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THE USE OF GPS/IMU FOR INTEGRATED AND DIRECT ORIENTATION OF AERIAL IMAGES

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Abstract. The paper deals with the project GA 103/03/0102 "Integration of orientation systems and cameras in photogrammetry". The navigation system Applanix was connected with metric aerial cameras RMK TOP 15, RMK TOP 30 and digital non-metric camera Hasselblad 555 ELD. These integrated systems were tested and calibrated on test field. Accuracy of orientation parameters were determined and various block configuration and number of ground control points were proved. The project confirmed some conclusions of the former OEEPE project. The use of direct orientation is not possible for stereoevaluation because the accuracy of rotation from inertial unit is not sufficient. The used system Differential GPS NovAtell and IMU Applanix POS AV 310 showed better accuracy then declarated one. Interior orientation parameters and additional parameters were not necessary to use for metric cameras. The use of GPS/IMU data in automatic aerotriangulation have saved the time of image measurements. The middle format digital cameras are suitable for small projects, but precise calibration is needed. Smaller oblong format of images makes worse geometry of the block. The overlap 70-80%, more number of images and more control points are recommended.

Key words: GPS/IMU, integrated orientation, direct orientation

INTRODUCTION

The determination of the image orientation is a basic task for every type of photogrammetric project. This task has been solved in aerial photogrammetry using aerial aerotriangulation. Differential kinematic GPS positioning is standard tool for determination of the camera projection center today. Using GPS measurements in the bundle adjustment a geometrically stable block based on tie points only, ground control points are necessary only for check and reliability purposes. Gyroscopes of an inertial measurement unit (IMU) allow to determine the rotation elements of the exterior orientation. The accelerometers of IMU provide velocity and position. GPS/IMU combination can

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yield the exterior orientation elements of images without aerotriangulation. This technology we called as direct sensor orientation. Introducing GPS/IMU measurements as additional parameters within a bundle adjustment we obtain a method called as integrated sensor orientation. A series of tests in the end of nineties showed the potential of both methods of orientation, direct and integrated as well. Errors sources have been identified also. In the last years were put across several project pointed on investigation of sensor orientation using GPS/IMU. The most important project was the OEEPE test on Integrated Sensor Orientation [1]. The European Organisation for Experimental Photogrammetric Research, now EuroSDR (Euro Spatial Data Research), embarked on a test investigating sensor orientation using GPS and IMU in comparation with aerial aerotriangulation. The aim of the test was accuracy for large scale mapping using aerial metric cameras. There were used following systems: Applanix POS/AV 510 DG + Leica RC 30 and

IGI GmbH AEROcontrol IIb + RMK Top, both with camera constant 153 mm. Conclusions were following. The accuracy obtained with direct orientation from check points for image scale 1:5000 was 2-times lower then standard photogrammetric results. The direct orientation can be used for orthoimages and point determination with less accuracy requirements. Stereoplotting is not always possible using direct orientation due to y-parallax in some models. Using integrated orientation with minimum control points the accuracy is very similar to that is achieved of convencial photogrammetry. The reliability of the results remains weak point due to lack of redundancy in absolute orientation. Therfore is recommended to involve several ground control points in project area. Why to use IMU? We are able to increase the accuracy and realibility using GPS/IMU integration. We need les number of control points. There is advantageous to use less accurate IMU for photogrammetric purposes, because orientation of images in the bloch are kept by tie points. The use of GPS/IMU data in automatic aerotriangulation save the time of image measurements. Basic importance in the field of stability of calibration parameters in time has had the project „Investigations on long term stability of system calibration for direct georeferencing“ [2]. The system IGI AERO Control IId with cameras RMK TOP 15 a RMK TOP 30 were tested during 6 weeks. The stability of boresight misalignment were relatively good, but from time to time some systemathic errors caused shifts in results. Therfore is recommended integrated orientation with several control points.

PROJECT “INTEGRATION OF ORIENTATION SYSTEMS AND CAMERAS IN FOTOGRAMMETRY“.

Company Geodis Brno, ltd. used Applanix POS AV 310 since 2002. This fact allowed us to test systém. In the frame of the project GA CR N. 103/03/0102 **“**Integration of orientation systems and cameras in fotogrammetry“ were done following investigations in the years 2003-2004. The calibration field was based with 18 control points. The calibration block have 4 strip, each with 7 images. Used coordinate system is UTM. The first calibration flight with camera RMK TOP 15 (aircraft Cesna 206) was done in 2003 (IMU1). The images in scale 1:5000 were digitised with pixel size 14 μm. We have used two type of software, ORPHEUS (TU Wien) and ISAT (Intergraph). There were tested various solution see Table 1. Standart aerotriangulation is marked „A“, integrated orientaion „B“, using additinal parameters „AP“. The solution IMU1-A1 means aerotriangulation of the whole block with determination of 6 exterior orientation paremeters. The solution IMU1-A1- 4 means aerotriangulation of the whole block with determination of 6 exterior orientation paremeters usingnly 4 control points. The solution IMU1-A2 means aerotriangulation the first half of block with determination of 6 exterior orientation parameters etc.

Table 1. Solutions in the years 2003 (RMK TOP 15)
Tabela 1. Rozwiązania w roku 2003 (RMK TOP 15)

Solution	St.Dev. σ_0 [μm]	Number of strips	Number of control points
IMU1-ORP-A1	5,3	4	18
IMU1-ORP-A1-4	5,3	4	4
IMU1-ORP-A1AP	5,3	4	18
IMU1-ORP-A2	5,0	2	11
IMU1-ORP-A2-4	4,9	2	4
IMU1-ORP-B1	5,4	4	18
IMU1-ORP-B1-4	5,2	4	4
IMU1-ORP-B2	5,2	2	11
IMU1-ORP-B2-4	5,1	2	4
IMU1-ISAT-A1	3,8	4	18

Apriori standard deviations in the programme ORPHEUS were following:
Image coordinates $\sigma = 5\mu m$, control points $\sigma = 0.03m$ in each coordinate, projection centers in each coordinate $\sigma = 0.10m$, angle of orientation $\sigma = 0.006\,gon$. Reference GPS station was 3 km far from calibration field.
The results showed better accuracy of GPS/IMU then was declared one (standard deviation in: position 0.05-0.30 m, pitch and roll 0.013gon, yaw 0.035gon). Introduction of the interior orientation parameters and additional parameters into adjustment did not show significant influences. Some of results are in the following tables:

Table 2. Accuracy of orientation parameters and BSMA (whole block IMU1)
Tabela 2. Dokładność elementów orientacji oraz BSMA (cały blok IMU1)

	X_0 [m]	Y_0 [m]	Z_0 [m]	ω [gon]	φ [gon]	κ [gon]
St.d. A1	0.054	0.064	0.028	0.0042	0.0035	0.0013
St.d. B1	0.033	0.025	0.034	0.0029	0.0040	0.0041
St.d. BSMA	**0.075**	**0.098**	**0.051**	**0.0073**	**0.0070**	**0.0047**

In the Table 2 are compared accuracy of exterior orientation parameters of classical orientation using aerotriangulation, integrated orientation and boresight misalignment. The main task of calibration is determination of boresight misalignment (BSMA) from aerotriangulation, there are differences between orientation of camera coordinate system and IMU coordinate system and also differences between both origins of coordinates systems. Using only 2 strips provides the same accuracy as whole block see Table 3.

Table 3. Accuracy of orientation parameters and BSMA (½ block IMU1)
Tabela 3. Dokładność elementów orientacji oraz BSMA (1/2 bloku IMU1)

	X_0 [m]	Y_0 [m]	Z_0 [m]	ω [gon]	φ [gon]	κ [gon]
St.d. A2	0.056	0.068	0.028	0.0044	0.0036	0.0015
St.d B2	0.029	0.025	0.017	0.0025	0.0034	0.0042
St.d. BSMA	**0.072**	**0.103**	**0.039**	**0.0069**	**0.0063**	**0.0055**

By integrated orientation we can obtain very good results using only 4 control points see Table 4, 5.

Table 4. Accuracy of orientation parameters and BSMA using integrated orientation
Tabela 4. Dokładność elementów orientacji oraz BSMA przy użyciu orientacji zintegrowanej

	X_0 [m]	Y_0 [m]	Z_0 [m]	ω [gon]	φ [gon]	κ [gon]
St.d. B1	0.039	0.041	0.025	0.0026	0.0025	0.0014
St.d. BSMA	**0.051**	**0.048**	**0.039**	**0.0042**	**0.0044**	**0.0043**
St.d. B1-4	0.041	0.042	0.028	0.0027	0.0026	0.0015
St.d. BSMA	**0.051**	**0.048**	**0.039**	**0.0042**	**0.0044**	**0.0043**

Table 5. Average differences betwen IMU1-B1 a IMU1-B1-4
Tabela 5. Średnie różnice pomiędzy IMU1-B1 a IMU1-B1-4

IMU1 DIF B1/B1-4	X_0 [m]	Y_0 [m]	Z_0 [m]	ω [gon]	φ [gon]	κ [gon]
Aver. diff.	0.012	0.015	0.020	0.0010	0.0016	0.0006

The Table 6 show increasing of accuracy using automatic aerotriangulation (ISAT). The average differences between orientation parameters comparing Orpheus and ISAT v IMU1-A1 we can see in Table 7. These differences are in good coincidence with standard deviations shown in Table 6.

Table 6. Comparation of average standard deviations of orientation parameters using Orpheus and ISAT in the block IMU1-A1, n – number of unknowns, m - number of measurements
Tabela 6. Porównanie średnich odchyleń standardowych parametrów orientacji uzyskanych z programów Orpheus oraz ISAT (automatyczna aerotriangulacja) dla bloku IMU1-A1, gdzie: n – liczba niewiadomych, m – liczba obserwacji

IMU1-A1	X_0 [m]	Y_0 [m]	Z_0 [m]	ω [gon]	φ [gon]	κ [gon]	*n*	*m*
AT-OR	0.054	0.064	0.028	0.0042	0.0035	0.0013	1752	870
AT-ISAT	0.030	0.035	0.022	0.0021	0.0018	0.0009	5984	2775

Table 7. Average differences between orientation parameters comparing Orpheus and ISAT in block IMU1-A1
Tabela 7. Średnie różnice pomiędzy parametrami orientacji uzyskanymi z programu Orpheus oraz ISAT dla bloku IMU1-A1

	X_0 [m]	Y_0 [m]	Z_0 [m]	ω [gon]	φ [gon]	κ [gon]
Aver. diff.	**0.099**	**0.097**	**0.025**	**0.0045**	**0.0038**	**0.0013**

In the year 2004 were done tests with camera RMK TOP 30 placeing in the board of aircraft Cessna 402 – block IMU2. With regard to constant of camera are obtained accuracy whorse by manual measurents of tie points see Table 8. Using automatic aero-triangulation with large number of tie points we obtain sufficiently accurate results see Table 9. The average differences between both solutions confirmed this fact see Table 10. The values of the boresight misalignment were during year relatively stable, this fact confirmed aerotrinagulations of commercial projects.

Table 8. Accuracy of orientation parameters and BSMA (whole block IMU2)
Tabela 8. Dokładność parametrów orientacji oraz BSMA (cały blok IMU2)

	X_0 [m]	Y_0 [m]	Z_0 [m]	ω [gon]	φ [gon]	κ [gon]
St.d. A1	0.19	0.21	0.05	0.0078	0.0072	0.0014
St.d. B1	0.09	0.09	0.04	0.0034	0.0033	0.0013

Table 9. Comparation of average standard deviations of orientation parameters using Orpheus and ISAT in the block IMU2-A1, n – number of unknowns, m - number of measurements
Tabela 9. Porównanie średnich odchyleń standardowych parametrów orientacji uzyskanych z programów Orpheus oraz ISAT (automatyczna aerotriangulacja) dla bloku IMU2-A1, gdzie: n – liczba niewiadomych, m – liczba obserwacji

	X_0 [m]	Y_0 [m]	Z_0 [m]	ω [gon]	φ [gon]	κ [gon]	n	m
OR	0.19	0.21	0.05	0.0078	0.0072	0.0014	1752	870
ISAT	0.06	0.07	0.03	0.0024	0.0022	0.0007	7300	3276

Table 10. Average differences between Orpheus and ISAT in the block IMU2-A1
Tabela 10. Średnie różnice pomiędzy Orpheus-em a ISAT dla bloku IMU2-A1

	X_0 [m]	Y_0 [m]	Z_0 [m]	ω [gon]	φ [gon]	κ [gon]
Aver. diff.	0.21	0.30	0.08	0.0109	0.0063	0.0014

The last part of project was test with middle format digital camera Hasselblad 555 ELD with lens Zeiss Distagon CFI 50mm. The digital back Phase One H 25 provide images with 22 MP, size of image is 48.9 x 36.7 mm, used sensor CCD 5488 x 4145 pixels. The size of pixel is 9x9 μm. There were some troubles with connection of GPS/IMU with camera. After solving these problems we obtained from calibratin flight folloving results see Table 11. The differences in ω and φ are too large. The overlap 70-80% , more number of images and control points were recommended.

Table 11. Accuracy of orientation parameters (whole block IMU3) and standard deviation of differences between orientation parameters GPS/IMU and AT
Tabela 11. Dokładność parametrów orientacji (cały blok IMU3) oraz odchylenie standardowe dla różnic pomiędzy parametrami orientacji z GPS/IMU i AT (aerotriangulacji)

IMU-DC	X_0 [m]	Y_0 [m]	Z_0 [m]	ω [gon]	φ [gon]	κ [gon]
St. dev.	0.069	0.063	0.024	0.008	0.009	0.002
St. dev. of diff.	0.166	0.179	0.152	0.029	0.019	0.008

CONCLUSIONS

The project confirmed some conclusions of the OEEPE project. The use of direct orientation is not possible for stereoevaluation, because the accuracy of rotation from IMU is not sufficient. For some other purposes (special orthophotomaps) can be used. If we use 4-10 control points in the integrated orientation, the accuracy is the same as in the clasical aerotriangulation. There is necessary to have the real accuracy for introduction of GPS/IMU measurements in adjustment. Calibration flight having two strips with 7 images is sufficient. Suitable configuration of block increasing of redudancy of measurements could be one strip, where the images are taken in the both directions. The configuration generate a large number of tie points. The calibration of aerial camera connected with GPS/IMU is suitable to do in the start of imaging period and then by the analyzis of the aerotriangulation of the commercial flights. Used system Differential GPS NovAtell and IMU Applanix POS AV 310 showed better accuracy then declarated one. The modern cameras were used in the project. Therefore interior orientation parameters and additional parameters were not necessary to use in the calibration. There is advantageous to use less accurate IMU for photogrammetric purposes, because orientation of images in the block are kept by tie points. The use of GPS/IMU data in automatic aerotriangulation save the time of image measurements. The middle format digital cameras are suitable for small projects, but precise calibration is needed. Smaller oblong format of images make whorse geometry of the block. The overlap 70-80% , more number of images and control points are recommended.

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ZASTOSOWANIA GPS/IMU DO ZINTEGROWANEJ I BEZPOŚREDNIEJ ORIENTACJI ZDJĘĆ LOTNICZYCH

Streszczenie. Niniejsza praca odnosi się do projektu GA 103/03/0102 „Integracja systemów orientacji i kamer pomiarowych w fotogrametrii". System nawigacyjny Applanix połączono z metrycznymi kamerami lotniczymi RMK TOP 15, RMK TOP 30 oraz z cyfrową niemetryczną kamerą Hasselblad 555ELD. Tak zintegrowane systemy były testowane i kalibrowane na polu testowym. Została wyznaczona dokładność elementów orientacji oraz wypróbowano różne konfiguracje bloków zdjęć i liczby punktów kontrolnych. Projekt potwierdził wnioski osiągnięte w poprzednim projekcie OEEPE. Użycie dla opracowań stereometrycznych uzyskanych bezpośrednio elementów orientacji zewnętrznej nie jest możliwe, ponieważ dokładność kątów obrotu uzyskanych z systemów inercjalnych jest niewystarczająca. Użyte systemy Differential GPS NOVAtell oraz IMU Applanix

POS AV310 uzyskały dokładność większą od deklarowanej. Elementy orientacji wewnętrznej oraz parametry dodatkowe nie były konieczne w przypadku użycia kamer metrycznych. Użycie danych z GPS/IMU w procesie automatycznej aerotriangulacji pozwoliło na zaoszczędzenie czasu przy pomiarach obrazu. Kamery cyfrowe średniego formatu okazują się odpowiednie dla małych projektów, lecz konieczne jest precyzyjne skalibrowanie. Mniejsze, wydłużone formaty obrazów powodują pogorszenie geometrii bloku obrazów. Zalecane jest pokrycie 70-80%, większa liczba obrazów oraz więcej punktów kontrolnych.

Słowa kluczowe: GPS/IMU, orientacja zintegrowana, orientacja zewnętrzna

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