MULTI-RAY MATCHING FOR AUTOMATED 3D OBJECT MODELING

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ABSTRACT:

Traditional photogrammetry exploits stereoscopic image measurements to reconstruct the shape of objects. This technology is well-known and understood for over a century. Since the age of the stereo comparator human operators have been able to recognize the depth of a scene with remarkable accuracy. In principle, this has not changed during the time that image processing has been introduced into the photogrammetric production chain. Only a certain degree of automation has been derived, when matching and image correlation has replaced the human eyes.
Nevertheless, we need to confess that shape from stereo is not very robust and that a time-consuming and therefore expensive control and verification process is needed after the automated reconstruction process.
To overcome such problems, we argue that a process based on *multiple* image overlap is the appropriate solution. In the age of digital aerial cameras such multiple overlaps can be commanded without extra costs for additional images. A forward overlap of at least 80 % supports a robust and highly redundant measurement. Automation and verification starts to become an easy job, and based on the level of redundancy, we can expect a much more reliable means of automated production.
In urban areas we have an additional benefit in the reduction or elimination of occlusions.

In this paper we present several examples of multiple image matching, based on images taken with the new large format digital aerial camera UltraCam-D from Vexcel Imaging

1. INTRODUCTION

Aerial Photogrammetry has developed a number of rules and guidelines to successfully plan and carry out an aerial photo mission. Most prominent among others is the 60%-20% layout of flightlines, which has not changed over several decades. Pros and cons of such a layout are well known, but in fact we must confess that it is meets only the minimum requirement for any photogrammetric production,
By moving to a fully-digital approach, photogrammetric practicioners may rethink such old rules and ensure that a possible added value of new production schemes will find their way into the final products.

In this contribution we want to focus on the digital aerial cameras which have emerged during the last few years. We are convinced, that such cameras have the potential to renovate and rejuvenate the photogrammetric production chain and to add value to the final image-derived product, be it a higher degree of automation in successive parts of the production chain, a more complete documentation of the project area and its objects, or just as importantly the ability to enhance robustness or even accuracy.

2. FROM ANALOG TO DIGITAL

Photogrammetry has its source in the all-analog world. Films (or even the glass plate) have served as the medium for image information, and mechanical instruments were used to collect vector data. The transition from the analog to the digital workflow was long and inhomogeneous, starting at the end of the production line – namely the recording of three-dimensional vector data into a digital CAD system. The last step – the initial digital recording of the source image data – is now in progress.

Such a long evolutionary process may bring out a number of hybrid solutions, which may have their benefit in commercial application. This was the case in photogrammetric operations, e.g. when analog stereo plotters were modified to become analytical or when the orthophoto-projector was developed at a time when images could not yet be scanned.

The benefit of a digital workflow was first proclaimed at a time when the handling of large datasets (e.g. digital images at a file size of up to 500 MByte) was cumbersome or expensive. This has changed during the last few years and photogrammetry is finally now able to exploit such products of the IT industry which show rapid processing, huge data storage capability and fast data transfer rates.

More and more the accessibility of such an IT infrastructure has shown its impact on photogrammetric production and more and

more softcopy photogrammetry has become the rule – even if the digital images are produced through use of a precision scanner after a traditional analog photo flight. This is finally changing, driven by the advent of the large-format digital aerial camera.

Based on this current transition, photogrammetric operations will change by no longer simply minimizing the number of film images required for a given project, but by instead maximizing the levels of automation, robustness, completeness and added value.

3. DIGITAL CAMERA DESIGN ISSUES

The benefit of a digital aerial camera will be measured by several parameters. We try to work out this by comparing a digital camera to the traditional film based camera.
Obviously we have advantages:

- Superior economy since there is no cost for film, development and scanning and nearly no cost for duplicating;

- Superior image quality based on better radiometric and geometric performance, no film grain noise, color and near infrared simultaneously recorded;

- Superior workflow through applying an end-to-end digital processing solution, i.e. initial quality control during the photo mission, archiving and retrieval supported and highly automated throughout.

In order to avoid drawbacks, we need to make sure that the productivity of the digital camera is at least equal to the film camera. This dictates the following:

- Number of flight lines needs to be unchanged as much as possible, in order to keep operational costs and risks at a minimum;

- On-board storage capacity shall enable an all day flight mission without the need of a disruptive data transfer;

- Frame-rate and stereo capability: A high frame rate must enable the system to go for a large scale stereo mission, e.g. 60 % overlap at a GSD of 1 inch.

Based on these design issues, the UltraCamD large format digital aerial camera has been developed. It offers an image of nearly 90 Megapixels at a frame size of 11,500 pixels across track (equivalent to the 9 inch aerial film scanned @ 20 µm pixel size) and 7,500 pixels along track. The image interval is in the range of 1 frame per second, the on-board storage capacity is close to 2700 frames.
UltraCam D has the ability to simultaneously record panchromatic images as well as true color RGB and False color NIR [Leberl, 2003].

Fig. 1: UltraCamD Sensor Unit and Storage/Computing Unit
ULTRACAM$_D$ consist of four main components, namely the Sensor Unit (SU), the Storage and Computing Unit (SCU), the Interface Panel (IP) and the Mobile Storage Unit (MSU).

- Sensor Unit: The front end of the system is the SensorUnit (SU) with its 13 area CCD sensors. A distributed parallel sensing concept offers the fast frame grabbing of almost 90 MegaPixel images in one second.

- Storage/Computing Unit: The Storage/Computing Unit (SCU) offers a capacity of dual redundant storage of up to 2692 images and is equipped with a set of 15 small size computers configured in such away that each CCD module of the Sensor Unit is accompanied by a separate "private" and dedicated storage and computing component.

- Interface Panel: The Interface Panel (IP) provides inflight control of the camera as well as the post-processing of the image data.

- Mobile Storage Unit: The Mobile Storage Unit (MSU) serves as the image tank for off loading and data transport whenever the SCU needs to be cleared.

4. MULTI-RAY MATCHING

The traditional stereo set-up at a 60%/ 20% overlap layout offers the minimum image data required for conventional three-dimensional data collection. Not much has been done so far to overcome this situation and to avoid the manual interaction typically required in order to remove blunders and to mark up occlusions. This obviously is the major drawback on the way towards fully automated production.
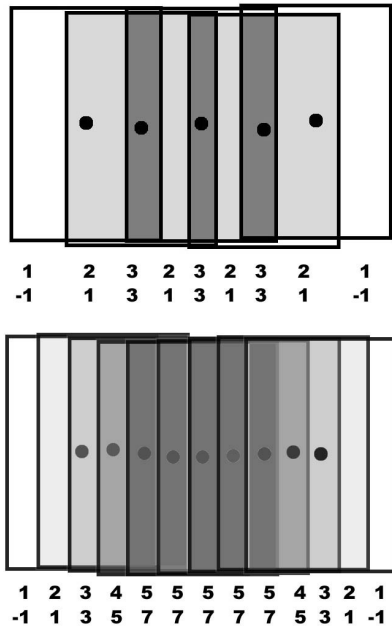
Fig. 2: Multi-overlay at a 60% layout (top) vs. 80 % forward overlap (bottom). The number of frames and intersecting rays (top line) doubles, but the redundancy (i.e. # of observations – 3 coordinates of the tie point, bottom line) increases by a factor of up to 7 times.

4.1 Multi-Ray Matching for AT

The positive impact of multiple overlapss becomes obvious when comparing the results from aerotriangulation. We demonstrate this by a small strip with 11 images. The aerotriangulation was performed twice, once by excluding every second image and therefore reducing the overlap to 70 % (cf. Fig. 3a) and secondly by processing the triangulation for the entire data set resulting in a forward overlap of about 85 % (cf. Fig. 3b).
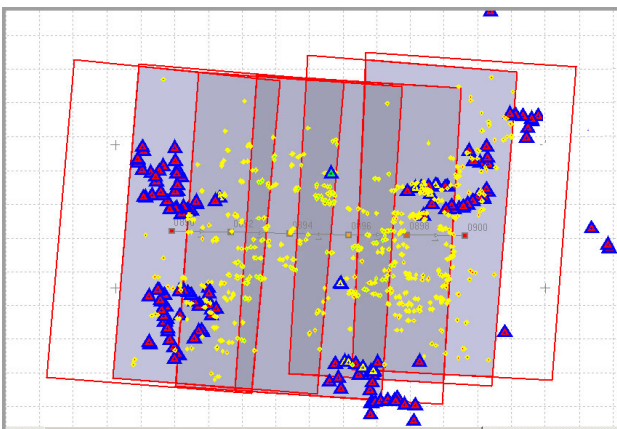

Fig. 3a: Results from the aerotriangulation by MATCH-AT of 6 images at about 70 % forward overlap (Project A).
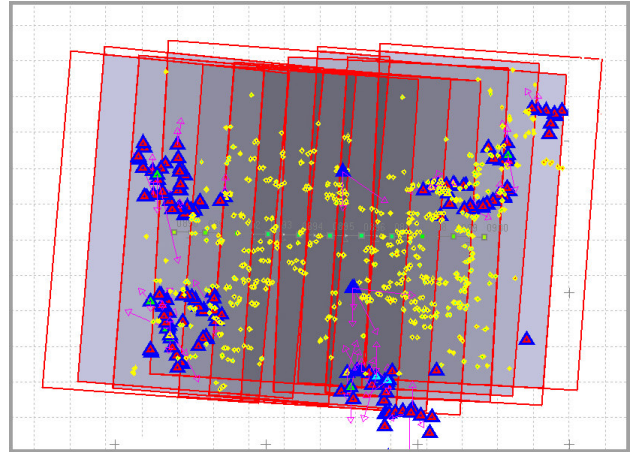

Fig. 3b: Results from the aerotriangulation by MATCH-AT of 11 images at about 85 % forward overlap (Project B).

Project A (6 images @ 70% forward overlap)

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Sigma_o:  ±1.85 µm

Based on
  found        193 points connecting   2 photos
  found        344 points connecting   3 photos
  found        184 points connecting   4 photos

  Number of observations      4437
  Number of unknowns          2229
  Redundancy                  2208

 Mean standard deviations of terrain points
         x          ± 0.019 [meter]
         y          ± 0.025 [meter]
         z          ± 0.102 [meter]

Tie Point z quality by
Number of links/Standard deviation
4    z  ±0.077 – ±0.060 [meter]
3    z  ±0.158 – ±0.082 [meter]
2    z  ±0.287 – ±0.160 [meter]
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Project B (11 images @ 85% forward overlap)

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Sigma_o:  ±1.75 µm

Based on
  found         48 points connecting   2 photos
  found         80 points connecting   3 photos
  found        116 points connecting   4 photos
  found        160 points connecting   5 photos
  found        146 points connecting   6 photos
  found        173 points connecting   7 photos
  found         47 points connecting   8 photos


  Number of observations       8244
  Number of unknowns           2394
  Redundancy                   5850

 Mean standard deviations of terrain points
         x          ±  0.016 [meter]
         y          ±  0.020 [meter]
         z          ±  0.085 [meter]
```

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Tie Point z quality by
Number of links/Standard deviation
8   z   ±0.043 - ±0.046 [meter]
7   z   ±0.046 - ±0.057 [meter]
6   z   ±0.059 - ±0.072 [meter]
5   z   ±0.065 - ±0.083 [meter]
4   z   ±0.082 - ±0.130 [meter]
3   z   ±0.110 - ±0.260 [meter]
2   z   ±0.160 - ±0.330 [meter]
----------------------------------------------------------------
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Table 1: Statistic of the two triangulation experiments

The results of the triangulation experiments show that the overall geometric performance of Project B is superior to that of Project A by about 20 %. Even more differences can be detected, when focusing on the deviation of z-values of tie points. We show that the number of images where a distinct point could be measured (Number of links in Table 1), have a clear impact on the quality of the z-value (i.e the standard deviation with 8 images is ¼ of the standard deviation with 2 images).

4.2 Multi-ray Matching for Object Reconstruction

Based on a novel matching strategy we have compared the output of a DSM experiment. A set of images at high overlap was processed and 3D point clouds were created (Fig.4 - Fig.7).

Fig. 4: UltraCamD image from a suburban scene in Colorado Springs. The GSD is about 10 cm
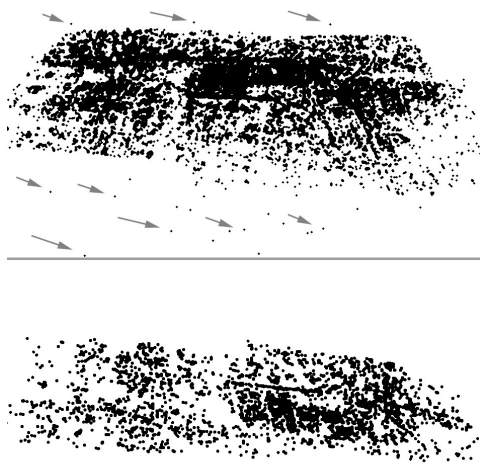

Fig. 5: Automatically processed 3D Point cloud of the scene. Result from 2 intersecting rays (top) and from 3 intersecting rays (bottom) show the reduction of mismatches (marked up by arrows).
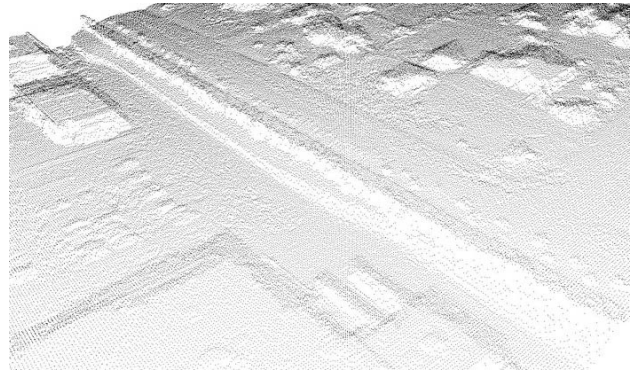

Fig. 6: The final result of the pointcloud : Dense and blunder-free data at a mean density of 1.5 point / sq.meter.

Fig. 7: Three dimensional data set including phototexture.

The result of the experiment clearly shows the impact of a multi-ray concept. We observe a reduction of blunders to an almost blunder-free data set and we observe a remarkable improvement in the geometric quality of the points.

5. CONCLUSIONS

We have presented the concept of a multi-ray matching strategy as a promising tool to enhance the quality of the photogrammetric output, whether it targets the result of the automatic aerial triangulation, or the result of an automatic DEM (DSM) data collection process. The results of our data experiments show a remarkable reduction of blunders, thus a significant better robustness of such automated processing and an overall better geometric performance.

The basis for such enhanced processing is the highly-redundant image data set, thus aerial images taken at high forward overlap and of high radiometric quality to support dense matching results. For the first time, the standard cost driver for aerial photogrammetry operations is removed through the arrival of the large-format digital aerial camera which can then be used to generate such highly-redundant overlapping imagery at negligible incremental cost. The initial demonstration of this concept therefore holds out strong promise for application in practice.

6. REFERENCES

Leberl, F. et al. (2003): The UltraCam Large Format Aerial Digital Camera System, Proceedings of the American Society

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