WORLDVIEW-1 STEREO EXTRACTION ACCURACY WITH AND WITHOUT MIN PROCESSING

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ABSTRACT

WorldView-1 is a high precision, commercial, satellite imaging sensor. This paper presents a recent assessment of its 3D extraction accuracy based on 50 overlapping and contiguous stereo pairs of WorldView-1 imagery covering approximately 50,000 square kilometers of the earth's surface. Absolute horizontal and vertical accuracy are assessed for both ground point extractions based on single stereo pairs of imagery, and for ground point extractions based on the fusion or combination of information across all stereo pairs of imagery. Absolute accuracy is both predicted using error propagation and measured using ground truth (check) points. The fusion of information across all stereo pairs was implemented using Metric Information Network (MIN) technology. MIN processing is equivalent to extraction following a single simultaneous image block adjustment of all 50 stereo pairs (100 images), but is more flexible, timely, and efficient. MIN processing can sequentially process either individual stereo pairs or individual cells (groups) of stereo pairs. Performance results are presented for both methods and compared to a single simultaneous image block adjustment. Results are also extended to the use of a sparse set of ground control points (GPS surveyed points) in addition to the WorldView-1 imagery.

INTRODUCTION

An assessment of WorldView-1 extraction accuracy is presented based on 50 overlapping and contiguous stereo pairs of WorldView-1 high precision, panchromatic, imagery, which cover approximately 50,000 square kilometers of the Southwestern United States. Absolute accuracy is both predicted using error propagation and measured using ground truth points. Error propagation is performed for 1347 extracted 3D ground points, and of these, 101 are directly compared to available ground truth (GPS surveyed) points. Details of the WorldView-1 (WV1) sensor, launched in September 2007, and its imagery are available in (DigitalGlobe, 2009).

An accuracy assessment is performed for each of two different processing approaches: the first based on individual stereo pairs, and the second based on the fusion of information across all stereo pairs. The first approach is essentially WorldView-1 stereo extraction accuracy "out of the box". For a given ground point, its extracted 3D location is based on an image block adjustment of one and only one stereo pair of images without the use of control.

The second approach corresponds to Metric Information Network (MIN) processing, which is equivalent to extraction following a single simultaneous block adjustment involving all stereo pairs, again without the use of control. For a given ground point, its extracted 3D location is based on all stereo pairs in which it was measured as well as the combination of independent information across all contiguous stereo pairs. MIN processing is a sequential and flexible process, and more practical, efficient, and timely than a single simultaneous block adjustment (Dolloff, et. al., 2008). With MIN processing, either individual stereo pairs or groups (cells) of stereo pairs can be processed sequentially. MIN processing can also include the use of sparse control, if available, as discussed in the last section of this paper.

Available Imagery and Corresponding Data

Fifty stereo pairs of WV1 imagery and corresponding image support data were made available by DigitalGlobe for this study. Each stereo pair corresponds to DigitalGlobe's "Basic Stereo Pair Imagery" product. The stereo pairs were collected as part of seven 1 degree x 1 degree cells, and three other "bridging" cells. Together these ten cells cover a contiguous area of the Southwestern United States as depicted in Figure 1. Each cell consists of 2 to 7 overlapping stereo pairs of imagery.

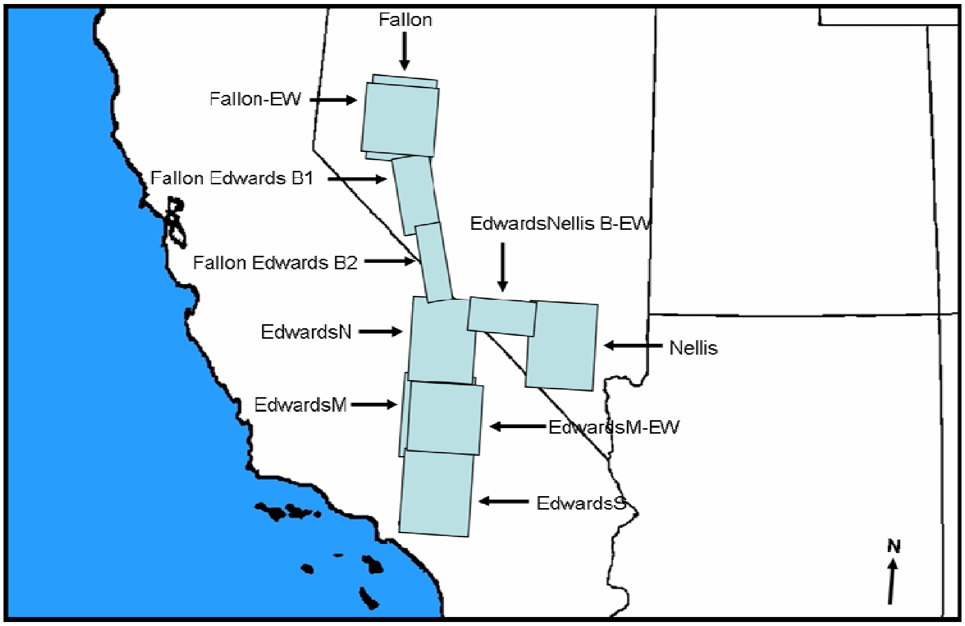

Figure 1. Geographic location of 10 cells containing 50 stereo pairs.

Table 1 presents imaging metrics, averaged over the images making up each cell. The images (strips) are large, each made up of multiple image segments. Two images making up an arbitrary stereo pair were collected on the same orbital pass, while all stereo pairs were collected on different passes (days). There is one exception - a pair in EdwardsM-EW and a pair in Fallon-EW were both taken on the same pass on July 30, 2008. Also note that cells Fallon and Fallon-EW completely overlap geographically, where "EW" corresponds to an East-West collect as opposed to the nominal North-South collect. Similarly, EdwardsM and EdwardsM-EW completely overlap as well.

Table 1. Average imaging metrics per cell

Cell	# Stereo pairs	Collection date range mmyy	lines x1000	samples x1000	scan duration (sec)	gsd (m)	off-nadir angle (deg)	conv angle (deg)
Fallon	5	0308-0608	197	36	16	0.6	27	39
Fallon-EW	7	0708-0908	161	36	13	0.6	27	44
FallonEdwardsB1	3	0209-0209	275	36	23	0.6	23	37
FallonEdwardsB2	2	0409-0509	233	36	19	0.6	25	40
EdwardsN	6	0108-0708	191	36	16	0.6	29	40
EdwardsM	6	1207-0608	199	36	17	0.6	26	36
EdwardsM-EW	7	0708-0808	167	36	14	0.6	27	43
EdwardsS	6	1207-1208	202	36	17	0.6	24	35
EdwardsNellisB-EW	3	0309-0309	197	36	16	0.6	25	42
Nellis	5	0608-0608	199	36	17	0.6	28	34

Figure 2 presents the corresponding image footprints for all 100 images making up the 50 stereo pairs – note that this figure is oriented East-up for ease of viewing.

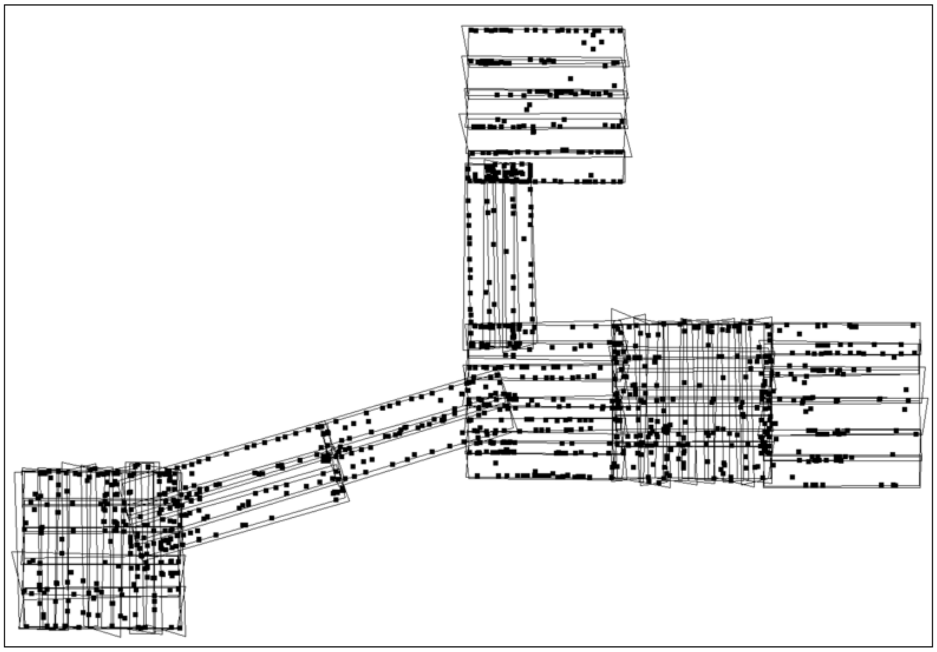

Figure 2. Image footprints of 50 stereo pairs and 1347 tie point locations (East-up).

This figure also depicts the nominal horizontal locations of 1347 3D ground points that were measured in the overlapping images and extracted as part of the accuracy assessment. These points are both tie points and check points. Their corresponding numbers and associated images rays are presented in Table 2. A 2-ray point corresponds to the same ground point measured in both images of a stereo pair, a 4-ray point corresponds to the same point measured in four images in two overlapping stereo pairs, etc. A ray corresponds to a two-dimensional (line, sample) image coordinate in one image.

Table 2. Number of image rays

RAYS	TIE	CHECK	TOTAL
2	431	41	472
4	659	38	697
6	134	18	152
8	22	4	26
TOTAL	1246	101	1347

The 101 check points have associated ground truth (GPS surveyed) 3D locations available for comparison. Figure 3 presents their nominal horizontal locations within the image footprints. A typically conservative summary for ground truth *a priori* accuracy is 0.5 m CE and 0.5 m LE, where CE corresponds to 90% predicted horizontal accuracy and LE to 90% predicted vertical accuracy.

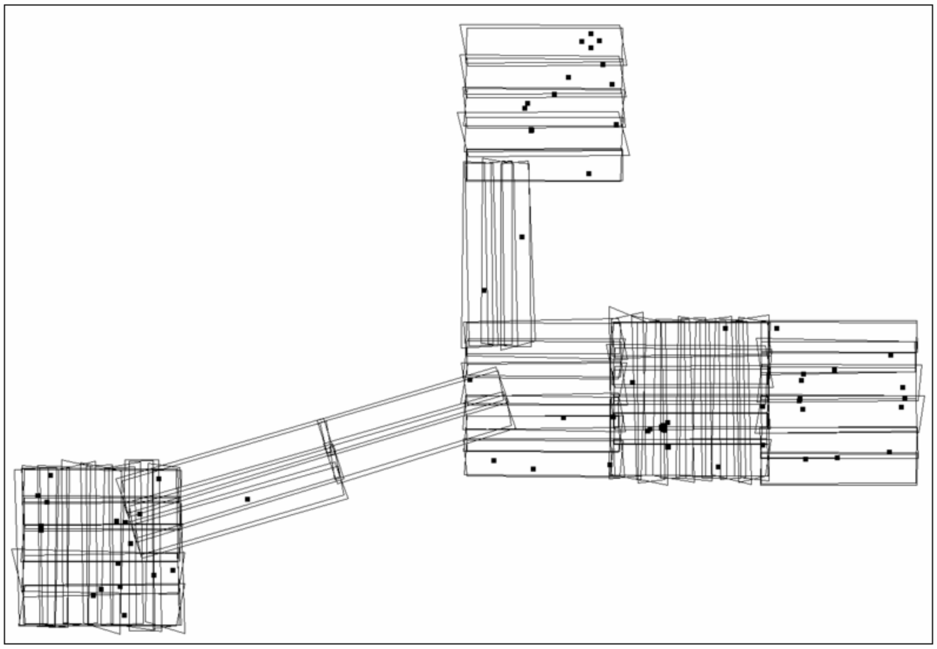

Figure 3. Image footprints of 50 stereo pairs and 101 check point locations (East-up).

Figure 4 presents an image chip of one of the measured check points in one of the WV1 images (prefix number 07DEC19182720). The cursor is centered on the control point, which is a corner of a parking lot.

Figure 4. Check point in WorldView-1 image.

The term "check point" usually implies that the point does not participate in (potentially influence) an image block adjustment. However, in this accuracy assessment, check points are used in two different ways: (1) as a tie point involved in an image block adjustment with ground truth available for comparison to its solution as part of the block adjustment, and (2) as a ground point solved for either before or after an image block adjustment (e.g., using a stereo pair equal-weight point extraction) for comparison to ground truth. It should be clear by context which is applicable. Note that (1) was used primarily because it automatically includes optimal weighting and error propagation. Also, the corresponding influence of the check points on an image block adjustment is negligible since they typically make up only 7% of the total tie points in the adjustment and there are a large number of tie points (redundancy).

WV1 Sensor Model

The WV1 sensor model used for accuracy assessment is available in SOCET SET® v5.5.1. It utilizes a high fidelity atmospheric correction model and contains adjustable parameters relative to the whole image, not to each of the individual image segments that make up the whole image. (There are typically 4 overlapping segments per image.) There are 6 adjustable parameters per image: 3 attitude corrections and 3 attitude rate corrections. Their *a priori* uncertainties are 5 urad and 0.5 urad/sec, respectively, one-sigma. Corresponding adjustable parameters from different images are assumed uncorrelated except if from the same pass, in which case they are modeled as temporally correlated 75%. Note that the WV1 sensor model implemented is a rigorous or physical sensor model and not an RPC sensor model. (RPC coefficients are also included in the image support data of DigitalGlobe's Basic Stereo Pair Imagery product.)

Image mensuration (measurement) *a priori* uncertainty was set to 1.0 pixel, one-sigma, in both the line and the sample directions for all image measurements. It statistically quantifies estimated automatic and interactive image measurement error. It also reflects the effects on image measurements of any possible high frequency sensor support data error not observable by the adjustable parameters. Image measurement error is assumed independent between measurements. All check points were measured interactively and all other tie points were measured automatically. A common set of image measurements was made available to all experiments, and the appropriate subset used.

Both the adjustable parameter *a priori* uncertainties and the image mensuration *a priori* uncertainties were set to somewhat conservative (larger) values in order to promote conservative error propagation. Together, they represent the *a priori* uncertainty of the WV1 image support data and the ability to identify and measure ground points in the corresponding images.

WV1 ACCURACY BASED ON INDIVIDUAL STEREO PAIRS

A two-image block adjustment was performed independently for each stereo pair. Specifically, a simultaneous best estimate of image support data corrections to both images (6 per image) and 3D ground coordinates for each tie point was generated using corresponding tie point image measurements and *a priori* sensor (adjustable) parameter estimates. No ground control was utilized, including surface or elevation models. (See (McGlone, 2004) and (Mikhail, Bethel, and McGlone, 2001) for details regarding image block adjustments.)

All applicable tie points corresponding to each stereo pair were included in that pair's adjustment, and the subsequent *a posteriori* solution (i.e. extracted 3D ground coordinates and corresponding error covariance) were analyzed in detail. There was an average of 48 tie points per stereo pair, including any available check points. Typical root-mean-square *a posteriori* image residuals were 0.25 pixels. Solution results are summarized over all points and all stereo pairs in Table 3. They represent WV1 inherent single stereo pair extraction accuracy.

Table 3. WV1 Single Stereo Pair Extraction Accuracy

Stereo Pair Extraction	Measured Error (meters)			Predicted Accuracy	
	50%	90%	95%	Average CE or LE	% within CE or LE
Horizontal	2.1	3.4	3.6	6.5	99
Vertical	2.6	4.5	5.9	6.5	95

Measured errors are relative to the 101 check points, i.e., a comparison of their 3D locations extracted from the block adjustment to the corresponding ground truth locations. Horizontal errors are radial errors (root-sum-square of East and North errors), and vertical errors are absolute vertical errors. Measured errors are categorized by percentile; for example, a 50% horizontal error of 2.1 meters means that 50% of the check point horizontal errors were 2.1 meters or less.

Predicted accuracy, also in meters, is relative to all 1347 ground points. "Average CE" is CE averaged over all points, where an individual point's CE is computed from it's *a posteriori* 3x3 error covariance from the block adjustment and represents 90% probable horizontal error. Average LE is similar but relative to 90% probable vertical error. "% within CE" is the percentage of all check points with horizontal error less than or equal to their corresponding CE. The check point's ground truth CE is root-summed-squared to the predicted CE prior to the test. "% within LE" is similar but relative to vertical error and LE. If everything is modeled correctly (including *a priori* accuracy of check point image measurements and corresponding ground truth locations) and if enough samples are taken, we expect "% within" to approach 90%.

Effect of a Single Stereo Pair Block Adjustment

A block adjustment of a single stereo pair of WV1 imagery without control is stable but does little to improve accuracy relative to single point extraction. It is used primarily to better align the images (e.g., reduce any y-parallax for improved stereo viewing). If the check points are extracted individually without the benefit of a block adjustment and with each ray given equal weight, the corresponding 90% measured error entries in Table 3 only increase by approximately 0.1 meters. If extracted after a block adjustment (but not as a participating ground point in the block adjustment), the corresponding 90% measured error entries in Table 3 are virtually identical.

We now proceed to discuss significant improvements in extraction accuracy when information across stereo pairs is fused together. In a later section, we also directly compare the extraction accuracy of both methods: single pair versus fusion of stereo pairs. Comparisons include detailed distribution plots of all measured errors.

WV1 ACCURACY BASED ON THE FUSION OF INFORMATION ACROSS STEREO PAIRS

The information inherent in each stereo pair was fused together across all 50 stereo pairs. The corresponding ground point extraction accuracy is equivalent to one simultaneous image block adjustment for all 50 stereo pairs. That is, extracted ground coordinates and their error covariance correspond to the *a posteriori* solution of all tie points in the block adjustment, and again, without the use of ground control. However, the actual processing performed was not based on a single simultaneous block adjustment, but on MIN processing, outlined as follows for the WV1 accuracy assessment.

MIN Processing

Information was processed (fused) sequentially one stereo pair at a time. For each stereo pair, a two stage process was implemented: a stage 1 adjustment followed by a stage 2 update. The stage 1 adjustment is simply a standard image block adjustment for a stereo pair. The stage 2 update implements a fusion algorithm that combines information from different stereo pairs directly in ground space. There were 49 stage 1 adjustments and stage 2 updates – the *a priori* image support data was correlated between two stereo pairs taken on the same pass, and as such, they were processed together as one image block.

In general, MIN processing is faster, more efficient, and more flexible than a single simultaneous image block adjustment of all stereo pairs. It is also more timely, in that the stereo pairs can be processed upon receipt, i.e., all do not have to be gathered first prior to their adjustment. Note that MIN processing (wall clock) time for the WV1 accuracy assessment averaged approximately 1 minute per stage 1 adjustment plus stage 2 update, including data storage and i/o, or approximately one hour total for all 50 stereo pairs. This was based on the following system: Sun Fire 880, CPUs 6x1050MHz, Memory 12GB; it excludes image measurement time associated with image block adjustments.

MIN processing automatically generates a MIN ground control point database which includes the 3D locations of the extracted ground points, their full *a posteriori* error covariance, and corresponding image patches to facilitate future image measurements. Any time a new image block (e.g., stereo pair) is processed, the MIN database automatically increases in size and the accuracy of all of the points improves. For the WV1 accuracy assessment, a total of 1347 points were generated, using only the fused information from the 50 stereo pairs. These points are "internally-generated" ground control points, not "external" or traditional (e.g., GPS surveyed) ground control points.

A MIN (ground control point) database remains available to control any future set of images or image-based products, yielding accuracies comparable to the accuracies of the MIN ground control points themselves. The availability of the full (joint) error covariance for all points in the MIN database also allows for the proper weighting of an arbitrary subset when used in a control process. MIN ground control points can also be used as check points in support of Quality Assurance processes.

If external ground control points are available any time during MIN processing, they can be inserted into the MIN database and subsequent MIN processing will propagate their information to all other ground points already in the MIN database. See Appendix A for further details regarding MIN processing.

MIN Processing Flexibility

MIN processing can fuse information between images from different sensors or sensor types. If so desired, individual stage 1 image block adjustments can have a mix of image types, or be conveniently limited to images from one sensor or the other(s) – when finished, extraction results are equivalent. MIN processing can also be performed one cell at a time instead of one stereo pair at a time. In particular, WV1 extraction results are virtually identical (within a few millimeters for all 1347 points) whether based on MIN stereo pair processing, MIN cell processing, or a single simultaneous block adjustment. However, in terms of MIN processing time, there is a trade-off regarding the size of the stage 1 block adjustments (e.g., pairs versus cells). The smaller the stage 1 adjustment, the less individual stage 1 processing time and the less total stage 1 processing time. On the other hand, more i/o is required as are more stage 2 updates. Figure 5 presents corresponding total MIN processing time using stage 1 image block adjustments based on individual stereo pairs, individual cells, and all cells. The later is actually a single simultaneous block adjustment with corresponding population of the MIN data base. As a reminder, the overall scenario involves 50 contiguous stereo pairs - 100 large images and 1347 ground points.

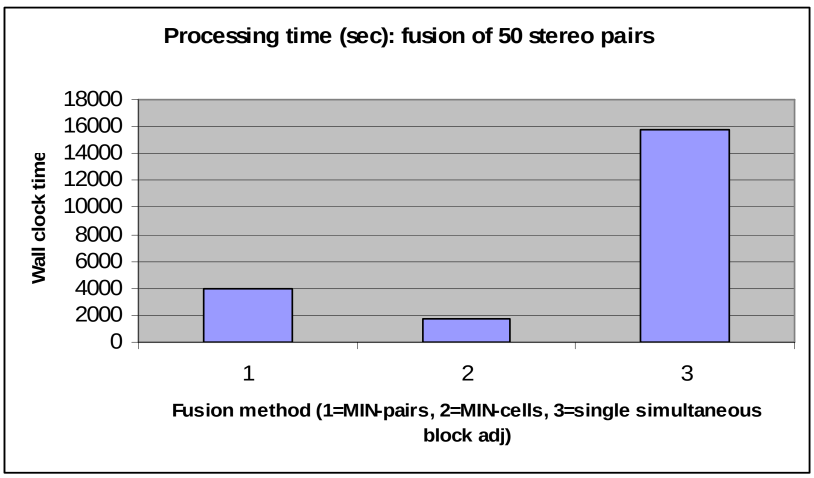

Figure 5. Total processing time versus fusion method.

Corresponding Fusion-based Accuracy

Table 4 presents corresponding extraction accuracy based on the fusion of 50 stereo pairs - predicted accuracy across all 1347 tie points and measured accuracy across all 101 check points. Accuracy based on fusion (Table 4) is significantly better than when based on single stereo pairs (Table 3). This is due primarily to the statistical independence of the information content in stereo pairs imaged in different passes. And since the *a priori* accuracy of image support data is reasonably accurate for each stereo pair prior to their combination or fusion, subsequent results are quite accurate without the use of traditional ground control (e.g., GPS surveyed points).

Table 4. Fusion-based WV1 Extraction Accuracy

Fusion - based Extraction	Measured Error (meters)			Predicted Accuracy	
	50%	90%	95%	Average CE or LE	% within CE or LE
Horizontal	1.2	2.2	2.7	1.7	81
Vertical	0.7	1.5	1.8	2.2	97

Predicted accuracy for a given ground point is dependent on its individual proximity to each of the 50 (contiguous) stereo pairs. This is illustrated in Figure 6 which presents the predicted CE (color coded) for each of the 1347 tie points based on the fusion of 50 stereo pairs. Note that the points with the best predicted accuracy are concentrated in areas where information from more stereo pairs is contributing to knowledge of the ground; in particular, the Edwards Middle area has overlapping coverage from EdwardsM (N/S strips) and EdwardsM-EW (E/W strips), as well as information flowing in from EdwardsS and EdwardsN.

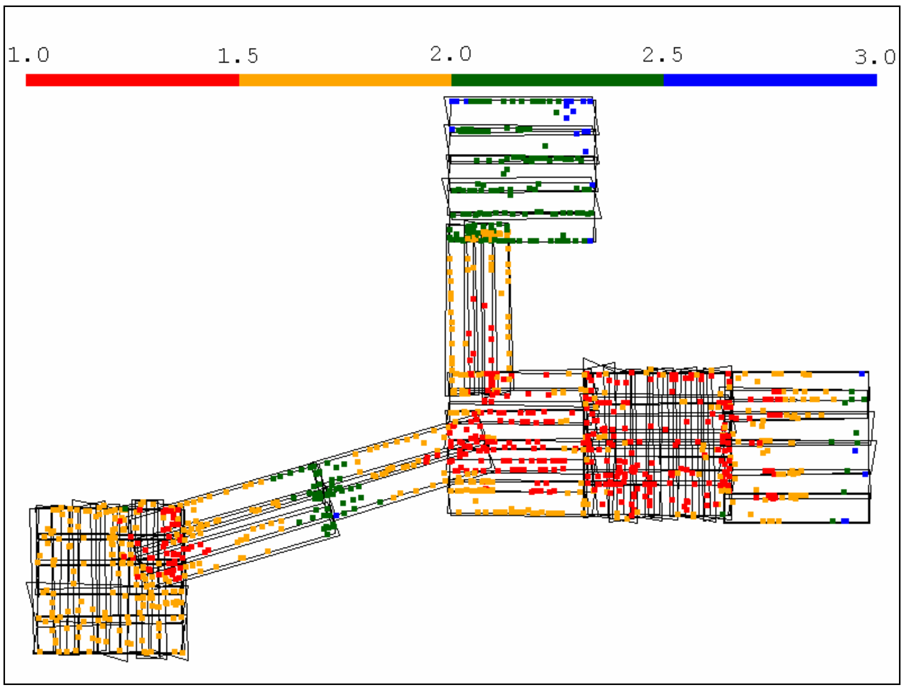

Figure 6. Predicted Accuracy: CE(0.9p) in meters.

DIRECT COMPARISON OF PROCESSING APPROACHES

This section compares individual stereo pair processing with fusion of stereo pair processing, with respect to the distributions of measured errors.

Accuracy Comparison

Figure 7 presents the detailed horizontal errors for all check points for both approaches. Figure 8 presents a similar plot for vertical errors. Because there are 101 check points, there are 101 error samples for fusion of stereo pairs processing, but 187 error samples for individual stereo pair processing since points with more than 2-rays are in more than one stereo pair (see Table 2). Note that the results presented for individual stereo pair processing include some outliers when beyond the 95th percentile (9 largest errors).

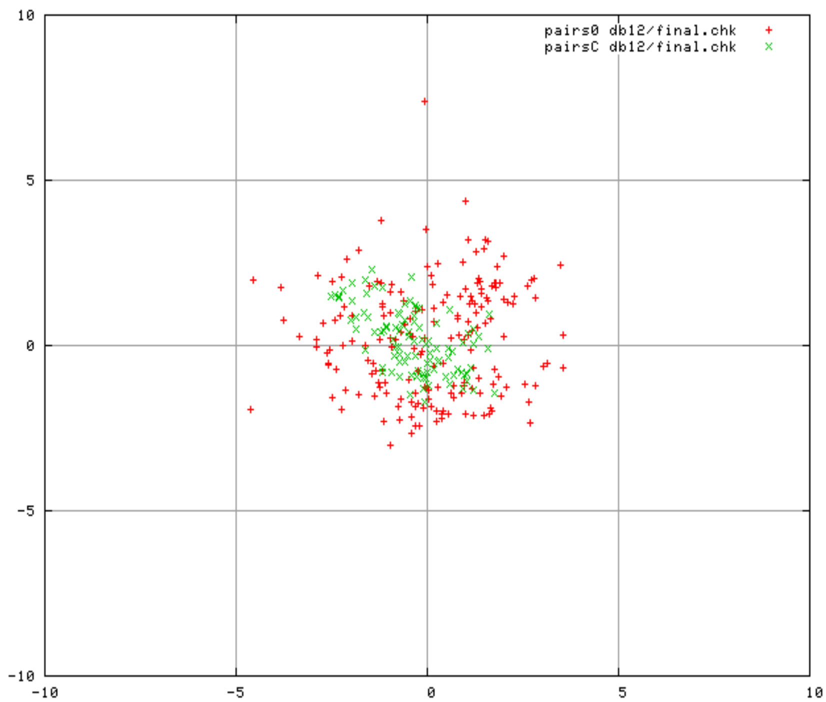

Figure 7. Distribution of measured North versus East (signed horizontal) errors in meters: individual pairs (red plus) and fusion of pairs (green x) methods.

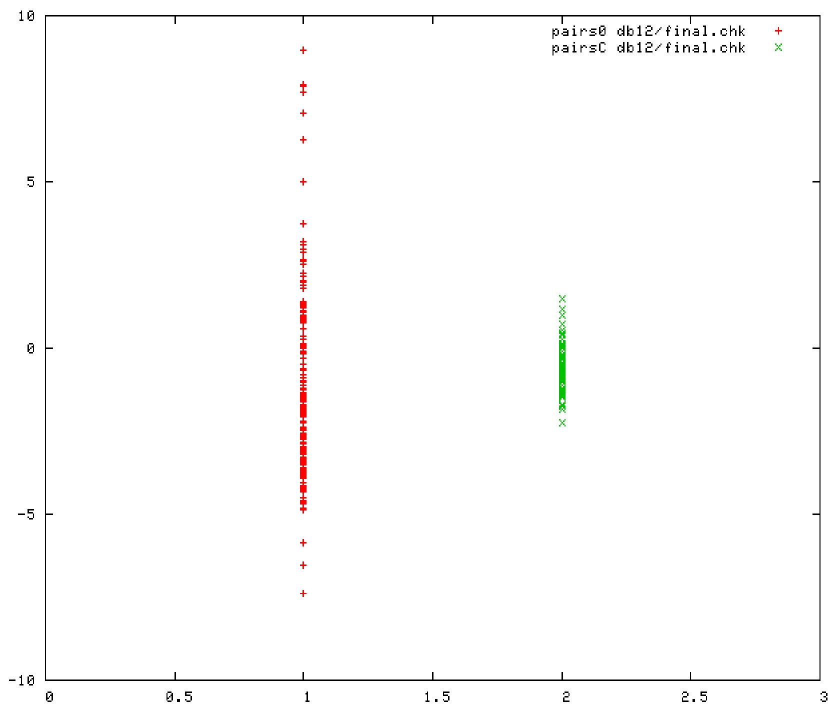

Figure 8. Distribution of measured Vertical (signed) errors in meters: individual pairs (red plus) and fusion of pairs (green x) methods (ignore x-axis).

ENHANCED FUSION ACCURACY

The accuracy corresponding to the fusion of WV1 stereo pairs can be enhanced further. The first approach is to obtain more cells of WV1 stereo pairs over the area of interest. For example, instead of the 10 overlapping cells analyzed previously, assume that a large horizontal grid of full (1 degree x 1 degree) cells contains the corresponding area of interest, such as 100 cells in a 10 cell x 10 cell grid. Most of these cells would then have 4 direct neighboring cells. The corresponding amount of "close" stereo pairs in the area under one of these cells is analogous to the "Edwards Middle" area from the 10 cell case analyzed previously. This area is directly underneath the EdwardsM and EdwardsM-EW cells, with EdwardsN directly north and EdwardsS directly south. Table 5 presents corresponding 10 cell fusion results restricted to points in Edwards Middle, which includes 25 of the 101 check points. Accuracy has improved relative to previous results tabulated over all points in the 10 cells (see Table 4). Of course, the amount of data (check points) was necessarily reduced for this new analysis, decreasing somewhat the statistical significance of the results.

Table 5. Fusion-based WV1 Extraction Accuracy with More Stereo Pairs

Fusion Edwards Middle	Measured Error (meters)			Predicted Accuracy	
	50%	90%	95%	Average CE or LE	% within CE or LE
Horizontal	0.9	1.5	1.6	1.3	80
Vertical	0.7	1.3	1.5	1.5	95

The other approach to enhance accuracy is to include external (GPS surveyed) ground control if available. For example, fusion of the 10 cells was repeated using MIN processing but with 9 of the original 101 check points used as external ground control points instead of check points. They were located throughout 6 of the 10 cells, with 3 points in the Edwards Middle area. Table 6 presents the results, again restricted to the Edwards Middle area, which now contains 22 check points. With the inclusion of a sparse set of external control, accuracy has improved even more. In general, external control may be difficult to get - too costly or much of the corresponding area inaccessible; hence, the applicability of a sparse set. The fusion process "leverages" the information in the sparse set to all extracted points.

Table 6. Fusion-based WV1 Extraction Accuracy with Sparse External Control

Fusion Sparse Control Edwards Middle	Measured Error (meters)			Predicted Accuracy	
	50%	90%	95%	Average CE or LE	% within CE or LE
Horizontal	0.5	1.0	1.2	0.8	82
Vertical	0.3	0.7	0.8	1.2	91

SUMMARY

Analysis of 50 WorldView-1 stereo pairs of imagery and 101 check points indicates that, for single stereo pair ground point extraction "out of the box", 50% of measured ground point horizontal and vertical extraction errors are less than 2.1 and 2.6 meters, respectively, and 90% are less than 3.4 and 4.5 meters, respectively.

Fusion of independent information across contiguous stereo pairs improves this extraction accuracy significantly. In the case analyzed, 50% of measured ground point horizontal and vertical extraction errors are less than 1.2 and 0.7 meters, respectively, and 90% are less than 2.2 and 1.5 meters, respectively.

The fusion process was implemented with MIN processing, demonstrated as a flexible, timely, and efficient process. MIN processing also automatically produced a MIN database containing 1347 ground control points generated from the fused information from the 50 stereo pairs alone. These points include the 101 check points, whose measured accuracies are indicative of the accuracies for all 1347 points. The 1347 ground control points, including their full and rigorous error covariance and image patches, can be used to control future images and image products that intersect the underlying 50,000 square kilometer area.

As a reminder, ground truth (GPS surveyed) points were never used as ground control points in any of the extraction and other processes summarized above. They were simply used for comparison to check point extraction results.

The ability to further enhance stereo pair fusion was also explored based on increasing the number of stereo pairs in the area of interest, and also adding sparse external (GPS surveyed) ground control points during MIN processing – a total of 9 external points were added through out the 50,000 square kilometer area. This combination of increased information was analyzed over the 8000 square kilometer Edwards Middle (sub)area which contained 22 of the 101 check points and 3 of the 9 external control points. 50% of measured ground point horizontal and vertical extraction errors are less than 0.5 and 0.3 meters, respectively, and 90% are less than 1.0 and 0.7 meters, respectively. Table 7 summarizes measured WV1 extraction accuracy as a function of processing method.

Table 7. Measured WV1 Extraction Accuracy versus Processing Method

Method	50% Errors (meters)		90% Errors (meters)	
	Hor	Vert	Hor	Vert
single stereo pairs	2.1	2.6	3.4	4.5
MIN fusion of stereo pairs	1.2	0.7	2.2	1.5
MIN enhanced fusion	0.5	0.3	1.0	0.7

Finally, we refer the reader to a companion paper recently accepted for publication (Dolloff and Settergren, 2010). It discusses the same general WV1 data and analysis presented in the current paper using slightly different notation/terminology. However, it does not: (1) discuss MIN flexibility, (2) present cell-level stage 1 adjustment results, or (3) present details regarding MIN processing as does the current paper. On the other hand, it does present new information not available in the current paper: (1) the detailed methodology used for WV1 accuracy assessment, and (2) more detailed accuracy assessment results, including measured shear between overlapping stereo pairs, a form of relative accuracy. Shear distributions are presented for both individual stereo pair processing and fusion of stereo pair (MIN) processing. The latter decreases shear and improves relative accuracy substantially.

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APPENDIX A: MIN PROCESSING DETAILS

This appendix presents a more detailed overview of MIN processing, some of which is unique to this paper. Figure A-1 presents an overview of MIN sequential processing, in particular a stage 1 adjustment and a stage 2 update corresponding to an image block (m). The stage 1 image block adjustment utilizes any underlying ground points currently in the MIN database (aka MIN Repository) as control points. These points are weighted (constrained) by their corresponding full multi-point error covariance also in the MIN database. The subsequent changes to the locations of these points due to the adjustment reflects the independent information from the new image block, and the stage 2 update then updates all other ground control points already in the MIN database based on these changes. In addition, the stage 2 update inputs into the MIN data base any adjusted tie points from the stage 1 adjustment as new ground control points. The corresponding full error covariance for all ground control points is also updated in the MIN database. (A vector of coordinates for multiple ground control points is designated by X and the corresponding full error covariance as P in the figure).

After both the stage 1 adjustment and stage 2 update are performed, block m's image support data and all ground points from blocks 1-m are equivalent to their corresponding solution in a (hypothetical) single simultaneous image block adjustment for all m blocks, which solves for image support data from blocks 1-m and all ground points from blocks 1-m. Note that the term "equivalence" includes mathematical equivalence. Also, with MIN processing, image block (*m*) can be of arbitrary size, ranging from one image to hundreds of images, and can be processed sequentially in any order, e.g., *m*-2 instead of *m*.

As indicated by Figure A-1, the MIN data base actually supports two independent processes: (1) the control of arbitrary imagery (products) not involved in MIN generation, and (2) the MIN generation process itself. In addition to ground control point coordinates and error covariance, the MIN database also contains image patches to facilitate measuring the points in other images or image products. See (Dolloff and Iiyama, 2007) and (Dolloff, et. al., 2008) for further details regarding MIN processing, including applicable equations.

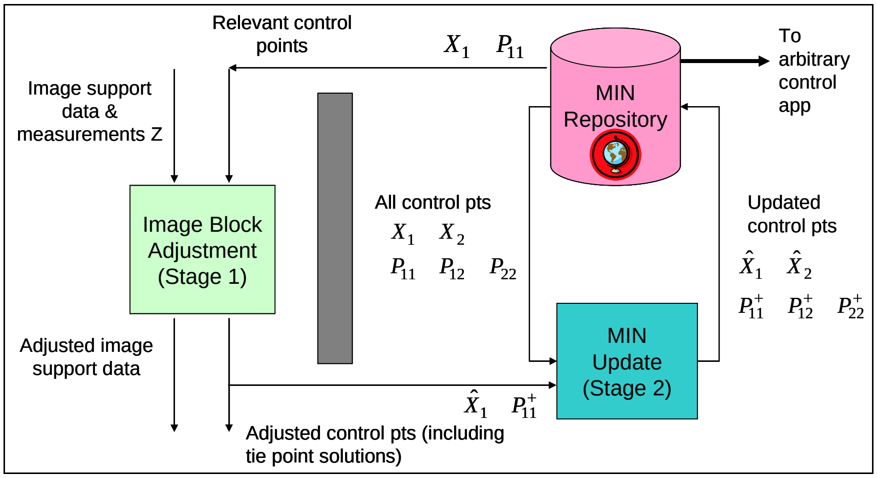

Figure A-1. MIN Generation and Support Applications**.**

We now describe optional MIN++ processing which extends MIN processing and is useful for certain applications. Assume that *n* image blocks have been processed to-date via MIN processing corresponding to a particular MIN data base. If MIN++ processing is then implemented, all image support data for all *n* blocks become virtually identical to that from a single simultaneous block adjustment of all *n* blocks, just as all ground points for all *n* blocks are with standard MIN processing.

MIN++ processing is fast as it only involves redoing the stage 1 adjustments (no stage 2 updates) for the previous *n*-1 blocks (or a selected subset) using all previously measured and underlying points in the current MIN data base as ground control. (Note: the *a priori* image support data going into a stage 1 (re)adjustment is correlated with the underlying MIN points since the corresponding image block contributed to the generation of the MIN points earlier; however, the larger *n* the less the correlation. One approach to account for this correlation is to simply de-weight the *a priori* image support data going into the (re)adjustment, e.g., multiply its *a priori* error covariance by a factor of 10^2. A theoretically rigorous approach is also available that is nearly as fast.)

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