

VisionMap A3 - The New Digital Aerial Survey and Mapping System

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SUMMARY

VisionMap was established in 2004 in order to develop a new automatic mapping system. Today the system is fully operational and the paper will discuss the system design, the operational functions, workflow, and the advantages of the system. VisionMap A3 system is a fully automated mapping system. The system is comprised of an airborne digital step-framing double lens metric camera and a ground processing system. During the flight sequences of frames are exposed in a cross-track direction at a very high speed in order to provide a very wide angular coverage of the ground, thus acquiring both vertical and oblique images. The airborne system consists of dual CCDs with two 300mm lenses, a fast compression and storage unit, and a dual frequency GPS. The scanning mechanism of the camera provides a FOV of up to 104 degrees. The post-processing system consists of a PC server configuration and software that processes the data obtained during the flight into mapping products in an automatic manner. The workflow normally carried out in a typical flight consists of the following: flight planning, aerial survey, copying images and meta-data from the camera storage unit, aerial triangulation block adjustment, digital surface model (DSM) creation, digital terrain model (DTM) creation, orthophoto and mosaic production. All the processes are executed in a fully automated mode. The technology is patent pending.

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1. INTRODUCTION

Many words were said and many articles were written about digital aerial camera systems for mapping since 2000 – the de-facto beginning of the new digital aerial camera era. Today there is no question what to use in photogrammetry workflow – digital or analog cameras. We believe that there is wide acceptance that the fully digital photogrammetry workflow, including a digital aerial camera is in many senses preferable to the analog one. CCD detectors have evolved, achieving film comparable output qualities.

Since the year 2000, the development and use of digital photographic systems for photogrammetric mapping has gained momentum. Today, there are many digital aerial photographic systems intended for aerial photogrammetric use. The various systems differ by camera design, photography method, accuracy, work procedures, and the computer software which is provided with the systems.

It is possible to differentiate between digital aerial cameras according to the following characteristic features:

- small, medium or large format cameras,
- frame or push-broom cameras,
- single or multi-lens cameras,
- camera stability and system consistency,
- GPS/IMU integration,
- FMC and a stabilizing platform,
- camera weight and simplicity of installation,
- different types of workflow automation,
- accuracy.

There are advantages and disadvantages almost in every existing camera design. Many of them are optimized for specific photogrammetric tasks, such as corridor mapping or just orthophoto production.

However, some of the abovementioned features are crucial for real photogrammetric mass production:

- full automation: for triangulation, DEM/DSM and orthophoto production,
- large format and accuracy for stereo photogrammetric mapping (which remains a manual process).

We, in VisionMap, have always believed that it is possible to fully automate the processing of mapping products, while maintaining the industry standard accuracies and qualities. VisionMap A3 has achieved this goal, integrating innovative multidisciplinary technology into a mapping product.

An emphasis was put into generating highly efficient, productive aerial survey and mapping system. The design was motivated by the need to reduce flying cost, as well as the processing cost.

VisionMap A3 system is a fully automated aerial survey and mapping system. The system consists of an airborne digital rotating step-framing double lens metric camera and a ground processing system. During the flight sequences of frames are exposed in a cross-track direction at a very high speed in order to provide a very wide angular coverage of the ground. The airborne system consists of dual CCDs with two 300mm lenses, a fast compression and storage unit, and a dual frequency GPS. In the current configuration, given the aircraft installation, the scanning mechanism of the camera provides a total FOV of up to 104 degrees. The post-processing system consists of PC servers' configuration and software that automates the mapping workflow. The later is comprised of: flight planning, downloading frame images from the camera storage unit, pre processing, preparation and processing tasks, aerial triangulation bundle block adjustment with self-calibration, digital surface model (DSM) creation, digital terrain model (DTM) creation, orthophoto and mosaic production. All the processes are executed in a fully automated manner. The main characteristics of the system are:

- total automation of all processes (from planning the flight to orthophoto creation),
- super large format (SLF) images for stereo compilation,
- high resolution multi-directional vertical and oblique imagery,
- the 300mm focal length enables operation at high altitudes (this is crucial in urban areas in order to support true orthophoto generation and because some countries limit the flight altitude over urban areas);
- high photogrammetric accuracy and process stability,
- a single flight yields both an orthophoto as well as accurately solved oblique and vertical images from multiple directions,
- high efficiency – for a given resolution, throughput in km² per hour is substantially better than with other systems that are operated at lower altitudes,
- no preliminary DTM is required,
- no ground control points are needed,
- no IMU is needed.

2. DESIGN CONSIDERATIONS

2.1 Camera Design

The main features required by the design team were developing a metric mapping camera, with better imagery acquisition efficiency than traditional photogrammetric cameras such as the RC-30. A further analysis of this requirement yielded the following functional specifications:

- The field of view of the camera, and thus – the ground coverage, should commensurate to flying altitudes, in order to provide an optimal base ratio between strips for the AT;
- Resolution should be high, in order to allow mapping of small objects;

- Stronger photogrammetric accuracy can be achieved using frame camera;
- Multi-directional images will contribute to the accuracy and the robustness of the bundle adjustment;
- The system should be operable in fast aircrafts, in order to maximize the imagery acquisition figures.

The final design of the camera, influenced by the abovementioned requirements provided the following:

- Rotating step framing camera, providing field of view of more than 100 degrees. Considering side lap of 50%, this allows accurate photogrammetric bundle adjustments and maximizes the distance between two consecutive flight lines.
- Long focal length. The 300mm focal length maintains high resolution in high altitudes. This provides highly accurate mapping products while maximizing the acquisition efficiency.
- The super large frame is a synthetic quasi-panoramic model combined of multiple 11 Mpix frames. This solution benefits from the inherent strength of frame solution, but is not limited to the frame size.
- All frames, vertical and oblique, participate in the bundle adjustment.
- Vertical and oblique images, covering an area with several parallel flight lines, provide multi-directional images for any point in the area of interest.
- The camera does not require any external stabilization aids. A lightweight, accurate motion compensation mechanism was embedded in the camera. Since the motion compensation was designed to compensate for the fast angular velocity of the camera, it easily provides FMC for faster aircraft, including jets.

2.2 Ground Processing System

The ground processing system is tightly coupled with the camera. The main features of the ground processing system were influenced from the following requirements:

- The imagery acquisition figures of the camera cover thousands of square kilometers, high resolution in one day. The ground processing system should be capable of processing such area into mapping products within few days.
- The ground processing system should be fully automatic in order to maintain the superior imagery acquisition efficiency of the camera.
- The processing should rely on well known photogrammetric methods, in order to ensure accuracies. As a result of the highest pixel rate of the camera, bundle adjustment with significant number of frames should be adjusted.
- QA should not be a bottleneck in the processing workflow.
- Self calibration should be calculated in order to provide accurate mapping products.

As a result, the design of the ground processing system provided the following:

- Scalable parallel computing processing. The scalability allows the user to utilize more computers in order to obtain better performance. Experiments carried out with a typical hardware configuration showed that 1000 sq. km in 12 cm GSD are processed, forming a bundle adjustment, SLF stereo pairs for mapping and an orthophoto within approximately two days.
- The system is automatic. After a pre-process stage in which the user specifies the required outputs and output specifications, the system solves the AT and bundle adjustment automatically. Then a manual geo-referencing stage may be carried out, followed by an automatic processing of DSM, DEM and orthophoto.
- The entire processing is purely photogrammetric. In order to ensure accuracy and robustness, all images are matched into one bundle adjustment, which means that oblique imagery is also solved. Robustness is provided by maximizing the number of tie-points: a typical bundle adjustment of 1000 sq. km contains millions of tie points.
- As the system is fully automatic, a comprehensive set of QA reports is provided to the user. This set includes textual, visual and geographical reports, allowing the user to concentrate the QA effort only in areas requiring attention, thus providing shorter QA phases.
- The system is self calibrating. Camera parameters are calculated by the ground processing system, This feature minimizes down time caused by routine maintenance, as well as securing better accuracies.

3. AIRBORNE MODULE KEY CHARACTERISTICS

3.1 Camera Design

A camera module consists of a frame for mounting the camera on the craft, two lenses, and a motor unit. The lenses are sweeping simultaneously on the camera axis across a flight line direction. Sweep Motion System consists of the motor and transmission mechanism, encoder and switches, and support structure.

The camera is linked to a custom made on-board computer, which includes:

- low power Pentium M based computer,
- GPS receiver,
- a power supply unit,
- interface to the camera module,
- removable flash type storage up to 0.5 TB,
- interface to debug console and navigator application.

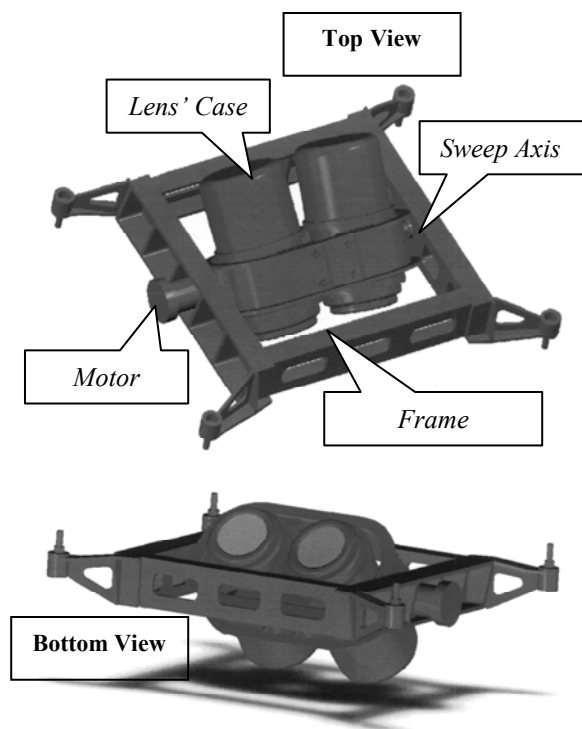


Figure 1. Camera Design

CCD (dual)	Kodak KAI-11002
Single Frame Size (pix)	4006 x 2666 11 Mpix
Single Lens FOV (degree)	6.9 x 4.6
Max. Sweep FOV (degree)	104
Number of Double Frames per Max. FOV	27
Sweep Time (sec.)	3-4
Color	RGB
Bit per Channel (bit)	12 pre LUT, 8 post LUT
Pixel size (µm)	9.0
Optics (lens)	Dual Reflective Lens System
Focal length (mm)	300
Aperture	f/4.5
Forward Motion (FMC) Sweep Motion (SMC) Vibration (Stabilizer)	Mirror based optical compensation and stabilization
Frame rate (fps)	7
Readout rate	155 MB/sec
Compression	Jpeg2000
Data collection capacity	5 hours
Storage Type	Flash Drive
Storage capacity (GB)	500
GPS (Omni Star Supported)	Dual-frequency GPS + L-Band
Camera Unit Size (cm)	50 x 50 x 40

Table 1. Camera technical characteristics

3.2 Optics Design

As seen in Table 1, a folded reflective optical system is used for the lenses. The lens is an optical assembly with a total focal length of 300 mm. The long focal length yields comparatively high ground resolution when flying at high altitudes, enabling efficient photography of large areas in high resolution. In addition, mirror based folding optical system considerably reduces the complete dimensions of the optic assembly.

Finally, in order to support operation in a wide range of ambient temperatures, from -30 °C to +45 °C, the optics are a-thermal (designed and manufactured to ensure minimal sensitivity to temperature changes).

3.3 Angular and Movement Stabilization

There are three different movements which affect the image quality – forward motion, sweep motion, and general vibrations of the aircraft. A unique mirror based optical compensation and stabilization method for all potential movements was developed. The traditional stabilization methods are based on using the stabilization platform for the entire camera system stabilization. In digital cameras, three methods are generally used to compensate forward motion: changing the read out time to minimize the forward motion effect, mechanical FMC for the CCD.

The design implemented by VisionMap is based on using acceleration sensors, GPS data (for aircraft velocity calculation), and the motor encoders for calculation and control of the required motion compensation. Both linear and angular compensations are done by tilting the mirror mounted on the folding optics. Since the total weight and size of the mirror are small, motion compensation is performed efficiently.

3.4 On-Board Image Processing

The imagery grabbing and processing is based on real-time lossless JPEG2000 compression. Since writing raw images at the system's bit rate exceeds the standard capabilities of a common SATA bus, on-board compression is crucial in order to enable usage of standard I/O interfaces to storage devices. The compression is done with custom made compression cards, designed to provide high performance lossless J2K compression on board, while using less than 10% of the on-board CPU resources.

4. FLIGHT OPERATIONAL ASPECTS

4.1 Image Capture Principles

The camera is mounted on the plane so that the sweep axis is along the fuselage (which is the flight direction). The two lenses of the camera sweep simultaneously across the flight direction from one side to the opposite side. The maximum sweep angle is 104 degrees. During the sweeping motion, each CCD captures ~27 frames (54 frames for two CCDs). After completing the first sweep, the lenses return to the start position and are ready for the next sweep. The sweep back time is 0.5 sec. Each CCD captures 7 frames per second (1 frame in 0.142 sec.). Therefore, a single sweep is completed in approximately 3.6 sec. The time between sweeps depends generally on the aircraft speed, flight altitude, and the required overlap between two

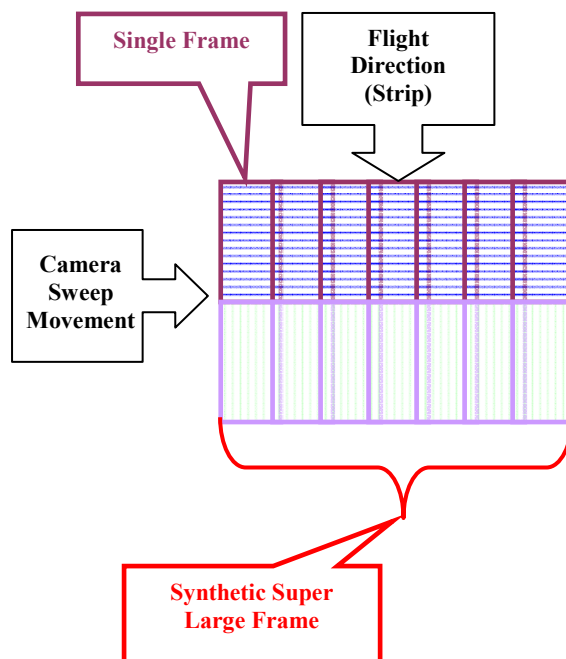


Figure 2. Flights with the VisionMap A3 Camera

consecutive sweeps. Some technical parameters of the flights at different altitudes are presented in Table 2.

The sweeping motion of the camera during image capture and exposure is smooth and not incremental. This is enabled by the Sweep Motion Compensation (SMC) which is carried out by the compensation mechanism described in section 3.3.

There are overlaps between the frames. Two adjacent Single Frames along the flight form one Double Frame (Fig. 2). The overlap between them is about 2% (~100 pix). The overlap between two adjacent double frames across the flight direction is about 30%. The overlap between two consecutive sweeps along the flight direction is typically 55%, but it may be different according to the defined specifications of the aerial survey. The overlap between two consecutive flight lines is generally 50% or more to enable stereo photogrammetric mapping. All overlaps are defined during flight planning, and may be changed during the flight. There is some shift between two adjacent double frames along the flight direction. With typical aircraft speed of about 72 m/sec (140 knots), the shift between adjacent frames along the flight direction results in about 9.6 m. The total shift between the first and the last frame in one sweep results in approximately 260 m.

4.2 Oblique Images

As previously said, the Sweep FOV of the camera is 104 degrees. It provides orthogonal coverage of the nadir area and oblique coverage of the remainder of the sweep image. As all images participate in all stages of the analytical computations, after performing matching and block adjustment, we have accurate solutions for all images including the oblique images. The resolution for oblique images acquired from different flight altitudes is presented in Table 2. In our opinion, the possibility to obtain accurately solved oblique images simultaneously with regular verticals is a unique and highly important feature of the A3 system.

4.3 Synthetic Super Large Frame for Stereo Photogrammetric Mapping

Synthetic Super Large Frame is composed of all double frames of one sweep (Figure 2). The size of the Super Large Frame (SLF) is 7812 pixels along the flight and 62,517 pixels across the flight direction. The ordinary overlap between two consecutive SLFs in one strip is 55%. The overlap between two SLFs in adjacent flight lines is 50% or more. The SLFs may be used for stereo interpretation and stereo photogrammetry map production.

The angular coverage of the SLFs is constrained by the mechanical characteristics of the platform aperture. However, in lower altitudes (lower than 9000 feet), as V/H increases, the system decreases the angular coverage in order to maintain the inter-sweep overlap.

Map Scale	250	1,250	2,500	5,000
Photo Scale	5,000	10,000	14,000	25,000
Flight Altitude (m)	1,500	3,000	4,200	7,500
Flight Altitude (ft)	4,921	9,842	13,779	24,606
SLF' Short Side (m)	354	709	992	1,772
SLF' Long Side (m) (Swath)	1,435	7,679	10,751	19,198
SLF' Area (sq.km)	0.5	5.4	10.7	34.0
Stereo Area between Sweeps, 56%,(sq.km)	0.3 *	3.0	6.0	19.1
Stereo Area between Strips, 50%,(sq.km)	0.7	2,7	5,3	17.0
Base Ratio Between Sweeps (B/Z)	1:7.6	1:7.6	1:7.6	1:7.6
Base Ratio Between Strips (B/Z)	1:0.8	1:0.8	1:0.8	1:0.8
Nadir GSD (m)	0.05	0.10	0.14	0.25
Oblique GSD (m)	0.08	0.16	0.23	0.41

(*) – Swath for 5,000 photoscale is decreased to 1,435 m for stereo area between sweeps.

Table 2. Flight technical characteristics

5. GENERAL WORKFLOW

5.1 Workflow Supported by the System

The workflow supported by the system consists of aerial and ground segments operation. The aerial segment includes the following components:

- VisionMap A3 camera and dual frequency GPS,
- A pilot flight management system,
- A camera computer system for managing aerial survey processes. This computer manages the activity of the camera, carries out on-board testes, changes camera settings, and executes automatic exposures. The system reports to the operator or to the pilot about errors or faults in task execution and makes it possible to repair the faults on the fly. The system enables viewing of the collected images during the flight.
- Data collection system with removable FD storage.

After the landing, the FD storage with GPS data, meta-data and images are taken to the processing system.

The ground segment consists of two sub-systems:

1. A pre-flight application for aerial flights planning and an immediately post-flight application for preliminary data processing.
2. A processing sub-system includes:
 - a. A WEB-based process management application to manage and monitor the processing workflow and to enable parallel processing and prioritization of multiple tasks and projects.
 - b. The automated photogrammetric application, used for image matching, block adjustment, DSM/DTM generation, orthophoto and ortho mosaic production.

Significant advantages of the system are multi tasking and scalability. Multi-core processors are used to process multiple projects and tasks in parallel. The user may define new groups of computer resources. Utilization of additional computers may be done instantaneously. This workflow and the system design provide a highly efficient workflow that is able to process very large areas that consist of hundreds of thousands of image frames.

5.2 Processing Workflow

After the landing, the images and meta-data are transferred to the processing station for the next stage:

1. The project is formed according to the properties defined in the flight plan,
2. GPS data preprocessing is carried out, using standard DGPS or PPP methods. For DGPS processing it is possible to use National GPS permanent stations,
3. The area of interest is specified. The system can also retrieve previous flights in order to cover the area of interest.
4. Preliminary (coarse) matching for flight lines is carried out. QA is done to confirm that raw material for the area of interest is available and adequate.
5. Accurate block adjustment is carried out. In this stage, if it is necessary, Ground Control Points (GCP) may be used. The QA may be done versus existing blocks or with extra control points. Accuracy report is compiled.
6. DSM and DTM are calculated (optional).
7. Super Large Frames are calculated and exported (optional). Each SLF is solved and provided after radiometric correction.
8. Orthophoto is calculated. The process includes a rectification, mosaicing, and radiometric correction. All the processes are executed automatically. A final image is provided in TIFF format.
9. The products are stored in the internal storage system.

A status and progress of all processes are reported to the management module.

5.3 Final Products

The processing system is designed to provide high performance processing of the imagery obtained during the flight. The products of the processing system are:

1. Accurately solved single images (vertical and oblique) of the area of interest. The solution for each image is the result of the photogrammetric bundle block adjustment with self-calibration.
2. SLF - Super Large Frame. The synthetic image covers a large area and is useful for stereo photogrammetric mapping.
3. DSM – Digital Surface Model. The DSM is calculated in high resolution and may be provided at 30-50 cm density.
4. DTM – Digital Terrain Model. The DTM is generated from DSM for orthophoto production.
5. Orthophoto with the resolution up to the source frame resolution. Global and local radiometric correction is applied to all frames. The mosaicing process is fully automated and is based on the topographic data (DSM) and radiometric analysis of the area.

Altitude (feet)	Area (sq. km)	GSD (m)	Forward Overlap	Side Overlap	Strips	GCP/ChP	RMSx (m)	RMSy (m)	RMSz (m)
12000	195	0.11	55	55	8	0/22	0.26	0.19	0.63
12000	195	0.11	55	55	8	11/11	0.19	0.11	0.23
28000	247	0.26	66	82	7	0/27	0.54	0.44	0.47
28000	247	0.26	66	67	4	0/27	0.57	0.58	0.83
28000	247	0.26	66	82	7	11/14	0.21	0.35	0.44
28000	247	0.26	66	67	4	11/14	0.29	0.30	0.56
8500	215	0.08	65	48	10	0/66	0.49	1.15	0.59
8500	215	0.08	65	48	10	18/48	0.16	0.18	0.28
8500	215	0.08	65	48	5	13/39	0.17	0.19	0.16
8500	215	0.08	65	48	5	16/22	0.06	0.08	0.10

Table 3. Automatic Block Solution Accuracy

6. AERIAL TRIANGULATION ACCURACY

After Matching, block adjustment is carried out. 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 INS 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 very high redundancy and robustness of the solved system and, therefore, to high final accuracy and to solution stability. The system was tested in many projects (over 40,000 sq.km).

7. CONCLUSIONS

This paper presented the operation and workflow of A3. The main advantages of the system, as presented, are:

- Total automation of all processes,
- Oblique and vertical multi-directional images,
- Super Large Images,
- Operation in high altitudes,
- No ground control needed,
- Designed to handle urban areas with high-resolution,
- Inherently (almost) true orthophoto,
- Light weight and simple air craft installation,
- Industry standards accuracies

In practical terms, the utilization of A3 provides the following advantages:

1. Lower data production cost
 - Full automation, even in urban areas,
 - Very high area coverage rate reduces drastically the flight/operation cost,
 - No need to buy DTM for rectification purposes.
2. Lower cost of operation

- Coverage rate reduces sensitivity to weather conditions,
 - Less planes/cameras cover more area,
 - High flight altitude provides more flexibility to fly over urban areas.
3. Integrated DTM/DSM capability – supports automatic ortho-rectification.
 4. Integrated mosaicing capability – automatic optimal cut-line selection in dense urban areas.
 5. Integrated geo-registered oblique imagery provides extra value.
 6. Super Large Frames for stereo models enable efficient and accurate stereo mapping.
 7. All in one – from autonomous imagery, through automatic solution, toward accurate orthophoto and map production.

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