TEST GOALS AND TEST SET UP FOR THE OEEPE TEST “INTEGRATED SENSOR ORIENTATION”

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ABSTRACT

The European Organisation for Experimental Photogrammetric Research (OEEPE) has embarked on a multi-site test investigating sensor orientation using GPS and IMU in comparison and in combination with aerial triangulation. The test was expected to demonstrate the extent to which direct and integrated sensor orientation are accurate and efficient methods for the determination of the exterior orientation parameters for large scale topographic mapping. Another test goal was the transfer of the recently developed technology from the research arena to potential users.

In this paper we first give some background on sensor orientation. We then describe the test goals and the expected results, followed by an explanation of the test procedure and organisation. The test consists of two phases. The first phase comprises the system calibration and direct sensor orientation. The second phase deals with the integrated sensor orientation, i e. the integration of the GPS/IMU data into a bundle adjustment. The used test data are described in Nilsen Jr. (2002), the obtained results and an in depth analysis can be found in Heipke et al. (2002).

1 INTRODUCTION

1.1 Background

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 for many decades. 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 (global positioning system) in the eighties and the pioneering work of Mader (1986). In this regard it is interesting to note that in the same year Ackermann predicted that “the performance of new navigation systems will allow in-flight measurements of carrier position and attitude to an accuracy which will change the photogrammetric methods fundamentally” (Ackermann 1986, p. 93).

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 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 the effect of GPS errors such as cycle slips, for reliability purposes, and possibly for datum transformations. One can distinguish between a loose coupling of photogrammetric and GPS observations, sometimes called the “shift and drift approach” (Ackermann 1994; Jacobsen 1997) and a more rigorous GPS/aerial triangulation combination (Jacobsen, Schmitz 1996; Kruck et al. 1996; Schmitz 1998).

Gyroscopes and accelerometers are the components of an inertial measurement unit (IMU)[1]. Using gyroscopes, one is able to determine the rotation elements of the exterior orientation. The accelerometers provide sensor velocity and position. Thus, in principle a GPS/IMU sensor combination can yield the exterior orientation elements of each image without aerial triangulation. This technology opens up

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

many new applications (Schwarz et al. 1993; Colomina 1999; Skaloud 1999; Colomina 2002; for a short historical note on IMU, see Mostafa 2001).

A series of tests and pilot projects has been conducted and has convincingly shown the potential of this new technology (e.g. Skaloud, Schwarz 1998; Wewel et al. 1998; Abdullah, Tuttle 1999; Burman 1999; Colomina 1999; Cramer 1999; Toth 1999; Jacobsen 2000; Kinn 2002). At independent check points (ICP) on the ground, root mean square differences down to 0.1 to 0.2 m were obtained. These results have proven that the determination of image orientation using GPS/IMU observations is a serious alternative to conventional aerial triangulation. In addition, 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 (system calibration parameters), the stability of these parameters over time (especially the stability of the attitude values relating the IMU and the camera coordinate systems), and the time synchronisation between the various sensors.

In aerial triangulation control information in the form of GCP coordinates and the object space coordinates of tie points to be determined are both located on the object surface. Therefore, the computation of the tie point coordinates can be thought of as an interpolation task. Using GPS/IMU observations, on the other hand, the control information is measured at the height of the sensors and is subsequently transferred down to object surface. Therefore, the new approach must be considered as an extrapolation, and thus a compensation of different error sources due to a strong correlation between the related parameters, is much less effective. This fact is particularly true for possible changes in the interior orientation of the camera, which can no longer be compensated by a change in the exterior orientation (e.g. Schenk 1999; Habib, Schenk 2002). In this light, the choice of the object space coordinate system also needs a closer look (see e.g. Jacobsen 2002; Ressl 2002), since the photogrammetric collinearity equations need a Cartesian system, a requirement that the curvilinear mapping systems do not fulfil.

1.2 Some comments on terminology

As is the case with many new technologies, some confusion has arisen about terminology. The traditional task of aerial triangulation is twofold, namely to simultaneously determine the parameters of exterior orientation (and possibly additional parameters for self calibration) of a block of images and the object space coordinates of the tie points and other points. The parameters of interior orientation (calibrated focal length, image coordinates of principal point) are, of course, needed but are assumed to be known and constant. Before it became possible to store and transfer exterior orientation parameters from one compilation session to the next, the tie point coordinates were the most important results, and thus the whole task was also named *point determination*. With the advent of analytical photogrammetry, the focus started to change slowly, and the orientation parameters became more important. Thus, the same task was increasingly called *determination of image orientation*. Today, we observe two new developments: (1) the exterior orientation parameters of a camera can be determined without tie points using GPS/IMU technology, and (2) the same technology is also used to determine the orientation of non-traditional sensors such as laser scanners and SAR sensors. Consequently, *image orientation* has been replaced by the more general term *sensor orientation*. *Sensor orientation* includes all related parameters, regardless of whether they are assumed to be known or unknown, and constant or changing over time. Thus, sensor orientation includes the system calibration parameters of a sensor system (i.e. calibration parameters of each sensor, e.g. the interior orientation parameters of the camera, and parameters relating the individual sensor observations in space and time to a common reference frame) and the exterior orientation parameters of the sensor system.

We further differentiate between *direct sensor orientation* and *integrated sensor orientation*. *Direct sensor orientation* stands for the determination of sensor orientation without image coordinates using only GPS/IMU observations. The system calibration parameters need to be known and thus have to be determined in a separate step beforehand. On the other hand, *integrated sensor orientation* uses all available input, namely image coordinates of tie points, control information in image and object space, and GPS/IMU observations in a simultaneous adjustment to determine all relevant sensor orientation parameters.

In current literature, sensor orientation (whether direct or integrated) is also called *georeferencing* or *geocoding* (e.g. Schwarz et al. 1993; Cramer 2001). Ackermann writes: "A geo-reference is a global or regional coordinate system to which sensors or spatial object data are related. Hence, georeferencing or geocoding is close to the well known photogrammetric concept of exterior or absolute orientation." (Ackermann 1997, p. 28). *Georeferencing* and *geocoding* have their origin in remote sensing. G*eoreferencing* is also increasingly being used in the spatial information sciences. They emphasise the fact that the sensor orientation parameters are usually only a by-product of photogrammetric processing, and the final results in form of three-dimensional terrain coordinates, a digital terrain model (DTM), an orthoimage and/or structured vector data are needed in a global or regional coordinate system. Consequently, in remote sensing we talk about *georeferencing* or *geocoding an image* and the result is a *georeferenced* or a *geocoded image*, often used as a synonym for an orthoimage. In spatial information sciences we georeference an object (e.g. a road crossing) and mean that we provide coordinates relating to the Earth surface for this object. However, a *georeferenced* or *geocoded image* may have been generated by applying a two-dimensional polynomial rectification based on a few identical points rather than by differential rectification based on the central projection including the image orientation and a DTM. Thus, *georeferencing* and *geocoding* are more general terms, which include various mathematical models for the transformation from image to object space, and which have object space products as output.

In order to emphasise the fact that in topographic mapping from imagery (1) three-dimensional modelling of the imaging process is necessary, and (2) the image orientation parameters have a physical meaning and constitute a result by themselves (although only intermediate) we prefer to use the term *sensor orientation* as described above, when we talk about the interior and exterior orientation parameters of images and the system calibration parameters of a sensor system. We use *georeferencing* when we are concerned with determining object space quantities. Within the test these quantities are exclusively three-dimensional coordinates of terrain points.

2 TEST OBJECTIVES AND EXPECTED RESULTS

The European Organisation for Experimental Photogrammetric Research (OEEPE) has embarked on a multi-site test investigating sensor orientation using GPS and IMU in comparison and in combination with aerial triangulation (see also Heipke et al., 2000; 2001).

The focus of the test was on the obtainable accuracy for large scale topographic mapping using photogrammetric film cameras. The accuracy of the results was assessed with the help of independent check points on the ground in the following scenarios:

- conventional aerial triangulation,
- GPS/IMU observations for the projection centres only (direct sensor orientation),
- combination of aerial triangulation with GPS/IMU (integrated sensor orientation).

The test was expected to demonstrate the extent to which direct and integrated sensor orientation are accurate and efficient methods for the determination of the exterior orientation parameters for large scale topographic mapping.

A further test goal was the transfer of the recently developed technology from the research arena to potential users. This goal is in line with the mission of OEEPE, and it was the main reason for choosing a multi-site test approach. As a consequence, the duration of the test was somewhat lengthy when compared to a single-site investigation. The authors feel, that this disadvantage can be tolerated because they believe that in the long run technology transfer is more important than obtaining results quickly.

3 TEST SETUP

3.1 Preparation

The test consisted of a preparatory period and two analysis phases. It was decided at the outset to organise special test flights to control all aspects of the investigation. In order to enable a fair and meaningful comparison between the two competing technologies the following selection criteria were established for the data acquisition:

- geometrically stable photogrammetric block,
- modern photogrammetric film camera,
- dual frequency GPS receivers using differential carrier phase measurements with a data rate of 2 Hz preferably with identical receivers for the aircraft and reference station,
- a short base line between aircraft 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 GCPs.

The Institute for Photogrammetry and GeoInformation (IPI), University of Hannover, acted as pilot centre for the multi-site test. In this capacity IPI put together and distributed the test data, and collected and analysed the results received from the test participants. The Department of Mapping Sciences (IKF), Agricultural University of Norway in Ås, carried out data acquisition including the organisation of test flights and the necessary fieldwork.

For the test the IKF test field in Southern Norway was selected. It fulfils all the mentioned criteria and had a number of additional, practical advantages. In order to ensure that potential error sources could be identified individually it was decided to perform two calibration flights at different heights/scales (1:5 000 and 1:10 000) followed by the actual test flight (scale 1:5 000) and a third calibration flight (1:10 000) at the end of the flight mission. During the test flight a GPS reference station, placed in the test field to ensure a short base line and to avoid additional errors, was operated. Details of the data acquisition can be found in Nilsen Jr. (2002).

Next, the raw GPS/IMU data of the whole flight needed to be pre-processed into object space coordinates for the centre of projection of each image accompanied by attitude information in terms of roll, pitch, and yaw values. In order to enable the system calibration (see below) and to create material for checking, the pilot centre measured the image coordinates of all visible GCPs and of a large number of tie points.

3.2 Phase I: System calibration and direct sensor orientation

The first analysis phase comprised the determination of so-called system calibration parameters, i.e. the determination of the boresight misalignment (the angular difference between the IMU and the image coordinate systems), and possibly additional parameters modelling GPS shifts, the interior orientation of the camera, GPS antenna offsets, time synchronisation errors etc. from the information of the calibration flights. Phase I also comprised the direct sensor orientation of the actual test flight based on the GPS/IMU data and the results of system calibration and – as part of the analysis of the results - the derivation of object space coordinates via a least squares forward intersection using the orientation parameters as constant values. Thus, all elements of direct sensor orientation were contained in phase I.

The test scheme of phase I is depicted in figure 1. The data to be sent out to interested test participants consisted of a subset of the measured tie point coordinates for each calibration flight image, the

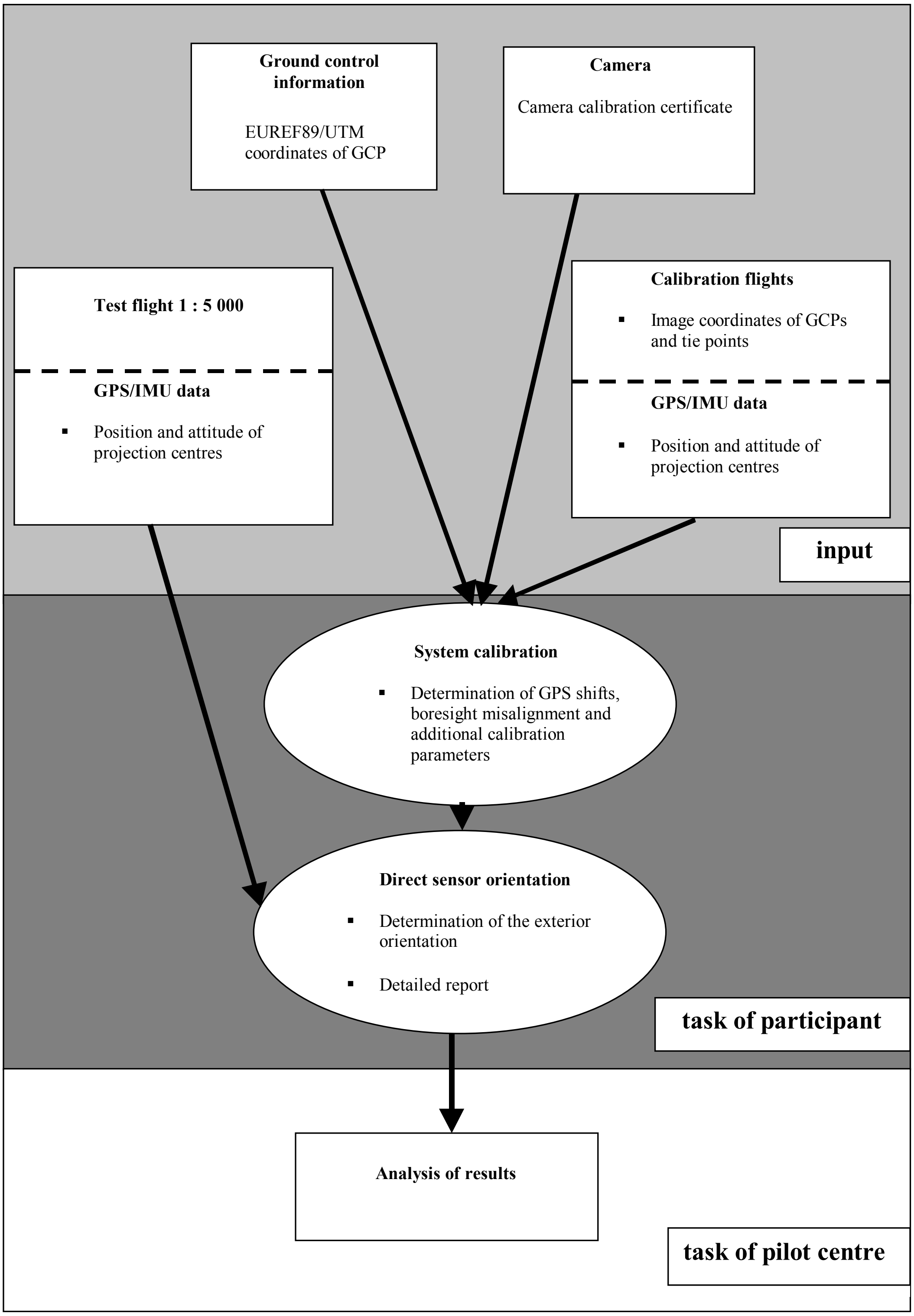

Figure 1: Flowchart of phase I

camera calibration certificates, a sufficient number of GCP coordinates in object space, and the preprocessed GPS/IMU data of the whole flight (all calibration flights and the test flight). The derived system calibration parameters together with the orientation parameters for the calibration flights and the test flight and a detailed report about the work carried out were to be delivered back to the pilot centre for the analysis of the results (see Heipke et al. 2002 for details of the analysis of the whole test).

3.3 Phase II: Integrated sensor orientation

The second phase dealt with the integration of the GPS/IMU data into the bundle adjustment i.e. the integrated sensor orientation. After having returned the results of phase I, the participants were to receive image coordinates of tie points and GCPs of a subset of the test flight images. No object space coordinates of GCPs were to be distributed, and GCPs used in phase I were not to be used as tie points in phase II. Thus, the participants were to receive only information in image space, and not in object space. This decision was taken, because we wanted to explore the advantage of combining GPS/IMU measurements with tie points alone, since (1) tie points can be generated without field work and automatically, and (2) as soon as GCPs are included, their influence may dominate the results, and thus we would run the risk of ending up with a GPS-assisted photogrammetric bundle adjustment.

Combining the information received with the system calibration parameters determined in phase I, the participants would then perform an integrated sensor orientation, refining the exterior orientation (and possibly also the system calibration parameters), and estimating the object space coordinates of the tie points and the GCPs. These values were subsequently to be returned to the pilot centre together with a detailed report describing the adopted model for the integration. The test scheme of phase II is depicted in figure 2.

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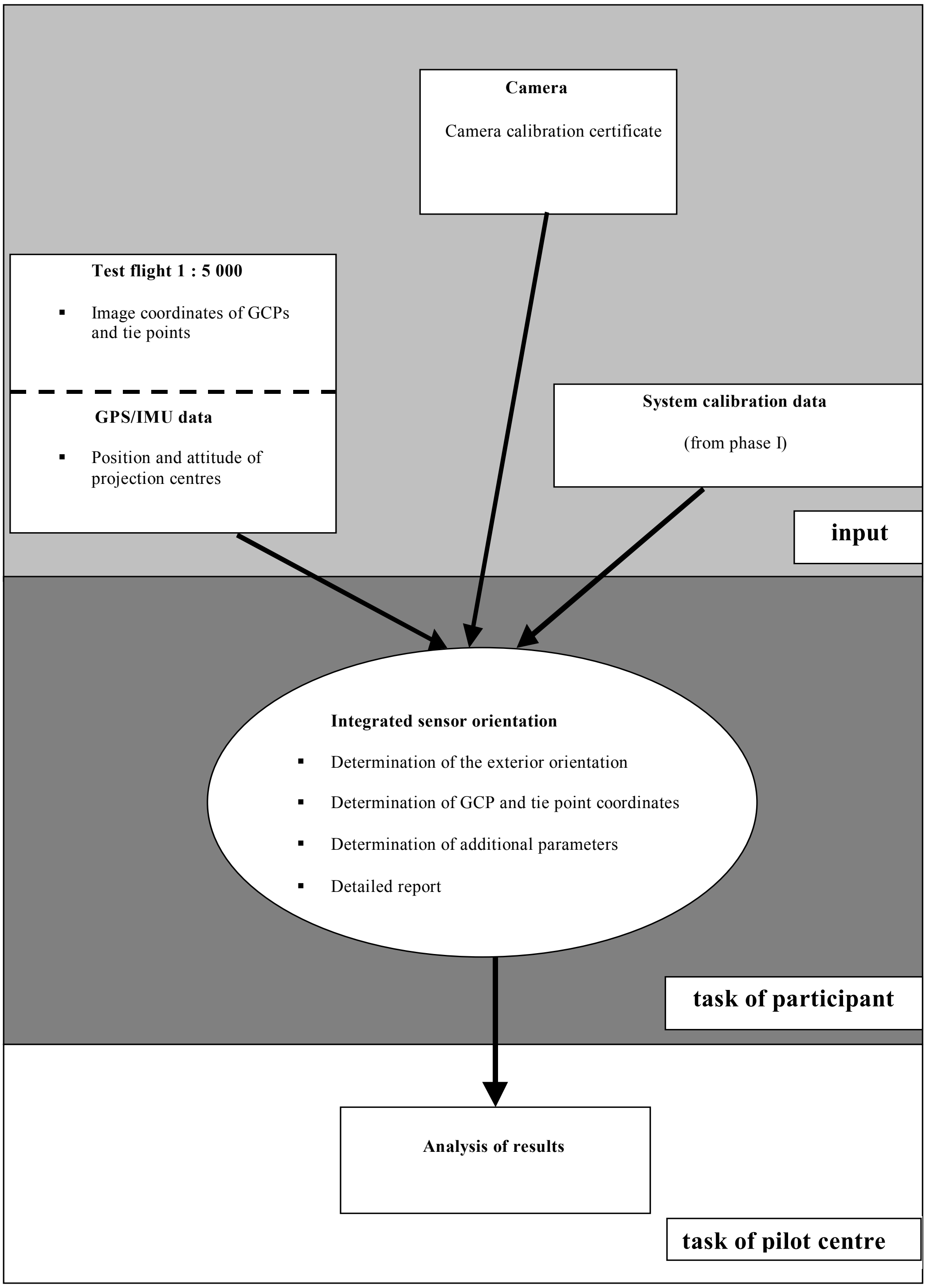

Figure 2: Flowchart of phase II

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