



Ministry of Agriculture and Lands
Integrated Land Management Bureau
Base Mapping and
Geomatic Services Branch

Specifications for Aerial Triangulation

**Edition
Version 1.0**

April 2008

Victoria BC

**Ministry of Agriculture and Lands
Integrated Land Management Bureau (ILMB)
Base Mapping and Geomatic Services Branch**

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1.0 RECORD OF AMENDMENTS

Revision No.	Revision made by	Page #	Revision Description	Approved by	Signature	Date

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Aerial Triangulation Specifications

2.0 INTRODUCTION

The main objective of aerial triangulation is to produce from known, geodetic control values, sufficient points in the photogrammetric models to ensure that each model can be oriented accurately as required for stereo compilation in either orthophoto or line mapping in either digital or analogue form. This manual is intended to be used to produce aerial triangulated, densified control points, for large, medium and small scale digital and analogue mapping produced for B.C. Provincial Government and any other mapping projects in British Columbia.

A Community of Practice involving experts from academia, mapping, photo interpretation, aerial triangulation, and digital image capture and system design was constituted to provide input and direction to the development of this set of specifications and procedures that would realize the objective of obtaining consistent, high quality Aerial Triangulation results and products as deliverables.

These Aerial Triangulation Specifications supersede all previous Aerial Triangulation Specifications.

The term "Branch" when used herein shall mean Base Mapping & Geomatic Services Branch (BMGS) of the Ministry of Agriculture and Lands in the Province of British Columbia.

For the purpose of these specifications, the word "shall" indicates a mandatory requirement and "should," indicates a desirable requirement.

The Branch shall be the final authority on acceptance or rejection of submitted Aerial Triangulation results, products and materials.

All Aerial Triangulation material, data and products delivered to the Branch shall meet or exceed the following specifications.

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3.0 GENERAL BACKGROUND

As is the case with any procedures that rely on technology, the field of aerial triangulation has changed significantly since 2000. Not only have computing systems greatly enlarged capacity for data, they have also become faster. Likewise, aerial triangulation software has become more sophisticated and available from a broadening array of developers. Control data is available from on-board GPS as well as Inertial Navigation Systems (INS) utilising Inertial Measurement Units (IMUs). Feature recognition algorithms have led to the ability to do "automated" aerial triangulation. These realities have resulted in the need to produce this Aerial Triangulation Specification in order that these technological developments can be appropriately utilized in delivering product to the BC Provincial Government.

4.0 SCOPE AND PURPOSE OF SPECIFICATIONS

The scope of these Aerial Triangulation Specifications covers all aspects of the process. The intent is to focus on the results required and not on the procedures. The producer can implement a process of their choice but must comply with the content and results specified here in.

The sections on Quality Control and Quality Assurance will provide both the producer and the procurer a clear indication of how the results will be evaluated.

5.0 AERIAL TRIANGULATION METHODS

The main objective of aerial triangulation is to produce from control, sufficient points in the photogrammetric models to ensure that each model can be oriented accurately as required for either orthophoto production or stereo compilation for line mapping in digital or analogue form.

Aerial triangulation is a complex operation which brings together several components of the mapping process including planning the photo flight and exposure stations, establishing location for control points, performing interior orientation, measuring and transferring all tie, check, and control points appearing on all photographs, and performing a least squares block adjustment.

Aerial triangulation provides the exterior orientation parameters (X, Y, Z, omega, phi and kappa) for all photographs in the block and the three-dimensional coordinates for all measured object points.

Recent progress in digital photogrammetry - advancement of computer technologies, image processing techniques and drift corrected IMU data (GPS/INS data) has brought to light new possibilities in the aerial triangulation process.

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Manual or semi-automatic operator-assisted image correlation is used where operator manually selects the point in one or two images and the image matching correlation technique is used to transfer the point in all overlapping images.

One of the significant advantages of softcopy AT is that the point coding, measurement and transfer is done by one person and at the same time.

Note: Point coordinates and exterior orientation parameters are equally important output results since both could be used to setup the models from one compilation session to the next.

5.3 GPS/IMU assisted Auto Aerial Triangulation (AAT)

Input and Tools:

- *Digital scanned images or digital images*
- *Digital point marking*
- *Softcopy Auto/Manual point Measurements*
- *Bundle Block adjustment*
- *AGPS*
- *IMU (drift corrected)*

Automated point selection and point transfer process utilize the digital image correlation. The point selection is done by searching for a candidate point with predefined rules and then transferring the point from primary image to all the overlapping images. Several methods for auto AT process are being developed and are currently based on two basic matching algorithms of image feature-based and least square matching techniques.

Auto tie point extraction is followed by a verification and editing stage carried out by a human operator. Editing of the AAT results includes a manual stereo measurements in order to satisfy reliability and stability of the AT block as well as the required precision - accuracy of the measurements.

Combination of all three techniques (AAT, AGPS and IMU) will yield the most reliable results.

Note: Point coordinates and exterior orientation parameters are equally important output results since both could be used to setup the models from one compilation session to the next.

5.4 Direct Geo-referencing or Direct Sensor Orientation

Input and Tools:

- *Digital scanned images or digital images*
- *AGPS*

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Input and Tools:

- *Digital scanned images or digital images*
- *Digital point marking*
- *Softcopy Auto/Manual point Measurements*
- *Bundle Block adjustment - without ground control*
- *AGPS*
- *IMU*

In direct sensor orientation due to sometime large y-parallaxes in individual models stereo plotting is not possible and high accuracy orthophoto production can not be done. Introduction of additional pass/tie points (without GCPs) eliminates the y-parallax and to some extent improves the accuracy in the object space. Also pass/tie points could be used to model the effects in image space using additional parameters.

Note: Exterior orientation parameters are the most important output results.

6.0 AERIAL TRIANGULATION PREPARATION

6.1 Naming and numbering convention

□ **Block naming system**

A BMGS AT block name shall be based on the British Columbia Geographic System of Mapping. An AT block name shall consist of the 4 digits of the photo acquisition year followed by the appropriate N.T.S. 1:250000 map number(s):

Ex.: 2006-93LM103IP

If the photo acquisition was from more than one year, then the numbering will reflect the years of photography based on the descending order of prevalence followed by the appropriate N.T.S. map number(s):

Ex: 2006-05-03-93LM103IP

□ **Strip numbering system**

Strip numbers shall be assigned unique 3 digit strip numbers, starting with 101 for the very first strip. Strip numbering order is open and could be:

- Either on the north or on the south side of the block
- for the flight lines running east/west.
- Either on the west or on the east side of the block -

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for the flight lines running north/south.
The AT report must clearly identify the strip numbering scheme.

□ **Aerial Triangulation Block Photo numbering system**

Photo shall be assigned unique 6 digit photo numbers. The first 3 digits will be the strip number and the next 3 digits will be the individual photo numbers. Photos shall be numbered consecutively from left to right (ex. west to east). Photo numbering system is open and the AT report must clearly identify the strip numbering scheme.

For example if the first strip (#101) happens to be the most northerly and the very first photo in that strip is named as 101, then the numbering would be as follows:

101101, 101102, 101103, etc.

Line break - when lines of photography are overlapping, then:

- One overlapping photo must be used in the A/T process in order to avoid so called "hybrid models".
- In order to keep all photo numbers sequential or lined-up and still with 6 digits, for the overlapping flight line photo numbers shall increase for 100.

Ex.: Strip #203 photo 135
Strip #203 photo 235

Or

... 203133, 203134, 203135
203235, 203236 ...

Line break - where there is a gap in flying:

- Photo numbers shall be assigned as though there were photos in the gap. This procedure will ensure that the structure of the sequential photo numbering system is kept and there is no need for a key map during the mensuration phase since all of the photos are numbered in a grid system.

101101, 101102, 101104, 101105 etc.

Please refer to Appendix A for the graphical sample.

□ **Point numbering system**

Manual analytical or softcopy AT methods:

Point numbering system is open and the AT report must clearly identify the point numbering scheme.

The recommended point numbering method is as follow:

Point numbers can be assigned unique 8 digit numbers:

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AAABBBCD

- **AAA** - First 3 digits will be strip numbers
- **BBB** - Next 3 digits will be photo numbers
- **C** - 1 digit for photo position number:
 - 0 at the center/bottom position of the photo
 - 9 at the center/top position of the photo
- **D** - 1 digit for the point type number:
 - 9 - pass point
 - 8 - tie point
 - 7 - elevated point (ex. tree top or building)
 - 6 - tie point - cross lines
 - 5 - ocean point
 - 4 - lake point
 - 2 - river point

Note: Water points (ocean, lake and river) shall be measured only as pass points in just one flight line and with minimum 1 water point per photo. For every river wider than 10 metres, there will be at least one river point measured per model. For every lake that is substantially large (at least 1/4 of the model area) at least one lake point will be measured.

Water points are not mandatory and will be read only if required for the solid aerial triangulation solution.

Auto AT method:

Most of auto AT packages will assign random numbers for each sub-block starting at ex. 10000000 for sub-block 1, then 20000000 for sub-block 2 etc. The point numbers are unique for each sub-block and are random since, for example, from 5000 points per photo that could be generated at a certain image level, only 50-150 points will meet the criteria for the process of tie point feature correlation in the least-square matching processing and thus be present at the end of the adjustment in the image measurement file.

Point numbers could be either numeric or alpha numeric and unique in an AT block regardless of the sub-block division.

Manual QC/QA of the automatic tie point generation is mandatory. All missing points at the Gruber positions will have to be added manually following the required point numbering system for manual AT methods.

TRIM I/TRIM II ground control points:

In order to avoid duplicate ground control numbers when more than one TRIM I/TRIM II AT project is used as the sources for the ground control points, renumbering of the original TRIM I/TRIM II ground control points may be required.

Renumbering system is open and the AT report must clearly

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7.3 Interior Orientation Readings

The sequence of measuring the fiducial marks shall be done as stated in the camera calibration report.

If the aerial triangulation package does not support the use of unique camera definition then detailed sketches of creating left/right cameras must be supplied as part of the aerial triangulation report.

Please refer to Appendix B for more information on the sequence of measuring the fiducial marks for most common cameras and USGS style of the camera calibration report:

- Zeiss Camera
- Wild Camera
- Jena Camera

7.4 Interior Orientation Settings and Results

The camera calibration report must not be older than 2 years at the time of the photo flight. The calibration report will be in accordance with the Province of British Columbia Aerial Photography Specifications.

All available fiducial marks shall be measured and used during inner orientation. If only 4 fiducial marks are available then a similarity transformation (4-parameter solution) shall be used during measurements in order to detect possible problems.

The final calculation shall be performed with an affine transformation.

Applying two-dimensional conformal or affine transformation will remove the uniform distortion of film deformation.

Residuals at the fiducial marks must be:

- ≤ 15 microns.

Sigma naught of the inner orientation must be:

- ≤ 10 microns.

If these results cannot be obtained for a photograph, a notice must be included in the final report submitted to Base Mapping and Geomatic Services.

If these results cannot be obtained for more than 5% of the photographs, measurements shall be stopped and Base Mapping and Geomatic Services must be informed immediately to discuss the matter.

Any error made during the Interior Orientation phase of an AT adjustment process would have an undesirable effect on the final aerial

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triangulation result.

If specified tolerances can not be reached the reasons may be:

- Wrong fiducial mark measurements.
- An inadequate camera calibration report.
- Poor geometric quality (calibration) of the scanner.
- Other, undetected errors

7.5 Interior Orientation Deliverables

- Original camera calibration reports** - for all used cameras in the AT project
- Generated camera calibration files in text format that were used in the AT process** - generated camera definition files
- Sketch of the sequence of measuring fiducial marks** - if the sequence of measuring the fiducial marks is not done according to the original camera calibration report.
- IO XLS file** - Excel file that shows the relationship between image and camera and IO results (as specified in 7.6).

7.6 Quality Control / Quality Assurance of Interior Orientation

The results of Interior Orientation shall be delivered in spreadsheet format with the following header definitions and as a part of the final excel table that is required for the delivery (see section 11.3.4):

Camera Serial # - camera serial number from the Camera Calibration Report
Lens Serial # - lens serial number from the Camera Calibration Report
Focal Length - calibrated focal length from the Camera Calibration Report
Camera Calibration Date - camera calibration date from the Camera Calibration Report
Number of Fiducials measured - number of fiducials measured in the process of IO
IO sigma naught - value of the IO sigma naught
Max residual - Highest individual residual in microns
Max residual at the fiducial mark # - fiducial # of the max residual

8.0 RELATIVE ORIENTATION

Relative orientation shall produce a parallax free model settings based on coplanarity equations. The quality of any AT block in regard to

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Average rays/point	4.5
Average points/photo	17.4

2-ray points = NO reliability. If 2-ray points represent more than 50% of all measured points in the block, the AT block should be considered unstable and with no reliability. Therefore all potential measuring errors in 2-ray points will remain undetected in the final bundle block adjustment. The final ground adjusted coordinates and exterior orientation parameters will absorb all the effects of undetected blunders. Compounding this problem is that all statistical data output will give no indication to the user that the blunders still exist in the set of automatically measured points. If many 2-ray points are present in the set of measurements, then the average redundancy will be < 0.5 and will not satisfy the specifications nor reliability requirements.

3-ray points = Bad/Partial reliability. All auto AT packages apply the automatic blunder detection procedure where all the measurement errors are being flagged. With 3-ray points it is impossible to localize the erroneous point observation. The tie point can be only flagged as erroneous in the automatic blunder detection, but the measuring error cannot be found. It can be in any of the three point observations.

Multi-ray points (4, 5, 6, 7+) = Good reliability. It is possible to localize the erroneous point observation; i.e. to find (and eliminate) the measuring error in the automatic blunder detection process - which is extremely important for the strength and reliability of the block.

8.2 Stability of an AT Block

The objectives for any auto aero triangulation package is, compared to the conventional analytical approach, to achieve equal or better accuracy, improved efficiency, and faster production.

As with conventional aerial triangulation, an image is divided into a regular 3x3 von Guber areas where the availability of tie points is a prerequisite for a stable geometric block connection. The points in those so called von Gruber positions have the maximum effect on the orientation parameters. The farther away a tie point is measured from those theoretical positions, the less is its influence on the calculation of the EO parameters.

Any auto AT package searches for a candidate tie point in those areas and then transfers the point from the primary image to all the overlapping images.

In general the additional use of GPS/INS data should improve the quality of tie point matching and increase the overall stability and reliability of the block.

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Except in images on the perimeter of the block, image points appearing only within a flight line i.e. points not located in any overlap regions of a flight line, shall be transferred and mensurated in stereo-comparator mode with the preceding and succeeding images in that flight line, providing three-ray mensuration and three-ray image points.

Except in perimeter images, all image points appearing in overlapping flight lines i.e. points located in the lateral overlap regions in the current flight line, shall also be transferred and mensurated in stereo comparator mode and each with the successive and preceding images, providing six-ray mensuration and six-ray image points. In cases where the image centers in the overlapping flight lines are inadvertently staggered, five-ray mensuration and five-ray image points are acceptable.

In projects where 5 von Gruber points per image are specified, two image points in each of the two lateral overlap regions plus one point near the principal point are required. The maximum mensuration opportunity or maximum fold mensuration is:

$$(2(L/R) \times 2 \text{ lateral points} \times 6 \text{ rays}) + (1 \text{ central point} \times 3 \text{ rays}) = 27 \text{ data entries / model}$$

The data entries in a six-fold point are evenly distributed over two flight lines, resulting in the image in each line logging not less than:

$$(2(L/R) \times 2 \text{ lateral points} \times 3 \text{ entries}) + (1 \text{ central point} \times 3 \text{ entries}) = 15 \text{ data entries / model}$$

8.3 Precision of measurements in an AT Block

Manual point measurement accuracy is approximately 1/3 pixel. Automatic measurement accuracy is up to 1/10 pixel on open flat terrain while under less favourable conditions the measuring accuracy is in order of 1/5 to 1/3 of a pixel.

One free net adjustment - bundle block adjustment that does not use any ground control points or AGPS/IMU or any EO parameters - shall be performed and statistical results delivered as defined in the appropriate section of the AT report. The results will include:

1. Sigma naught - the computed a posteriori standard deviation of the AT block adjustment in relative mode:
 - shall be < ±10 microns
2. Max rx and ry - maximum residuals in x and y coordinates in image space:
 - shall be < ±25 microns

The RMS values and Max residuals in X and Y direction from the free net adjustment shall be delivered in tabular format in the AT report:

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	X microns	Y microns
RMS value	3.798	3.855
Max residual	23.160	23.460

The results of free net adjustment such as:

- RMS values in x and y direction and
- Residuals of all measured points

shall be exported from the adjustment package in the form of log file and delivered along with other AT files - see section 11.3.6):

8.4 QC/QA of Relative Orientation

Project contractors shall perform manual data cleaning of all photogrammetric observations and produce a set of measurements that shall satisfy all specified tolerances of the aerial triangulation solution that are related to the relative solution.

The maximum image point residual for any point shall not exceed 25 microns. With manual data cleaning all observations shall be rejected and re-measured if their residuals > 25 microns.

All single observations (points measured only in one photograph) shall be removed and not present in the final set of the photogrammetric measurements.

9.0 ABSOLUTE ORIENTATION

Absolute orientation transforms the three dimensional model to the local object space by means of a three-dimensional similarity transformation.

9.1 Bundle Block Adjustment Programs

The computer program for the block adjustment could be any reliable bundle adjustment package.

The bundle adjustment package shall have the following features:

- The block adjustment program shall perform a rigorous bundle adjustment.
- The block adjustment program shall allow proper apriori standard deviations (or weights) for all groups of observations (photogrammetric observations, terrain measurements of control points, GPS observations, drift corrected IMU observations).
- The block adjustment program shall allow different apriori standard deviations (or weights) within each group of observations.

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- ❑ The block adjustment program shall support proper data cleaning by providing RMS values for all types of observations and all groups used with different apriori standard deviations (or weights) and marking of all observations with residuals.
- ❑ The block adjustment program shall feature simultaneous adjustment of additional unknown parameters used also as observations to correct for systematic image deformations (self-calibration).
- ❑ For GPS/INS supported aerial triangulation the block adjustment program shall do a simultaneous adjustment of all observations including observations from kinematic GPS and drift corrected IMU attitude observations.
- ❑ The block adjustment program shall provide the correction of the antenna offset for different strips in case the antenna offset of the kinematic GPS observations is not corrected by GPS post-processing or on the flight.
- ❑ The block adjustment program shall provide the correction of the boresight misalignments roll, pitch and yaw of the IMU sensor from given reference sensor.
- ❑ The block adjustment program shall allow a drift correction (constant and linear term) for all three co-ordinates of kinematic GPS observations.
- ❑ The block adjustment program shall allow a drift correction (constant and linear term) for all three attitude observations of IMU (roll/omega, pitch/phi and yaw/kappa)
- ❑ The block adjustment program shall supply sufficient statistical information in the log file such as: input parameters, statistics of the block, statistics of the orientation parameters, residuals and standard deviations etc.
- ❑ The block adjustment program shall include a graphical block analyzing tool where the visual checking of all results and statistical information is possible including the visualization of image footprints, overlaps, ground control and tie points, residuals and error ellipses etc.

9.2 Corrections in the AT process

- ❑ **Lens distortion** - shall be done at the mensuration stage and always applied. Modern frame aerial camera lenses have a very small distortion usually smaller than the calibration measuring accuracy. Some digital cameras produce already corrected images and distortion correction is not necessary. However for some small format metric cameras which have large correction values the distortion corrections are mandatory.
- ❑ **Earth Curvature** - shall be done during rigorous bundle block adjustment and not within the relative orientation. Earth

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9.3 TRIM I & TRIM II Control Sources and Check Points

Unless otherwise specified by BMGS, a minimum of the following control data is required:

Two (2) control points per map sheet are required.

One (1) additional control point per map sheet shall be used as a check point. The root mean square (RMS) of all check points shall be delivered in a spreadsheet.

All three (3) required control points shall be used in the very final AT bundle block adjustment.

This requirement will allow the evaluation of the RELATIVE accuracy of an aerial triangulation block to the existing TRIM I or TRIM II AT block(s) used as the source.

The use of a certain number of check point data in the AT block is required to provide redundant data for quality assessment and quality control.

- There shall be 1 check point per map sheet

If errors are present these check points in the test site may serve as additional control data to compensate the error effects. This must be discussed with BMGS to determine the course of action.

Check points are critical to analysis of best fit to existing control or Block Ties. The Check points will be used in the final adjustment. However, it is required to make 2 final runs: first one to determine "the FIT" of the check points and later the very final adjustment with all of the TRIM I/TRIM II control points including check points as any other control point.

The RMS results of all check points shall be delivered in spreadsheet format with the following header definitions:

Mapsheets # - Mapsheet number.

TRIM I / TRIM II project name /number/year - Existing AT block/project used as a source for the ground control points.

Point # - Ground control point number as listed in the TRIMI / TRIM II project

TRIM I / TRIM II adjusted coordinates - Given adjusted coordinates of a ground control point.

New AT project adjusted coordinates - Adjusted coordinates of a ground control point that has been used as a check point.

Residual - Residual in X, Y and Z for each individual ground control point that has been used as a check point. Residuals show the true errors by showing the difference between given coordinate and adjusted coordinate.

- ❑ Max Residual in X, Y and Z for TRIM I ground control points shall be < ±5 metres.

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- < ±21 micron in horizontal
- < ±30 micron in vertical

As part of the AT report project contractors shall fill in the following **self/QC/QA table** and validate if the aerial triangulation solution meets the required specifications:

AT Phase	Item	Spec	Achieved	Comment
IO				
	Max IO sigma naught (microns)	=< ±10 microns		
	Max residual (microns)	=< ±15 microns		
RO				
	Average redundancy	>= ±0.5		
	RO sigma naught	=< ±10 microns		
	Max residual	=< ±25 microns		
AO				
PRECISION	TRIM I control	RMS X	=< ±2.5 metres	
		RMS Y	=< ±2.5 metres	
		RMS Z	=< ±2.5 metres	
		Max X residual	=< ±5 metres	
		Max Y residual	=< ±5 metres	
		Max Z residual	=< ±5 metres	
	TRIM II control	RMS X	=< ±1.5 metres	
		RMS Y	=< ±1.5 metres	
		RMS Z	=< ±1.5 metres	
		Max X residual	=< ±3 metres	
		Max Y residual	=< ±3 metres	
		Max Z residual	=< ±3 metres	
	AGPS	RMS X	=< ±1.5 metres	
		RMS Y	=< ±1.5 metres	
		RMS Z	=< ±1.5 metres	
		Max X residual	=< ±3 metres	
		Max Y residual	=< ±3 metres	
		Max Z residual	=< ±3 metres	
	IMU	RMS omega	=< ±0.01 degrees	
		RMS phi	=< ±0.01 degrees	
		RMS kappa	=< ±0.01 degrees	
Max X omega		=< ±0.03 degrees		
Max Y phi		=< ±0.03 degrees		
Max Z kappa		=< ±0.03 degrees		
URA	Terra in	STDV X	=< ±15 microns	
		STDV Y	=< ±15 microns	
		STDV Z	=< ±30 microns	

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Photo EOS	STDV X	=< ±1 metre		
	STDV Y	=< ±1 metre		
	STDV Z	=< ±1 metre		
	STDV omega	=< ±0.01 degrees		
	STDV phi	=< ±0.01 degrees		
	STDV kappa	=< ±0.01 degrees		
GCP	Density	3 GCPs/mapsheet		

9.5 Weighting system

Project contractors are responsible to apply appropriate weighting system for photogrammetry measurements, TRIM I, TRIM II and any other available control, GPS and IMU data in order to meet specified tolerances of the aerial triangulation solution.

Proper a priori standard deviations shall be used for all different types and groups of observations. They shall be chosen in accordance with the actual accuracy of the observations.

If the assumed values of the a priori standard deviations can not be confirmed by the bundle block adjustment, they shall be modified in accordance of the preliminary result and the block adjustment shall be repeated.

9.6 Handling Sub-blocks

Due to production pressures on larger projects, it is sometimes required to release preliminary adjustment results of the sub-blocks to in-house ortho or compilation departments or to other contractors.

All successive sub-blocks shall have an overlap of:

- One row of mapsheets across strip direction and/or
- One row of mapsheets in strip direction.

Note: Sufficient ground control point is required on the edges of the sub-block.

When all sub-blocks are processed a common single adjustment off all photos shall be performed and the output files used for the final delivery.

The difference between adjusted coordinate values of the final overall adjustment and the preliminary adjustment of each sub-block shall be delivered in tabular format as separate files:

Point #	FINAL adjusted coordinates	SUB-BLOCK # adjusted coordinates	Residual
------------	----------------------------------	--	----------

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	X	Y	Z	X	Y	Z	X	Y	Z

The RMS results of all adjusted points shall be delivered in spreadsheet format with the following header definitions:

Point # - Pass or Tie point number.

SUB-BLOCK 1 adjusted coordinates - Adjusted coordinates of a point in the sub-block 1.

SUB-BLOCK 2 adjusted coordinates - Adjusted coordinates of a point in the sub-block 2.

FINAL adjusted coordinates - Adjusted coordinates of a point in the final adjustment of the complete project.

Residual - Residual in X, Y and Z for each individual point.

- Max Residual in X, Y and Z shall be < ±1 metre.

Combined RMS - RMS in X, Y and Z for all common:

- RMS value for each combined RMS of TRIM I in X, Y and Z shall be < ±0.5 metres.

RMS Value (m) - RMS value in metres

Combined RMS	RMS Value (m)
RMS - X	
RMS - Y	
RMS - Z	

Other reasons why an aerial triangulation project may be split into sub-blocks are:

- Shorter computation time and easier error analysis on smaller block of photos.
- Not all images for a project are available or not enough "online" storage space for all of the images of the project.

10.0 OUTPUT DATA AND MODEL SETUP PROCEDURE

Users of soft copy AT data should recognize that there are three files that should be used to achieve highest accuracy in stereo model setups.

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type and GCP class. GCP type could be: HV, H, V and Check

11.1.3 Airborne GPS

extension ***.agps** - shall contain the AGPS data and classes (X, Y, Z and GPS Time). The file structure shall contain: Photo#, X, Y, Z_ortho, GPS Time and GPS class.

11.1.4 IMU

extension ***.imu** - shall contain the drift corrected IMU data and classes (Omega, Phi and Kappa). The file structure shall contain: Photo#, omega, phi, kappa and IMU class.

11.2 Output Aerial Triangulation Files

11.2.1 Aerial Triangulation Log Files

This log file shall be as complete as possible and shall contain sufficient statistical information such as: input parameters, statistics of the block configuration, statistics of the orientation parameters, residuals and standard deviations etc.

11.2.2 Adjusted Image Measurements

extension *.cor - shall contain output photo coordinates computed from the final bundle block adjustment run.

11.2.3 Adjusted Ground Coordinates and Standard Deviation

extension *.adj - shall contain computed ground coordinates for all points in the AT block, with the file structure of Point#, X, Y, Z and standard deviations for each dimension.

11.2.4 Adjusted EO Parameters

Adjusted EO parameters shall be delivered in two different formats:

1. extension *.xyzopk - shall contain the results of the exterior orientation parameters with the file structure of Photo#, X, Y, Z, Omega, Phi and Kappa (in degrees).

2. extension *.ori - shall contain the results of the exterior orientation parameters in PATB format where beside the photo number, three coordinates of the projection center and the elements of the rotation matrix are listed.

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As mentioned in "10.0. Output data and model setup procedure" in order to use EO parameters (free of the selfcalibration additional parameter effects) directly in the production of the orthophoto and planimetry collection, another two set of files shall be produced and delivered (if possible):

3. extension *.WSxyzopk – same as *.xyzopk but with selfcalibration option turned off in the extra final bundle block adjustment where all of the adjusted points were used as control points.

4. extension *.WSori - same as *.ori but with selfcalibration option turned off in the extra final bundle block adjustment where all of the adjusted points were used as control points.

11.3 Other Aerial Triangulation Files

11.3.1 Aerial Triangulation Report

A complete AT report shall be written which covers all work carried out on the block as well as all QA/QC results for each phase of the AT process. This report will include:

- Photography, Cameras and control used;
- Horizontal and Vertical datum and units;
- Equipment and Software used;
- Methodology and specifications used;
- Numerical adjustment results;
- Additional information such as items of concerns, weak areas in the block, recommendations, etc.;
- Note any stereo gaps or any stereo dead areas encountered;
- Summary and block precision and accuracy classification

11.3.2 Aerial Triangulation Index-Georeferenced (dgn/shape)

A Geo-referenced AT index shall be submitted in digital format and in either dgn or in shape format.

11.3.3 Final AT data in the excel format - "AT_block_name.xls"

AT code	File Name	Adjusted EO parameters					
		X	Y	Z	Omega	Phi	Kappa
		m	m	m	degree	degree	degree
101	101_BCB96013_113_14n_at						
102	102_BCB96013_114_14n_at						
103	103_BCB96013_115_14n_at						
...							

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UTM zone	Photo Date	Camera serial #	Lens serial #	Focal length (mm)	Camera Calibration Date	Number of fiducials measured	IO sigma naught (microns)
		Wild 5163	13203	152.823	18-May-1995	8	8.9
		Wild 5163	13203	152.823	18-May-1995	8	7.6
		Wild 5163	13203	152.823	18-May-1995	8	8.1

Max residual (microns)	Max residual at the fiducial mark #	Mapsheet #	AT block	Contractor	Hard drive label	Submission date
-11.1	7					
-9.4	1					
-10.1	7					

11.3.4 RMS of the check points in the excel format

As described in the section "9.3. TRIM I & TRIM II Control Sources and Check points"

11.3.5 RMS of the common adjusted points - sub-blocks vs final adjustment in the excel format

As described in the section "9.6. Handling sub-blocks"

11.3.6. Log file - free net adjustment

As described in the section "8.3. Precision of measurements in an AT Block Handling sub-blocks"

12.0 DATA HANDLING and DELIVERY:

12.1 Handling:

Digital imagery will be delivered on USB 2 compliant hard drives or on fire wire or as specifically defined in the contract.

12.2 Shipping:

Shipments of data will be via courier and to the address specified in the contract.

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14.0 APPENDIX A - Sample of the aerial triangulation strip and photo numbering system

Strip 101	101103	101104	101105	101106	101107	101108	101109	101110	101111	101112	101113	101114	101115	101116	101117	101118	101119	101120	101121			
Strip 102	102102	102103	102104	102106	102106	102107	102108	102109	102110	102111	102211	102212	102213	102214	102215	102216	102316	102317	102318	102319	102320	102321
Strip 103	103101	103102	103103	103104	103105	103106	103107	103108	103109	103110			103115	103116	103117	103118	103119	103120	103121			
Strip 104		104103	104104	104105	104106	104107	104108	104208	104209	104210	104211	104212	104213	104214	104215	104216	104217	104218	104219	104220	104221	
Strip 105	105101	105102	105103	105104	105105			105109	105110	105111	105112	105113			105117	105118	105119	105120				
Strip 106	106101	106102	106103	106104	106105	106106	106107	106108	106109	106110	106111	106112	106113	106114	106115	106116	106117	106118	106119	106120		

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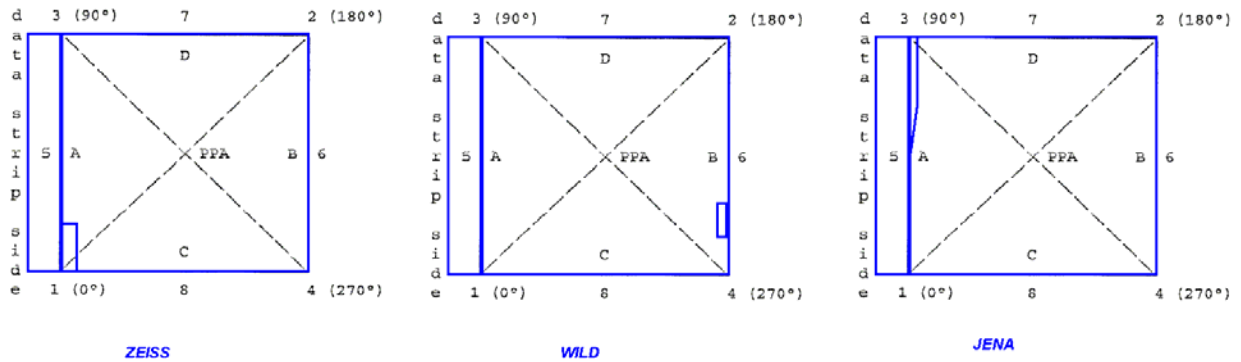
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**15.0 APPENDIX B - The sequence of measuring the fiducial marks –
USGS Camera calibration report.**



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16.0 APPENDIX C - Issues with Auto AT measurements

Manual point mensuration - points are being placed in von Gruber areas on a flat stable ground and are visible in all overlapping images.

Auto AT mensuration - points are selected using local interest operators only, therefore points sometimes lie on the tops of a trees, shadow edges, in the middle of lakes and even on moving cars leading to many incorrect results.

□ **Tree top points** - Even if a spot on a tree is correctly identified and matched among all of the overlap images, it is still not desirable to have those points in the final block adjustment due to the possibility of movement caused by external forces such as wind. Although numerous methods have been proposed to avoid such situations, there is no effective way to solve this problem.

□ **Shadow points** - Shadow points within a strip (as pass points) are of course not critical because these images are acquired immediately one after the other. But shadow points between strips (as tie points) often show high residuals especially for long strips where a considerable amount of time can go by before the plane comes back to the same area and in the meantime the shadow has moved. The shadow point issue is even greater between the strips flown at different times of day (10 o'clock/2 o'clock flights). Although numerous methods have been proposed to avoid such situations, there is no effective way to solve this problem

The use of automatic point selection including automatic point transfer process offers promise to the photogrammetric community for increased productivity in the AT process.

It is important to mention that the use of auto AT could improve productivity very significantly in some areas under favorable conditions (open and flat terrain, good texture, etc) but will only partially help or fail to produce correct and accurate results in the areas which contain steep terrain (mountainous) covered by trees, snow or water and with poor texture in general.

The use of auto AT is especially beneficial for corridor mapping projects, for railroads, powerlines, pipelines, and highways, where the majority of the points are pass points.

Some of the major challenges to the existing auto AT software are

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ability to handle:

- Large height differences within block of photos
- Terrain topography - mountainous
- Land cover - forest, water, snow
- Different scale of photos in a block
- Photos flown on different dates and with different cameras

In a production environment the auto AT results must be verified by an operator and if necessary to employ manual/conventional point measurements in some parts of the AT block of photos in order to produce a reliable AT solution. The need for manual interaction depends on a number of factors including among other things the terrain type and terrain height differences.

17.0 APPENDIX D - Tier I, Tier II, Tier III Data Requirements

It is recognized that not all projects require the same level of accuracy. Through discussion at the various Communities of Practice (CoPs), the concept of Tier(s) of application could be used for designation of accuracy requirements. Tier I, Tier II, and Tier III (engineering/municipal, resource, and reconnaissance) levels of application have been identified.

17.1 Tier I - Engineering/Municipal

This is the highest level of accuracy requirement. Accuracies of the final product are in the order of centimeters to a few metres. All precautions must be taken to ensure that the system(s) are functioning according to the manufacturer's specification and will provide an accuracy suitable for the designated product. It requires denser and more accurate control. It may also require additional steps for quality control and quality assurance to verify the results obtained. Project specifics will be provided in the contract or the specification for that project.

Tools such as the error propagation tool in Section 5.0 of this document should be used to verify that such accuracies can be obtained within the system parameters.

17.2 Tier II - Resource

This level of product relates to traditional overview operational levels of mapping (TRIM, VRI, resource analysis). Accuracies of the final product are in the order of 5 to 20 metres. Each product will have its own requirements. Project specifics will be provided in the contract or the specification for that project.

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17.3 Tier III - Reconnaissance

This level of product is intended for viewing only. Applications may be to get a quick evaluation of a forest fire site, a flood in progress, a natural disaster. It may be used in such applications as search and rescue, disaster response, equipment and personnel deployment. It is not intended for accurate mapping or measurement purposes.

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18.0 APPENDIX E - Glossary of Terms

ACCURACY - degree of conformity with a standard. Accuracy relates to the quality of a result and is distinguished from precision which relates to the quality of the operation by which the result is obtained.

ADJUSTMENT, BLOCK - (1) The determination of corrections to the coordinates of a set of points extending over a large area, the solution being obtained simultaneously for all the points.

The term block adjustment is used to distinguish this process from that in which the points are arranged along strips or arcs. Corrections are obtained first for coordinates of points within each strip or arc and the results for these strips or arcs are then modified so that they fit together without any inconsistency.

ADJUSTMENT, FREE - An *adjustment* in which the number of independent constraints (*a priori* conditions among the quantities to be adjusted) is minimal, that is, just sufficient to ensure a unique solution. Such an adjustment is "free" of distortion that may be introduced by redundant constraints. A free adjustment produces residual and adjusted observables that are not dependent on the particular minimal constraints used and is preferred for statistical evaluation. Also called "adjustment using minimal constraints" or "inner adjustment".

AERIAL TRIANGULATION or **AEROTRIANGULATION** - *Phototriangulation* using aerial photographs. Aerotriangulation is also called aerial triangulation.

AERIAL TRIANGULATION AUTOMATED - aerial triangulation wherein the point measurement is done by software through the correlation of image pixels

AEROTRIANGULATION ADJUSTMENT, BLOCK - An *aerotriangulation adjustment* in which the ground points whose coordinates are to be determined are not necessarily imaged on a single strip of photographs but mutually consistent corrections are determined without regard to the possible occurrence of the photographs in strips. The photographs, when assembled, generally form a rectangular (block-like) array.

AEROTRIANGULATION ADJUSTMENT, BUNDLE - An *aerotriangulation adjustment* based on the principle of collinearity, i.e, the geometry underlying this adjustment is that of bundles of rays passing through perspective centers and joining ground points to image points.

AERIAL TRIANGULATION SOFT COPY - aerial triangulation using digital images in a computer system for the measuring environment

AIRBORNE GLOBAL POSITIONING SYSTEM (AGPS) - a process whereby control values are obtained by placing a Global Positioning System on board the air craft and capturing GPS positions for each image exposure. There is a trigger from the camera exposure that time tags the GPS data for the instant of exposure. The offsets from the camera centre to the GPS antenna must be precisely measured and then verified by in-situ or total system calibration.

APRIORI STANDARD DEVIATIONS - refers to the knowledge of the accuracy of a

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adjustment can be compared to the original values thus providing a quality control, quality assurance evaluation of the closeness of fit between the two adjustments.

COMPARATOR, STEREOSCOPIC - A photogrammetric instrument that permits stereoscopic viewing of two photographs and measurement of the coordinates of corresponding points, the coordinates of one point and the stereoscopic parallax of its conjugate, or just the parallax between the two points. Often called a stereocomparator.

COLLIMATION - process of calibration of a film camera. (1)The process of bringing the optical elements of an optical system into proper relation with each other.
The process of bringing the collimated system into proper relation with the pointing mechanism is called *alignment*.
2) Adjusting the fiducial marks in a camera so that they locate the principal point.
Also called adjustment for collimation.
(3) The act of making a collimation adjustment.
This use of the term may lead to confusion; the process should always be identified as a collimation adjustment.

COMMUNITY OF PRACTICE (CoP) - a group of individuals, representing different perspectives on the same topic, who are intimately knowledgeable on the topic, with a common goal, who work together to further certain aspect to the community. The individuals can come from industry, government, academia and represent producers, users and custodians of the product. In this particular case the area of interest is to develop and maintain aerial triangulation specifications.

Control, Ground - A point or set of points, the coordinates of which have been determined by survey, used for fixing the scale and position of a photogrammetrically determined network.
Also called photogrammetric control or field control.

CONTROL MAPPING - Points of established position or elevation, or both, which are used to fix references in positioning and correlating map features. Fundamental control is provided by stations in the national networks of triangulation and traverse (horizontal control) and leveling (vertical control). Usually it is necessary to extend geodetic surveys, based on fundamental stations, over the area to be mapped, to provide a suitable density and distribution of control points. Supplemental control points are those needed to relate the aerial photographs used for mapping with the system of ground control. These points must be positively photoidentified; that is, the points must be positively correlated with their images on the photographs.

CONTROL, PHOTOGRAMMETRIC - (1)control derived from photogrammetric observation in an environment with known ground values established to provide scale, location, and orientation for a photogrammetric network that is yet to be adjusted to ground values.
(2) Geodetic control established by photogrammetric methods.

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CONTROL STATION - Point on the ground whose position (horizontal or vertical) is known and can be used as a base for additional survey work.

COORDINATE, PHOTO - One of a pair of coordinates of a point on a photograph, given in a coordinate system lying in a plane approximating the surface of the photograph.
A rectangular Cartesian coordinate system, established by the measuring engine (comparator) that was used for measuring the coordinates.

COORDINATE SYSTEM, CARTESIAN - A coordinate system consisting of N straight lines intersecting at one common point (the origin) and determining $N-1$ distinct hyperplanes; the n -th ($1 \leq n, \leq N$) coordinate of a point is the distance, along the n -axis, from the origin to the point where that axis is intersected by the hyperplane containing that point, through the $N-1$ other axes.

In three-space (X, Y, Z), the coordinate system consists of three straight lines (the axes) intersecting at a common point (the origin) and determining three planes; coordinates are assigned to a point by passing three planes through that point, each plane intersecting one axis and parallel to the other two. The distances from the origin to the points of intersection are the coordinates. The units used for measuring distances along the axes need not be the same on all axes, and the axes need not intersect at right angles. If the axes all intersect at right angles, the coordinate system is called a rectangular Cartesian coordinate system; otherwise, it is called an oblique Cartesian coordinate system. An alternative but equivalent definition often useful is: 'a coordinate system comprising three families of planes'. The planes within any one family are parallel and consecutively (but otherwise arbitrarily) numbered; the planes from separate families are not parallel, and a set of three planes from separate families intersect at a single point to which is assigned, as coordinates, the numbers of the three intersecting planes.

COPLANARITY CONDITION - The condition, in photogrammetry, requiring that the following three lines be coplanar: the two lines from a point in the object space to its image on two photographs and the one line joining the perspective centers of the two photographs.

The coplanarity condition has been found to be less easy to adapt to numerical computation than the *collinearity* condition.

CURVATURE - At a given point on a surface, the rate of change of the inclination of the tangent with respect to change of arc length of a normal section curve passing through that point.

CURVATURE, EARTH - must be taken into consideration in photogrammetry. As the scale of photography increases (greater flying height) the earth curvature cause a radial displacement outward from the perspective centre of the photograph.

DATUM - In surveying, a reference system for computing or correlating the results of surveys. There are two principal types of datums: vertical and horizontal. A vertical datum is a level surface to which heights are referred. In British Columbia, the generally adopted vertical datum for leveling operations is the Canadian Geodetic Vertical Datum of 1928. The horizontal

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datum is used as a reference for position. The North American Datum of 1983 is based on the spheroid (GRS80); it is an Earth-centered datum having no initial point or initial direction.

DE-CENTRALIZED FILTER GPS/INS - Precise GPS observables (only) will be applied to a Kalman filter to determine the state of error of an orientation sensor such as an IMU. The resulting IMU drift correction, system biases and scale factors will be used in a post process to determine final position and orientation data. Different from the centralized GPS/INS filter, undetected cycle slips in the kinematic GPS data can cause integration error leading to larger noise of the final position and orientation.

DIAPOSITIVES - a positive image produced on a clear film back, made from the original, negative aerial film for the express purpose of observation and measurement in a stereo imaging device.

DIGITAL AERIAL CAMERA OR CCD FRAME CAMERA - is composed of lens or series of lenses and a back frame device. Light enters the camera through the lens and is focused on an array of photo sensitive pixels that measure the light intensity. The relative coordinate of each pixel is precisely known. The data from each pixel is stored and can be recreated to produce an image. The larger the number of pixels relative to the size of the backframe, the greater the resolution.

DIGITAL POINT MARKING - a method to identify a photogrammetric point in a digital image by altering the pixel density to "appear" like a PUG point in an emulsion.

DIRECT GEOREFERENCING - a method of establishing the exterior orientation parameters for absolute orientation of a stereo model by using on board GPS and INS/IMU to measure the position, omega, phi, and kappa of the left and right image at the exact time of exposure.

DRIFT CORRECTION - due to earth rotation and gravitational forces, IMU/INS have a natural tendency to drift from absolute values over time. By establishing known points of reference with GPS and running free adjustments, it is possible to calculate the drift and apply a correction to each point as a function of time, assuming the drift is linear.

EARTH CURVATURE - must be taken into consideration in photogrammetry. As the scale of photography increases (greater flying height) the earth curvature cause a radial displacement outward from the perspective centre of the photograph.

ELLIPSOID - A closed surface, whose planar sections are either ellipses or circles. Algebraically, an ellipsoid with center at the point (x_0, y_0, z_0) and with axes parallel to the coordinate axes is given by the set $\{x, y, z\}$ of coordinates satisfying the equation $(x-x_0)^2/a^2 + (y-y_0)^2/b^2 + (z-z_0)^2/c^2 = 1$. The general form of the equation is obtained by rotating the coordinate system to a different position. An ellipsoid is specified by giving the values of three characteristic dimensions. The most common method is to fix the lengths $a, b,$

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and c of the three semi-axes, with a the longest and c the shortest. Another is to give the length (usually the longest, a) of one semi-axis, and the *eccentricities* of the equatorial and polar sections. The *ellipsoid of revolution* is biaxial, and is obtained by rotating an ellipse about either its major or its minor axis. The ellipsoid with a different length for each of its three axes is sometimes called the triaxial ellipsoid.

ELLIPSOID, REFERENCE - (1) An ellipsoid of specified dimensions and associated with a *geodetic reference system* or a geodetic datum. Coordinates given in this system are said to be "with respect to the reference ellipsoid". Reference ellipsoids are most commonly ellipsoids of revolution (i.e., have two of three possible axes of equal length) and are sometimes called reference spheroids.

(2) An *ellipsoid* on which the potential of gravity is constant and to which the potentials of other points are referred.

(3) An *ellipsoid* on which the potential of gravity is constant and which approximates the geoid in size and position.

EQUATION, PHOTOGRAMMETRIC - The equation of a straight line that joins an identified point in object-space to the corresponding point in the image and passes through the perspective center. A system of six photogrammetric equations referring to points on a single photograph suffices to determine the location and orientation of the photograph if the coordinates of the points in image-space and in object-space are known.

ERROR - (1) The difference between the observed value of a quantity and the theoretical or defined value of that quantity. Symbolically, ϵ (error) = y (observed) - y (theoretical).

(2) The difference between an observed or calculated value of a quantity and the ideal or true value of that quantity.

This definition differs from (1) in using the words "ideal" and "true". Theoretically, the definitions are quite different. Practically, they are equivalent, except that the second permits use of calculated values as well as observed values. Since the ideal or true value of a quantity cannot, with few exceptions (see below), be known with exactness, the term "error" is applied to a difference between an observed value of a quantity and some value determined by established procedure and used in lieu of the ideal or true value. The exceptions are as follows. The ideal or true value of a quantity can be known exactly if it is (a) mathematically determinable and independent of observation (for example, the sum of the angles of a plane triangle is 180°); and (b) if it is a conventional (defined) value (for example, the length of the metre as defined by the wavelength of the orange line of the spectrum of Kr [86° ~30]. Errors are of various kinds, depending upon how and where they originate. An appropriate adjective or qualifying clause is used to designate the kind of error, such as accidental error, index error, or error of observation. In some usage the sign of the error as previously defined is reversed.

ERROR, GROSS - A very large error.

The usual implication is that such a large error was made by a person rather than an instrument. If the supposition is correct, the error is called a *blunder*.

ERROR, MEAN-SQUARE - The square of the *root-mean-square error*.

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amount (shifted). It is possible to determine the shift by running a free adjustment.

GROUND CONTROL - a point located on the ground with known surveyed values, that can be identified in the imagery and used to fix the location of the stereo image.

INERTIAL MEASUREMENT UNIT (IMU)- a sensor system of very precise gyroscopes that determine direction in X/Y and in Z coupled to an accelerometer and a precise clock. Measuring from a known position using a direction vector, speed and time, any position along the vector and be determined by interpolation.

INERTIAL NAVIGATION SYSTEM (INS) - An inertial navigation system includes at least a computer and a platform or module containing accelerometers, gyroscopes, or other motion-sensing devices (see IMU). The INS is initially provided with its position and velocity from another source (GPS, other), and thereafter computes its own updated position and velocity by integrating information received from the motion sensors. INS suffer from integration drift, small errors in the measurement of acceleration and angular velocity are integrated into progressively larger errors in velocity. Drift correction is modeled using a de-centralized or centralized Kalman filter approach and involves post processing. Most common system in use are strap down GPS aided Inertial Navigation Systems (GPS/INS).

IMAGE MATCHING - a process of correlation between images that match like objects

KALMAN FILTER - The Kalman filter is an efficient recursive filter that estimates the state of a dynamic system from a series of incomplete and noisy measurements. Kalman filtering is often used in GPS and GPS/INS integration software to determine IMU drift correction parameter and kinematic GPS cycle slips.

KINEMATIC GPS - the utilization of GPS on a moving platform.

LENS DISTORTION - A Seidel aberration that causes the scale of the image to change from point to point in the image. It is commonly separated into two components: radial distortion, which is change of scale along a line radially outward from the optical axis, and tangential distortion, a change of scale in a direction perpendicular to a radial line.

LINE BREAK - see GAP

LINE, FLIGHT - (1) The path taken by an airplane during an aerial survey.
(2) The line, drawn on a map, that represents the path followed by an airplane while taking aerial photographs.

NAD'83 COORDINATES - Cartesian coordinates based on the North American Datum of 1983

NADIR, PHOTOGRAPH - The point at which a vertical line through the perspective center of the camera's lens system pierces the plane of the photograph.

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Also called nadir point.

N.T.S. MAP NUMBER - National Topographic Series of maps that are uniquely identified by a numbering system.

ORIENTATION, ABSOLUTE - (1) The process of fixing the scale, location, and orientation with respect to an object space coordinate system of a stereoscopic model formed by using a pair of photographs in correct relative orientation.

ORIENTATION PARAMETERS, EXTERIOR - (1) Determining, analytically or in a photogrammetric instrument, the location of the camera station and the orientation of the camera at the instant of exposure. Exterior orientation, in a stereoscopic plotting instrument, is divided into two parts, relative and absolute. Also called outer orientation.
(2) The set of quantities that fixes the location of the camera station and the orientation of the camera at the instant of taking the photograph. The set of quantities consists of three coordinates (location) and three angles (orientation).

ORIENTATION PARAMETERS, INTERIOR - The determination of the position of the coordinate system of a photograph with respect to the coordinate system of the camera used to take the photograph, or with respect to the coordinate system of the photogrammetric plotter in which the photograph is used. At least three constants, called the elements of interior orientation, specify the position of the photograph's coordinate system. These are (a) the distance (principal distance) along the perpendicular from the center of perspective to the plane of the photograph, and (b) the coordinates of the foot of the perpendicular in the coordinate system of the photograph. This definition implies that the plane of the photograph is perpendicular to the optical axis of the camera or projector and that the axes of the two coordinate systems are parallel. Where this assumption is unsatisfactory, one or more additional constants are introduced. Many American photogrammetrists consider that the corrections for radial and tangential distortion are part of interior orientation, and the corresponding constants are among the elements of interior orientation. In this case, the calibrated focal length, rather than the principal distance, (a), is specified.

ORIENTATION, RELATIVE - The reconstruction (mathematically or instrumentally) of the same geometric relationships (except for scale) that existed between a pair of photographs when the photographs were taken. In the instrument, this is achieved by a systematic sequence of rotational or translational movements of the projectors. This procedure is sometimes called clearing γ -parallax. If the two photographs have enough image points in common (at least five), one photograph can be visually oriented with respect to the other.

OMEGA, PHI AND KAPPA - angular rotations around the X,Y and Z axis.

PARALLAX - (1) The apparent displacement of the position of an object with respect to a reference system, or to a set of points or objects, because of a shift in the location of the observer.
(2) The difference in direction of an object as seen from two different

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PIXEL SIZE - the actual physical dimension of the pixel

PRINCIPAL DISTANCE - (1) The perpendicular distance from the internal perspective center to the plane of a photographic negative or print. This distance is equal to the calibrated focal length of the camera that took the original photograph, corrected both for the enlargement or reduction ratio and for the shrinkage or expansion of the film or paper since the photograph was taken.

(2) The perpendicular distance from the internal perspective center of the projector of a stereoscopic plotting instrument to the plane, in the projector, of the emulsion side of the diapositive.

PRINCIPAL POINT, - (1) (optics) The intersection of a *principal surface* with the optical axis of an optical system.

(2) (photogrammetry) (a) The foot of the perpendicular from the interior perspective center to the plane of the photograph. (b) The point at which lines through corresponding fiducial marks on a photograph intersect, or the point taken as the average location of such points of intersection. This is an approximation to definition (a). The difference can be determined by calibration. (c) The point at which the optical axis of the projector's lens system intersects the plane of the image being projected.

PRINCIPAL POINT OF AUTOCOLLIMATION - PPA

PRINCIPAL POINT OF SYMMETRY - PPS

REFRACTION - The bending of sonic or electromagnetic rays by the medium through which the rays pass. The amount and direction of bending are determined by the refractive index of the medium.

RELATIVE ORIENTATION - The reconstruction (mathematically or instrumentally) of the same geometric relationships (except for scale) that existed between a pair of photographs when the photographs were taken.

In the instrument, this is achieved by a systematic sequence of rotational or translational movements of the projectors. This procedure is sometimes called clearing *y*-parallax. If the two photographs have enough image points in common (at least five), one photograph can be visually oriented with respect to the other.

RESOLUTION - (1) In general, a measure of the finest detail distinguishable in an object or phenomenon.

(2) In particular, and usually, a measure of the finest detail distinguishable in an image.

Resolution usually varies from point to point of an image, so an average value (area-weighted average resolution), is often used as the resolution of the entire image.

(3) A measure of the shortest distance over which differences of gravity can be distinguished.

In particular, the length of arc along a great circle of a sphere representing the Earth corresponding to the term of highest degree present in a representation of the gravity potential by spherical harmonics.

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(4) The reciprocal of the width of the beam from a unidirectional antenna, measured in degrees.

(5) The separation of a vector into its components.

(6) See *resolving power*.

"Resolution" and "resolving power" are often used as if they were synonymous. However, it is better to use resolution when referring to details of the object (image) and resolving power when referring to capability of the instrument used for observing.

ROOT MEAN SQUARE (RMS)

SCANNED AERIAL FILM - analogue images taken with a frame camera that are then converted to a digital format by "scanning" the film. The scanning can occur at different resolutions depending on the scanner capability and the requirements of the project.

SELF-CALIBRATION

SENSOR SIZE

SAR SENSORS - Side looking Airborne Radar

STANDARD DEVIATION - (1) The quantity, s_x , of a set $\{x_n\}$ of N random numbers with an average value 0, and a proportional weight (w_n) for each x_n , given by 76A.

(2) If x is a continuous, random variable with probability-density $p(x)$, the standard deviation, σ_x , given by 77A in which 0 is the average value of x . Other terms for standard deviation are standard error, mean error, and dispersion. These terms have unfortunately acquired a multiplicity of meanings and should not be used when clarity is desired. Standard deviation is sometimes restricted for use with populations with a *Gaussian distribution*, while root-mean-square (rms) error is used with populations with any kind of *distribution*.

SYSTEM CALIBRATION (INCLUDING GPS/INS COMPONENTS AND CAMERA SELF-CALIBRATION - a system is composed of several components (camera, GPS, LiDAR, IMU/INS) all of which must work correctly and be individually calibrated and which must work in unison as a whole system. A system calibration (in-situ) requires that the whole system be made operational over a ground site with many well know points that are identifiable in the resultant data. This information is used to verify the calibration and interoperability of the system components and is often a component of the bore sight testing.

von GUBER AREAS - these are the classic points of photogrammetry and are located in the extremity corners and median side locations of an aerial image. These points provide the best geometry for the selection of pass and tie points in aerial triangulation and are the usual points selected for the removal of parallax in the model.

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