AUTOMATION IN QUALITY ANALYSIS OF TRIANGULATION RESULTS FROM ADS IMAGES

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ABSTRACT:

This paper describes the algorithm used to further automate the workflow to triangulate images from the multi-line Aerial Digital Sensor ADS from Leica Geosystems. Up to now many parts of the triangulation process have been successfully automated like point measurement, bundle adjustment with automatic blunder removal, automatic variance components estimation and automatic selection of self-calibration parameters. What still requires human interaction is the quality analysis. The key to full automation in triangulation is the quality control. The new process is characterized by a loop, which consists of automatic point measurement, bundle adjustment and automatic quality control. The goal of the process is to obtain the orientation for the block automatically with minimum user interaction. The required quality of the project in terms of accuracy on the ground is specified by the user at project start. The process starts from a sparse tie point pattern, which is successively densified until the requested quality is achieved. Typical for triangulation of line sensors is the use of orientation fixes. In this new approach the time or distance between two orientation fixes is no longer constant. Instead orientation fixes are placed at variable intervals. Those intervals are automatically determined. For quality control each strip is divided into sections, which are defined by the region between two orientation fixes. Each section is further divided into cells. The analysis based on statistical criteria is applied to each cell. To trust in automatically generated results the reliability is important. Therefore the quality criteria are based on external reliability values. As the quality is based on regions on the ground it can be presented in a simple colour coded form. Green means that the requested quality was achieved and red means that this region requires further attention. This way the user is directly guided to those areas where the algorithm could not fulfill the requested criteria. The advantage of the new algorithm is that it works much faster compared to the approach with constant spacing of orientation fixes and very dense point pattern. The old approach was always aiming at best quality, which may not be needed in every project. The new approach will create orientation values with a quality, which is sufficient for the project.

1. INTRODUCTION

Triangulation basically consists of three major tasks namely measuring, bundle adjustment and analysis of results. Inputs into the bundle adjustment are image point measurements plus coordinates and angles measured by GPS and IMU. Those measurements are obtained with little human interaction. GPS and IMU data is recorded during the flight and preprocessed before it goes into the triangulation. Tie points are measured automatically by point matching technique. Control point measurement still requires some human interaction. The primary task of the bundle adjustment is to obtain the exterior orientation of the images. Blunders in image points are automatically filtered out by robust estimation technique. Weights between different types of observations are automatically adjusted using variance components estimation technique. Self-calibration of the sensor is done by automatic selection of sensor parameters through weight adjustment based on reliability criteria, Tempelmann, Hinsken 2007. The analysis of the adjustment results requires interpretation of statistical criteria and geometrical understanding, Hinsken, Miller, Myint, and Walker 1999.

Triangulation of multi-line sensors like the ADS is different compared to that of Frame sensors, Müller 1991. For Frame sensors the exterior orientation of each image must be calculated. For line sensors the exterior orientation is calculated at certain intervals along the flight line. The location at which the exterior orientation is calculated is called orientation fix. In the first generation of ADS ground processing software the workflow was divided into three sequential steps: automatic point matching, bundle adjustment using equally spaced orientation fixes and analysis of the results, Hinsken et. al. 2002, Tempelmann et. al. 2000.

2. AUTOMATED WORKFLOW

In the second generation of the ADS ground processing software the workflow is no longer sequential, the orientation fixes are no longer spaced evenly along the flight line and the analysis is automated.

The key difference between triangulation of Frame sensors and multi-line sensors is the location where exterior orientation parameters are calculated. For Frame sensors the exterior orientation must be calculated at the location where the image was taken. Due to the fact that the multi-line sensor works as a scanner and the exterior orientation of each scan line is measured by IMU supported by GPS, there is more freedom where the exterior orientation is calculated by image points. The used mathematical model to determine the orientation fix parameters is so flexible that the number of orientation fixes can be as little as two per flight line, one at each end, or as many as one per small base length.

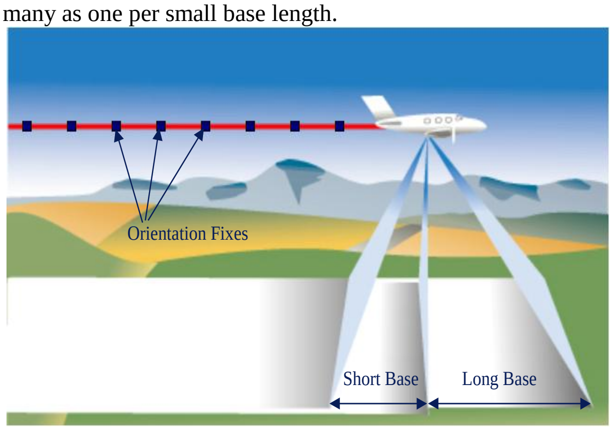

Figure 1. Evenly spaced orientation fixes as used formerly.

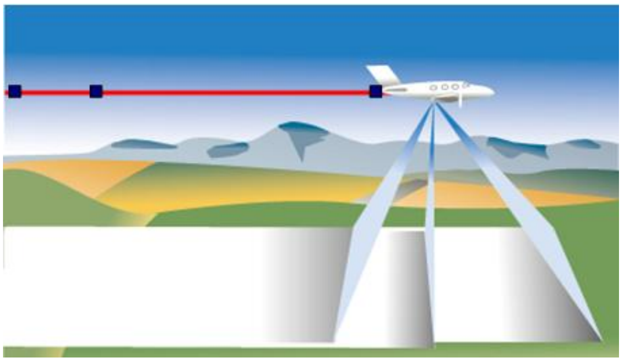

Figure 2. Variable spacing of orientation fixes as used nowadays.

Any combination between these two extremes is supported by the mathematical model. The only requirement is that there are enough tie points between two orientation fixes to determine the orientation parameters. Actually the working principle has been reversed. Now the orientation fixes are placed based on the number of points between two orientation fixes.

With generation one ADS ground processing software it was the goal to always obtain the best possible orientation. With generation two the goal is to obtain the orientation just as good as needed for that project. Therefore at project start the user defines which accuracy on the ground is required for that specific project. The triangulation process then starts and measures a certain number of points per flight line. This number of points is sufficient to determine a small number of orientation fix parameters per line; the minimum number is two orientation fixes. Based on these initial measurements the bundle adjustment is executed with a predefined set of parameters. The results of the adjustment, parameters plus their statistical quality criteria are analyzed whether they fulfill the quality criteria specified for that project. If the quality criteria are met the triangulation process is finished. If the criteria are not met the automatic point measurement is restarted. As the quality analysis is based on location the automatic point measurement is guided to measure more points in those areas which require more points.

Triangulation loop

Define required quality

- Automatic point measuring
- Compute spacing for orientation fixes
- Run bundle adjustment
- Check quality criteria

The iterative process is open to include more rules into the process. If the requested quality cannot be achieved by adding points then a variation of parameters can be included into the process.

3. QUALITY ANALYSIS

For quality analysis each flight line is divided into sections. A section is the region on the ground between two orientation fixes. Each section is further divided into 9 cells C_{11} – C_{33}. Each cell of a section has the same size.

C_{11}	C_{12}	C_{13}	C_{11}	C_{12}	C_{13}	C_{11}	C_{12}	C_{13}
C_{21}	C_{22}	C_{23}	C_{21}	C_{22}	C_{23}	C_{21}	C_{22}	C_{23}
C_{31}	C_{32}	C_{33}	C_{31}	C_{32}	C_{33}	C_{31}	C_{32}	C_{33}

The figure above illustrates a strip with four orientation fixes causing three sections with 9 cells in each section.

The analysis is performed on each cell. Therefore it is also called cell based analysis. The goal is to fulfill the quality criteria of the project in each cell. The quality indicator for a cell depends on the points inside the cell.

The following list of criteria is used for each cell in the automated quality analysis:

1. Number of points tying two strips
2. Number of strips that overlap
3. Array of counters, each element counts points by number of rays, e.g. 6 points with 4 rays and 3 points with 6 rays.
4. Number of images which overlap (this defines the maximum possible for 3.)
5. Number of blunders
6. RMS of image residuals without blunders (this corresponds to remaining parallax)
7. Reliability values

When points are measured automatically their reliability is very important. Reliability is a criterion to describe how well measuring errors can be found at an observation. Multi-ray points allow for good error detection whereas two-ray points allow for almost no error detection. Internal reliability is a statistical measure to express how good the blunder detection test can find errors at this observation (image point). Of more interest is the impact of potentially undetected errors on the parameters (ground points and orientation parameters). This can be expressed by the external reliability, which projects the internal reliability from the observation space onto the parameter space. The quality analysis in each cell is based on the quality criteria listed above and especially on the modified external reliability of points in the cell, which is also used in ORIMA, Hinsken, Miller, Myint, Walker 1999.

$$\Delta y_i = \sigma_0 \frac{\tau}{\sqrt{p_i r_i}} \qquad (1)$$

Δy_i = internal reliability of observation i
r_i = local redundancy of observation i
p_i = weight of observation i.
τ = value derived from τ-distribution function required for the blunder test

$$\Delta\lambda_i = \Delta\mathbf{x}_i^T \mathbf{A}^T \mathbf{P} \mathbf{A} \Delta\mathbf{x}_i / \sigma_0^2 \qquad (2)$$

where

$(\mathbf{A}^T\mathbf{P}\mathbf{A})^{-1}$ = inverse of normal equation matrix
$\mathbf{A}$ = design matrix (n,u),
$\mathbf{P}$ = weight matrix (n,n)
$\Delta\lambda_i$ = external reliability of observation i

$$\Delta\mathbf{x_i} = (\mathbf{A}^\mathrm{T}\mathbf{P}\mathbf{A})^{-1}\mathbf{A}^\mathrm{T}\mathbf{P}\Delta\mathbf{y_i} \qquad (3)$$

where

$$\Delta\mathbf{y_i} = [0,0,0...,\Delta y_i,...0,0,0]$$

The vector $\Delta\mathbf{x}_i$ reflects the impact of the internal reliability of one observation onto all parameters. To obtain the impact of the internal reliability of all observations n vectors $\Delta\mathbf{x}_i$ are computed.

$$\Delta X = [\Delta\mathbf{x}_1, ..., \Delta\mathbf{x}_i, ..., \Delta\mathbf{x}_n] \qquad (4)$$

Each row of the (u,n) Matrix $\Delta\mathbf{X}$ contains the impact of the internal reliability of each observation onto this parameter. For analysis purpose only the worst case is of interest, which means the maximum value of each row.

$$\Delta x_1 = \max \in [\Delta X_{1,1} ... \Delta X_{1,n}]$$

$$...$$

$$\Delta x_j = \max \in [\Delta X_{j,1} ... \Delta X_{j,n}]$$

$$...$$

$$\Delta x_u = \max \in [\Delta X_{u,1} ... \Delta X_{u,n}]$$

$$\Delta\mathbf{x} = \begin{bmatrix} \Delta x_1 \\ ... \\ ... \\ \Delta x_j \\ ... \\ ... \\ \Delta x_u \end{bmatrix} \qquad (5)$$

The advantage of using this modified external reliability $\Delta\mathbf{x}$ as criterion is its strength. From the equations above it can be seen that it is influenced by many aspects. It is not only based on number of rays but also on their intersection angles, the lengths of the rays, the weight of each observation, the accuracy of the point and the impact of other observations and parameters like IMU observations and self-calibration parameters. In the end the criterion is a number with a geometrical meaning a cuboid around each point.

This criterion is computed for each point in a cell. Only the one which provides the best quality will be used to define the overall quality of this cell. Points with less quality in the cell do not impact the overall quality in this area and therefore can be ignored. In other words one high quality point in a cell is more important than many low quality points. Or even more simplified one 6-ray point cannot be compensated by three 2-ray points.

Quality is a function of accuracy and reliability. Accuracy can be expressed by standard deviation or error ellipsoids.

For visualization purpose a quality layer is introduced. This is useful because the cells of the strips do overlap. The quality layer is aligned with the ground coordinate system and not with the flight direction of a certain strip. The quality criterion for each cell in the quality layer is derived from those strip cells which are underneath the quality layer cell. The size of the quality layer cells within a project is fixed. The constant size of these cells does not match the size of the strip cells which varies in size.

3.1 Workflow

Based on the results of the analysis in the cells the automatic point measuring is guided to measure more points in predefined regions only. Depending on the results of the point measuring and other rules the spacing of the orientation fixes is adapted. This iterative process is repeated until the quality criteria for all cells are fulfilled. If the criteria cannot be met for all cells the process stops and a graphic map of the block indicates those cells for which the automation could not reach the required quality.

3.2 Examples

Throughout the examples the quality criterion being used is the accuracy at the most reliable point in each cell. More or other criteria from the list above could also be used in the analysis process.

3.2.1 Example 1: small block:

The block consists of four flight lines in East-West direction. The ground sample distance (GSD) is ca. 20 cm. Triangulation is performed in Swiss coordinate system. Flying time per line was ca. 6 minutes. Accuracy requirements 20 cm equals 1 x GSD.

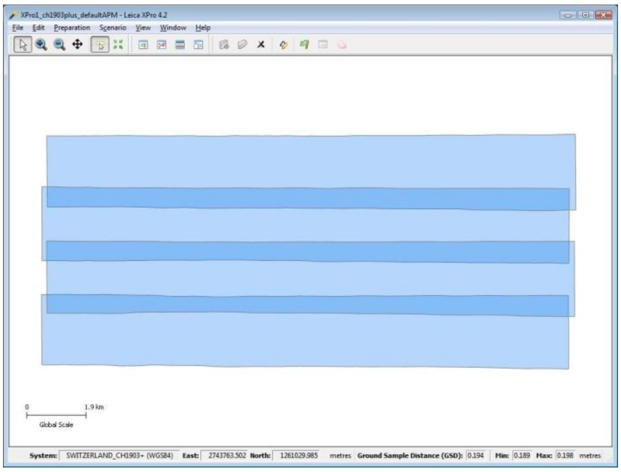

Figure 3. Block layout with footprints of four strips.

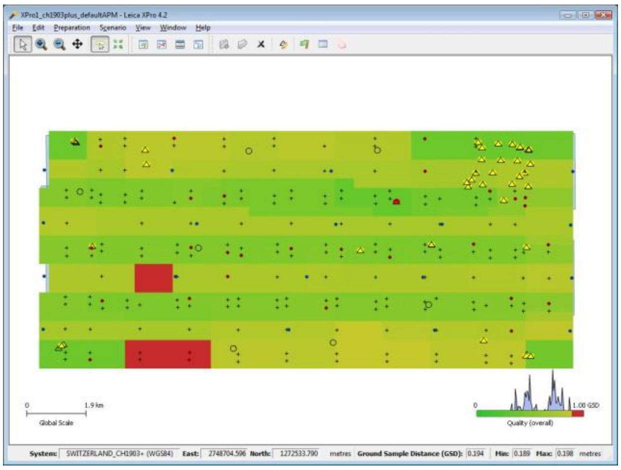

Figure 4. Quality layer of initial situation with at least 20 points between two orientation fixes.

Blue dots represent orientation fixes. Crosses represent automatically measured tie points. Triangles are manually measured control points. Circles are check points. Yellow color indicates unmeasured point and red is a blunder, which was automatically detected and eliminated. The requested quality of better than 1 GSD was not fulfilled in two regions, which are marked in red.
Next step: automatic point densification in those regions which don’t fulfill the requirements.

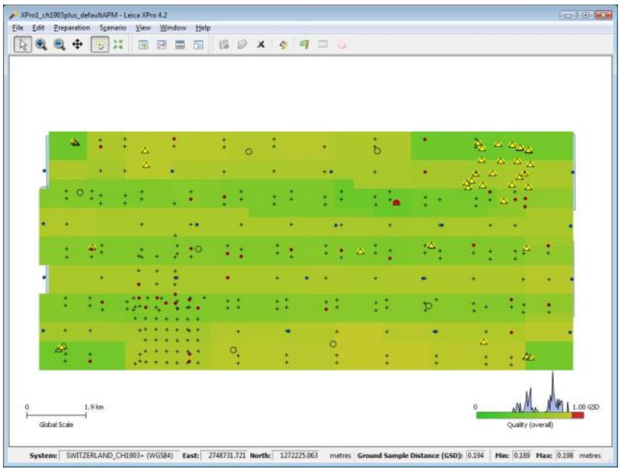

Figure 5. Quality layer after adding points in regions with poor quality.

The example demonstrates that by adding points just in those regions which were detected as poor quality in the initial calculation, the requirements can be satisfied. All regions in the block do have a quality better than 1 GSD. This quality analysis shows that within the whole block the remaining parallax is less than one pixel.
Final quality verification should always include a visual check. This visual check assures that all effects were modelled properly.

3.2.2 Example 2: large block

The block consists of 14 flight lines flown in North-South direction. The GSD is ca. 15 cm. Triangulation is done in UTM coordinates. Flying time per line was ca. 16 minutes. Length of each line ca. 85 km. Accuracy requirements 30 cm equals 2 x GSD.

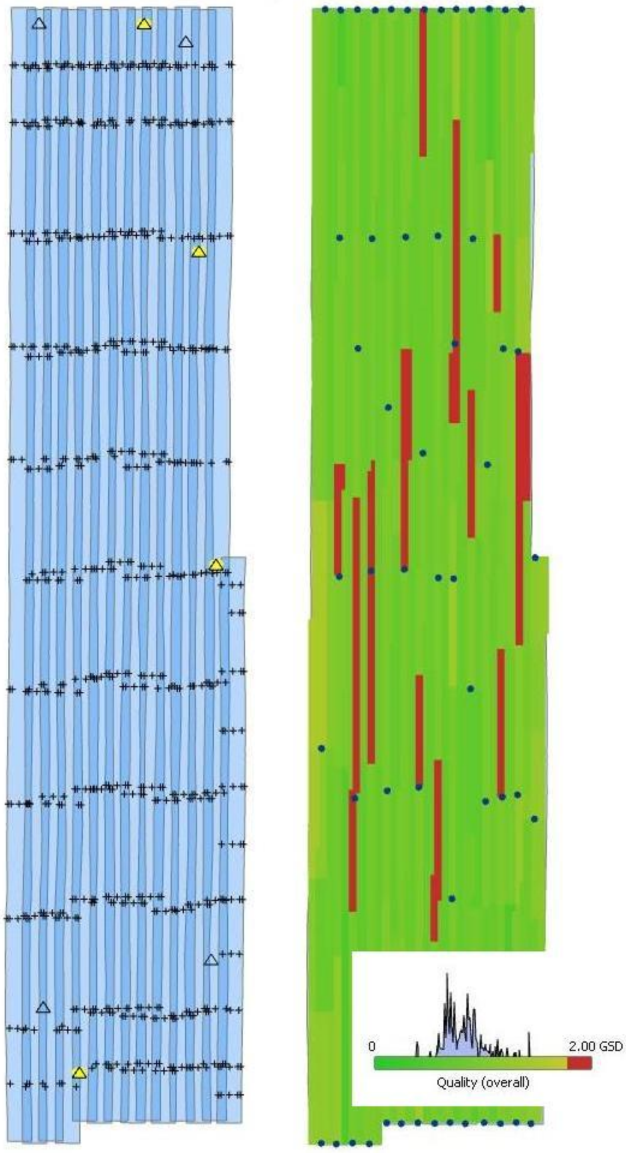

Figure 6. Left: Block layout with footprints of 14 strips with point distribution after initial automatic point measurement. Right: Quality layer with orientation fixes after initial bundle adjustment.

After the initial run of the bundle adjustment a few sections don’t fulfill the requirements, which are marked in red. In the first iteration the automatic point measurement will add points into those sections only.

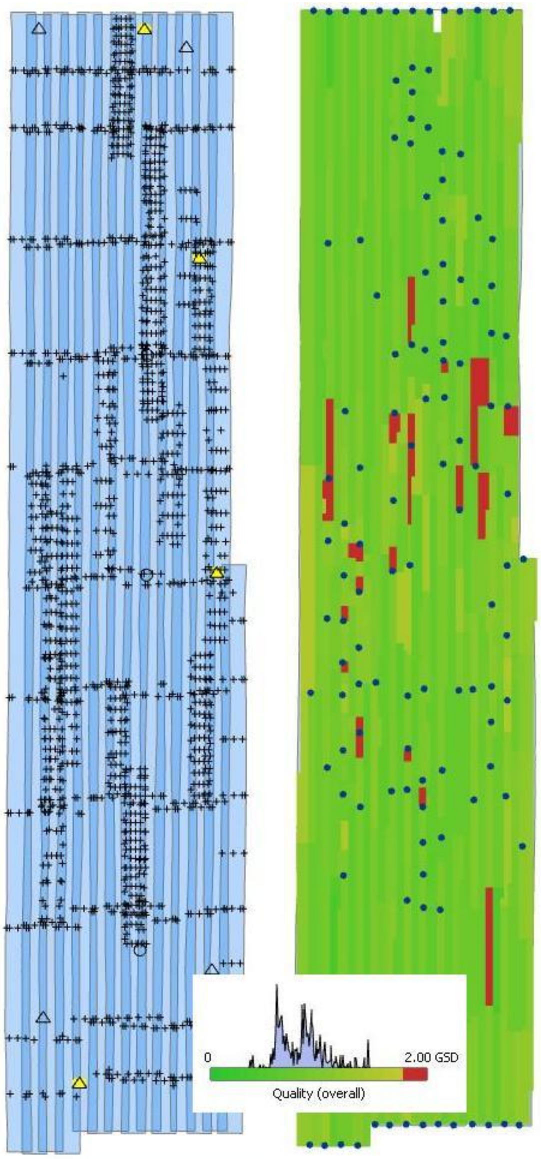

Figure 7. Left: Sections with point densification.
Right: Quality layer with new distribution of orientation fixes and less sections in red.

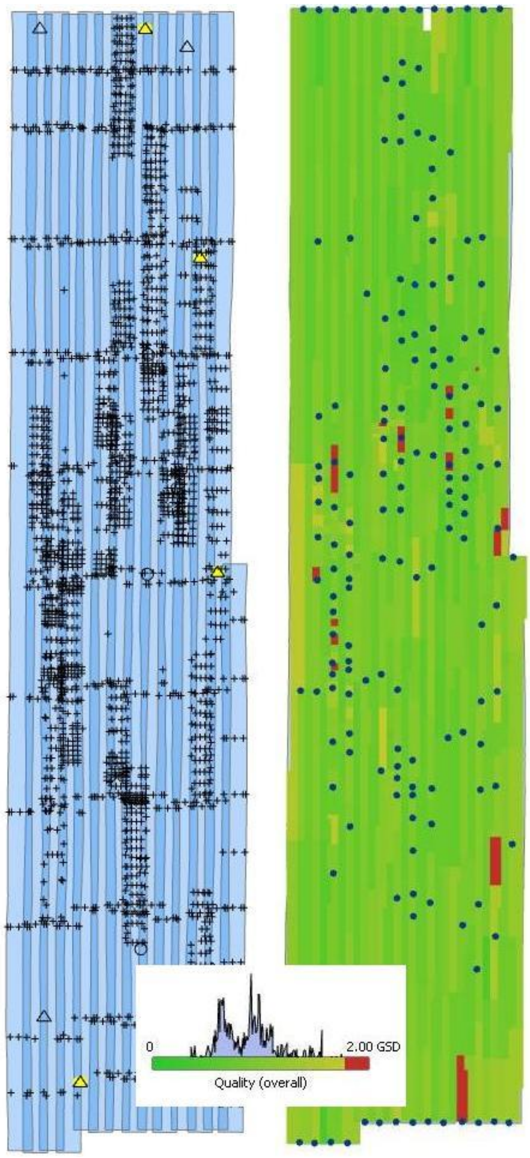

Figure 8. Quality layer left with newly added points and right with orientation fixes distribution.

The first iteration shows the new point distribution. Only in those sections which required more points a densification took place. Based on the new point distribution a new variable spacing of the orientation fixes was computed. The quality layer which is now based on the new distribution of orientation fixes and therefore has new sections shows improved quality. Now fewer regions exceed the required quality and are therefore marked in red. Due to the new layout of the sections some regions become red which were already better in the initial run.

The second iteration for point densification leads already to very good results. Only very few cells don't fulfill the required quality specification. In a production environment one will typically not try to reach a hundred percent fully automatically. In such a situation it is more economical to manually inspect the remaining sections to look for the cause of the quality.

The concept of cell based analysis is easily extensible to support a priori knowledge of the user. Areas where point densification will not be possible, like water bodies, clouds or other surfaces not suitable for matching, can be placed in another layer which is then utilized during the automatic cell based analysis.

4. SUMMARY

This paper describes the triangulation workflow used in the second generation triangulation software for ADS images. It is characterized by a loop over point measurements, bundle adjustment and automated analysis. The workflow utilizes the advantage of multi-line images using orientation fixes, which are now variably spaced. Both point density and orientation fix spacing are iteratively improved until the project specific quality criteria are fulfilled. The automated analysis is based on regions on the ground. Each region or cell is assigned a quality criterion, which is derived from a modified external reliability computation of points. The advantage over the first generation ADS triangulation workflow is that it is much faster and requires much less user interaction and knowledge.

5. REFERENCES

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