AERIAL PHOTOGRAPHIC COVERAGE OF IRELAND WITH GPS IN 12 DAYS

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ABSTRACT:

In 1995 the Ordnance Survey of Ireland commissioned Aerial Photography of Ireland to support its small scale mapping programme, and the production of Orthophotos for validating farmers claims under the European Economic Commission's (EEC) IACS program. The photography specified was black and white, full stereo near vertical Aerial Photography at a scale of approximately 1:40,000. Coordination of the photo centers by GPS was required with a RMSE of 1 m. Following a tendering exercise, Compagnia Generale Ripreseaeree (CGR) was awarded the job based on the merit of their technical proposal, commitment to completing the task with GPS and their aircraft capability. As a result of unprecedented good weather during the summer of 1995 the aerial photography was successfully completed in 12 days. Approximately 4000 photos were taken in 77 strips running east and west across Ireland. Because of the availability of the Learjet and the favorable meteorological conditions the photogrammetric crew made it possible to fly for seven hours per day while remaining within the specification of the contract. The automatic functioning of the camera by GPS has taken up about 90% of the entire work. During the flight the pilot used the GPS system as an assisted navigational instrument. Finally, thanks to carrier phase and C/A code GPS data was recorded during the flight by on board GPS receivers and at 3 GPS base stations on the ground, located at previously surveyed sites, it was possible to calculate the path of each strip. Data post processing was effected with commercial software supplied by Leica operating in kinematic mode without static initialization. The distance between the airborne GPS and the nearest ground station, varies from a few km to a maximum of 200 km.

1. INTRODUCTION

The Ordnance Survey of Ireland is the state mapping agency responsible for collecting, processing and distributing geographical and topographical mapping information of Ireland required by the public and private sectors.

One of its objectives is to provide a national up to date topographic database for users of mapping and geographic information systems in support of National Economic and Social Development. In order to meet this objective, Ordnance Survey are implementing a National Mapping Programme to meet customer driven requirements and future national mapping needs, which includes the development of a small scales digital database, surveyed to an accuracy consistent with 1:10,000 scale mapping to support graphical mapping products of scales in the range 1:10,000 to 1:500,000. Data collection for this database is over half way complete, and the priority mapping product is the 1:50,000 scale 'Discovery' map series, a widely acclaimed and technically advanced product which serves the tourist and general map user as well.

A range of analytical and semi analytical plotters are used for the small scales planimetric data collection, and up to 15 Leica/Helava Digital Photogrammetric Workstations (DPW's) are used to collect Digital Terrain Models (DTM's) using Helava autocorrelation techniques. To date this mapping has been based on 1:30,000 scale stereo aerial photography from the 1970's, but the need for up to date photography to complete the programme, and to maintain the mapping already undertaken became urgent.

In addition to this mapping requirement the Department of Agriculture, Food and Forestry (DoAFF) required up to date aerial photography (in the form of digital orthophotography) for the purposes of validating claims made by farmers for subsidies under the Common Agriculture Policy (CAP). These claims were supported by OS large scale (1:2500 scale) maps, with the areas claimed outlined by the farmer. EC Council regulation 3508/92 required an Integrated Administrative and Control System (IACS) to be established by January 1996, which would validate the claims made by farmers. This combined need was to be met by a contract for 1:40,000 scale, near vertical, stereo aerial photography, to be let and managed by Ordnance Survey.

Many reports were being written on the benefits of controlling aerial photography using GPS, particularly in reducing the amount of Ground Control required. Therefore this was an opportunity to examine the potential for GPS and photogrammetry and to test the claimed benefits.

Following a tendering process, Compagnia Generale Ripreseaeree (CGR) from Parma (Italy) were contracted to undertake the task. CGR were chosen on their technical merit, commitment to completing the task using GPS and their Learjet capability which would provide the highest likelihood of taking advantage of the expected weather windows. Over 20 years experience in flying aerial photography in Ireland led OS to conclude it was unlikely that the contract would be completed in one season (April to September 1995). A previous contract, let in the 1970's took 6 years to complete full cover at 1:30,000 scale, therefore there was an optimistic expectation of only 60% coverage in the first year for this project.

2. THE PHOTOGRAMMETRIC FLIGHT

2.1 The Planning

The entire flight project was executed by means of the "Flight-Planning" program (an Ascot routine see below) which identified the geographic coordinates in space within the Irish reference system ellipsoid of all the projection centers of the expected 4000 photographs. The data, stored on PCMCIA cards, permitted the automatic operation of the RC 30 camera driven by a PC connected to a Magnavox GPS receiver. CGR technicians used this planning methodology for the first time. The main difficulty experienced was the difficulty of minimizing the number of strips because the program assumes a flat ground and does not allow forvariations in ground relief; moreover, the transformation between geodetic datum (i.e. Irish Grid and WGS84) is performed by simple translations only, sufficient for a flying height of 6000 m, but probably inadequate for a low level flying heights. An illustration of the flight plan of the aerial photographic survey is shown in fig. 1.

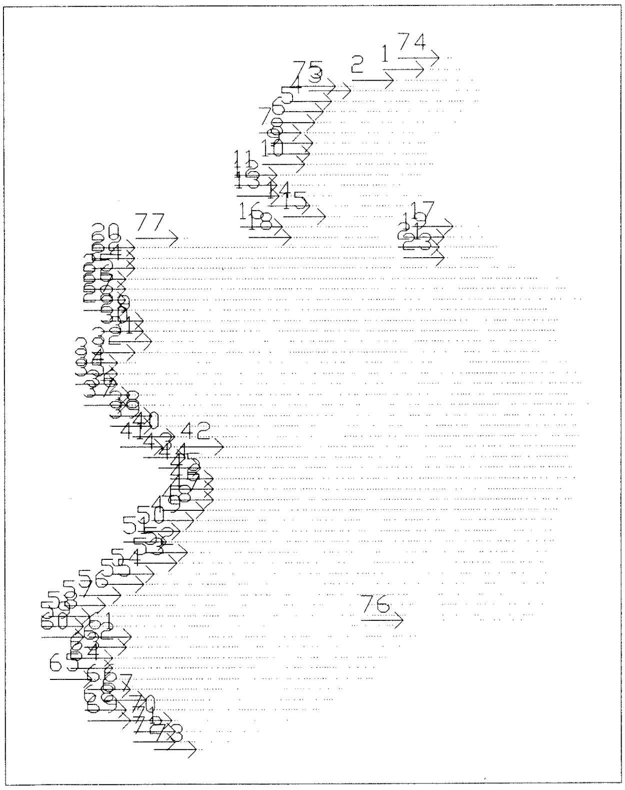

Figure 1 - Flight plan of the aerial photographic survey of Ireland

2.2 The flight

The execution of the survey was based on sun's rays inclinations as given in tables. Accordingly, hours of operation for the sun's inclinations of at least 30° are at a maximum in July, from 08.50 to 18.05 and an operational minimum in October from 11.55 to 14.30. As a result of unprecedented good weather during the summer of 1995 the aerial photography was successfully completed in 12 working days. Because of the availability of the Lear Jet and the exceptionally favourable meteorological conditions it was possible to fly for seven hours per day while remaining within the specifications of the contract. 4164 photos were taken in 77 strips running east and west across Ireland covering 70,025 square kilometres of land at a scale of about 1:40,000 with 60% end lap and 25% side lap. The survey was executed with the Lear Jet 25CI-BMFE (see figure 2) flying at an average height of 21,000 ft at a speed of 350 kts and utilising a Wild RC 30 FMC 15/4 camera with a calibrated lens of 152.93 mm and Kodak 2412 Aerografic Panatomic X film. The automatic functioning of the camera by GPS has taken up about 90% of the entire work. During the flight the pilot has used the GPS system as an assisted navigational instrument. The aircraft was based at in Shannon (in the south) and Baldonnel (near Dublin) airports to minimize transfer times to the area requiring photography. The total number of operative flights were 18 out of a total of about 50 flight hours.

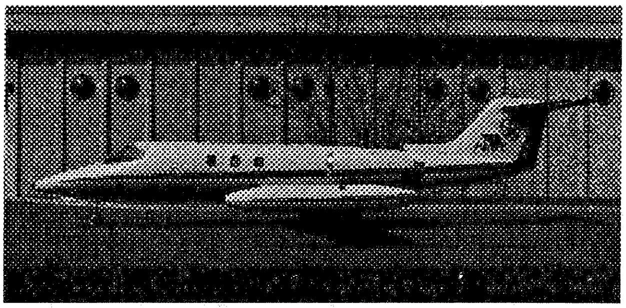

Figure 2 - The Lear Jet 25CI-BMFE used for the work.

2.3 Photos development

The film was developed, checked, and titled at the offices of the CGR in Parma, Italy. There was no need to repeat some of the photographs because of non alignment of the principal points (175°-180°), lack of parallelism between strips, failed coverage of coastal areas, cloud coverage of more than 5% in the area and 10% within a single photo, drift more than 5% and camera tilt more than 2°, exceeding average density of the negatives from 0.80 to 1.10 with variations from 0.20 to 1.50. The aerial photos were free of gaps shadows and clouds. A photo of an assembled mosaic of the aerial photo coverage of Ireland is given in figure 3.

3. GPS FOR AERIAL TRIANGULATION

In the last few years the use of the GPS system in aerial photogrammetry has increased both for navigation purposes and for aerial triangulation. In 1995 the satellite constellation has been concluded both for the minimum number of available satellites and for the daily windows of visibility. Thanks to the research experiences over the last few years with (Astori et al. 1992, Forlani et al. 1994) it was possible to face with competence the enourmous positioning task of such a project covering the survey of a whole country.

The tender signed between the Compagnia Generale Ripreseaeree (CGR) and the Ordnance Survey wanted together with the photos, photographic projection center coordinates with an accuracy of ± 1m. For this purpose, the CGR bought the whole Ascot Leica hardware and software package and the GPS receiver hardware for both the aerial and ground station segments of the operation. Leica equipment has been chosen for two purposes: first of all because the photogrammetric equipment to which the navigation system had to be linked is Leica and specifically Wild RC 30, finally CGR already had two GPS Systems 200 and an experienced staff able to handle GPS data and Leica Ski software.

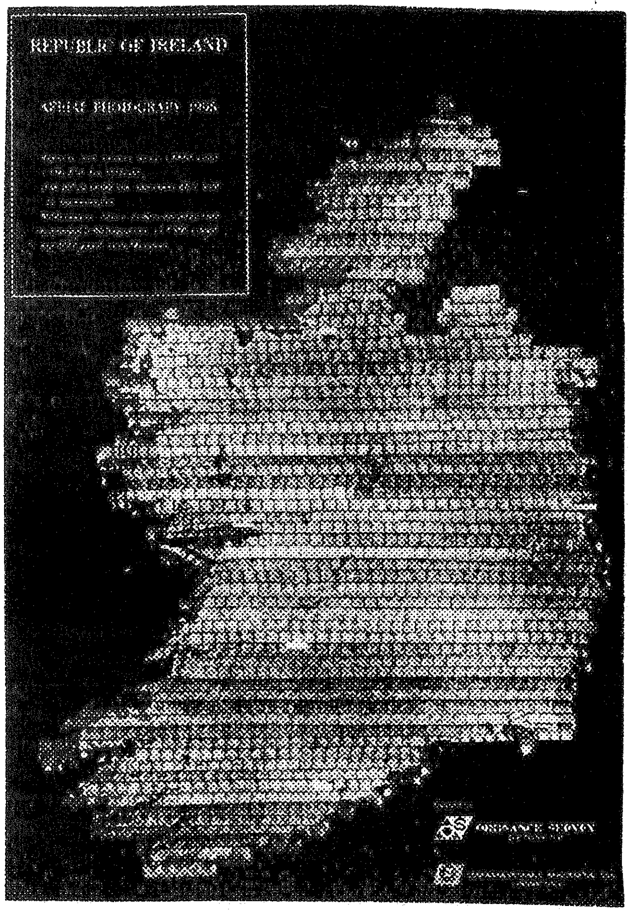

Figure 3 - Assembled mosaic of the aerial photo coverage of Ireland

It is important to state that the Ascot system has performed navigation functions (flight project, airplane navigation control and analysis of the flight path) fairly well, but some deficiencies have been pointed out as regard to the handling of the phase measures to achieve the antenna phase center positions. The Ascot system (Leica ASCOT, 1995) consists of a hardware element and a software element. The hardware element consists of a single frequency GPS receiver with kinematic antenna, a control unit computer with video graphic display for navigation, and a video graphic display for the pilot. The software element includes programs for the flight project planning, control of the GPS during the flight linked to the computer, the storage of the GPS data and the flight analysis once finished. The GPS receivers linked to the control computer can be different: Leica uses a Magnavox series MX9212 single frequency receiver with 12 channels; the choice was made with the intention of using cheap but reliable equipment for kinematic purposes. The standard data recording frequency is 1 Hertz, as given in literature as the frequency necessary to adequately sample the flight path without excessive use of receiver memory. The receiver has an RTCM interface for a radio link to a remote station: which makes differential corrections in real time (DGPS) possible. The antenna must be kinematic at single or double frequence according to the receiver. Leica sells a Sensor System antenna at double frequence L1/L2 of quite compact sizes (Φ = 89 mm and h=15 mm) as well.

3.1 The Topographic Control Framework.

In order to achieve the relative precision of 1 m RMSE required for the GPS controlled photo centers, differential GPS corrections need to be determined by utilising base stations with permanently recording receivers.

Following previous experience on a test field in the North of Italy the location of the base station should be no more than 200 km from the unknown position to be determined (i.e. the aircraft), with the particular receivers' system to be used (Leica MX9212 system which uses single frequency and C/A code measurements in Kinematic mode). Thus, three base stations were required to cover Ireland. These were located in the Dublin, Sligo and Ennis Ordnance Survey Offices (figure 4).

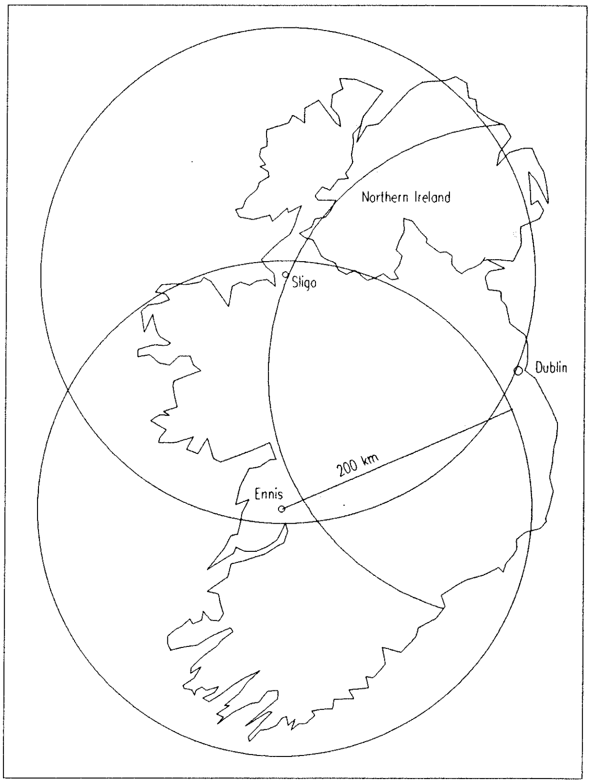

Figure 4 - Ground stations coverage

OS Offices were chosen as they provided secure, permanently manned facilities, with ample provision for power and communications. The GPS antenna's were placed on new stations built on the roofs of the offices.

Each base station was marked, then co-ordinated by static differential GPS observations relative to survey stations with known co-ordinates in the Irish National Grid, using Trimble SSE geodetic receivers, geodetic antenna and Trimble post processing software. Having solved the GPS solution, GPS vectors were then used to obtain the positions of the base stations in terms of the Irish National Grid.

During the flights GPS observations were directly recorded on PC Hard Disks and on PCMCIA cards, each initialization operation has been automatized, and these include the updating of file names for easy combination with the flight mission data.

3.2 Airborne GPS

A Leica MX9212 GPS receiver was placed on the aircraft near the vertical-navigation sight. This was the same type of receiver as that used at the ground stations. The kinematic antenna was placed near the vertical axis of the photogrammetric camera, the antenna eccentricity having been measured by a small survey network (eccentricities were $\Delta x=0.307$ m, $\Delta y=0.392$ m, $\Delta z=1.173$ m). The PC connected to the receiver allowed the recording of the C/A code, phase measurements on the carrier wavelength L1, and 'temporals events'. In addition, it allowed the use of GPS data for navigation purposes and the recording of alphanumeric data onto the photo frames. In order to store the data collected the system used a PCMCIA card onto which all the data necessary for post-processing were recorded. Because of the flying height (6000 m) it was not necessary to have radio link between the ground stations and the remote aircraft GPS.

3.3 Kinematic GPS data post-processing

In order to obtain the control points coordinates (fig. 3), that is to say the projection centers computed with GPS, a consolidated calculation process (Astori et al.,1992) using the Leica software has been used. Three steps have been followed:

- determination of antenna phase centers with regard to the fixed station;
- calculation of the position of the antenna phase center at the time of the camera shutter release;
- calculation of the position of the photogrammetric projection center.

For this last phase it is necessary to know the geometric offset which links the GPS antenna phase center and the photogrammetric camera projection center. It is also important to know the attitude of each photo determined before the A.T. adjustment; these operation are generally implemented in the adjustment program and are not carried out before. As already mentioned, the airborne and ground receivers are single frequency. The kinematic survey was not initialized statically and thus the unknown phase ambiguities were computed in a sequential way with Kalman filtering.

Leica supplied some customised calculation routines for kinematic positioning without initialization (AROF program) and interpolation of the GPS antenna coordinates at the moment of half exposure. The whole SKI software package, part of GPS-Leica equipment, was also available. However, having GPS data in Rinex standard format for GPS data it was possible to use other programs; the author has carried out different tests with the Turbo TOPAS program without finding any significant differences in the results. It is known that the modality of handling OTF processing of GPS data gives results with centimetric accuracy with short initialization given specific hypotheses; these are: dual frequency GPS receivers, P code recording, strong satellite costellation, baseline distances of not more than 10 km. However, it is possible, for photogrammetric purposes, not to determine 'precise' positioning in an 'absolute' sense -without bias-, but an intrinsically precise one with a little straggling of datas, because eventual systematic deviations can be recognized and eliminated in the A.T. block adjustment. This is the reason why the use of cheaper receivers can be accepted. Furthermore because a correct initialization and calculation of the deviations due to the refractions -for which a short length of the basline is necessary - may have systematic errors: at least 5 satellites are necessary. The GPS data post processing with the AROF software has been carried out as follows:

1. Processing of the differencial C/A code measurements for computing an approximate solution for differencial phase processing initialization.
2. Processing of the phase and code measurements (aero L1) for computing the precise solution.

Table 5 mentions some characteristic index of GPS data processing. It is important to say that the ground station for the relative positioning has always been the nearest except for some anomalies (mainly due to the no contemporaneity among the sessions of measure). From table 5 we can make the following considerations:

- It was not possible to compute 10% of the GPS coordinates of photo projection centers out of the 73 projected strips (the 76th and 77th strips are small strips for completion).
- Some strips have been subdivided to allow the post processing in spite of some survey anomalies (due to the photogrammetry or GPS).
- The photogrammetric survey was completed in 12 days.
- The Learjet speed was 12 km per minute, therefore the start and stop times for each strip allows the length of each strip to be calculated (the longest strip -number 57- lasted 33 minutes which gives a length of about 400 km).
- The satellite constellation was very good throughout the photographic capture, with an average of about 8 satellites (the cutoff angle was set at 12°).
- The accuracy shown in the last 3 columns of table relates to the final report of the Ski software. These values indicate an underestimate of about ten times. In spite of this the positioning accuracy is very good.

The GPS data post-processing took two CGR technicians 45 days to complete. Such a long period is due mainly to the difficulties experienced using the phase measurments with Ski software. A number of bugs were discovered; first of all the MX9212 receivers recording all 12 channels was incompatable with the Ski software which was designed to cope with the contemporary adjustment of a maximum of 9 satellites - such as the channels of System 200-. Thus it was necessary to edit data files where more than 9 satellites were recorded, and those with the worst S/N ratio were chosen. Because of the unprecedent good satellite constellation these files amounted to more than 50% of the total. Other bugs were found in the event files. There were errors in the conversion from Julian time to h:m:s, and in the absence of the time correction between UTC and GPS time this resulted in ten second errors during the summer of 1995.

In the data preparation it was also necessary to include the data dividing for each mission in each strip. In particular each flight including various strips of photos has been subdivided into data blocks which have been delimited by the first and the last shutter release times of each strip.

Stip	Date	Ref. St	Sart t	End t.	Sat	SDx	SDy	SDz
1 *	25-06	SLIGO	09:09	09:13	9	.0670	.0596	.2091
2	25-06	SLIGO	09:19	09:24	9	.1619	.1287	.2060
3 *	25-06	SLIGO	09:35	09:46	9	.1644	.1098	.2495
4	25-06	SLIGO	09:49	10:01	9	.0072	.0044	.0114
5	25-06	SLIGO	10:06	10:07	9	.0493	.0263	.0594
6	25-06	SLIGO	10:20	10:31	9	.1230	.0839	.2396
7	26-06	SLIGO	09:42	09:53	9	.0152	.0095	.0242
8	26-06	SLIGO	09:57	10:07	9	.0629	.0344	.0751
9	26-06	SLIGO	10:11	10:21	9	.0555	.0307	.0843
10	14-06	SLIGO	07:44	07:54	9	.0224	.0118	.0309
11	14-06	SLIGO	08:00	08:10	9	.1331	.0706	.1746
12	14-06	SLIGO	08:15	08:26	9	.0243	.0144	.0436
13	14-06	SLIGO	08:32	08:42	9	.0369	.0248	.0622
14	14-06	SLIGO	08:45	08:54	8	.1760	.0876	.1915
17	28-06	SLIGO	10:32	10:36	9	.0047	.0030	.0071
18	26-06	SLIGO	11:10	11:18	8-9	.0033	.0012	.0019
19	28-06	SLIGO	10:40	10:44	9	.0074	.0049	.0106
20	26-06	SLIGO	10:27	10:45	9	.0706	.0261	.0665
21	28-06	SLIGO	10:48	10:53	8	.0130	.0047	.0098
22	26-06	SLIGO	10:49	11:08	8-9	.0238	.0086	.0160
23	28-06	SLIGO	10:57	11:02	9	.0097	.0035	.0063
24A	26-06	SLIGO	11:32	11:54	7-9	.0313	.0220	.0422
24B	28-06	SLIGO	11:07	11:16	9	.0055	.0021	.0028
25	27-06	SLIGO	08:55	09:21	8-9	.0150	.0114	.0200
26	27-06	SLIGO	09:26	09:58	8-9	.0371	.0225	.0584
27	27-06	SLIGO	10:15	10:44	9	.0804	.0295	.0729
27/1	09-08	SLIGO	10:38	10:46	9	.3319	.2168	.3480
28	27-06	SLIGO	10:47	11:18	8-9	.0213	.0079	.0114
29	28-06	SLIGO	09:20	09:47	8-9	.0244	.0151	.0391
30	27-06	SLIGO	15:35	16:04	8-9	.1373	.0886	.2553
31	27-06	SLIGO	15:04	15:30	8-9	.1641	.1149	.2261
32	27-06	SLIGO	14:31	15:01	8-9	.0864	.0641	.1817
33	27-06	SLIGO	13:56	14:26	9	.0517	.0475	.1543
34	26-06	SLIGO	16:05	16:39	9	.1948	.1426	.3594
35	26-06	SLIGO	15:29	16:02	8-9	.2058	.1351	.3692
36	26-06	SLIGO	14:50	15:23	8-9	.1378	.0886	.2325
37A	13-06	ENNIS	12:34	12:55	8-9	.0415	.0280	.0602
37B	24-06	DUBL	10:48	11:04	7-9	.1635	.0596	.1357
38	26-06	SLIGO	14:17	14:44	9	.0548	.0417	.1565
39A	24-06	ENNIS	10:10	10:26	9	.0595	.0314	.0723
39B	24-06	DUBL	10:29	10:47	9	.0586	.0375	.0923
40A	13-06	ENNIS	12:05	12:28	8-9	.0261	.0102	.0189
40B	27-06	DUBL	16:10	16:21	7-9	.2134	.1416	.4526
41 *	24-06	ENNIS	10:02	10:06	8	.0883	.0542	.1422
42	24-06	ENNIS	09:39	10:02	8-9	.0168	.0104	.0270
42/1	09-08	DUBL	11:01	11:05	8	.0979	.0619	.0989
43/1	09-08	SLIGO	07:59	08:03	8-9	.0110	.0040	.0078
43/3	09-08	SLIGO	07:53	07:57	8	.0001	.0000	.0001
43A	13-06	ENNIS	11:26	11:54	8-9	.0182	.0066	.0141
44	24-06	ENNIS	09:08	09:35	8-9	.0317	.0239	.0428
45	24-06	ENNIS	08:37	09:02	9	.0377	.0311	.1259
45/1	10-08	DUBL	17:47	17:54	6-7	.1464	.0708	.1167
46	23-06	ENNIS	13:50	14:17	9	.4484	.2872	.4720
47	23-06	ENNIS	13:21	13:47	9	.2671	.1814	.2959
48	28-06	ENNIS	14:26	14:52	8-9	.0734	.0540	.1494
49	23-06	ENNIS	12:54	13:17	9	.2058	.1116	.3322
50A	23-06	ENNIS	12:39	12:42	7-8	.0142	.0085	.0181
50B	23-06	ENNIS	12:07	12:32	6-9	.0803	.0504	.0928
51	23-06	ENNIS	09:00	09:27	9	.1656	.1366	.2025
52	23-06	ENNIS	08:29	08:57	7-8	.0313	.0290	.0624
53	23-06	ENNIS	07:59	08:27	7-8	.0752	.0391	.0722
54	22-06	ENNIS	07:24	07:52	9	.1580	.0926	.2813
55	22-06	ENNIS	07:57	08:27	6-9	.0132	.0068	.0134
56	22-06	ENNIS	08:30	09:01	6-9	.2042	.1876	.4164
57	22-06	ENNIS	09:06	09:39	8-9	.0715	.0559	.0927
58	22-06	ENNIS	11:59	12:29	7-9	.0622	.0402	.0673
59A	22-06	ENNIS	12:34	12:58	7-8	.0648	.0365	.0928
59B	22-06	ENNIS	14:01	14:06	9	.1752	.1148	.1914
60 *	22-06	ENNIS	13:24	13:28	9	.0863	.0589	.1673
61	22-06	ENNIS	13:04	13:24	8-9	.1014	.0694	.1985
63	23-06	ENNIS	09:37	10:00	8-9	.0192	.0124	.0305
64	28-06	ENNIS	13:54	14:16	9	.1754	.0963	.2690
65	12-06	DUBL	08:22	08:42	8-9	.1122	.0712	.1997
66	12-06	DUBL	07:57	08:14	8-9	.1167	.0622	.1578
67	12-06	ENNIS	08:46	09:02	8-9	.0355	.0178	.0390
68	13-06	ENNIS	07:08	07:24	9	.1045	.0496	.0823
69 *	13-06	ENNIS	07:37	07:41	8-9	.0740	.0451	.1004
70	13-06	ENNIS	07:26	07:37	9	.0300	.0168	.0399
71	13-06	ENNIS	07:50	07:58	9	.0195	.0104	.0271
72	13-06	ENNIS	07:59	08:05	9	.1418	.0747	.1953
73	28-06	ENNIS	09:56	10:01	9	.0062	.0034	.0075
76 *	28-06	DUBL	13:43	13:48	8	.1453	.0941	.1556

Table 5 - Kinematic GPS post-processing of all GPS data.

In this way each strip has been initialized separately from the others. Any eventual systematic error caused by this operation will be erased at the time of the A.T. adjustment by adding, for each strip, 6 additional unknowns due to a linear drift (Forlani et al., 1994).

An interesting test has been carried out to study the incidence of the distance between ground station and rover GPS. For a short strip -number 72, made up of 19 photos- the kinematic data have been analyzed as regards to the three ground stations. Table 6 reports the relevant parameters of the various processing. The table shows that the positioning accuracy is not bad altrough the distance -estimated about in the strip center- is much bigger than the usual one (less than 200 Km). Besides, the differences among the photos coordinates computed with regard to the nearest station (Ennis) show only systematic and not very big errors without a significative SD (about 1 centimetre).

4. AERIAL TRIANGULATION TEST

The Ordnance Survey carried out a small test for six photos in strip number 64 comparing the differences between the PAT-MR Aerial Triangulation software results and the same coordinates obtained by GPS post processing. Table 7 show the differences for each of the 3 coordinates reported. Even if at first sight the differences may appear above the requested positioning accuracy, it is easy to understand that this is mainly due to a systematic error.

Strip	Ground station	Slope [m]	SDx [m]	SDy [m]	SDz [m]	Δx [m]	Δy [m]	Δz [m]	SDΔx [m]	SDΔy [m]	SDΔz [m]
72	Ennis	168,330	0.142	0.075	0.195	–	–	–	-	-	-
72	Dublin	324,675	0.120	0.064	0.165	–1.534	–0.953	–1.309	0.008	0.004	0.014
72	Sligo	330,095	0.122	0.065	0.167	–1.248	–0.012	–0.939	0.004	0.007	0.007

Table 6 - Statistical result of the strip processing test with three ground stations

In fact the Standard Deviation is 1.32 m in Est coordinate, 0.48 in North and 0.69 in Height.

Photos n.	ΔE [m]	ΔN [m]	ΔH [m]
8667	-4.66	3.58	-10.98
8668	-2.79	2.59	-10.64
8669	-3.13	3.69	-10.88
8670	-3.17	2.96	-10.94
8671	-2.00	3.67	-10.15
8672	-0.70	3.74	-9.21

Table 7 - Differences between GPS and A:T. data from PAT-MR adjustment.

Our test indicates some systematic shift in all three axes (easting, northing and height). However, possible causes, besides those due to the OTF positioning, are as follows.

1) Transformation at the nearest base station. The transformation parameters were derived from the nearest three or four surrounding irish primary triangulation points to the base station. The WGS84 co-ordinates of these points were themselves derived from a transformation based on doppler observations in the 1980's, therefore they are probably only good to 1-2 metres which is the limitations of WGS84 system.

2) Quality of the triangulation network. Recent tests on the irish triangulation network (on which the national grid is based) indicates distortions of up to 1 metre exist when compared to global reference systems (e.g. itrf or etrf89).

3) There are physical limitations in measuring fiducial marks and photo control on 1:40,000 scale photography and therefore the resulting quality of air trig, on which these GPS data have been compared.

Therefore, we would conclude that although there is an apparent systematic bias when compared against the national reference frame, it is within the limits of the quality of the irish grid, and certainly within the physical limits of measuring off this scale of photography. The requirement for ± 1m accuracy stated in the specifications relate to accuracy relative to the base station, within a global reference frame (e.g. WGS84).

If besides, the effect of a linear trend shutter release time depending is subtructed from the differences, the S.D. are ulteriorly reduced to values inferior to 1 m.

Finally it is important to underline that the linear trend drift is not significant for the N component.

Coord.	SD before removing linear drift [m]	SD after removing linear drift [m]
E	1.32	0.54
N	0.48	0.41
H	0.69	0.38

Table 8 - SD of differences in the projection center coordinates before and after removing linear drift.

5. CONCLUSIONS

The tender stipulated from OS and CGR provided for the photographic coverage, with GPS, at a scale 1:40,000, of the whole Ireland. This resulted in 77 strips, 4000 photos, and a total of 11,000 line km of flying, realized in only 12 days. The Leica ASCOT System has been used for flight planning and controlling and for computing photo projection centres. With regard to this the following things are concluded.

- The flight planning software assumes a flat ground. This does not allow for optimization in the number of strips and of the photos per strip. However we hope that future planning can be undertaken with the aid of a digital elevation model.
- The system has provided good flexibility with regard to navigation assistance. The only solution to record the projection center coordinates during camera manual use, is that provided by connecting an INS (Inertial Navigation System) to the GPS up to now available at good price.
- The use of the GPS receivers at single frequency has not penalized the aerial control points accuracy. The possibility of a OTF positioning, with double frequency receivers, would allow a subdecimetre accuracy suitable to any photogrammetry purpose.
- Finally the post processing has pointed out various deficiencies (as for example the use of different temporal scales for the measurement and the recording of external events). Presently, Leica staff are preparing an updated version of their software system thanks to the results obtained from this project.

The use of GPS to control the photo centres coupled with the size of the area covered and the importance of the work, makes this job unique within Europe, enabling an analysis of the use of GPS controlled aerial photography in a production environment.

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