High Throughput Aerial Photography, Ortho & 3D Processing

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ABSTRACT

The A3 is a family of digital aerial mapping cameras and photogrammetric processing systems, which is based on two main technologies: (a) fast scanning optics that enable high resolution capture of very large areas in a wide field of view, and (b) total automation of photogrammetric processing for very large projects.

A3 Edge, the new model in the A3 family, provides better image quality, an even higher GSD than other A3 models and even higher efficiency. The A3 Edge camera provides a complete solution together with the A3 LightSpeed Processing system. The latter, automatically performs aerial triangulation and produces orthophotos, stereo pairs and DSM from all A3 cameras. A3 LightSpeed deals with an incredibly large amount of imagery, which only grows as VisionMap customers take on larger and larger projects. Even so, the complete A3 Digital Mapping System meets all industry standards. During the past year, the A3 Digital Mapping System has received the IFPs stamp of approval, as noted in IFP's report, "VisionMap's A3 System obtained very satisfactory empirical accuracy results from this Vaihingen/Enz test." The next steps for LightSpeed will be introducing 3D modeling capabilities. In the last couple of years the use of aerial photogrammetry techniques to generate 3D models has become a real trend in the geospatial industry. VisionMap's A3 family is ideal for such 3D applications, as it provides high resolution with wide field of view.

This paper will review the applicability of data captured by A3 Edge for wide coverage orthophoto generation, mapping and 3D modeling.

1. A3 EDGE

A3 Edge is the new model introduced in the VisionMap A3 cameras family.

As all A3 cameras, the A3 Edge provides high resolution and a wide field of view at various altitudes. A3 Edge takes the A3 advantages to a higher level – with better image quality and even higher capture efficiency.

1.1. VisionMap A3 Technology

The A3 family is a family of digital aerial cameras and photogrammetric processing systems. The camera is based on a unique technology of two "sweeping" telescopes. The telescopes capture single frames while sweeping in a perpendicular direction to the flight direction. By doing so, they generate a wide field of view.

Each telescope consists of a folded lens which includes an innovative patented motion compensation mechanism. The motion compensation mechanism moves the secondary mirror in the folded lens telescope in order to compensate for forward motion, for the sweeping (roll) motion and for vibrations (FMC+RMC+VC).

Each telescope has 300 mm focal length, providing a very high GSD at even high altitudes.

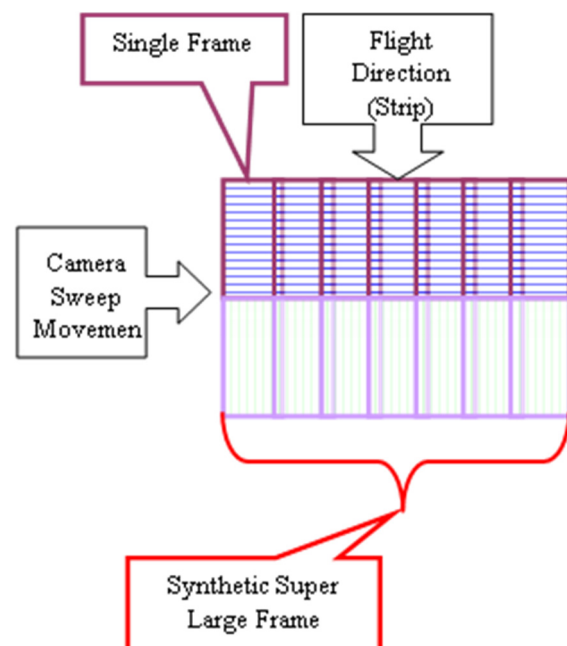Although each frame has a narrow field of view, the

Figure 1: Flights with the VisionMap A3.

sweeping mechanism which can capture up to 64 single frames in a sweep generates a wide field of view (up to 109°).

Another benefit of the sweeping mechanism is that both nadir and oblique images are captured simultaneously, in a single flight, using a single camera, providing ideal data for 3D products.

Due to the unique technology, in each flight of an A3 camera hundreds of thousands of frames are captured. Processing this huge amount of data is quite a challenge.

1.2. A3 Edge Advantages

As mentioned above, the A3 Edge provides better image quality, an even higher GSD than other A3 models and even higher efficiency.

A3 Edge utilizes KODAK KAI-16070 which pixel size is 7.4um and the frame size is 16MPix. The camera specification is as follows:

Figure 2: A3 Edge.

Total weight (Kg)	42
Camera dimensions (cm)	50*60*60
Max footprint (pix)	80,000 * 10,000
Pixel size (micron)	7.4
Focal length (mm)	300
Color	RGB (CIR also available)
CCD dynamic range (bit)	12
Motion compensation	Forward, Roll, Vibration (FMC,RMC,VC)

A3 Edge is the most efficient data capture solution in the market. See below some coverage figures for different flight scenarios:

Ortho GSD (cm)	GSD	5	10	15	20	25	30
Altitude above ground (ft)	H	5,542	11,084	16,626	22,168	27,709	33,251
Ground Speed (knot)	V	160	250	290	360	430	490
Effective angle (deg)	2α	25	35	50	55	60	65
Distance between Flight Lines (m)	Dv	712	2,024	4,490	6,683	9,265	12,268
Sweep Width (SLF, m)	W1s	1,658	4,558	10,030	15,129	20,575	27,364
Aerial Survey Productivity (ortho coverage, sq.km/hour)	COV4	211	937	2,411	4,456	7,378	11,133

Table 1. A3 Edge aerial productivity.

Comments:
1. Forward overlap – 55%, Side overlap – above 55%;
2. 2α – an effective angle of a full FOV used for orthophoto production:
   - $2\alpha=50°$ corresponds to 42% side overlap for RC30 camera with F=150 mm;
   - $2\alpha=65°$ corresponds to 20% side overlap for RC30 camera with F=150 mm;
3. The parameters above were calculated for A3 EDGE/S model with gyro stabilized mount.
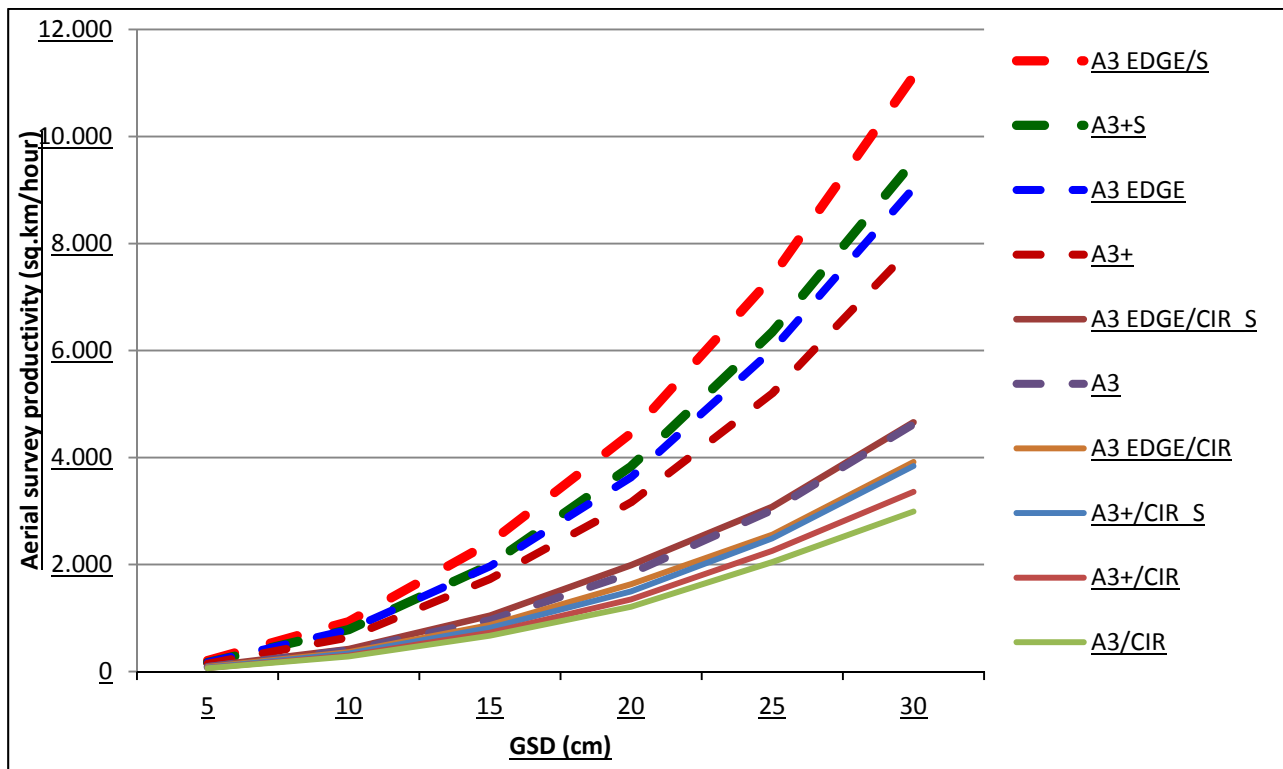
Figure 3: Aerial survey productivity for different models of A3 camera.

Due to its unique sweep technology which enables to capture oblique and nadir images simultaneously with large overlapping areas, as well as its exceptional productivity and extremely high resolution, VisionMap's A3 sensor is ideal for large area orthophoto production and 3D city modeling.

2. A3 LIGHTSPEED PROCESSING SYSTEM

A3 LightSpeed is VisionMap's automatic processing system. It automatically performs aerial triangulation and produces orthophotos, stereo pairs and DSM from all A3 cameras.

A3 LightSpeed can process an incredibly large amount of imagery, which only grows as VisionMap customers take on larger and larger projects. Last year one of VisionMap's customers captured around 5,000,000 frames in a single project.

For the standard cluster configuration, the single aerial triangulation block can consist of up to 250,000 images, which for 25 cm GSD will cover the area of 36,000 sq.km for orthophoto production.

2.1. Aerial Triangulation

The A3 system provides extremely robust and highly accurate aerial triangulation, with or without GCPs, and without an IMU.

The exceptional accuracy is achieved through a combination of features: high resolution, wide field of view which leads to the large side overlap and huge number of tie points which are extracted in the A3 LightSpeed software.

A3's wide FOV enables intersection of rays from multiple flight lines and thus ensuring exceptional AT accuracy. The large side overlaps resulting from A3's wide FOV provide many tie points between flight lines which contribute to high accuracy.

These tie points are observed from many different angles and all hundreds of thousands of the tie points collected are solved together in a single block.

2.2. Stereopairs for stereocompilation

There are two ways of using A3 images for stereocompilation:

1. Use of the single images.
2. Use of the Super Large Frames (SLFs), consisting of all single images of one sweep.

The SLF is characterized by a very large area for stereocompilation. The measuring accuracy of the SLF is the same as the measuring accuracy of a single image. It is ensured by a special DLL provided by VisionMap.
For stereocompilation one can use two consecutive SLFs from the same flight line or two adjacent SLFs from adjacent flight lines.
The following digital photogrammetric stations have already implemented the A3 camera model for stereocompilation: LPS, SocetSet, AtlasKLT, Photomode, Talka, Summit Evolution, OrbitGIS, MicroMap, ESPA 3D, ImageStation, ArcGDS, Menci, Virtiozo, SimActiv, Oblivision, Multivision.

2.3. Orthophoto Generation

A3 LightSpeed automatically produces wide area orthophotos from A3 imagery. The orthophoto process performs color balancing and automatic seam line detection.
Haze removal for high altitudes is a challenge, but the solution of course, lies in post-processing. Physicists have been studying light scattering and the atmosphere for quite a while. When light scatters from "clean" air, the scattering agents (air molecules) can be modeled quite well as point particles. And the scattering of small particles was understood pretty well by Lord Rayleigh.
However, empirical methods need to be used as well, since there are many effects too complicated for full modeling with purely theoretical methods.
The A3 LightSpeed processing software uses adaptive Rayleigh uniform-sky and Lambertian ground-reflection models, with empirical parameters.

Figure 4: Orthophoto generated by A3 LightSpeed.

3. AERIAL TRIANGULATION ACCURACY

3.1. VisionMap A3 Digital Mapping System Tested by IFP

The University of Stuttgart's Institute for Photogrammetry (IFP) is a prominent and highly esteemed research establishment that has been researching the fields of photogrammetry and computer vision, photogrammetric image processing, and geoinformatics for over 60 years. IFP operate a photogrammetric test site, where they investigate the performance of various photogrammetric systems. The test site is located in Vaihingen/Enz, a hilly area near Stuttgart, Germany, providing several types of vegetation and land use. Based on comprehensive testing, the esteemed organization determines and publishes their findings on the tested systems. Today's major digital aerial camera systems have been tested by IFP.

VisionMap's A3 Digital Mapping System faced the challenge of being tested by IFP, and measuring up to the institute's stringent standards for quality. In this test, the A3 Camera was flown over the test field with the following parameters:

- Average altitude: 1972 m
- Flight line direction: east-west, bi-directional
- Average ground speed: 113 knot
- Difference in ground speed in two directions: 23 knot
- GSD: 6 cm
- Number of flight line: 8
- Average forward overlap: p = 52%
- Average side overlap: q = 86% (when all 8 flight lines are considered)

The test field contains up to 200 signalized control points with geodetic accuracy of 1-2 cm. VisionMap received the full accuracy of only ten ground control points (GCP). The remaining GCPs were received with 1 m accuracy. VisionMap's main challenge was to process this flown block with only 5-10 GCPs, and to calculate the true coordinates of the remaining 190 GCPs.

IFP tested two different flight configurations – 8 and 5 flight lines in the block, which correspond to 86% and 73% side overlap respectively. Additionally, the adjustment was carried out with 5 and 10 GCPs. The accuracy was estimated on 136 check points inside the block area between outer flight lines. The following table presents the typical results:

Camera	Forward overlap (p%)	Side overlap (q%)	Strips	GCP	RMSx (m)	RMSy (m)	RMSz (m)	RMSx/ GSD (%)	RMSy/ GSD (%)	RMSz/ GSD (%)
A3 (Case 5b)	52%	86%	8	5	0.020	0.023	0.052	33%	39%	87%
A3 (case 6b)	52%	86%	8	10	0.015	0.018	0.030	24%	30%	50%
A3 (Case 7b)	52%	73%	5	5	0.017	0.023	0.050	28%	39%	84%
A3 (Case 8b)	52%	73%	5	10	0.016	0.017	0.035	27%	28%	58%

Table 2: Typical results in IFP test.

The results clearly depict that the typical accuracy of VisionMap's A3 Camera is well under 1 pixel.

The complete report can be found on   www.visionmap.com/files/IFP_Visionmap_A3_Report.pdf.

The A3 Digital Mapping System received the IFPs stamp of approval, as they noted, "VisionMap's A3 System obtained very satisfactory empirical accuracy results from this Vaihingen/Enz test." IFP's report concluded that A3 offers high accuracy, which along with the high flying altitudes and high image resolution yields very high productivity for photogrammetric image capturing and processing.

With regards to the A3 camera's unique sweep methodology, IFP wrote that while the concept of stepping frame cameras seems to be slightly more complex, it is completely controlled by the VisionMap workflow and offers high geometrical accuracy.

3.2. Aerial Triangulation Accuracy

In the A3 LightSpeed processing system, the block adjustment is carried out after matching. In order to achieve high accuracy, all images and coordinates of projection centers, obtained by GPS, take part in the simultaneous bundle block adjustment with self-calibration. No preliminary DTM is required, no ground control points are needed and no IMU is required.

As a huge number of single frames are obtained, with significant overlaps between them, a huge amount of common bundles are yielded. This leads to a very high redundancy and robustness of the solved system and, therefore, to high final accuracy and to solution stability.

Estimated accuracy of aerial triangulation (AT)											
GSD (cm)	5		10		15		20		25		30	
	RMSxy	RMSz	RMSxy	RMSz	RMSxy	RMSz	RMSxy	RMSz	RMSxy	RMSz	RMSxy	RMSz
AT (internal, pix)	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0
AT with PPP* without GCP (abs. in cm)	20.0	22.5	25.0	30.0	35.0	40.0	40.0	45.0	45.0	50.0	50.0	55.0
AT with DGPS* without GCP (abs. in cm)	10.0	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30.0	32.5	35.0	37.5
AT with DGPS/ PPP with GCP (abs. in cm)	4.0	5.0	6.0	7.5	7.5	10.0	10.0	14.0	12.5	18.0	15.0	21.0

Table 3: Aerial triangulation accuracy.

* Assuming PPP accuracy: RMSxy – not more than 18 cm, RMSz – not more than 18 cm.
* Assuming DGPS accuracy: RMSxy – not more than 8 cm, RMSz – not more than 8 cm.

Accuracies in the table above are subject to the following assumptions:
- Forward overlap – not less than 55%;
- Side overlap – not less than 55%;
- Number of strips in one AT block – not less than 2;
- Number of sweeps in one strip – not less than 20;
- GCP – signalized points with coordinates in WGS84;
- GCP placement – every second strip every 15th sweep;
- Accuracy assessment – in WGS84;

- Accuracy assessment on GCPs – regarding check points which are located between outer strips of the block;
- AT (internal) – AT accuracy assessed on tie points.
- Check Points Accuracy: RMSxy – not more than 2.5 cm, RMSz – not more than 2.5 cm.

4. CHALLENGES IN 3D PROCESSING

4.1. The Need for 3D

In recent years, there has been tremendous development in the field of 3D city modeling. This development was facilitated thanks to the new digital sensors that were introduced, which brought with them a new level of image quality and resolution, and made aerial imagery much more accessible. Another reason for the advancement of 3D city modeling is the academia's development of advanced algorithms such as semi global matching (SGM).

The demand for 3D products is rapidly growing in the mapping community. Such products can be used for various applications. Among these applications are architecture, urban planning and development, real estate, construction and engineering, insurance and tourism and, finally, we believe, 3D City models will be used for 3D cadastre.

4.2. Challenges in 3D Processing

VisionMap has recently conducted a test flight over its test field, which is located in Netanya, Israel. During the flight the area of interest was covered from eight different directions.

Original imagery was captured at 6 cm GSD at nadir, from an altitude of 5,000 ft. All the images were solved simultaneously with the final accuracy on GCPs of 1-2 cm.

From the imagery captured in this flight, a dense point cloud was computed using IFP Semi-Global Matching (SGM) algorithm. The density of generated DSM was 6 cm (~260 points per sq.m) with a precision (average standard deviation of depth estimation) of 4.09 cm which was achieved when all stereo models were included.
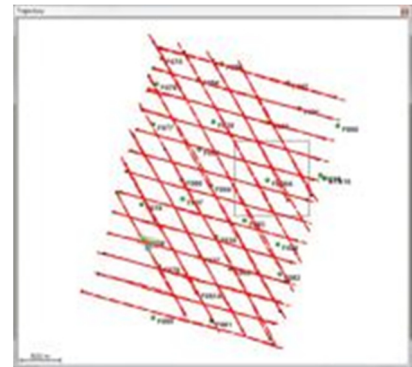

Figure 5: 3D Test flight trajectory.

Figure 6: Point cloud generated using SGM.

Today's technology truly enables us to do things that just a few years ago, seemed completely out of reach. A3 and LightSpeed have been integrated with 3rd party software that enable automated 3D model extraction, quickly and in high quality.
VisionMap is working on further optimization of 3D modeling with its partners and R&D team.

Figure 7: Photorealistic 3D automatic texturing with A3 images and Acute 3D engine.

5. CONCLUSIONS

The A3 camera family has always had superior efficiency. The A3 Edge, which is the new model in the A3 family, takes A3 advantages to an even higher level. The A3 Edge is a full solution, complemented by the A3 LightSpeed processing system which automatically produces all mapping products from all of the A3 cameras.
In the past years, VisionMap has also greatly improved the A3 LightSpeed processing capabilities. A3 LightSpeed can process an incredibly large amount of imagery and achieves extremely high accuracy.
VisionMap now recognizes that the future lies in 3D processing, and sees the A3 Edge as ideal for such 3D applications, as it provides high resolution with wide field of view.

6. REFERENCES

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