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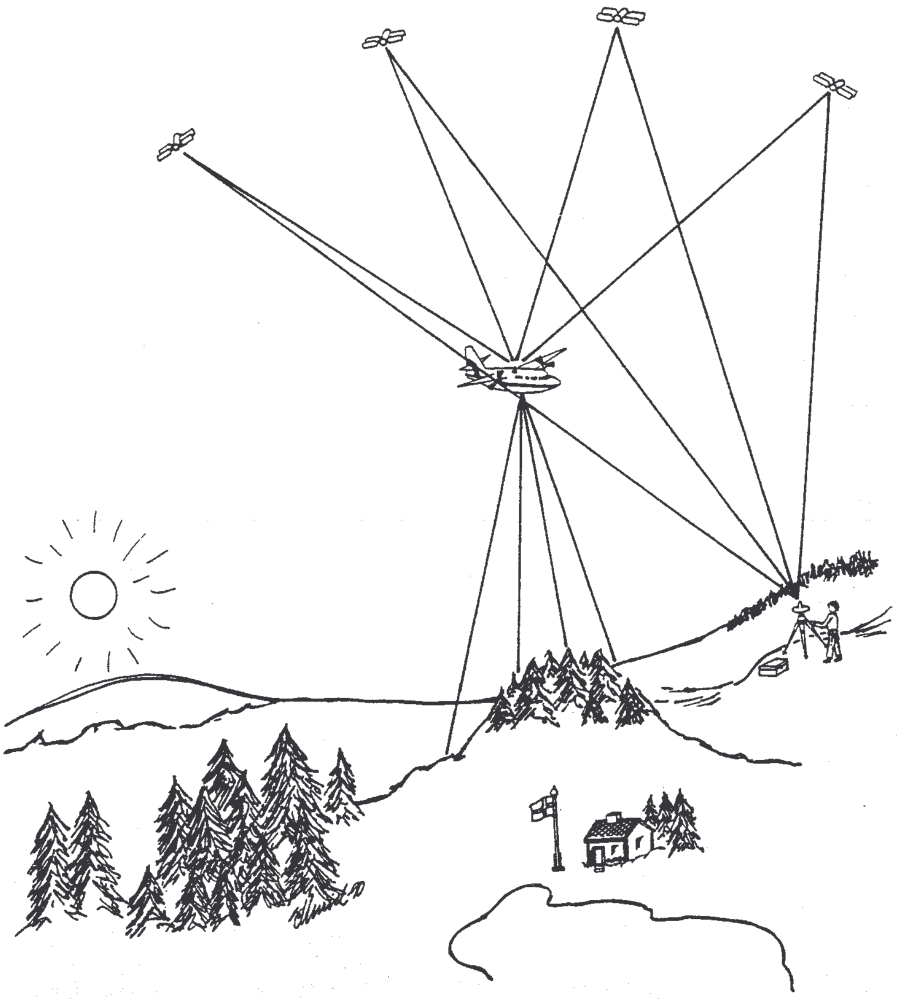
EXPERIENCES FROM KINEMATIC GPS MEASUREMENTS

by Bo Jonsson and Ann-Charlotte Jivall



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EXPERIENCES FROM KINEMATIC GPS MEASUREMENTS

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This report was presented at the 11th General Meeting of the Nordic Geodetic Commission in Copenhagen 1990.

Results and some practical experiences from kinematic GPS measurements in an airborne photogrammetric experiment are described.

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EXPERIENCES FROM KINEMATIC GPS MEASUREMENTS.

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ABSTRACT

Kinematic GPS measurements can be used for some geodetic applications and for airborne photogrammetry. This technique gives positions with centimeter accuracy from short observation periods.

The National Land Survey has tested Ashtech LXII GPS receivers in a geodetic positioning application and airborne photogrammetry. Some practical experiences from the airborne photogrammetric experiment are described in this report.

1. INTRODUCTION

Kinematic GPS techniques have potential applications at the National Land Survey (NLS) in geodesy and for airborne photogrammetry.

In August 1989 a kinematic GPS survey was carried out at the NLS observatory Mårtsbo as a diploma work by Kennet Fredriksson from the Royal Institute of Technology, Stockholm. The results and experiences of this study will be published as a Professional Paper from NLS.

In September 1989 an experiment in airborne photogrammetry was performed at an established photogrammetric test field at Rörberg airport 15 km west of Gävle. The goals for the use of the GPS-techniques in this experiment were the following:

- to give information to the pilot about the position of the aircraft with respect to the planned photo strip i.e. to navigate
- to enable automatic exposures to be made in preselected positions
- to determine the position of the airborne camera at the time of the exposure.

Ashtech LXII GPS receivers and an Ashtech GPPS post-processing software package were used. For the recording of the times of the exposures a PC card was put at our disposal by Institutt for Kontinentalsokkelundersökelser og Petroleumsteknologi AS (IKU), Trondheim, Norway. The airborne camera which was used was a Zeiss-Jena LMK, which was installed in a small Cessna aircraft, with a flying velocity of 180 km/h (50 m/s), see figure 1. The flying altitude was 500 meters.

Figure 1. The Cessna aircraft with installed camera and GPS equipment.

2. GPS-EQUIPMENT AND OBSERVATION METHODS

One basic requirement in the specifications for the purchase of GPS equipment at the Land Survey in May 1989 was that it should be possible to use the receiver for airborne photogrammetry i.e. the receiver should fulfill the following requirements:

- up-date rate for positions and measurements should be 1 second or less
- real time output of velocity and time-tagged position
- an output of 1 pulse per second timing signal
- a possibility to record the time of the exposure is desirable
- time tagged positions, raw carrier phase observations, intergrated doppler and pseudo ranges should be recorded in an internal memory in the receiver or on a connected PC
- simultaneous observations of at least 6 satellites
- carrier tracking in high dynamics (0,5 g - 4 g).

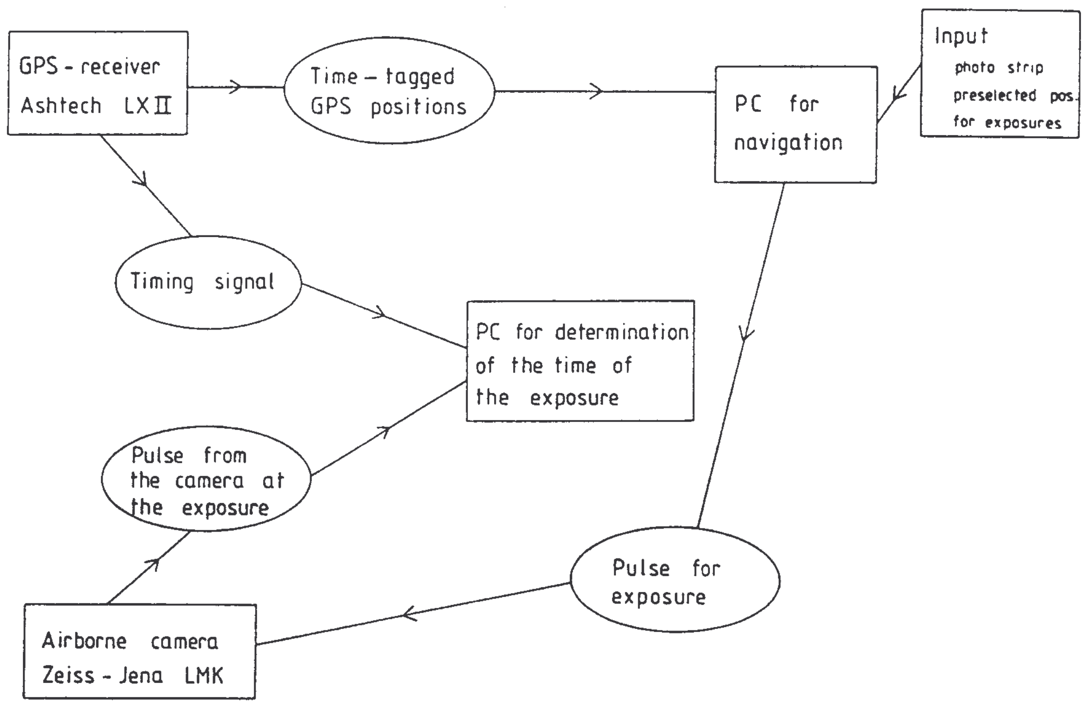

Figure 2. Functional diagram for the equipment in the aircraft.

The receiver which fulfilled these requirements in May 1989 was the Ashtech LXII.

The configuration of the equipment which was used in the experiment is shown in figure 2. Because of a delay in the delivery of the option "photogrammetry camera input" to the Ashtech receiver, two PCs were used in this experiment, one for navigation and steering exposures (navigation PC) and the other for the recording of the times of the exposures. Before the flight, the coordinates of the preselected positions for the exposures were entered into the navigation PC and the clock in the PC was synchronized with the timing signal from the GPS receiver. During the flight the GPS receiver transmits time-tagged positions and velocities every second to the navigation PC, which activates an exposure when the aircraft reaches the preselected position. The navigation PC also provides information to the pilot about the position of the aircraft with respect to the planned photo strip and about the predicted time for the exposure. In the future this information will probably be entered into the auto pilot of the aircraft. The PC card for the recording of the times of the exposures will in the future be replaced by the photogrammetry camera input option to the Ashtech receiver.

The methods relative carrier smoothed code and relative carrier phase measurements were used for the positioning of the aircraft at the exposure and the method carrier smoothed code measurement for the navigation. The following observation data was recorded: time-tagged pseudo ranges, integrated doppler and carrier phase. The ambiguities were determined by relative static observations on a reference mark with a known position before the flight. Signal lock on at least four satellites, which are common for the reference stations and the mobile receiver, are necessary during the whole flight in order to be able to compute the position of the camera using Ashtech's software package.

The GPS antenna was mounted on the aircraft in such a way that it was centered above the camera with an accuracy of a few centimeters during the photography. The camera was locked to the aircraft body during each photo strip.

3. PHOTOGRAMMETRIC TEST FIELD

A photogrammetric test field, based on the test field for EDM instruments and theodolites at the Rörberg airport (4), was established, see figure 3. The ground control stations have been located for the flying altitude 500 meters. The ground control survey was connected to both the national triangulation network (RT R10) and the levelling network (RH70).

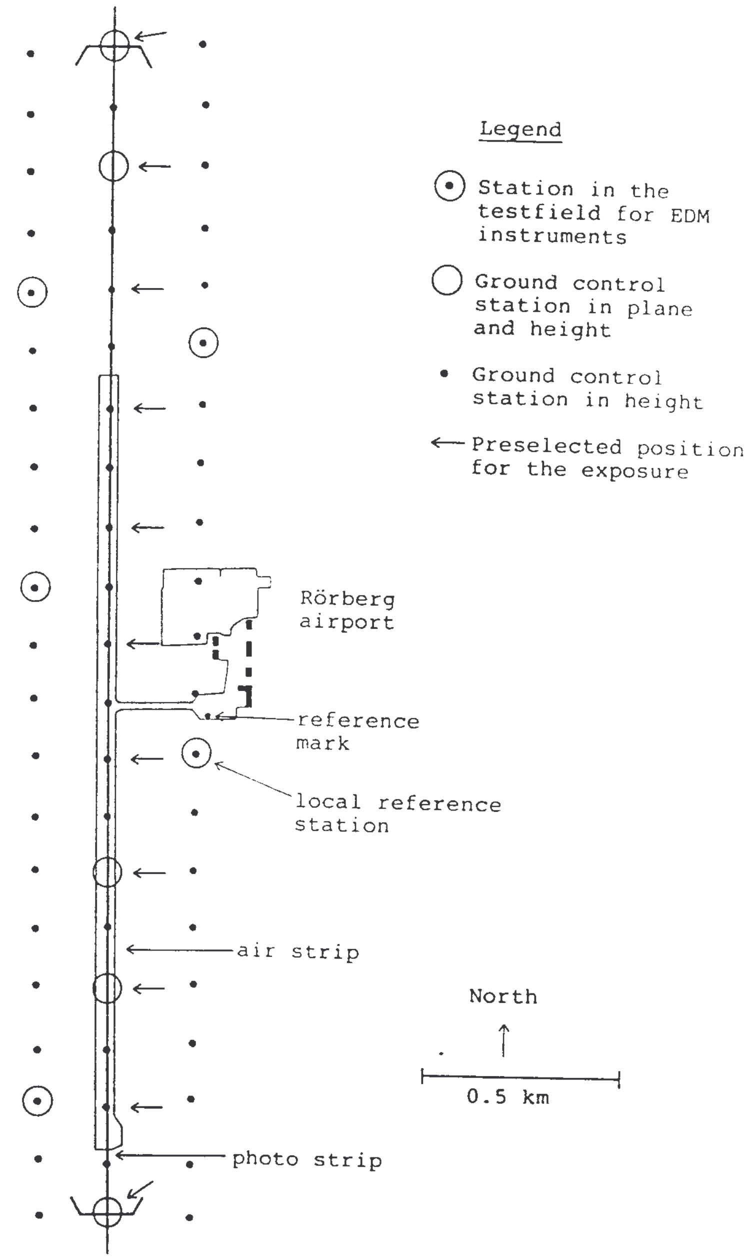

Figure 3. Photogrammetric test field at Rörberg airport.

4. GPS OBSERVATIONS

Because of delays in the preparations of the experiment the photography could not take place until the end of September 1989. The satellites were above the horizon early in the morning in September but the quality of the photos was satisfactory for an accurate photogrammetric determination of the coordinates of the airborne camera. We had problems with fog at sunrise, during some mornings.

One of the stations in the testfield for EDM instruments was used as a local reference station during the flight. A reference mark with a known position, close to the air strip was used for the determination of the ambiguities before take-off. The goal was to return to this reference mark after the flight with maintained signal lock on at least four satellites. However it was not possible to reach the reference mark after landing without a number of cycle slips.

In order to maintain signal lock to satellites with low elevations (20-25 degrees) it was not possible to bank the aircraft in the turns between the photo strips which resulted in very wide turns and a lot of observation data. In our experiment we had 1 Mb of internal receiver memory available, which is sufficient for about 1 hours observation of five satellites with one second between the observations.

The reception of the GPS signals was disturbed (cycle slips for all satellites) when the communication transmitter of the aircraft was used. It was no problem to use the receiver part of the communication equipment. Three strips were photographed and they are denoted strip 2, 3 and 4.

Table 1. Satellite visibility at Rörberg airport 22 September 1989.

Alm Ref	506	506	506	506	506	506	506	506	
SV Num	2	3	6	9	11	12	13	16	
UTC Time	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	
05:44:00	¦	31 182	¦	19 126	37 43	65 134	65 121	¦	
05:45:00	¦	32 182	¦	18 127	36 43	64 134	65 120	¦	
05:46:00	¦	32 182	¦	18 127	36 43	64 134	65 119	¦	← Strip
05:47:00	¦	33 182	¦	17 127	35 42	63 134	65 117	¦	no 2
05:48:00	¦	33 182	¦	17 127	35 42	63 135	65 116	¦	
05:49:00	¦	34 182	¦	17 128	35 42	62 135	66 115	¦	
05:50:00	¦	34 182	¦	16 128	34 42	62 135	66 114	¦	
05:51:00	¦	35 182	¦	16 128	34 42	61 135	66 113	¦	
05:52:00	¦	35 182	¦	15 128	33 41	61 135	66 111	¦	
05:53:00	¦	36 182	¦	15:129	33 41	60 136	66 110	¦	
05:54:00	¦	36 182	¦	14:129	33 41	60 136	66 109	¦	← Strip
05:55:00	¦	37 182	¦	14:129	32 41	59 136	66 108	¦	no 3
05:56:00	¦	37 182	¦	14:129	32 41	59 136	67 106	¦	
05:57:00	¦	38 182	¦	13:129	31 41	58 137	67 105	¦	
05:58:00	¦	38 182	¦	13:130	31 40	58 137	67 104	¦	
05:59:00	¦	39 182	¦	12:130	30 40	57 137	67 102	¦	
06:00:00	¦	39 182	¦	12:130	30 40	57 137	67 101	¦	
06:01:00	¦	40 182	¦	11:130	30 40	56 137	67 100	¦	← Strip
06:02:00	¦	40 182	¦	11:130	29 40	56 138	67 99	¦	no 4
06:03:00	¦	41 182	¦	11:131	29 40	55 138	67 97	¦	
06:04:00	¦	41 182	¦	10:131	28 40	55 138	67 96	¦	
06:05:00	¦	42 182	¦	10:131	28 40	54 138	67 95	¦	
06:06:00	¦	42 182	¦	9:131	27 39	54 138	67 93	¦	
06:07:00	¦	43 182	¦	9:132	27 39	53 139	66 92	¦	
06:08:00	¦	43 182	¦	9:132	27 39	53 139	66 91	¦	

The alert in table 1 shows that there were five simultaneous satellites available only during photo strip 2. During the photography of strips 2, 3 and 4 signal lock on at least four satellites was maintained both in the aircraft and at the reference station. But between the strips 2 and 3 only 3 common satellites were observed which, together with the fact that it was not possible to reach the reference mark after the landing with maintained signal lock, resulted in it being impossible to process the carrier phase measurements for the strips 3 and 4 using Ashtech's software package. More favourable locations of the satellites in the future and 5-6 simultaneous satellites will improve the possibilities for continous signal lock to at least four common satellites. Another possibility is to combine the GPS receiver with an inertial system.

5. PHOTOGRAMMETRIC EVALUATION

The goal for the photogrammetric evaluation was to determine the 3-dimensional position for the projection center of the camera at the exposure.

The evaluation has been carried out in two steps. In the first step a photogrammetric densification was carried out by arial triangulation in each strip. Then the position for the projection center of the camera was determined in each photo using single point intersection. The accuracy of the obtained photogrammetric positions is in the order of 5 cm per coordinate (1 sigma).

6. COMPUTATION OF THE GPS-OBSERVATIONS

Time-tagged positions and velocities of the aircraft have been recorded every second and can be used to improve the software in the navigation PC.

Recorded observation data have been processed using the programmes KINSRVY and PPDIFF from Ashtech. KINSRVY computes relative positions once a second from the carrier phase measurements and PPDIFF does the same from recorded pseudoranges and integrated doppler measurements.

The times of the computed GPS positions have been obtained from the conversion program between observation data in Ashtech format and the ARGO format. The position of the camera has been interpolated from the obtained relative GPS positions using the times of the exposures recorded by the PC card.

The GPS coordinates of the camera have then been provisionally transformed to the national coordinate system using the transformation formula between WGS84 and RT90, which has been developed for navigation purposes by NLS. Finally a local Helmert transformation have been performed using two transformation stations and a local connection to the national height system.

Table 2. Comparisons between actual exposed and preselected positions and between relative code and photogrammetric positions.

STRIP NO 2 (north to south)

Exp no		Int fac.	PDOP	Diff: exp pos - preselected pos (meters)			Diff: rel code pos - photogrammmetric pos (meters)		
				dx	dy	dh	dx	dy	dh
14	5	0.5	3.4	-33.2	-48.1	-17.4	-0.01	-1.37	-5.51
15	5	0.1	3.4	-45.5	-59.3	-18.2	1.87	-5.27	-1.62
16	5	0.5	3.4	-30.9	-64.2	-18.0	2.34	-4.90	2.99
17	5	0.5	3.4	-32.4	-63.9	-18.2	1.27	1.29	-1.15
18	5	0.6	3.4	-29.9	-53.7	-18.5	0.57	4.31	-0.05
19	5	0.1	3.4	-43.0	-33.7	-17.7	0.97	-2.56	-2.27
20	5	0.0	3.4	-27.8	-8.3	-17.1	-0.74	2.14	5.28
21	5	0.2	3.4	-26.4	15.6	-18.1	-0.26	2.81	-1.61
22	5	0.5	3.4	-32.9	18.7	-23.7	-2.72	3.49	0.46
23	5	0.7	3.4	-32.8	13.6	-23.1	-1.14	0.13	2.82
24	5	0.5	3.4	-30.9	15.4	-19.3	0.06	1.89	-0.53
	Mean:			-33.2			0.20	0.29	-0.11
	Stand. dev.:			5.87			1.44	3.25	2.95

STRIP NO 3 (south to north)

Exp no		Int fac.	PDOP	Diff: exp pos - preselected pos (meters)			Diff: rel code pos - photogrammmetric pos (meters)		
				dx	dy	dh	dx	dy	dh
25	4	0.0	17.9	15.1	-72.0	-16.8	-4.89	9.27	-1.47
26	4	0.1	17.6	24.9	-67.5	-14.0	2.11	-8.07	-8.53
27	4	0.1	17.4	14.5	-56.2	-16.1	4.44	-11.41	-8.70
28	4	0.4	17.2	19.2	-39.7	-18.1	0.35	-1.93	-1.40
29	4	0.6	17.0	17.6	-25.9	-19.0	0.73	-4.78	2.72
30	4	0.1	16.8	33.0	-7.7	-21.4	2.47	0.18	3.25
31	4	0.1	16.7	29.6	11.2	-23.6	-6.69	21.04	-1.75
32	4	0.1	16.5	19.5	27.8	-23.4	-5.18	15.48	-13.35
33	4	0.1	16.3	14.4	32.9	-21.7	4.21	-9.97	0.18
34	4	0.4	16.2	19.8	31.5	-19.0	4.95	-16.25	8.85
35	4	0.6	16.0	14.8	25.4	-14.9	5.28	-21.82	10.22
	Mean:			20.2			0.71	-2.57	-0.91
	Stand. dev.:			6.36			4.37	13.26	7.25

Table 2 (cont.)

STRIP NO 4 (north to south)

Exp no		Int fac.	PDOP	Diff: exp pos - preselected pos (meters)			Diff: rel code pos - photogrammetric pos (meters)		
				dx	dy	dh	dx	dy	dh
36	4	0.0	9.2	-38.0	34.8	-6.4	6.34	-16.39	12.43
37	4	0.0	9.1	-40.2	42.8	-4.6	1.48	-9.63	7.76
38	4	0.0	9.1	-49.4	51.5	-5.4	6.04	-9.29	-0.09
39	4	0.3	9.0	-36.2	56.0	-4.2	7.72	-21.02	13.77
40	4	0.6	9.0	-28.6	54.1	-3.0	9.56	-15.76	3.41
41	4	0.5	8.9	-28.4	52.5	-2.0	6.74	-17.38	4.43
42	4	0.6	8.9	-35.6	52.0	-1.9	3.79	-12.38	8.16
43	4	0.5	8.9	-36.0	53.1	-2.2	6.37	-15.27	10.85
44	4	0.3	8.8	-30.0	53.2	-2.2	5.27	-15.07	9.35
45	4	0.3	8.8	-31.9	52.8	-1.3	5.72	-15.80	13.68
46	4	0.1	8.7	-45.9	53.2	0.9	1.65	-6.22	7.96
	Mean:			-36.4			5.52	-14.02	8.34
	Stand. dev.:			6.81			2.42	4.24	4.40

7. RESULTS

7.1 Exposures in preselected positions

The differences between the actual positions of the exposures and the preselected positions are shown for photo strips 2, 3 and 4 in the left columns of table 2. dx denotes the difference along the photo strip, dy across the strip in the map projection plane and dh denotes the height difference.

The information from the navigation PC has been used very sparingly in this experiment because of shortage of time for instructions before the flight and the fact that there was no separate screen for the pilot. The navigation was principally performed in the following way: The navigator reported to the pilot on the position of the aircraft with respect to the planned photo strip using a standard navigation sight.

The shutter of the camera was opened by an electronic pulse which was sent from the navigation PC when the aircraft reached the preselected position of the exposure. Table 2 shows that the exposures were made 20-40 meters (ca. 0.5 seconds) too late and that the accuracy of an exposure at a preselected position was 6 meters (1 sigma) along the strip in this experiment. The SPS-concept is now implemented on the Block II-satellites which will degrade the accuracy in the future. The main part of the delay for the exposure can be explained by the fact that it was not possible to take into consideration the computation time in the GPS receiver. The position of the aircraft was tagged with the time for the arrival of the position data at the navigation PC.

Table 3. Comparisons between relative carrier phase and photogrammetric positions.

STRIP NO 2 (north to south)

Exp no		Int fac.	PDOP	Diff: rel phase pos - photogrammetric pos (meters) dx	dy	dh
14	5	0.5	3.4	-0.059	0.144	-0.141
15	5	0.1	3.4	-0.224	0.158	-0.185
16	5	0.2	3.4	-0.230	0.228	-0.156
17	5	0.5	3.4	-0.198	0.213	-0.196
18	5	0.6	3.4	0.000	0.223	-0.182
19	5	0.1	3.4	0.058	0.239	-0.139
20	5	0.0	3.4	0.015	0.126	-0.098
21	5	0.2	3.4	-0.249	-0.207	-0.189
22	5	0.5	3.4	-0.232	0.048	-0.168
23	5	0.7	3.4	-0.192	0.422	-0.203
24	5	0.5	3.4	-0.130	0.452	-0.198
	Mean:			- 0.131	0.186	-0.169
	Stand. dev.:			0.114	0.177	0.032

7.2 Positioning of the camera

The differences between positions from relative carrier smoothed code measurements and photogrammetric positions of the camera are shown in the right column of table 2. 5 simultaneous satellites were available in photo strip 2 and the PDOP-values (Dilution of Precision) were 3. In the strips 3 and 4 only 4 satellites were available and the PDOP-values were 16-18 for strip 3 and 9 for strip 4. The agreement between the GPS-positions and the photogrammetric is best for strip 2. It is not possible to study the relation between the number of simultaneously observed satellites and the satellite geometry (PDOP-values) with the present version of PPDIFF. Comparisons between positions from relative carrier phase measurements and photogrammetric positions are shown for photo strip 2 in table 3. The agreement between the positions is about 0.15 meters (1 sigma).

It was not possible to compute GPS-positions in strips 3 and 4 using the Ashtech processing software because of the cycle slip between the strips 2 and 3.

The following error sources will be further investigated:

- linear interpolation has been used for determination of the coordinates of the camera from the GPS-positions, but other interpolation methods will be investigated

- the offset between the GPS antenna and the projection center of the camera

- the possibility to start the kinematic computation on a reference mark which has been determined using photogrammetric methods will be investigated in order to obtain GPS coordinates for strips 3 and 4.

8. FUTURE PLANS

Phase 2 of the photogrammetric experiment will be carried out in July 1990. The following changes will be done:

- further development of the navigation software in the PC

- a more stable aircraft (Gulf Stream Commander 840)

- two reference stations

- recording of the times of the exposures in the GPS receiver

- possibility to make the exposures close to the time for the GPS measurements

- higher flying altitude

- investigations of the possibility to determine the offset between the GPS antenna and the projection center of the camera.

9. CONCLUDING REMARKS

The possibility to make automatic exposures in preselected positions was successfully demonstrated. It may be necessary to use relative navigation in the future because of the implementation of the SPS-concept in March 1990.

The result of the airborne photogrammetry test is promising, but further development is necessary before the GPS-techniques can be used routinely for the determination of the camera positions at the time of the exposure. Some remaining problems to investigate are: cycle slip fixing, ambiguity resolution and the determination of the offset between the GPS-antenna and the projection center of the camera.

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