NEW GEOMETRIC MODELING AND WORKFLOW FOR THE AIRBORNE DIGITAL SENSOR (ADS40): A FAST, EFFICIENT, RELIABLE AND HIGHLY ACCURATE APPROACH

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ABSTRACT

For the past several decades, there has been much interest in advancing photogrammetry, from acquisition to processing, from an analog technology to digital technology and much of this development has focused on using scanned aerial photographs. However, in order to truly bridge the gap between data acquisition and production, there has been a great need to develop digital acquisition capability. For the last few years, there have been a limited number of attempts to design two-dimensional photogrammetric digital cameras however, the limited number of pixels has hindered their applicability to extensive large scale mapping applications. Linear scanning technology can overcome such a limitation by increasing the number of pixels across the flying direction. Ground coverage along the flying direction is achieved by capturing adjacent image strips while advancing the airborne platform. The Airborne Digital Sensor ADS40 by Leica Geosystems is one such sensor that has been used for production since it was first released in 2000. It incorporates fully integrated GPS and IMU sensors that are used to observe the position and attitude of the camera in an integration process. However, the observations from the GPS and IMU sensors may be contaminated with bias values which will degrade the final adjustment results. In this paper, a new model for the ADS40 is developed. This model takes into account different GPS/IMU biases that are contained in the raw observations and/or result from the integration process. Estimating, and therefore correcting for, these bias values is achieved by utilizing a minimum number of ground control points. A new bundle adjustment procedure has been developed at North West Geomatics Ltd. that has been proven to generate highly accurate results. Based on this successful model, a new workflow that is fast, efficient and reliable has been adopted.

INTRODUCTION

Photogrammetry is the art and science of obtaining information about objects by means of photographs. Since its inception, conventional photogrammetry was film-based. Analog and later, analytical plotters were developed to facilitate measuring points on photographs, physically orienting them similar to their original orientation at the time of exposure (Relative and Absolute Orientation), then incorporating ground coordinates of many other points based on their locations on the photographs (Intersection). In this traditional workflow, photographs need to be captured, developed, reproduced and processed by operators to manually select fiducial marks, tie points and control points that are to be used in interior, relative, and absolute orientation processes. These have historically been very time consuming operations.

Digital Softcopy Workstations (DSW) were developed to speed up the workflow in part. Image processing techniques such as template matching and correlation analysis can speed up some of the conventional operations such as interior or relative orientations. However, as this process requires digital imagery, film-based photographs need to be scanned and inspected, which adds significantly to the time of this workflow.

Photogrammetric digital cameras have been designed with the prime objective of reducing the gap between data acquisition and production. With digital acquisition, the expense and time for film development and scanning is eliminated. Moreover, fiducial marks are no longer necessary to relate image contents to the calibration data as interior orientation of the digital sensors is rigidly fixed. Thus, the time for interior orientation is eliminated as well.

The next section discusses different technologies for digital cameras and the pros and cons of each. The following section also discusses the solution developed at North West Geomatics (NWG) for modeling the Aerial Digital Sensor (ADS40) by Leica Geosystems, followed by a description of the newly developed software packages supporting this workflow. Such a workflow allows processing very large data sets in a very short timeframe while maintaining very high accuracy and reliability. This has been proven by processing and producing ortho-images for the entire States of Texas, North Dakota, and large areas in California and Montana, for the National Agriculture Imagery Program (NAIP). In addition, many blocks of imagery have been successfully processed in Alberta and Saskatchewan in a very short period of time using this newly developed workflow. Two examples consisting of large blocks of imagery are presented in the production results section. Finally, the paper concludes with a summary and recommendations for future development.

BACKGROUND

In order to obtain high resolution digital imagery, the following two options of CCD arrangements are available:

- Two-dimensional CCD array, known also as digital frame cameras, used by Z/I Imaging's DMC system, and Vexcel's UltraCam (Tang et al., 2000; Leberl et al., 2003)

- One-dimensional CCD array, known also as line cameras or linear array scanners, used by Leica Geosystems' Aerial Digital Sensor (ADS40) (Sandau et al., 2000)

Digital frame cameras are easier to visualize since conventional photogrammetry depends heavily on perspective geometry from 2D frame imagery (Figure 1a). Line cameras only capture an image of a narrow strip of object space at each "exposure" perpendicular to the flight direction. As the aircraft travels, many 1D images are acquired and the final 2D image is formed through their combination (Figure 1b). Although line cameras are new in commercial aerial applications, they have been used in satellite imaging sensors (such as SPOT, IKONOS, QuickBird) and military applications for a number of years. Each of these approaches has their own advantages and disadvantages.

Before proceeding, it is important to unify some terminology regarding line cameras throughout the remainder of this paper. A 1D image will be referred to as "scan line", while a 2D image will be referred to as an "image" for simplicity (Figure 1b).

Also, sensor calibration is not considered as part of this paper as it is assumed that the manufactures provide a accurate calibration and inter-CCD offsets are fixed or accurately corrected in the sensor manufactures workflow.

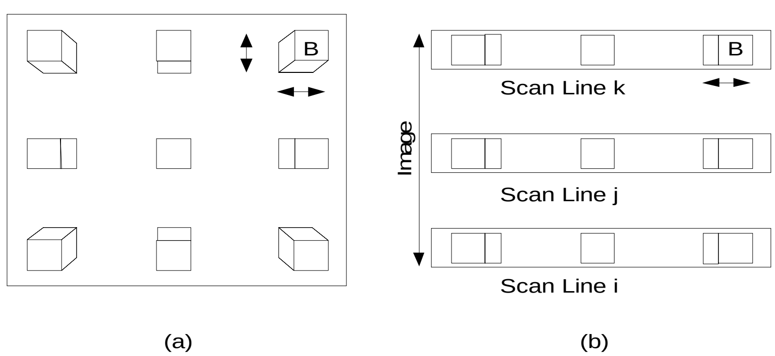


Figure 1. Imagery Captured by Frame or 2D Sensors (a) Versus that Captured by 1D Sensors (b).

Spatial/Spectral Resolution

From a CCD availabilty point-of-view, it is easier to design/implement a digital line scan sensor compared to a digital framing sensor. As evidenced by the DMC and UltraCam designs a digital frame sensor is very complex utilizing multiple lens and shutter systems to get adequate coverage performance due to the current restrictions on available CCD arrays. When the requirement to capture spectral information is added to the design requirements this further complicates the design as multiple CCD's must be added to capture the spectral channels. In the case of all currently available commercial digital frame sensors the spectral performance is greatly reduced by using methods such as pan sharpening to create color images. In the case of a line scanner there are no such restrictions as it is possible to capture full resolution spectral images.

Relief Displacement

In conventional metric film cameras as well as digital frame cameras, relief displacement tends to be radial from the nadir point (Figure 1a). In line cameras, relief displacement will be along the CCD direction (for nadir bands) (Figure 1b). For ortho-rectification, nadir bands provide superior quality ortho-images with a reduced DSM accuracy requirement.

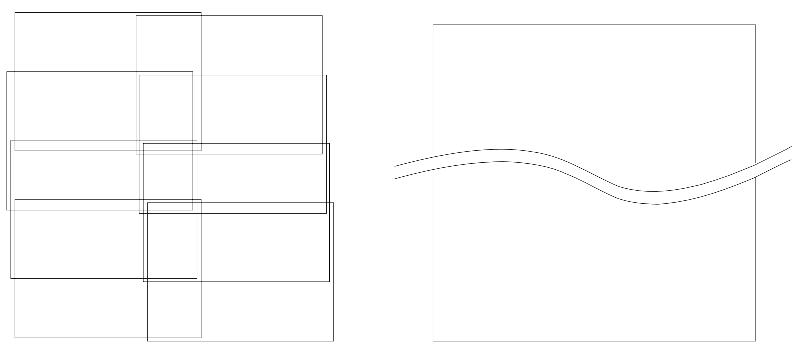
Height Inaccuracies

Typically, there are two major types of errors in ortho-rectification; height inaccuracy and height semantics. The former is caused by using wrong coordinates of the terrain, which causes rectification at the wrong elevation. The latter is caused by using Digital Elevation Models (DEM) rather than Digital Surface Models (DSM). DEM represents the bare terrain, while DSM represents the surface of the object space including building tops, trees, etc. In other words, DEM is an abstract surface, while DSM is the real (visible) surface. As sensors acquire imagery of the object space, they capture information about the real surface. Thus, a DSM, rather than a DEM, should be used in ortho-rectification in order to obtain true ortho-imagery. However, DSM's are not always available.

Regardless of the error sources in the elevations, two error components will occur in frame cameras, compared to one error component in line cameras (Compare building B in both Figures 1a, and 1b). Note that at the nadir point (only) large elevation errors cause no errors in the ortho-rectified imagery.

Mosaicing

For many applications, we cannot capture the whole area with one image while maintaining the required spatial resolution. Recall that digital line cameras provide higher spatial resolution than digital frame cameras. Thus, larger numbers of images have to be acquired using digital frame cameras to obtain the same coverage and resolution (panchromatic and spectral) as digital line cameras (Figure 2). Thus, mosaicing these images, considering relief displacements and DEM issues discussed previously, and searching for suitable areas for seamless mosaic lines between the images, is quite challenging. Digital line cameras provide seamless 2D imagery with large ground coverage and high spatial resolution, with at least a 50% reduction in the required seamlines.



(a) (b)

Figure 2. Typical 60% Overlap and 30% Sidelap in Frame Imagery causing many Mosaicing Challenges (a), while those Captured by Line Cameras Represent Seamless Imagery, Almost Infinite Along the Flight Line (b).

Exterior Orientation Parameters (EOP)

One of the major advantages of traditional film-based frame and digital frame cameras is that they capture a 2D image in one "exposure" or epoch. This 2D image is referenced to a single six degrees of freedom (three for position and three for orientation) known as Exterior Orientation Parameters (EOP). Such parameters can be obtained directly from GPS/IMU or they can be indirectly estimated using Ground Control Points (GCP). As GPS/IMU observations might be contaminated with errors, for highly accurate results it is essential to perform aerial triangulation (AT).

Digital line cameras capture a 1D image per "exposure". Thus, each scan line of the image has its own EOP and therefore, dimensionality of the problem increases. However, these EOP can be observed using GPS/IMU although they are often less than perfect. A critical question results: Given potentially inaccurate GPS/IMU and GCP, how can we reliably estimate the EOP of each scan line of the image? If we are able to answer this question, line cameras will be favored over digital frame cameras (recall the previous comparisons regarding spatial resolution, relief displacements, height inaccuracies, and mosaicing).

Due to the advantages discussed in this section, NWG has chosen to use the ADS40 by Leica Geosystems, which is a multi-line scanner. A complete sensor description can be found in (Sandau et al., 2000). The next section continues to present different methods of geometric modeling of line scanners, followed by a description of the new sensor model developed at NWG. Such a model requires a different work flow, which results in less human interaction, providing highly accurate results in a much shorter timeframe. The following sections describe the newly developed software packages and the new workflow at NWG along with a comparison to the old workflow, followed by production results.

GEOMETRIC MODELING

The ADS40 by Leica Geosystems is an airborne multi line scanner, where digital images are acquired as the aircraft travels. Modeling the scanner requires estimating six EOP for each scan line in the image. As EOP do not abruptly change from one scan line to the next, some interpolation functions can be used to reduce the number of EOP. Two major examples include:

- Orientation Fixes (OF), also known as orientation images. This has been adopted by ORIMA (Hinsken et al., 1999). EOP of selected scan lines at regular intervals are chosen to be unknown parameters, while EOP for the in-between scan lines can be interpolated by polynomial functions. The choice of the number and location of OF is quite challenging. Currently, for the ADS40, OF are placed every 8 seconds along the flight line. For a scanning frequency of 200 Hz, this will amount to one OF every 1600 scan lines. For imagery acquired in 26.5 minutes, 200 OF are required and 1200 EOP have to be estimated. This is a very large number of parameters that requires a very large number of tie points. Tie points are automatically selected using Automatic Point Measurement (APM). However, APM has many problems in areas where vegetation, water, shadow, low contrast, or repeated patterns exist. As a result, a large number of blunders result which necessitates manual operator intervention for hours or days, to accept, reject or manually re-measure tie points.
- Polynomial Modeling of EOP. In this case, polynomial coefficients are estimated in the AT. Again, and similar to OF, the selection of the order of the polynomial functions is quite challenging. For an aerial platform, it is difficult to find a function that represents the true trajectory. A high frequency spline is an option to represent the true trajectory however, it can result in similar problems as OF, since many tie points are required to recover the spline parameters.

Other approximate models exist such as Parallel Projection, Modified Parallel Projection, Rational Functions, SDLT, DLT (Morgan, 2004; Tao and Hu, 2001; Wang, 1999; Abdel-Aziz and Karara, 1971). Although some of these models provide highly accurate results for space-borne scanners, they risk hindering the accuracy for airborne line scanners due to flight turbulence.

Alternatively, at NWG, we have tackled the problem differently and more robustly. We began by analyzing EOP generated from the GPS/IMU integration results. If such an integration has no errors, EOP can be used directly in production, such as ortho-rectification. Unfortunately, such an integration is contaminated with errors. The next section discusses our model and approach to estimate the sensor model.

Rigorous Modeling at NWG

The rigorous model relating a point in image space (x, y) to a point in object space (X, Y, Z) is:

$$(x,y) = f\,(IOP, \underline{EOP}, X,Y,Z) \qquad (1)$$

where IOP is the camera's Interior Orientation Parameters. $\underline{EOP}$ is underlined to refer to the true parameters. Equation (1) is extended by modeling $\underline{EOP}$ errors as follows:

$$\underline{EOP} = g\,(EOP, E_{EOP}) \qquad (2)$$

where EOP are the observed values, and E_{EOP} are the systematic errors of the exterior orientation parameters. Such systematic errors are of much lower order (lower frequency) compared to the original EOP values. Thus, modeling these errors requires fewer parameters compared to the examples discussed earlier. E_{EOP} systematic errors are selected based on the study of GPS/IMU integration.

SOFTWARE

The rigorous modeling of the ASD40 has been extensively tested and examples are presented in the next section. Based on the successful sensor modeling at NWG, several software packages have been developed:

ADS Data Prep

ADS Data Prep was developed at NWG to store downloaded data in folders according to user preferences. At this stage, AT blocks are generated. Users can select as many lifts (flights) as desired (with the same or different cameras) to be processed in a single AT adjustment. As explained below, there is no limitation in the AT on the number of lifts or cameras used.

ADS Measure

ADS Measure was developed at NWG to enable measurement of control and tie points on the raw ADS40 images (known as Level 0 or L0) in manual, semi-automatic, and fully automatic modes. It uses the rigorous sensor model and the epipolar geometry of the line scanner in order to predict the location of conjugate points along the images. No pre-processing of the imagery is required. Other packages require the generation of intermediate images (known as L1) which are generated by planar rectification. However, ADS Measure uses the raw observations (L0) for a faster and more rigorous solution.

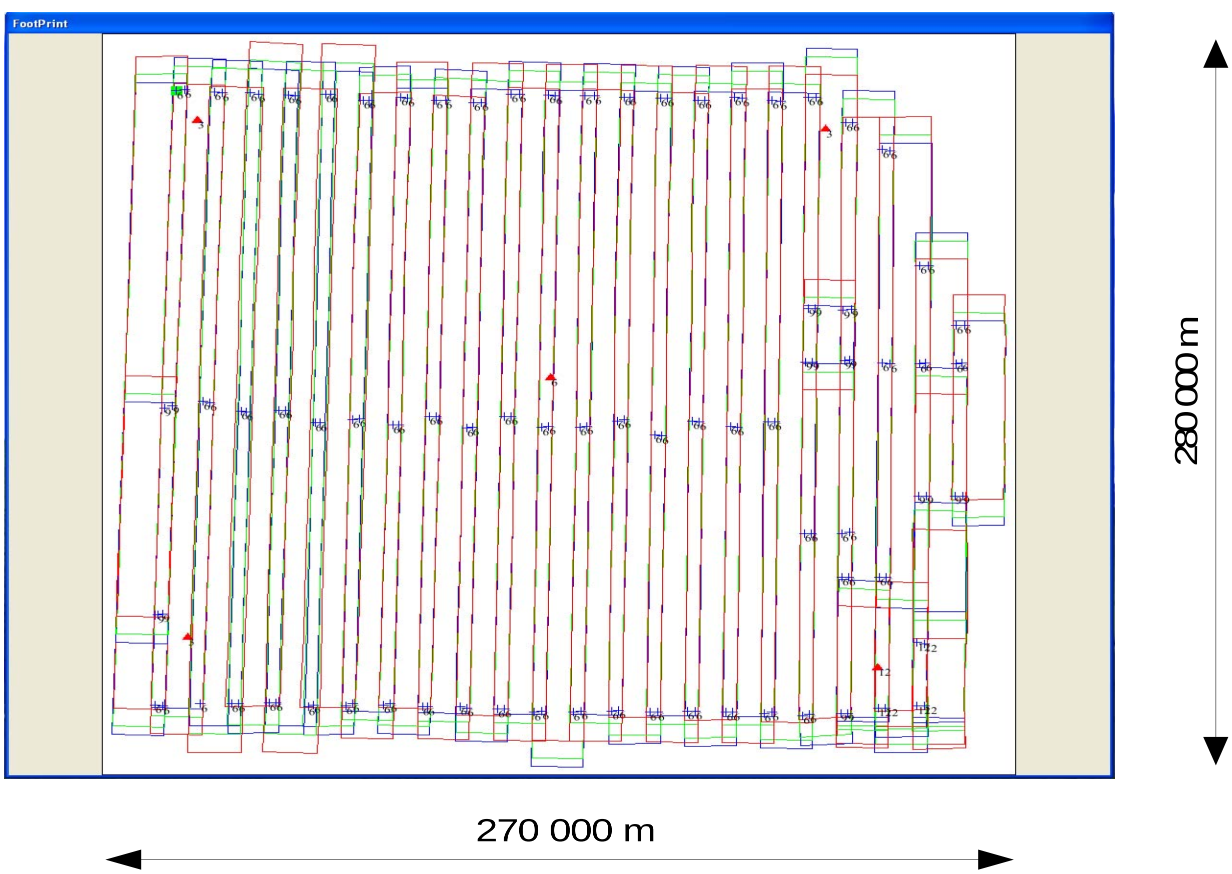


Figure 3. ADS Measure Displaying a Footprint of a Block Consisting of 87 Images. All are Used in a Single AT Project. Only 6 Tie Points are Required to Tie 6 Images (Forward, Nadir and Backward images in 2 Adjacent Lines Along the Flying Direction). Such Points are Transferred Automatically.

ADS Measure generates the footprint of the images by projecting them through the rigorous model onto the DEM (if available), or an average elevation if not (Figure 3). Tie points are generated automatically on the footprints and transferred automatically to all images through the rigorous sensor model and epipolar geometry. Users can select to densify the tie points by interacting with the footprint image. As we will see shortly, minimal tie points are required to reconstruct the sensor model and system errors.

GCP can be handled in two ways:

1) They can be loaded into ADS Measure from a text file where they are then automatically back projected into all images using the rigorous sensor model. The user then measures a point in any convenient view to match the GCP description. Finally, ADS Measure automatically transfers the point to all other views.
2) ADS Measure also supports measuring GCP off old ortho-images and DEM. First, the user selects a location on the footprint and then ADS Measure automatically displays the old ortho-image for the user to select a control point. The horizontal coordinates are chosen from the old ortho-image with the height from the DEM and the process continues as described above.

In the near future, ADS Measure will be modified to utilize linear features as tie and control entities. Currently, we are working on robust automatic feature matching.

ADS Master

ADS Master is the backbone of our development. It was developed to perform AT on the ADS40 images and estimate the systematic errors associated with the GPS/IMU integration together with the object space coordinates of the tie points. ADS Master has the following features:

- It has been developed using standard C++, QT cross-platform Graphic User Interface
- It handles GCP files in different datums, coordinate systems
- It uses Geoid models for North America. Geoid models for other parts of the world can be easily added
- It handles as many tie points as required (note that experimental results show that minimal tie points will provide highly accurate results).
- It generates text files for estimated parameters, variances, correlation values, residuals, variance component, etc.
- Although ADS Master was developed for a new workflow, it also can be placed in the old workflow if necessary by generating Orientation Data Files (ODF)
- Global blunder detection is utilized
- There is no limit to the number of lifts that can be used. Figure 3 shows a large block consisting of 8 lifts (87 images)
- It allows the use of different cameras
- It incorporates the DEM (if available) to verify the triangulation results and/or the validity of the DEM.
- If requested, the DEM can be incorporated as vertical constraints. Thus, even with an inaccurate DEM, rectification errors are minimized.
- It can easily handle adding lines or lifts to an old triangulation result (by performing some constraints). In this way, it is very easy to replace cloudy images with newer ones. Only a few tie points are required. In addition, because ADS Master is much faster than data acquisition, triangulation can be performed daily on the newly acquired images providing some constraints to previously triangulated results. In this case, for adjacent AT blocks flown on different days, block tieing is done through the orientation parameters rather than using tie points. One has to remember that with ADS Master, there is no limit to the number of lifts (or days) that can be used in a single AT. However, it is not desirable to wait until the last lift is flown to run AT.
- ADS Master can run stand-alone, or integrated into ADS Measure

ADS Rectify

ADS Rectify has been developed to use the triangulation results from ADS Master and generate ortho-rectified images. Fast transformation functions from image space to object space coordinates and vice versa were developed to speed up the rectification. Note that no assumptions have been made on the terrain or images. Rather, rectification is done rigorously (on a pixel-to-pixel basis, instead of patch-to-patch basis) and is compliant with the rigorous sensor model estimated by the ADS Master.   ADS Rectify utilizes the message passing interface (MPI) parallel programming model to allow virtually unlimited compute resources to be used to rapid generate ortho-rectified image strips.

ADS QC

Previously, in order to verify the quality of a generated ortho-image, an operator would have to load the image and overlay the control or check points to manually measure and determine the ortho accuracy. If two ortho-photos with an overlap were to be checked, an operator would have to select and measure random points on both. This is very time consuming since randomly selected points are never representative of the overlap areas. The denser these points are, the better is the representation, however this also results in an extremely time consuming effort.

In order to cope with the fast paced production by ADS Master, a new and fast QC tool was developed. ADS QC is developed to overlay overlapping areas between two adjacent images in a checkerboard fashion (Figure 4). The continuities of the features between the cells in Figure 4 is an indication of the goodness and alignment of the rectified imagery. The program enables measuring of the misalignment to determine whether they are within specifications. The program allows further densification of all (or some) of the cells for detailed examination of trouble spots. Control and check points can also be loaded and overlayed with the imagery for visual inspection. The program also supports overlaying original (ground truth ortho-images) if available with newly generated ortho-images in a checkerboard fashion to examine the absolute accuracy. More automated tools will be added in the future.

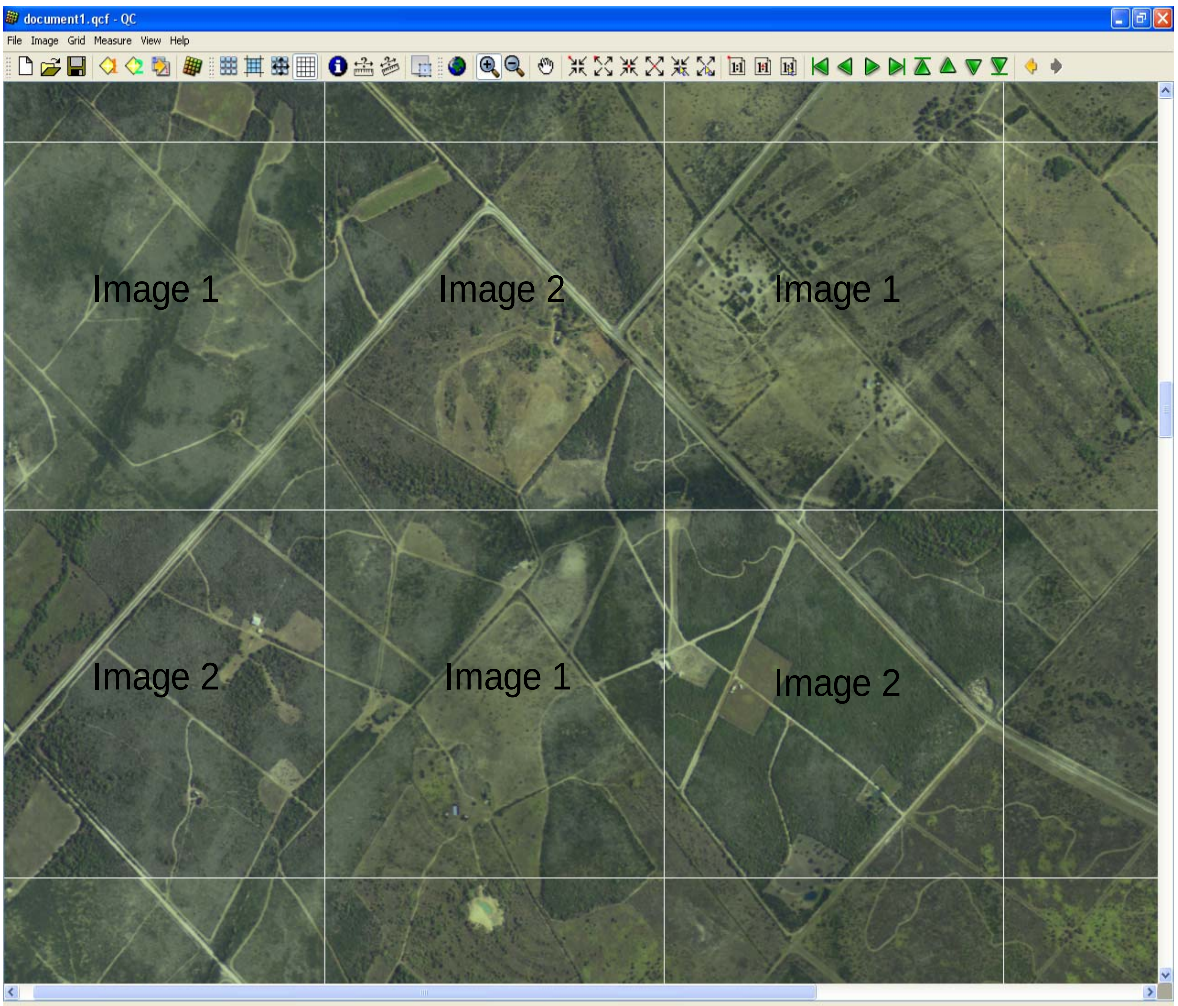


Figure 4. ADS QC Showing the Overlapping Area in a Checkerboard Fashion. This Speeds up Quality Control by Enabling Comprehensive Examination of the Entire Overlapping Areas.

WORKFLOW

Based on the successful modeling of the ADS40 (numerical results will be presented in the next section), the software described in the previous section formed the basis for a new workflow. Before describing the new workflow, let's briefly discuss the old workflow that was set up by Leica Geosystems (Figure 5a). In the old workflow, data has to be downloaded from the Mass Memory (MM40) unit which is the device that stores both images and raw navigation data including GPS and IMU observations. GPS/IMU integration has to be performed in order to interpolate orientation data for each scan line. Using these orientation data and an average elevation, raw images (L0) are ortho-rectified on a plane with the average elevation resulting in Level 1 (L1) images. Automatic Point Measurement (APM) uses L1 images and attempts to find conjugate points between the images. GCP are also measured at this stage. Matched results are then used in an aerial triangulation package to generate adjusted orientation parameters. These orientation parameters together with the DEM and calibration parameters are used to ortho-rectify the images. Radiometric correction and mosaicing are then done in two separate processes. The major problems in the old workflow can be summarized as follows:

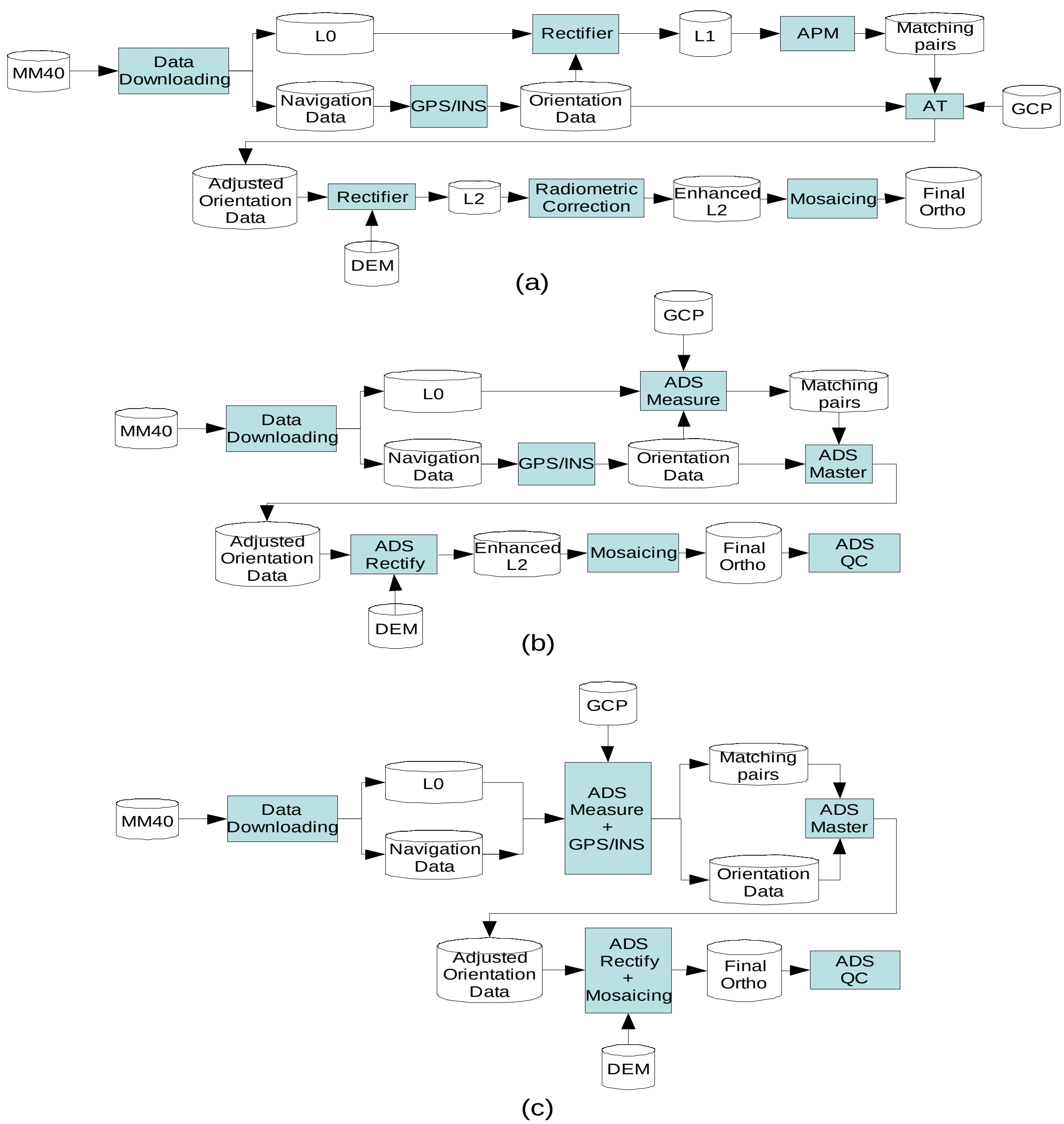


Figure 5. A Comparison Between the Old (a) and the Current (b) and the Anticipated (c) Workflows for the ADS40.

- The requirement for numerous tie points between images
- APM is not a reliable process. Thus, many blunders appear, and automatic blunder detection fails. As a result, AT fails most of the time.
- Although the workflow is designed with the objective of full automation, extensive human interaction is needed.
- The requirement of intermediate (L1) imagery consumes much time and disc space.
- The workflow tends to be fractured, and many processes need to be combined.

At North West Geomatics, we have developed an accurate and rigorous sensor model. As explained earlier, such a model does not require many tie points. The current work flow is shown in Figure 5b. In this workflow, software packages developed at North West Geomatics, described in the previous section, replace similar ones in the old workflow. In addition, the L1 creation is no longer required, saving much processing time and disc space. Furthermore, ortho-rectification and radiometric corrections are combined in a single process. It is important to mention that quality control takes place throughout the whole workflow in each process. Only final QC is shown in Figure 5b for simplicity.

Future development at North West Geomatics will combine more fractured processes into single ones, Figure 5c. We are planning to develop a combined adjustment to tackle both the AT and GPS/IMU integration. In addition, more attention to linear features, calibration, and automatic DEM generation will be given. From the radiometric perspective, combined mosaicing with rectification will be addressed.

PRODUCTION RESULTS

The newly developed AT and workflow processes have been used at NWG for many medium and high resolution projects. We will present results for two blocks showing medium and high resolution. It is very important to note that our rigorous model produces highly accurate results, however, the notion of medium vs high resolution mainly refers to the spatial resolution (ground sampling distance) which is a function of the flying height.

Experiment 1 is the same block shown in Figure 3. Eight lifts (87 images) were captured by two different ADS40 sensors. Ground resolution is 1.3m at nadir (flying height of 12600 m above ground). From Figure 3, we can see the tie points used between adjacent images. These points were generated automatically on the footprint as shown in the figure. They are then projected onto the images using the rigorous sensor model. Automatic point selection was not deployed at that time, so the user selected a point on one of the images, and then ADS Measure used the sensor model together with epipolar geometry to find corresponding points in all other images. Automatic matching was 100% successful. GCP for the area were obtained from old ortho-images (in Mr. SID format) and USGS DEM, and were of very low accuracy. ADS Measure supports measuring such control by displaying the original ortho-image for point selection to obtain planimetric coordinates, and then loads the DEM to obtain the elevation of the GCP. Matching GCP throughout the imagery is done automatically and was 100% successful. We can attribute the matching success to the rigorous model and epipolar geometry. ADS Master is then used to perform AT on the measured tie and control points. Errors of the GCP and check points are shown in Table 1. Absolute errors present the differences between the measured and adjusted coordinates of the GCP. Acknowledging that these points were measured from old ortho-images and DEM where the accuracy is questionable, adjustment results in Table 1 are far better than the original quality of the control points. This is attributed to the fact that the estimated sensor biases absorb much of the systematic errors associated with the control.

In this project, original ortho-images and DEM are considered as ground truth data. Therefore, adjustment results have to fit the ground truth data regardless of their inaccuracies. For this reason, ADS Master allows enforcing vertical constraints using the existing DEM. In addition, all points (GCP and tie points) were projected on the DEM and horizontal errors/misalignment were computed. These errors are called rectification errors, Figure 6. Here, all errors in the image space and object space are transformed into horizontal errors in the object space (at the rectification level). Misalignment/ortho-rectificaion errors are displayed as relative errors in Table 1 which are larger than those from the AT results giving more realistic figures. In general, ADS Master was able to estimate the sensor model and fit the imagery to the ground truth data with high accuracy.

A higher resolution (0.50 m ground resolution at flying height of 5000 m above ground) was also tested. A block consisting of 3 lifts (60 images) covering Wheatland County, Alberta, Canada was used for this analysis. Only a few tie points were considered and automatically matched with a 100% success rate. AT was performed and results are presented in Table 2. These results are very accurate considering a pixel size of 0.50 m. Note that GCP were of high reliability as they were observed using GPS, while in Experiment 1, accuracy of GCP was questionable.

Table 1. Absolute and Relative Accuracy for Experiment 1, with Inaccurate GCP (~10m worst case) and a Ground Resolution of 1.3 Meters

	Absolute Errors at the GCP, m			*Relative Errors at the Checkpoints, m*		
	X	Y	Z	X	Y	Z
Mean	0.000	0.000	0.000	0.509	0.119	-
Standard Deviation	1.458	1.59	1.245	1.870	1.82	-
Max Error	4.604	4.940	3.125	6.771	6.450	-

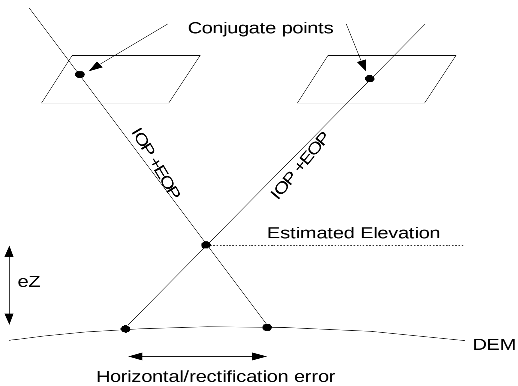


Figure 6. Derivation of the Rectification Errors from Adjusted Orientation Parameters and Available DEM.

Table 2. Absolute and Relative Accuracy for Experiment 2, with More Accurate GCP and a Ground Resolution of 0.50 Meters

	Absolute Errors at the GCP, m			*Relative Errors at the CheckPoints, m*		
	X	Y	Z	X	Y	Z
Mean	0.000	0.000	0.000	0.014	0.002	-
Standard Deviation	0.434	0.423	0.458	0.236	0.220	-
Max Error	0.667	0.797	1.101	0.980	0.940	-

Regarding efficiency, ADS Master takes 3 minutes to run the first block (Experiment 1) on a 2.0 GHz PC, and 2 minutes to run the second block (Experiment 2) on the same computer. One can note that in the old workflow, data acquisition was always ahead of production, while in the new workflow this has been reversed.

CONCLUSIONS AND RECOMMENDATIONS

Digital Line sensors are preferred over digital frame cameras due to their advantages of better quality spectral imagery, reducing relief displacements, ability to accommodate larger elevation errors for the nadir bands, and their less challenging mosaicing problem. The ADS40 by Leica Geosystems is one of the line scanners that have been in operation since 2000. The advantages of line sensors were hindered by problems in the original workflow which consisted of many unnecessary processes in an attempt to fit a line scan image into a frame image production process. The most problematic issue in the old workflow is the requirement of many tie points between adjacent images, which cannot be generated automatically with a high degree of reliability. Therefore, human interaction was necessary and time consumption was huge. At North West Geomatics, a new rigorous sensor model was developed. This sensor model incorporates systematic errors existing in the GPS/IMU integration. The model was tested for medium and high resolution projects and was proven to provide highly accurate results in both cases. In addition, very few tie points are required between images. The success of the sensor modeling encouraged the development of many software packages and automated tools. Thus, a new workflow has been implemented at North West Geomatics that is accurate, reliable, fast, and efficient. Many problems in the old workflow were addressed, including eliminating unnecessary processes, and combining fractured processes into single operations.

Ongoing development is addressing the utilization of linear features in aerial triangulation, self-calibration, automatic DEM generation and combining GPS/IMU integration with AT into a single adjustment. Radiometric issues are being addressed by combining mosaicing with ortho-rectification into a single process.

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