INTEGRATED SENSOR ORIENTATION – AN OEEPE TEST

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Working Group: III/1

KEY WORDS: Integrated sensor orientation, aerial triangulation, GPS, IMU, international test.

ABSTRACT

The topic of image orientation by combined aerial triangulation with GPS/IMU, also called integrated sensor orientation, has received much attention lately. One of the main questions of fundamental relevance is, if and under which conditions the direct determination of the parameters of exterior orientation via GPS and IMU can be a complete substitute for aerial triangulation. A more practical question deals with the possibilities of an optimum combination of the different methods using a minimum of ground control points. The European Organisation for Experimental Photogrammetric Research (OEEPE) has embarked on a test investigating these issues. The main focus of the test is on the obtainable accuracy of integrated sensor orientation for large scale topographic mapping as determined at exterior orientation elements and at independent points on the ground. In this paper we describe details of the test which, when presented at the ISPRS Congress in Amsterdam, is still open for interested participants to join.

1 INTRODUCTION

Image orientation is a key element in any photogrammetric project, since the determination of three-dimensional coordinates from images requires the image orientation to be known. In aerial photogrammetry this task has been exclusively and very successfully solved using aerial triangulation since many decades. Thus, aerial triangulation has become a key technology and an important cost factor in mapping and GIS. Over the years a number of additional sensors were used to directly determine at least some exterior orientation parameters, albeit with little success until the advent of GPS in the late eighties. Today differential kinematic GPS positioning is a standard tool for determining the camera exposure centres for aerial triangulation. Using the GPS measurements as additional observations in the bundle block adjustment a geometrically stable block based on tie points alone can be formed, and ground control points (GCP) are essentially only necessary for calibration, for detecting and eliminating GPS errors such as cycle slips and for reliability purposes (Ackermann, Schade 1993; Jacobsen 1993; Ackermann 1994; Jacobsen 1997; Andersen, Ackermann 2000). Applications involving image strips such as highway mapping, however, still need GCP in order to reliably determine the rotation of a plane around the flight axis.

Using gyroscopes, one is able to also determine the rotation elements of the exterior orientation. Gyroscopes and accelerometers are the components of an inertial measurement unit (IMU)[1], the accelerometers provide sensor velocity and position via integration. Thus, a GPS/IMU sensor combination can in principle overcome the mentioned GPS errors and can yield the exterior orientation elements of each image without aerial triangulation. This technology opens up many new applications for photogrammetry and remote sensing (Schwarz et al. 1993; Colomina 1999; Skaloud 1999). According to the first author four areas can be distinguished (Schwarz 1998), namely (1) topographic mapping in which very high accuracy requirements are to be met and standard photogrammetric film cameras are being used today and will continue to be used for some time to come, (2) applications using the emerging digital aerial line and frame cameras, (3) applications with less stringent accuracy requirements such as mobile mapping enabling the use of less expensive sensors in the air or on the ground, and (4) navigation applications which require a real-time response.

A series of tests and pilot projects have been conducted and have convincingly shown the great potential of GPS/IMU sensor integration in aerial photogrammetry (Skaloud, Schwarz 1998; Wewel et al. 1998; Abdullah, Tuttle 1999; Burman 1999; Colomina 1999; Cramer 1999; Toth 1999; Jacobsen 2000). At independent check points on the ground root mean square errors of down to 0.1 to 0.2 m were obtained. These results have proven that the direct determination of the exterior orientation elements is a significant component of highly accurate image orientation and is a serious alternative to aerial triangulation in a number of applications. Also, a number of potential error sources have been identified. These include the Kalman filtering of the GPS/IMU data for noise reduction, the determination of parameters for systematic position and attitude corrections of the GPS/IMU data, the stability of these parameters over time, especially the stability of the attitude values between the IMU and the camera, the time synchronisation between the various sensors, issues related to the correlation between the interior and the exterior orientation parameters of the imagery, and the quality of the resulting exterior orientation parameters for subsequent stereoscopic plotting.

[1] Note, that we use the term IMU instead of INS (Inertial navigation system). Following Colomina (1999), an INS box contains an IMU as a measurement device plus positioning and guidance functions, mainly realized in software.

2 TEST OBJECTIVES AND EXPECTED RESULTS

The European Organisation for Experimental Photogrammetric Research (OEEPE) has embarked on a test investigating integrated sensor orientation using GPS and IMU in comparison and in combination with aerial triangulation. The test has been set up as a multi-site test. The Institute for Photogrammetry and Engineering Surveys (IPI), University of Hanover acts as pilot centre for the test. Data acquisition and pre-processing including the organisation of test flights and the necessary field work was carried out by the Department of Mapping Sciences (IKF), Agricultural University of Norway in Ås.
The main focus of the test is on the obtainable accuracy for large scale topographic mapping using photogrammetric film cameras. The accuracy of the results will be assessed by investigating the exterior orientation elements of an image block and in particular with the help of independent check points on the ground in the following scenarios:

- aerial triangulation,
- GPS/IMU observation for the projection centres only,
- combination of aerial triangulation with GPS/IMU.

The test is expected to demonstrate to which extent integrated sensor orientation using GPS and IMU with and without aerial triangulation is an accurate and efficient method for the determination of the exterior orientation parameters for large scale topographic mapping. A comparative analysis will show in which way the mentioned potential error sources and an integrated bundle block adjustment, with or without using a minimum of ground control points have an influence upon the accuracy of the derived orientation parameters and ground control coordinates. Furthermore, the potential and problems of integrated sensor orientation will be assessed based on the comments of the participants. A detailed investigation into the transformation of the raw GPS and IMU measurements into flight trajectories and attitude values (roll, pitch, and yaw as a function of time), however, is out of the scope of this test. Rather, the flight trajectories and the attitude values as computed by the GPS/IMU systems, are considered to be the input of the test, and are to be processed together with the image data.

3 TEST DATA SET

3.1 Selection criteria and general description

The test will be carried out based on especially acquired imagery and GPS/IMU data. In order to enable a fair and meaningful test between the two competing technologies the following selection criteria for the data acquisition were set forward:

- geometrically stable photogrammetric block,
- modern photogrammetric film camera,
- dual frequency GPS receivers using differential carrier phase measurements with a data rate of 0.5 sec, preferably identical receivers for the plane and reference station,
- a short base line between plane and reference station,
- high quality off-the-shelf navigation grade IMU as typically used in precise airborne attitude determination,
- different image scales suitable for large scale topographic mapping,
- a well-controlled test field with a large number of ground control points.

Given these criteria and a few practical constraints a test field in Fredrikstad, Norway, was selected. Two companies producing suitable GPS/IMU equipment agreed to participate in the test, namely Applanix of Toronto, Canada, using their system POS/AV 510-DG (Hutton J., Lithopoulos E. 1998; Applanix 2000), and IGI mbH of Hilchenbach, Germany, with the system AEROcontrol II (IGI mbH 1999).

3.2 Test field Fredrikstad

The test field Fredrikstad lies in the south of Norway near the capital Oslo. It is maintained by IKF. The test field has already been used in a prior OEEPE test on GPS photogrammetry (Andersen, Ackermann 2000), its size is approximately 5 x 6 km^2. 51 well distributed signalised ground control points with UTM/EUREF89 coordinates and ellipsoidal heights known to better than 0.01 m are available. The ground control point targets have a size of 40 x 40 cm^2.

3.3 Test flights

The test flights were carried out by the Norwegian companies Fotonor AS and Fjellanger Widerøe (FW) Aviation AS. Fotonor used an Ashtech GPS receiver and the Applanix POS/DG AIMU equipment tightly coupled to a wide angle Leica RC30, the latter mounted on the gyro-stabilised platform PAV30. The PAV30 data and thus rotations of the camera and the IMU relative to the plane body were recorded and introduced into further processing. FW also had an Ashtech GPS receiver and the AEROcontrol II system fitted to a wide angle RMK Top from Z/I Imaging GmbH on board. A second gyro system was used by IGI to register possible movements of the camera with respect to the plane body during the flight. In order to obtain redundant observations for the differential GPS data processing, a number of GPS reference stations at various distances from the test field were in operation during data acquisition. The reference stations were also equipped with GPS receivers from Ashtech.
All flights were carried out on October 7, 1999 with an end overlap and a side overlap of 60 % each using black and white film material. In the morning Fotonor AS flew the Applanix-Leica equipment, in the afternoon FW acquired data with the IGI-Z/I system. In total, approximately 250 images per company, were acquired. Each company flew two so-called calibration flights, the first one in 1:5000, the second one in 1:10000, followed by the actual test flight in 1:5000. The 1:5000 calibration flight consists of two strips in east/west direction and two strips in north/south direction, see figure 1. The two directions are necessary for dynamic GPS/IMU alignment. Each pair of strips was flown in opposite direction to each other in order to be able to determine and to separate GPS shift parameters and the angles of misalignment between the IMU gyro axes and those of the image coordinate system, also called boresight misalignment. The 1:10000 calibration flight comprises five parallel strips and two cross strips and covers the complete test field, see figure 2. Apart from the possibility to check the GPS shifts and the boresight misalignment in another image scale the second scale is needed to resolve the high correlation between the vertical GPS shift and possible errors of the calibrated focal length of the camera.

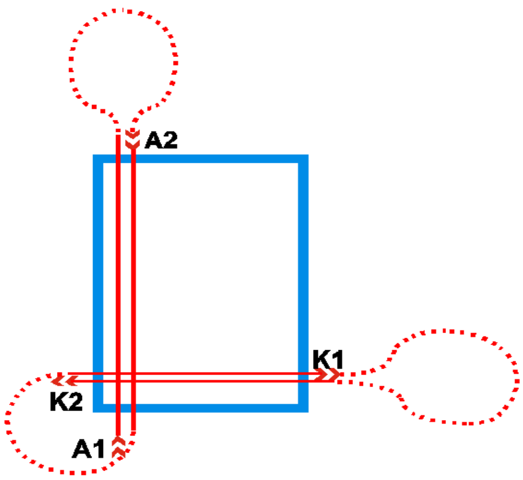


Figure 1: Calibration flight, image scale 1:5000

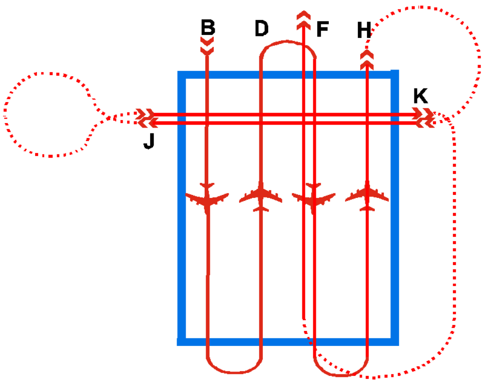
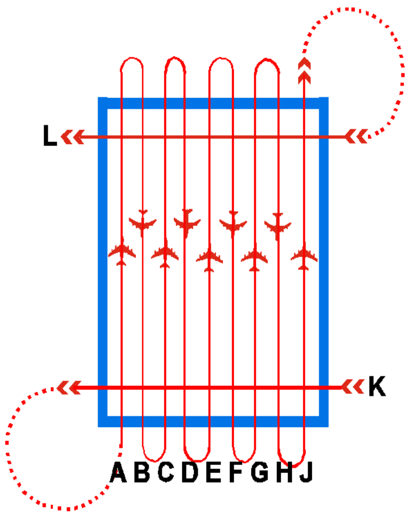


Figure 2: Calibration flight, image scale 1:10000



Following the calibration flights, the actual test flight in the scale 1:5000 covering the complete test field was carried out, see figure 3. It comprises 7 parallel strips and 1 cross strip. Originally, it was planed to carry out another calibration flight at the end of the mission in order to assess possible time-dependent effects of the GPS shifts and the boresight misalginment, but due to weather conditions this flight could only be flown by Fotonor. In order to create identical conditions for both systems, this flight is not further considered in the test.

Figure 3:
Test flight, image scale 1:5000

4 TEST PROCEDURE

4.1 General workflow

The test consists of two phases (see chapters 4.2 and 4.3 for details). The first phase comprises the determination of so-called system calibration parameters. The second phase deals with the integration of the GPS/IMU data into the bundle block adjustment. The object space coordinate system of the whole test is UTM/EUREF89.
The test participants will receive various sets of test data in both phases and process them using existing experimental or commercial software. The results will then be communicated back to the pilot centre. They must include the system calibration data and the exterior orientation parameters of the projection centres of the actual test flight (first phase) and the adjusted object coordinates of the test field in the second phase. For both phases a report detailing the employed method of processing, the adopted workflow and a general assessment of the obtained results and problems encountered needs to be delivered to the pilot centre.
At the pilot centre, the results will be analysed and compared to reference data. Upon preliminary completion of this analysis a workshop on "Integrated sensor orientation" will be organised. At this occasion the test participants and other interested individuals can discuss the results and share their experience. In this way a broad dissemination of the results will be achieved.

4.2 Phase I: System calibration

The first test phase deals with the determination of the GPS shifts, the boresight misalignment and possibly additional parameters from the information of the calibration flights. In the following the determination of these parameters is called "system calibration", which motivates the name of the first phase and also the term "calibration flight". It should be noted that the system calibration does not include the camera calibration, i. e. the determination of the parameters of interior orientation. Only corrections to the calibrated focal length can possibly be computed. Phase I also comprises the determination of exterior orientation parameters of the actual test flight based on the GPS/IMU data and the results of system calibration.
The test scheme of Phase I is depicted in figure 4. The camera calibration protocol was provided by the flight companies. Processing of the raw GPS/IMU data into flight trajectories of the camera projection centre given in UTM/EUREF89 as well as roll, pitch and yaw of the plane around the camera projection centre as a function of time was performed by Applanix and IGI, respectively. They also provided the instant of exposure of each image. Interpolation of initial values of exterior orientation for each image from these data was carried out at IPI. IPI also measured the image coordinates of the GCP and the tie points in the calibration flight images using an analytical plotter.
The first task of the participants consists in the system calibration using a suitable geometric model. There is a choice of processing the calibration flights 1:5000 and 1:10000 separately, or to use a combined approach. A detailed description of the employed system calibration model and the computed parameters are the first results of phase I. Subsequently, the system calibration parameters are to be applied to the GPS/IMU data of the actual 1:5000 test flight in order to calculate the exterior orientation parameters of each image of this flight. These orientation parameters are the second part of the participants´ results of phase I.
The results will be collected by the pilot centre. The analysis of phase I consists of three parts. First, the individual sets of system calibration parameters and the exterior orientation parameters of the test flight will be compared taking into account the different system calibration models employed. In the second part, the exterior orientation will also be computed based on traditional aerial triangulation using the image coordinates of tie points and the GCP determined interactively at IPI, and these results will also be compared to the participants´ results. As a third analysis step, the interactively measured image coordinates of the GCP will be transformed into object space via a least-squares forward intersection with the exterior orientation of the participants being introduced as constant values. The resulting object space coordinates will then be compared to the known values of the GCP, and the residuals in image space can be interpreted as remaining y-parallaxes in stereo models formed using the participants´ exterior orientation.

4.3 Phase II: Integrated bundle block adjustment

The second phase deals with the integration of the GPS/IMU data into the bundle block adjustment in order to obtain an optimum, i. e. the most accurate solution. The scheme of phase II is depicted in figure 5. After returning the results of phase I the participants will receive image coordinates of tie points and GCP of the test flight images together with some additional GCP coordinates in UTM/EUREF89. Together with the system calibration parameters determined in phase I they can then perform an integrated bundle block adjustment, estimating the exterior orientation, the system calibration parameters and the object space coordinates of the tie points and the GCP. These values will subsequently be returned to the pilot centre together with a detailed report describing the adopted model for the integration. Again, the pilot centre will compare the results and check them against the known reference values for the object space coordinates, yielding insight into the quality of the different solutions being used by the individual participants.

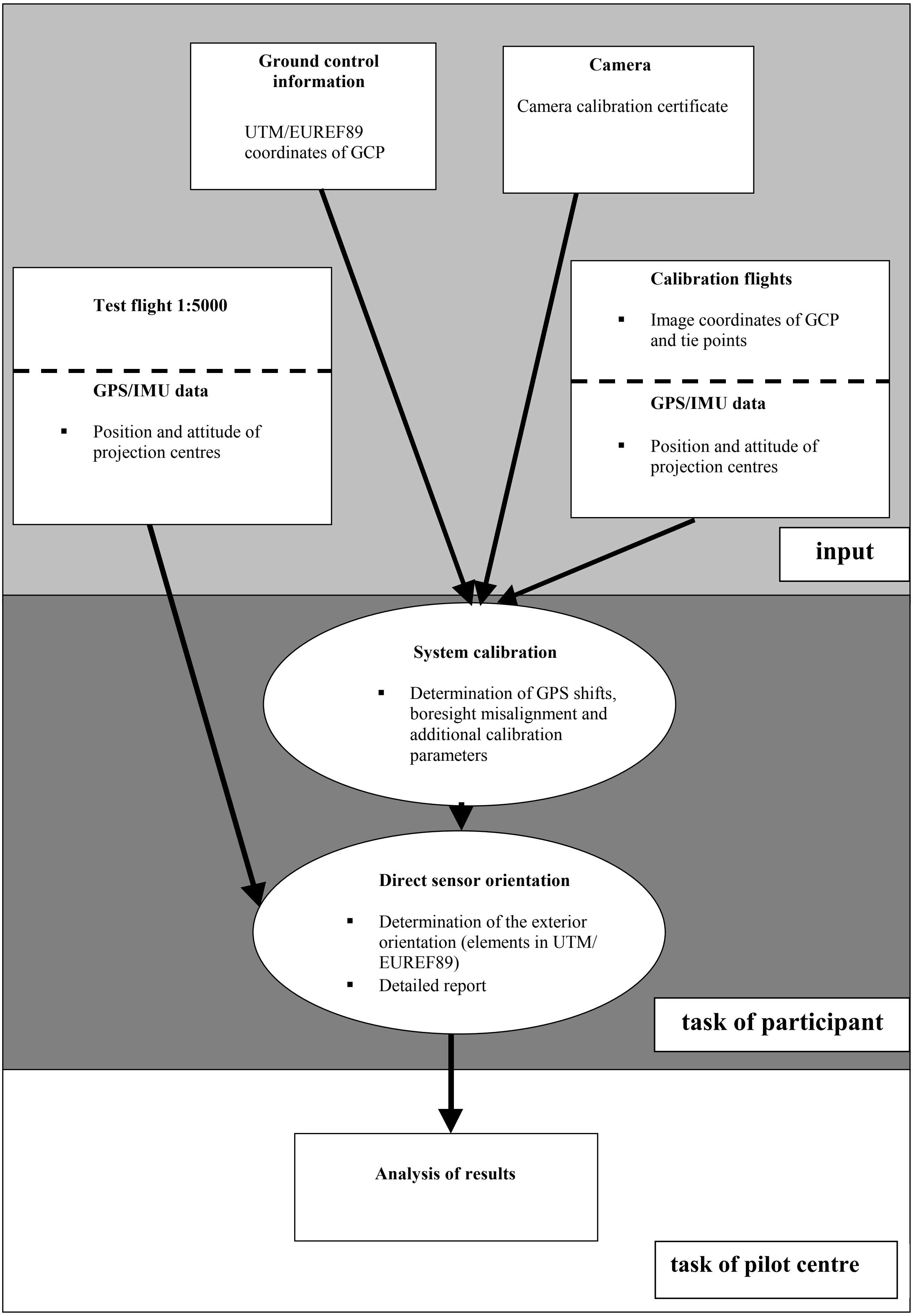


Figure 4: Test scheme, phase I

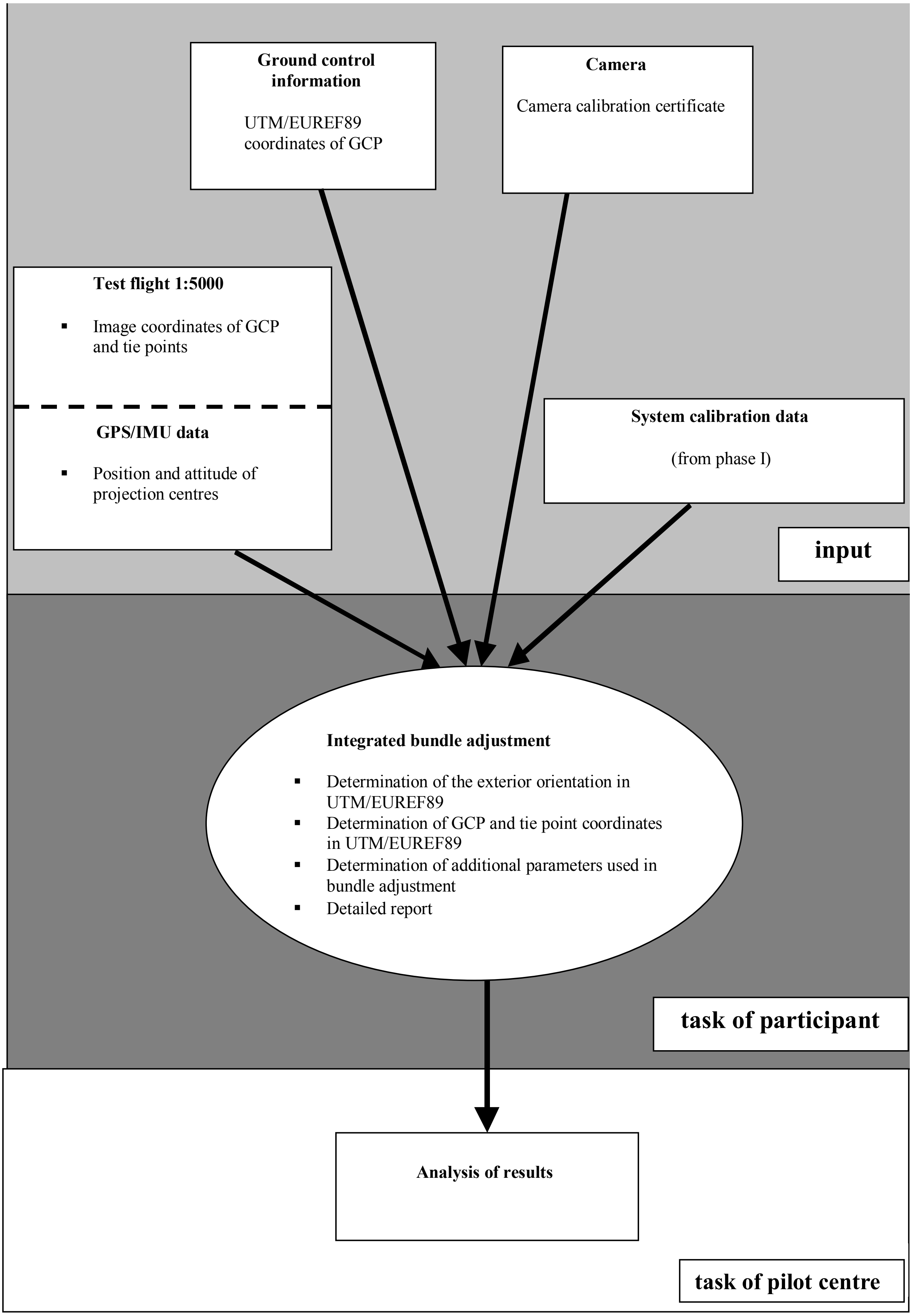


Figure 5: Test scheme, phase II

5 PROJECT SCHEDULE

Activities for the test have started in May 1999. At the time of writing (March 2000) the companies Applanix and IGI mbH are carrying out the GPS/IMU data pre-processing. The proposed schedule for the test is as follows:

Test preparation	May 1999	Creation of the OEEPE Working Group “Integrated sensor orientation”
	September 1999	Initial WG meeting during the Photogrammetric Week
Acquisition and preparation of test data	October 1999	Test flights in Norway
	Winter 1999/2000	GPS/IMU pre-processing and image coordinate measurement
Phase 1	Spring 2000	Delivery of phase I test data set to participants
	September 2000	Collection of phase I results
	Autumn 2000	Analysis of phase I results
Phase 2	Early 2001	Delivery of phase II test data set to participants
	Spring 2001	Collection of phase II results
	July 2001	Analysis of phase II results
Final activities	Autumn 2001	Workshop on “Integrated sensor orientation”
	Winter 2001/02	Preparation and publication of final report

Table 1: Project schedule

6 ACKNOWLEDGEMENTS

The authors are grateful to the companies Applanix, IGI mbH, Fotonor AS and Fjellanger Widerøe Aviation AS for participating in the test and for having acquired and provided the tests data. We would also like to thank the Norwegian Mapping Authority Statens Kartverk, Hønefoss for making available the measurements of the GPS reference stations and the OEEPE for their support of the project.

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