Integrated Sensor Orientation Simulator: Design and Implementation

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Abstract
The results of Integrated Sensor Orientation (ISO) depend heavily on its input parameters. In real applications, it is difficult to determine how much ISO could improve the accuracy of directly measured Exterior Orientation (EO) parameters and under which conditions of tie-points. This paper discusses an implementation of an ISO simulator that offers the operators the ability to explore the optimum configurations that lead to their accuracy requirements for EOs. The results obtained from the simulator correspond to those from existing research, suggesting that the proposed simulator can be a useful tool to assist the photogrammetrist in flight planning and on-site verification of data acquisition.

Keywords: Simulator, integrated sensor orientation, aerial triangulation, direct georeferencing, image matching.

Introduction
A fundamental photogrammetric problem is the accurate determination of the Exterior Orientation (EO) of the camera at the time of exposure [McGlone, 2004]. Aerial Triangulation (AT) has long been a solution to this problem, but it requires knowledge of ground control points and corresponding tie-points on a block of images [Schenk, 1999]. Although recent advancements in computer-based image matching have expedited the selection of tie-points [see Heipke et al., 2004; Liu et al., 2008; Barazzetti et al., 2010; Tanathong and Lee, 2010; Zhang et al., 2011; Barazzetti et al., 2014], ground control points must still be established through ground surveying, which is both an expensive endeavor and impracticable for inaccessible areas or dangerous locations.

With the advancement of Micro-ElectroMechanical Systems (MEMS) and improvements in sensor technology, direct georeferencing have played an increasingly important role in many photogrammetric applications, especially georeferencing and mapping [see...
Schwarz et al., 1993; Cramer et al., 1997; He and Orvets, 2000; Yastikli and Jacobsen, 2002; Kim and Sukkarieh, 2004; Zilli et al., 2005; Lee et al., 2006; Eisenbeiss and Sauerbier, 2011; Pirotti et al., 2013. The GPS/INS (Global Positioning System/Inertial Navigation System) enables real-time acquisition of imaging orientation parameters without post computational operations allowing to achieve considerable savings of both cost and time [Grejner-Brzezinska, 1999; Cramer et al., 2000; Khoshelham, 2009; Eisenbeiss and Sauerbier, 2011].

However, some researchers have shown the accuracy of direct georeferencing to be inferior to the results of conventional aerial triangulation [Yastikli and Jacobsen, 2005; Khoshelham, 2009]. Although highly accurate GPS data are increasingly available for an affordable cost, but in the near term, Inertial Measurement Unit (IMU) are unlikely to achieve reliable accuracy, at scale, for an accessible price [El-Sheimy, 2000]. Even though a very highly accurate direct georeferencing system can be achieved by employing a high quality but expensive IMU, a proper system calibration is still troublesome [Heipke et al., 2002]. This concern must be seriously addressed regardless of the quality of the sensing devices since an infinitesimal error of the calibration of GPS/INS and the camera can produce large inaccuracy [Sanchez and Hothem, 2002]. Another serious problem with direct georeferencing is that it results in large y-parallax in stereo models [Casella and Franzini, 2003]. A y-parallax above 20 µm complicates stereo compilation [Jacobsen, 2004; Khoshelham, 2009], especially in large-scale photography.

The y-parallax may be reduced by increasing the accuracy of imaging orientation measurements. However, the improvement of DGPS (Differential-GPS) accuracy is still work in progress [Ip et al., 2007]. Presently, the y-parallax problem may be addressed by implementing Integrated Sensor Orientation (ISO) [Casella and Franzini, 2003]. ISO is another alternative approach to georeferencing that combines the advantages of direct georeferencing and aerial triangulation [Ip et al., 2007]. This technique employs a number of tie-points over a block of images together with directly observed EOs as constraints for a bundle block adjustment process. The introduction of tie-points in ISO makes it possible to obtain accurate EOs from consumer-grade sensing devices. Since it does not require ground control points [Yastikli and Jacobsen, 2005], they can be eliminated or used for quality control. The ISO technique has been shown to reduce y-parallaxes to an acceptable scale [Heipke et al., 2002; Jacobsen, 2004; Khoshelham, 2009]. Yastikli and Jacobsen [2005] showed that some models derived through direct georeferencing have the y-parallax error greater than 30 microns, while the ISO technique can reduce the error of involved stereo models to be less than 20 microns. Therefore, ISO results in greater accuracy in large scale mapping.

Problem statement and proposal of the study
Since the inclusion of tie-points is a major contributing factor to the accuracy of ISO, the operators usually perform interactive post operations after automated tie-point selection to ensure the quality of tie-points. As, in this case, tie-points are nearly flawless, the operators may wonder how many tie-points are sufficient to refine the accuracy of the directly measured EOs, and how much the accuracy can be improved. Are the positions of tie-points significant and do the distribution of tie-points influence
the adjustment result? Honkavaara and Hogholen [1996] and Khoshelham [2009] have presented their investigation on these tie-point factors in their work. The problem is more complicated when tie-points are subjected to contaminate with some outliers such as those tie-points produced for real-time applications, for example airborne multi-sensor rapid mapping systems or disaster monitoring systems. For said applications, tie-points must be produced in real-time and interactive quality check of tie-points is hardly possible. In this case, the accuracy of tie-points is still questionable. The question arises as to whether less accurate tie-points can still benefit the refinement of EOs. Can a large number of tie-points compensate for their less accuracy?

In an attempt to address the aforementioned problems, this paper presents an implementation of an integrated sensor orientation simulator. The simulator imitates real ISO systems with adjustable input parameters such that it can be used to approximate the results of the systems prior to real applications. To be applicable for real-time automated image matching, in addition to the number and distribution of tie-points, we also consider the accuracy of tie-points in the computation. The simulator tool can benefit automatic image matching developers in designing and implementing their software to obtain suitable tie-points for AT. Photogrammetrists may use the simulator to assist in planning their flight missions to achieve their accuracy requirements. The tool may possibly be used to evaluate the accuracy of data acquisition immediately after flight, which allows flight missions to be re-performed within the same day if necessary.

**A framework for an ISO simulator**

The simulator consists of two main processes: I) ISO parameter generator process; II) aerial triangulation process. The first process generates parameters used to perform a bundle adjustment; mainly of exterior and interior orientation parameters, tie-points and corresponding ground points for accuracy evaluation. The second process is the actual implementation of the aerial triangulation with a bundle block model. The simulator also offers an accuracy evaluation process to help operators in analyzing the results. Figure 1 illustrates the high-level overview of the simulator. In Figure 2, the tasks performed by the simulator are presented.

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**Figure 1 - High-level overview of the ISO simulator.**
Input of the simulator
The simulator uses the input passed-in by operators for its computation. The user-defined parameters can be categorized into four groups as follows.

Trajectory and terrain
This set of parameters involves the planned or real trajectory and average terrain information based on surface roughness or a Digital Elevation Model (DEM). The trajectory involves the velocity and altitude of the platform. The simulator assumes that the aircraft moves with a constant velocity. Therefore, the number of images per strip is unchanging throughout the trajectory. It also requires the dimension of the ground coverage or project area such that the system can calculate the number of photographs per strip and the total number of strips from the given sidelap ratio.

Camera parameters
This involves the interior orientation parameters, pixel size and detector dimension. Also, the camera frame rate is required, in conjunction with the aircraft velocity, to compute the distance between each photograph.

Tie-point conditions
In this work, the simulator is designed to simulate tie-points based on an automated image matching scheme. It requires a tie-point distribution pattern in which each image area is divided into separate, non-overlapping blocks (Von Gruber regions). The maximum number of tie-points per block must also be specified.

Accuracy control
The system requires the knowledge of uncertainties from all involved components in order to
imitate the characteristics of real systems. This includes the accuracies of GPS and IMU sensors, which are required to determine the reliability of the position and orientation parameters. Since matching accuracy depends on the image matching and on used outlier removal techniques, we require the percentage of correctly matched points and the expected discrepancy between the positions of true image points and outliers to generate a set of tie-points at the same accuracy as real systems. It is well-known that the accuracy and the stability of multi-sensor system calibration are crucial factors limiting the quality of the process. However, a simulator, by its nature, never matches perfectly the reality. Note that the manuscript neglects everything about the stability of the multi-sensor system and only focuses on the analysis of optimal number and distribution of tie-points and their reliability towards the results of AT.

**ISO parameter generator process**

This process uses those user-defined input parameters to compute the set of variables required for the internal computation of the simulator and generate a set of output parameters for the next process. The results can be categorized into four sets: I) auxiliary parameters which are non-influential output but used for internal computation; II) EO parameters for all images; III) a set of tie-points; IV) ground points that correspond to the generated tie-points. The section below discusses how these outputs are calculated. Since tie-points and ground-points are generated simultaneously, the methods to compute them will be discussed together.

**Determining auxiliary parameters**

This stage involves a geometric computation of fundamental properties in planning aerial photographic missions. The variables to be determined are nominal scale, nominal altitude, image ground resolution, area of image coverage on the ground and the along track overlap ratio. These parameters are computed through basic formulas; consult Falkner and Morgan [2002] for mathematic expressions. Using the user-defined project area, the image dimension, sidelap ratio and the resulting along track overlap ratio, the numbers of strips and photographs per strip can be computed. Finally, the total number of images in this project can be derived. The auxiliary parameters computed in this step are illustrated as Figure 3.

![Figure 3 - Fundamental parameters in planning aerial photogrammetric missions.](image-url)
Generating EOs
The EO parameters for each image defined in the project are generated in this stage. The set of EO parameters is referred to as ‘true EO’ and will be used for generating tie-points, their corresponding ground points and for further evaluation. This process also establishes the set of EOs which have been contaminated with noises attributable to the uncertainty of the GPS/IMU sensors. This latter set of EOs simulates the directly measured data acquired through the integrated sensors and is referred to as the ‘noisy’ or ‘directly measured’ EOs. The first step of the EO generation process defines the EO parameters of the first photograph, which is located at the top-left corner of the project area (the origin is at the bottom-left corner), as shown in Figure 4. The EOs of the subsequent photographs are then generated by adding a displacement to the first image plus some noises that are computed as random numbers bounded by the standard deviation of the platform position. The trajectory path starts at the top-left corner of the project area and proceeds to the right-most side such that the Y coordinates of the principal points are nearly constant. Once reaching the right-most side of the project area, the trajectory path flows in the opposite direction (right to left) and the Y coordinates of the new set of photographs are deducted by a factor of sidelap. It is impossible to avoid all errors, not only from the devices themselves but environmental factors as well. In order to simulate the real acquisition of data by GPS/IMU sensors, random noises that are bounded within the standard deviation of positioning errors and orientation errors from GPS/IMU system are added to the generated true EOs. In this study, we assume the random noises follow a Gaussian distribution model.

Simulating tie-points and ground points
This stage generates a set of tie-points for each image and derives corresponding ground points through the collinearity equation using the previously simulated true EOs. It starts from the first photograph by dividing the entire image area according to the user-defined pattern, such as $3 \times 3$, and for each block randomly generates an operator-specified number of image points. The process then divides the second image’s area into the same number of blocks and projects the generated ground points into the image space of the second image through the collinearity equation using its generated true EOs. According to user input, the terrain where the ground points are located can either be flat for a rough estimation or
extracted from a DEM to imitate real applications. In case of flat terrain, the elevation of each ground point is added with a randomly generated value to impose roughness on the terrain. Additional image points are generated at random positions inside the blocks in which the number of image points is less than the maximum defined value. The process continues following the same procedure for all images in the list. Figure 5 provides an overview of the process of generating tie-points and ground points simultaneously.

In photogrammetric practice, trained operators typically determine conjugate points in the overlapping area of multiple images by considering both along track overlap and sidelap. In this case, tie-points tend to repeatedly appear in a number of images that most benefit aerial triangulation. Some automatic image matching systems also offer this function [such as Honkavaara and Hogholen, 1996; Barazzetti et al., 2010; Shragai et al., 2011]. In real-time automatic tie-point extraction, many applications, particularly those that are implemented on ordinary CPU (Central Processing Unit), determine corresponding points from a single stereo pair of images from the image sequence at a time. In this case, which is referred to as feature tracking, only along track overlap is considered [such as Roncella et al., 2005; Tanathong and Lee, 2010]. In this study, we refer to the process of generating tie-points that involves both along track overlap and sidelap as a full overlap mode, while the process which considers only along track overlap is defined as an along track overlap mode. For these two cases, the processes for generating image points from existing ground points differ, as illustrated in Figure 6. In the full overlap case, Figure 6(left), all existing ground points, presented as blue points, are involved in determining image points, whereas in the latter case, Figure 6(right), only ground points appearing in the previous image are used to generate image points of the current image. New image points and their corresponding ground points, shown as red points, are then generated as discussed in the earlier part of this section.
Figure 6 - The procedure of generating tie-points and ground points: full overlap mode (left), and along track overlap mode (right).

In order to imitate the characteristics of image matching systems, we generate a number of outliers (mismatched points) that corresponds to the mismatched ratio of the matching system. The procedure for generating outliers from the simulated image points is illustrated as Figure 7. Firstly, the total number of mismatched points is calculated from the expected percentage of points correctly matched by the image matching system. The process then randomly selects the number of mismatched points from the list of image points and adds a random noise generated by a Gaussian distribution model in which its standard deviation is the predicted mismatched discrepancy of tie-points. Note that good image matching typically addresses the position of conjugate points with no or very small discrepancy to the true positions.

Aerial triangulation with bundle block adjustment process

Among aerial triangulation techniques, the bundle adjustment is the most widely used method [Mikhail et al., 2001]. It enables the exterior orientation parameters of all images to be determined simultaneously such that the technique produces more accurate and consistent mapping across the whole block of adjustment [Schenk, 1999; Wolf and Dewitt, 1999; Mikhail et al., 2001]. The fundamental equation of the bundle block is the collinearity equation and its symbolic mathematical model can be expressed as Equation [1] [Schenk, 1999].

\[
(x_i^j, y_i^j) = f(EO_i^j, GP_i) \quad [1]
\]
The photo coordinate \((x_i^j, y_i^j)\) results from the collinearity equation, \(f\), that involves the unknown exterior orientation parameters, \(EO^j\) of image \(j\) with \(j=1,\ldots,m\), and the unknown ground point \(GP^i\) with \(i=1,\ldots,n\). Since the collinearity equation is nonlinear, to enable the (weighted) least squares adjustment, a first-order Taylor series expansion is applied to linearize Equation [1]. After linearization, the Gauss-Markov model for estimating the unknowns is presented as Equation [2].

\[
y_i = A\xi + e_i, \ e_i \sim (0, \sigma_0^2 P_i^{-1}) \quad [2]
\]

where \(y_i\) is the observation vector of conjugate points; the coefficient matrix \(A\) is the design matrix of partial derivatives with respect to the unknowns \(\xi\) (6\(m\) unknowns for EO plus 3\(n\) unknowns for GP), and \(e_i\) is the error vector associated with the observation vector \(y_i\). To overcome rank deficiency from eliminating ground control points (GCPs), the equation requires a sufficient number of tie-points and the directly observed GPS/IMU data are combined as stochastic constraints, Equation [3].

\[
\begin{bmatrix}
y_i \\
y_e
\end{bmatrix} =
\begin{bmatrix}
A_e & A_p \\
K_e & 0
\end{bmatrix}
\begin{bmatrix}
\xi_e \\
\xi_p
\end{bmatrix} +
\begin{bmatrix}
e_i \\
e_e
\end{bmatrix} \sim
\begin{bmatrix}
0 \\
0
\end{bmatrix}
\sigma_0^2
\begin{bmatrix}
P_i^{-1} & 0 \\
0 & P_e^{-1}
\end{bmatrix}
\]

where \(y_e\) is the vector of directly measured GPS/IMU and \(K_e\) is the design matrix related to the constraints (which is written as the identity matrix). The design matrix \(A\) from Equation [2] is decomposed into \(A_e\) and \(A_p\) in Equation [3]. \(A_e\) is the Jacobian matrix with respect to the unknown EOs, \(\xi_e\), while \(A_p\) is with the unknown coordinates of ground points, \(\xi_p\). The elements of \(A_e\) and \(A_p\) can be derived directly from the GPS/IMU data. \(e_i\) and \(e_e\) are the errors associated with the observation \(y_i\) and \(y_e\). \(P_i\) and \(P_e\) are the weight matrices corresponding to said error vectors, and they indicate the quality of the measurement data. The observations in Equation [3] can be categorized into three groups: tie-points, position parameters and attitude parameters. A least square adjustment is then iteratively applied to Equation [3] to satisfy the collinearity equation by minimizing the square sum of the residuals [Schenk, 2004].

**Experimental results and analysis**

This section presents the use of the ISO simulator in empirical analysis of tie-point factors towards the ISO results. Prior to performing experiments, we summarize the parameters for controlling the simulator in Table 1. Since the experiments presented in this study involve investigation of the number and accuracy of tie-points on the result of ISO, the user-defined parameters related to trajectory, terrain, camera and sensor accuracy are fixed, as in Table 2, and the tie-point parameters are varied, as in Table 3. Table 4 lists the standard deviations of error associated with each observation \(x\), which are used to determine the weight as \(w_x = \sigma_0 / \sigma_x^2\) where, in this work, \(\sigma_0\) is defined as \(l\). In this empirical study, the standard deviation of error in image points is the predicted discrepancy between the true conjugate point and the mismatched point. In this present study, the project area is defined as 180\(\times\)200 m\(^2\).
According to the trajectory and camera input parameters, the results of computing auxiliary parameters are as in Table 5.

| Parameters | Values |
|------------|--------|
| Accuracy of GPS/IMU sensors | Depends on device specification. Typically, a ±0.30m position accuracy and ±0.1deg angular accuracy are defined for medium-grade systems; while ±2~2.5m and ±2deg for MEMS or low-cost devices. |
| Percentage of correct matched of image matching system | Varies according to the image matching and outlier removal technique used. Highly accurate systems may achieve more than 90%. |
| Tie-point generating mode | Either full overlap mode or along track overlap mode. |
| Tie-point distribution pattern | Varies but typical values are 1 × 1 (random distribution – no pattern), 3 × 3, 4 × 4 and 5 × 5. |
| No. of tie-points per block | Depends on the redundancy requirement. The minimal value is 1 point/block (9 points for a 3 × 3 pattern; 16 points for a 4 × 4 pattern etc.). |
| Mismatched discrepancy (pixels) | Varies according to the performance of image matching and image size. |

| Table 2 - Controlled parameters. |
|-----------------------------------|
| **Trajectory & terrain** | **Camera** | **Accuracy** |
| velocity: 36 km/h | pixel size: 3.45×3.45µm | medium-grade GPS: 0.3m |
| altitude: 200 m | image size: 2456×2058 pix | medium-grade IMU: 0.1deg |
| coverage: 180×200 m² | focal length: 17 mm | MEMS GPS: 2.5 m |
| sidelap: 30% | frame rate: 2 frames/sec | MEMS IMU: 2 deg |
| terrain elevation: 0 m | |

| Table 3 - Tie-point parameters. |
|---------------------------------|
| **Parameters** | **Values** |
| Tie-point generating mode | Full overlap |
| Tie-point distribution pattern | 3×3 |
| No. of tie-point | 1/ 2/ 3/ 4/ 5 points/block |
| Accuracy of image matching | 100% with 0-pixel mismatched discrepancy |
| | 97% with 10-pixel mismatched discrepancy |
| | 90% with 10-pixel mismatched discrepancy |

| Table 4 - Standard deviation of errors associated with each observation. |
|-----------------------------------|
| **Parameters** | **Standard deviation values** |
| Medium-grade GPS | 0.3 m |
| Medium-grade IMU | 0.1 deg |
| MEMS GPS | 2.5 m |
| MEMS IMU | 2 deg |
| Image point with 0-pixel mismatched discrepancy | 0.000345 mm¹ |
| Image point with n-pixel mismatched discrepancy | n × pixel size |

¹In computation, the 0-pixel mismatched discrepancy is substituted by 0.1-pixel.
This experiment investigates the influence of the number of tie-points on ISO in order to refine the accuracy of the directly measured EOs from medium-grade sensing devices and MEMS. The numbers of tie-points per image used in the comparison are 9, 18, 27, 36 and 45. With the $3 \times 3$ tie-point distribution pattern, these numbers are implemented by increasing the number of tie-points in each block by one, starting from 1 to 5. Because the simulator is designed to randomly simulate tie-points, the positions of image points are different every time they are simulated. We notice that, even with the same number of tie-points, the different positions of image points yield different results for the adjustment process. Therefore, we run the simulator 5 times for each test scenario and select the median set as our analysis result. The difference of the residuals in image space among these 5 simulated results (standard deviation) is about 0.08 pixels.

Similar to the work of Khoshelham [2009], but without check points, the residuals of the estimated EOs in the object space are evaluated by the RMS of the discrepancies between the resulting EOs and the simulated true EOs. The tie-point residuals in the image space are measured as the distances between the true conjugate points and the image points computed using the resulting EOs through the collinearity equation.

Figure 8 presents the residuals of the adjusted EOs in object and image space with various numbers of tie-points when using EOs from medium-grade sensors as input. With a maximum of one tie-point per block (nine tie-points per image), ISO can reduce the residual in image space from 12.85 pixels to 4.76 pixels, which is 62.92% improvement in accuracy. Adding one more tie-point per block can reduce the image residual for 1.40% in average. This indicates that increasing the number of tie-points can, although slightly, improve the accuracy of the directly measured EOs. This finding corresponds to those of previous studies from Honkavaara and Hogholen [1996] and Khoshelham [2009]. The result also applies to the case of MEMS, see Figure 9. However, the latter case reduces the residual in image space for only 0.10% in average when one more tie-point is added to each block. For the case of less accurate tie-points, it also shows that increasing the number of tie-points can still reduce the EO residuals. Schenk [1999] also discussed this point in his book. For example, when the percentage of the number correct tie-points is 90%, increasing one more tie-point per block can improve the accuracy in image space but as small as 0.17%, see Figure 8.

Figure 10 shows that the computational time for the bundle adjustment process consumed for processing EOs from medium-grade sensors is less than those used for MEMS case for about 37%, and the time increases significantly when the number of image points increases. For medium-grade sensors, the AT process consumes 2.83sec when assigning a maximum of nine tie-points per image. Increasing the number of tie-points per image to 18/27/36 and 45, the computational time consumed by AT is 3.6, 11.9, 26.7 and 51.8 times larger than...
that of nine tie-points per image (one tie-point per block). These numbers of times are also close to that of MEMS case.

Figure 8 - RMS of EO residual from medium-grade sensors.

Figure 9 - RMS of EO residual from MEMS.
Conclusions
ISO is a promising technique to solve the image orientation problem as it combines the advantages of both direct georeferencing and aerial triangulation. The inclusion of tie-points is a major contributing factor to the results of ISO. How many tie-points are sufficient for ISO to improve the accuracy of directly measured EOs and, what if tie-points are less accurate, can a large number of tie-points compensate for their being less accurate? This paper presents an implementation of an ISO simulator to address the mentioned problems. We have demonstrated a case study to investigate the influence of the number and accuracy of image points on the results of ISO systems. The results can be summarized as follows:

1. Increasing one tie-point per block can improve the precision of the directly measured EOs from medium-grade sensing devices for 1.40% in average and 0.10% for MEMS.
2. A large number of tie-points, even of less accuracy, can still improve the accuracy of the directly measured EOs. For example, when the percentage of the number correct tie-points is 90%, increasing one more tie-point per block can improve the accuracy in image space for 0.17%.
3. The computational time of the bundle block process increases significantly as the number of image points increases. In the experiment, the computational costs are 4, 12, 27 and 52 times larger when the number of tie-points increases from 1 tie-point per block to 2, 3, 4 and 5 tie-points per block, respectively.

The results we obtained using the simulator correspond to the results from existing research works, indicating that the proposed simulator can be used in real ISO applications. In the future, we plan to perform an empirical study on the influence of various combinations of tie-point factors from automated matching systems on ISO results using both simulated and true data.

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References
Barazzetti L., Remondino F., Scaioni M. (2010) - Extraction of accurate tie points for automated pose estimation of close-range blocks. In: Pararoditis N., Pierrot-Deseilligny M., Mallet C., Tournaire O. (Eds.), IAPRS, Saint-Mande (France), 38 (3): 151-156.
Barazzetti L., Scaioni M., Gianinetto M. (2014) - Automatic co-registration of satellite time series via least squares adjustment. European Journal of Remote Sensing, 47: 55-74. doi: http://dx.doi.org/10.5721/EuJRS20144705.
Casella V., Franzini M. (2003) - Definition of a methodology for local reduction of parallaxes in directly oriented images. In: Proceedings of ISPRS International Workshop Group I/5, Castelldefels, Spain.
Cramer M., Stallman D., Haala N. (1997) - High precision georeferencing using GPS/INS and image matching. In: International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, Banff, Canada, pp. 453-462.
Cramer M., Stallmann D., Haala N. (2000) - Direct georeferencing using GPS/Inertial exterior orientations for photogrammetric applications. In: Proceedings of IAPRS, Amsterdam, 18 (B3): 198-205.
Eisenbeiss H., Sauerbier M. (2011) - Investigation of UAV systems and flight modes for photogrammetric applications. The Photogrammetric Record, 26 (136): 400-421. doi: http://dx.doi.org/10.1111/j.1477-9730.2011.00657.x.
El-Sheimy N. (2000) - Capturing road network data using mobile mapping technology. In: Proceedings of International Archives of Photogrammetry and Remote Sensing, Amsterdam, 33 (B2): 272-277.
Heipke C., Jacobsen K., Wegmann H. (2002) - Analysis of the results of the OEEPE test “Integrated Sensor Orientation”. In: Proceedings of the OEEPE Workshop: Integrated Sensor Orientation, Institute for Photogrammetry and Geoinformation, Hannover, Germany, pp. 31-41.
Heipke C., Schmidt R., Brand R., Oberst J., Neukum G. (2004) - Performance of automatic tie-point extraction using HRSC imagery of the MARS express mission. In: International Archives of Photogrammetry, Remote Sensing, 35 (B4): 846-851.
Honkavaara E., Hogholen A. (1996) - Automatic tie point extraction in aerial triangulation. In: International Archives of Photogrammetry and Remote Sensing, Vienna, pp. 337-342.
Ip A., El-Sheimy N., Mostafa M. (2007) - Performance analysis of integrated sensor orientation. Photogrammetric Engineering & Remote Sensing, 73 (1): 89-97. doi: http://dx.doi.org/10.14358/PERS.73.1.89.
Jacobsen K. (2004) - Direct/integrated sensor orientation - Pros and cons. In: Proceedings of ISPRS, Istanbul, Turkey, pp. 829-835.
Khoshelham K. (2009) - Role of tie-points in integrated sensor orientation for photogrammetric map compilation. Photogrammetric Engineering & Remote Sensing, 75 (3): 305-311. doi: http://dx.doi.org/10.14358/PERS.75.3.305.

Kim J., Sukkarieh S. (2004) - Complementary SLAM aided GPS/INS navigation in GNSS denied and unknown environments. In: Proceedings of the 2004 International Symposium on GNSS/GPS, Sydney, Australia, pp.1-6.

Lee S., Choi K., Joo I., Cho S., Park J. (2006) - Design and implementation of 4S-Van: a mobile mapping system. ETRI Journal, 28 (3): 265-274. doi: http://dx.doi.org/10.4218/etrij.06.0105.0143.

Liu L., Wang Y., Wang Y. (2008) - SIFT based automatic tie-point extraction for multitemporal SAR images. In: Proceedings of the International Workshop on Education Technology and Training, pp. 499-503.

McGlone J.C. (2004) - Manual of photogrammetry. (5th Ed), Maryland, American Society for Photogrammetry & Remote Sensing. ISBN: 1570830711.

Mikhail E.M., Bethel J.S., McGlone J.C. (2001) - Introduction to modern photogrammetry. New York, John Wiley & Sons. ISBN: 9780471309246.

Pirotti F., Guarnieri A., Vettore A. (2013) - State of the art of ground and aerial laser scanning technologies for high-resolution topography of the earth surface. European Journal of Remote Sensing, 46: 66-78. doi: http://dx.doi.org/10.5721/EuJRS20134605.

Roncella R., Remondino F., Forlani G. (2005) - Photogrammetric bridging of GPS outages in mobile mapping. In: Beraldin El-Hakim, Gruen, Walton (Eds.), Proceedings of SPIE-IS&T Electronic Imaging, 5665: 308-319.

Sanchez R.D., Hothem L.D. (2002) - Positional accuracy of airborne integrated global positioning and inertial navigation systems for mapping in Glen Canyon, Arizona. U.S. Geological Survey Open-File Report 02-2222.

Schenk T. (1999) - Digital photogrammetry. Ohio, Terra Science. ISBN: 0967765307.

Schenk T. (2004) - From point-based to feature-based aerial triangulation. ISPRS Journal of Photogrammetry & Remote Sensing, 58 (5-6): 315-329. doi: http://dx.doi.org/10.1016/j.isprsjprs.2004.02.003.

Schwarz K.P., Chapman M.A., Cannon M.E., Gong P. (1993) - An integrated INS/GPS approach to the georeferencing of remotely sensed data. Photogrammetric Engineering & Remote Sensing, 59 (11): 1667-1674.

Shragai Z., Even-Paz A., Klein I. (2011) - Automatic tie-point extraction using advanced approaches. In: Proceedings of the ASPRS 2011 Annual Conference, Wisconsin.

Tanathong S., Lee I. (2010) - Speeding up the KLT tracker for real-time georeferencing using GPS/INS data. Korean Journal of Remote Sensing, 26 (6): 629-644.

Wolf P.R., Dewitt B. (1999) - Elements of photogrammetry with applications in GIS. Boston, McGraw-Hill. ISBN: 0072924543.

Yastikli N., Jacobsen K. (2002) - Investigation of direct sensor orientation for DEM generation. In: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 34b (1): 298-304.

Yastikli N., Jacobsen K. (2005) - Direct sensor orientation for large scale mapping - potential, problems, solutions. Photogrammetric Record, 20 (111): 274-284. doi: http://dx.doi.org/10.1111/j.1477-9730.2005.00318.x.

Zhang J., Zhang Z., Ke T., Zhang Y., Duan Y. (2011) - Digital Photogrammetry Grid
(DPGrid) and its application. In: Proceedings of the ASPRS 2011 Annual Conference, Wisconsin.
Zilli S., Frezza R., Beghi A. (2005) - Model based GPS/INS integration for high accuracy land vehicle applications: calibration of a swarm of MEMS sensors. In: Proceedings of International Conference on Advanced Intelligent Mechatronics, Monterey, California, USA, pp. 952-956.

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