GPS/INS SYSTEMS FOR COMPILATION
OF DIGITAL LARGE-SCALE ORTHOPHOTOS

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ABSTRACT:

The paper describes the first results of a study, supported by an Italian research project "Integrated Inertial Positioning Systems in Aerial Photogrammetry" on the potential use of these techniques for production of digital large scale orthophotos. The study has been done with aerial photographs collected from two different flights executed in Sicily: the former, relating to the city of Palermo, at average scale of 1:9300; the latter, over the city of Catania, at average scale of 1:2000. For both flights the orthorectification was carried out by direct georeferencing methods and by traditional photogrammetric techniques, using ground control points surveyed by means GPS techniques and aerial digital triangulation. The orthophotos generated by both methods were compared between themselves checking the influence of integrated sensors on the accuracy of the final product.

1. INTRODUCTION

The problem of the direct georeferencing is nowadays one of the most interesting and current topics in the aerial photogrammetry sector. In fact, the possibility to obtain directly the exterior orientation parameters of all photographs (angular attitude and perspective centers coordinates) without recurring to ground control points seems particularly advantageous especially in the sphere of the aerial photography for mapping purposes, giving new expectations that were unimaginable until a few years ago.

The results regarding the accuracy of direct exterior orientation for photogrammetric flights at scale of 1:5000 have highlighted values compatible with accuracy required for the orthophoto production (Heipke et al., 2002); the introduction of a certain number of tie points and some GCPs improves the accuracy of orientation remarkably and reduces the existing parallax errors. This approach, called integrated orientation systems, seems to be the one that permits to obtain the highest accuracy (Cramer, 2003).

This research, conducted within the national interest research program (COFIN2002) "Integrated positioning systems in aerial photogrammetry" coordinated by Prof. Galetto (Galetto & Casella, 2003), shows the first results of an experimentation on the capability of the GPS/INS integrated systems, realized on two different photogrammetric blocks. The flights were executed by CGR from Parma (Italy) and aimed towards the commercial production of inner cities digital orthophotos at large (1:2000) and very large (1:500 and 1:200) scale.

2. DESCRIPTION OF DATA SETS

Aerial photographs used for the experimentation are relative to two flights done on the 6th October 2001 and 10th October 2003 on the cities of Palermo and Catania (fig. 1), within the project regarding the realization of the main Italian cities digital orthophotos at large scale. Photographs were taken by a Leica RC30 camera, with a focal length of about 300 mm and provided with POS/AV 510 Applanix system. The flight over inner city of Palermo consists of three strips with E-W direction, each one having 7 photographs at average scale of 1:9300 (fig. 2); regarding to the flight over old city centre of Catania, a block was taken in consideration consisting of three strips with E-W direction, with 19 photographs in all at average scale of 1:2000 (fig. 3). All the photographs were scanned by Zeiss SCAI scanner with a resolution of 14 μm, corresponding to about 13 cm at scale of 1:9300 and 3 cm at scale of 1:2000. CGR provided the exterior orientation parameters of each photograph, obtained directly from the Applanix system.

Before photogrammetric operations some ground control points (GCPs) and check points (CPs), chosen in correspondence of natural, well-defined, objects and well-distributed on the photographs, were surveyed by GPS method. 47 and 12 points, for the blocks of Palermo and Catania respectively, were surveyed in all, using three Topcon Legacy-H dual frequency GPS receivers. RMS coordinates is in the order of one centimeter.
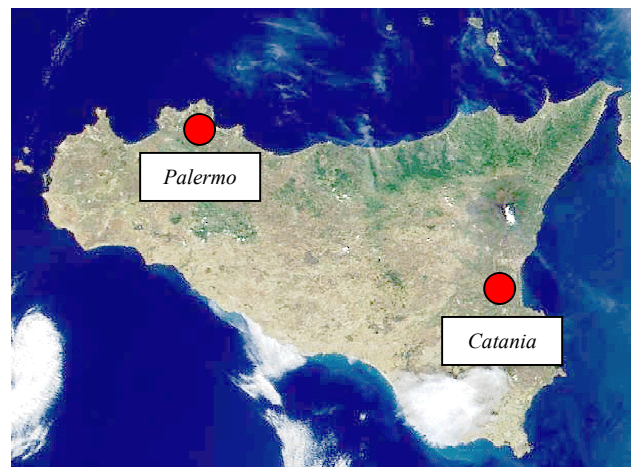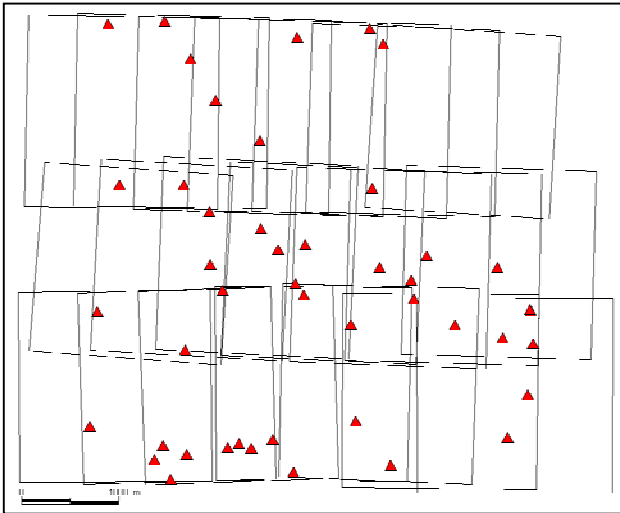

Figure 1. Test's areas

Figure 2. Overview of block of Palermo with all the ground point.

3. DESCRIPTION OF THE EXPERIMENTATION

The experimentation was carried out comparing the direct exterior orientation parameters with those calculated by means of an aerial triangulation (AT), and using some GCPs to check their accuracy in different configurations taken into consideration.

At first the parameters directly provided by Applanix system (APP) were compared with those calculated by an aerial triangulation (AT) performed introducing the direct orientation parameters and measuring an adequate number of tie points (AT1).

A second comparison was done by a traditional AT, using some GCPs without exterior orientation parameters (AT2).

Further comparisons were done by AT operations carried out integrating the direct orientation parameters with some tie points and GCPs; particularly, two configurations were considered: the one with a single GCP located in the middle of the blocks (AT3a), another with four GCPs in the corner of blocks (AT3b).

For the Catania flight other AT operations were also carried out, with only the perspective centres and four (AT4a) or seven
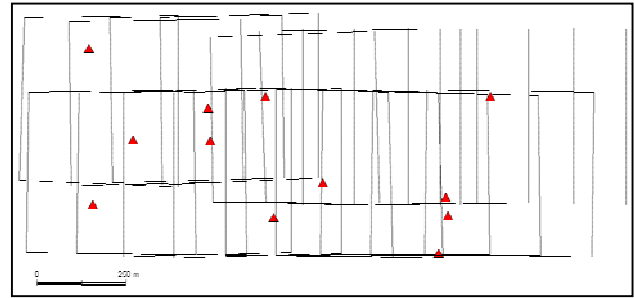

Figure 3. Overview of block of Catania with all the ground point.

GCPs (AT4b).

Various procedures of orientation were executed by Inpho MATCH-AT software and Bea Systems Socet Set 4.4 software. From the exterior orientation parameters provided by Applanix system and ones calculated in the different types of AT taken into examination, some digital orthophotos were produced. From the relative comparison, made in correspondence of well identifiable image points by means of a Arcview environment specially compiled software, it has been possible to draw conclusions about the influence of the parameters variations on the orthophotos accuracy.

DEMs necessary for making orthophotos were derived from available maps: at scale of 1:10000, for the city of Palermo, and 1:2000, for Catania.

3.1 The Palermo project

As regards AT2 operation conducted in Palermo, 9 tie points per photograph were observed, choosing points visible on several photographs, between adjacent models and strips. 63 tie points were observed above. To calculate exterior orientation parameters, only 12 of 47 points surveyed by GPS were employed as GCPs, and the remaining points as CPs.

Table I shows the aggregate results of the comparison between the exterior orientation parameters provided by Applanix system (APP) and ones calculated by Socet Set software for different configurations taken into account. The comparison with AT2 operation highlights the most relevant discrepancies, even if not particularly significant; in the other cases the discrepancies are of a smaller order of magnitude and independent of the GCPs presence and number.

		X	Y	Z	Omega	Phi	Kappa
APP-AT1	*Mean*	0.000	0.000	0.000	-0.0003	0.0007	0.0024
	St. Dev.	0.002	0.001	0.003	0.0035	0.0041	0.0029
APP-AT2	*Mean*	0.067	0.045	0.130	-0.0041	0.0026	0.0040
	St. Dev.	0.589	1.114	0.206	0.0221	0.0129	0.0049
APP-AT3a	*Mean*	0.000	0.000	0.000	-0.0003	0.0017	0.0022
	St. Dev.	0.002	0.001	0.003	0.0030	0.0045	0.0030
APP-AT3b	*Mean*	0.000	0.000	0.000	-0.0043	0.0024	0.0047
	St. Dev.	0.001	0.001	0.003	0.0036	0.0033	0.0057

Table I. Statistical parameters of the comparison from exterior orientation parameters for Palermo project (X, Y, Z, in meters – omega, phi e kappa in grad)

	APP			AT1			AT2			AT3a			AT3b		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
Mean	-0.145	-0.112	0.281	0.054	0.107	-0.216	0.031	-0.046	-0.183	0.012	0.122	-0.114	-0.012	-0.096	-0.288
St. Dev.	0.142	0.102	0.436	0.107	0.099	0.131	0.078	0.140	0.271	0.140	0.080	0.126	0.086	0.129	0.154
Min.	-0.480	-0.350	-0.310	-0.318	-0.081	-0.440	-0.225	-0.300	-0.613	-0.438	-0.011	-0.342	-0.285	-0.364	-0.603
Max	0.150	0.080	1.110	0.267	0.305	0.124	0.169	0.240	0.198	0.287	0.289	0.217	0.111	0.197	-0.022

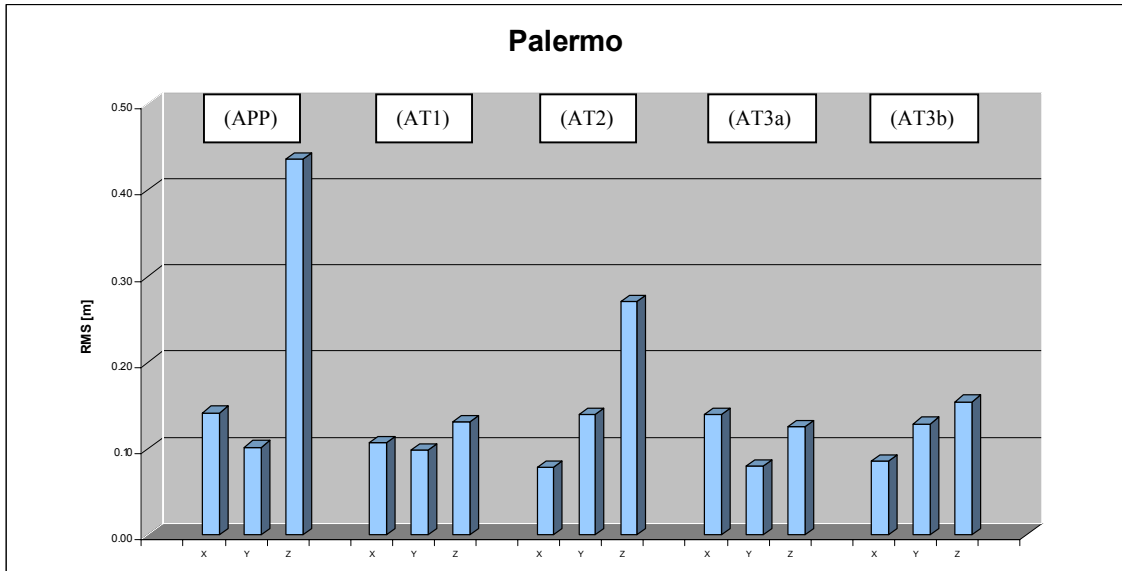Table II. Check point statistical parameters for Palermo project (in meters)

Figure 4. Check point quality (RMS) from AT based from different input data (Palermo project)

Figure 5. Ortophoto of Palermo (APP) with raster map at scale 1:2000

	APP - AT1			APP - AT2		
	RMS	*RMS X*	*RMS Y*	*RMS*	*RMS X*	*RMS Y*
Mean	0.226	-0.005	0.202	0.142	-0.014	0.111
St. Dev.	0.081	0.089	0.093	0.065	0.073	0.080

Table III. Statistical parameters of the comparison from the ortophotos for Palermo project (in meters)

Table II and relative figure 4 show overall statistics of residuals calculated for each considered configuration, in correspondence of the 33 surveyed CPs. A first control was made using APP data; the obtained results denote a high accuracy above all from an altimetric point of view. The following controls, made for the other provided configurations, confirm the good quality of the obtained results, with a sharp improvement of altimetric accuracy.

Three digital orthophotos at scale of 2000 were produced, for APP, AT1 and AT2 configurations. A first control of the APP orthophoto accuracy was carried out comparing the coordinates of an adequate number of points with those derived from the orthophotos related to other two configurations (tab. III). The obtained results are always much lower than those required for national map accuracy standards at scale of 1:2000. A further control was made placing the raster map at scale of 1:2000 over the APP orthophoto (fig. 5).

3.2 The Catania project

For the Catania area an automatic AT was executed by MATCH-AT software, determining for each photograph a several hundreds tie-points. A summary of the most relevant parameters of the automatic AT are shown in table IV. The AT2 operation was done with 7 GCPs, using the remaining points as CPs.

Table V shows the aggregate results of the comparison between the APP exterior orientation parameters and those calculated by AT software for different configurations taken into account. The obtained values are not much higher than those of Palermo project.

Results of control made on the CPs (tab. VI e fig. 5) confirm the good quality of APP data; also in this case the increasing of the GCPs number does not generate a relevant improvement of accuracy.

Finally, three digital orthophotos at scale of 200 were produced, for APP, AT1 and AT4b configurations. Table VII shows

			St. Dev. a priori				*Tie point generator*	
N. photos	19	*GCP X Y Z [m]*	0.030	0.030	0.050	*N. of observations*		17560
N. strip	3	*GPS X Y Z [m]*	0.020	0.020	0.020	*N. of unkows*		6146
Photo scale	1:2000	*INS omega phi kappa [grad]*	0.0050	0.0050	0.0050	*Redundancy*		11354

Table IV. Parameters of the automatic AT (Catania project)

		X	*Y*	*Z*	*Omega*	*Phi*	*Kappa*
APP-AT1	*Mean*	-0.004	-0.037	-0.008	-0.0106	-0.0055	0.0093
	St. Dev.	0.024	0.025	0.035	0.0099	0.0047	0.0069
APP-AT2	*Mean*	-0.069	-0.103	-0.066	0.0014	-0.0105	0.0223
	St. Dev.	0.204	0.017	0.068	0.0054	0.0163	0.0067
APP-AT3a	*Mean*	-0.006	-0.036	-0.008	-0.0103	-0.0052	0.0094
	St. Dev.	0.024	0.024	0.035	0.0099	0.0047	0.0070
APP-AT3b	*Mean*	-0.005	-0.030	-0.009	-0.0077	-0.0050	0.0122
	St. Dev.	0.029	0.022	0.035	0.0087	0.0048	0.0071
APP-AT4a	*Mean*	-0.004	-0.015	-0.003	-0.0075	-0.0062	0.0219
	St. Dev.	0.041	0.027	0.031	0.0059	0.0046	0.0068
APP-AT4b	*Mean*	-0.005	-0.016	-0.004	-0.0079	-0.0057	0.0226
	St. Dev.	0.042	0.027	0.030	0.0056	0.0046	0.0068

Table V. Statistical parameters of the comparison from exterior orientation parameters for Palermo project (X, Y, Z, in meters – omega, phi e kappa in grad)

	AT1			AT2			AT3a			AT3b			AT4a			AT4b		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
Mean	-0.014	-0.047	-0.027	-0.015	-0.014	-0.090	-0.021	-0.049	-0.015	-0.016	-0.009	-0.005	0.011	-0.001	-0.006	0.001	-0.023	-0.005
St.Dev.	0.059	0.100	0.052	0.042	0.038	0.055	0.058	0.102	0.048	0.040	0.081	0.055	0.033	0.047	0.054	0.042	0.041	0.058
Min.	-0.137	-0.156	-0.134	-0.063	-0.049	-0.169	-0.136	-0.150	-0.127	-0.093	-0.088	-0.099	-0.044	-0.052	-0.098	-0.047	-0.057	-0.094
Max	0.081	0.120	0.060	0.039	0.045	-0.019	0.072	0.122	0.062	0.030	0.133	0.066	0.063	0.074	0.062	0.059	0.044	0.042

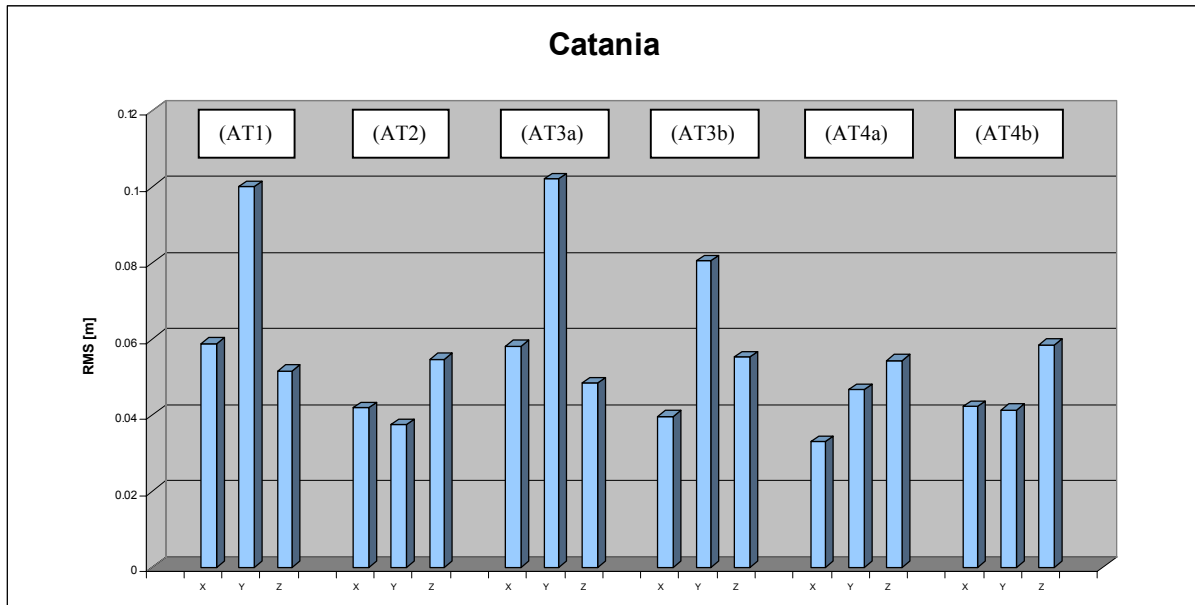Table VI. Check point statistical parameters for Catania project (in meters)

Figura 5. Check point quality (RMS) from AT based from different input data (Catania project)

Figure 6. Ortophoto of Catania (APP)

	APP - AT1			APP - AT4b		
	RMS	*RMS X*	*RMS Y*	*RMS*	*RMS X*	*RMS Y*
Mean	0.114	-0.071	0.084	0.140	-0.096	0.101
St. Dev.	0.035	0.036	0.030	0.015	0.010	0.017

Table VII. Statistical parameters of the comparison from the ortophotos for Catania project (in meters)

results of the comparison between the coordinates of some points located over the APP orthophoto (fig. 6) with those of the same points derived from the orthophotos related to other two configurations; the average discrepancies are in the order of 10 cm.

4. CONCLUSIONS

Results obtained in both tests confirm precision and reliability of this innovative technique. The use of the direct georeferencing, also for production of digital large scale orthophotos, seems to insure geometric accuracy required by map standards.

Several check were carried out comparing the exterior orientation parameters derived from GPS/INS sensor (APP) with those computed by AT according to different configurations; particularly the following configurations were considered: AT with APP data and tie points (AT1); traditional AT with tie-points and GCPs (AT2); AT with APP data, tie-points and 1 GCP (AT3a) or 4 GCPs (AT3b). Besides, for one of the two available flights, a calculation was done considering only the perspective centre position and a small number of GCPs, respectively 1 GCP (AT4a) and 7 GCPs (AT4b). Discrepancies between these values and APP ones always result very small, both with regard to the perspective centres and the orientation angles.

The accuracy of the different AT configurations was computed using some points surveyed by GPS method and employed as CPs in the AT procedures. The residuals are always resulted within geometrical tolerance required by National map standards for digital orthophotos produced at scale of 1:2000 and 1:200.

A final check was done comparing the othophotos produced from APP data with those related to AT1 and AT2 configurations for Palermo and AT1 and AT4b configurations for Catania. The results show RMS in the order of few centimetres for both projects.

Using direct exterior orientation parameters and some tie-points (AT1 configuration) it is possible to get results equivalent to those obtained with use of some GCPs. However such procedure does not permit to check the presence of systematic or gross errors. The use of a certain number of CPs seems to be essential to control the geometric accuracy of data also with reference to national map standards.

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