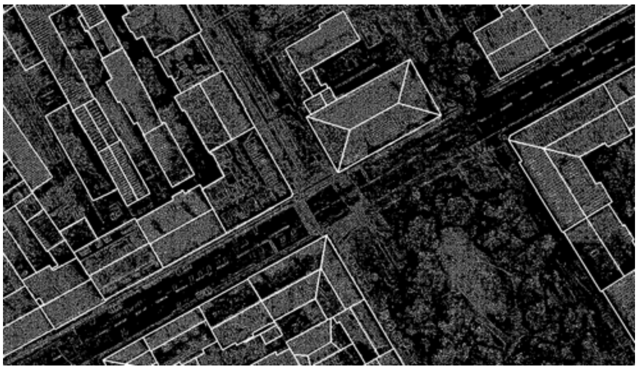

Figure 3. Extracted building from MATCH-T DSM point cloud

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