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CCNS / AEROcontrol - an Integrated GPS/IMU System for Direct Georeferencing of Airborne Image Data

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Summary

The precise positioning of an airborne image sensor for direct georeferencing, and the guidance display of the sensor aircraft have very different requirements for the position and attitude determination of the navigation system. On the one hand, guidance needs a typical position accuracy in the 10m to 100m range and a heading accuracy about one degree (the roll and pitch angles are mostly irrelevant). This information has to be available in real time. On the other hand the determination of the exterior orientation (EO) parameters for direct georeferencing requires an accuracy which is typically two orders of magnitude better. For this purpose, real time availability of the EO parameters is mostly not necessary.

With the *CCNS4* and its *AEROcontrol* option, IGI provides an integrated system for both tasks. The *AEROcontrol* is a GPS/IMU system, consisting of a dual frequency GPS receiver and a fiber optic gyro (FOG) based IMU. For the guidance purpose real time GPS is used together with either the IMU, or with the aircrafts directional gyro. For direct georeferencing a carrier phase differential DGPS solution is combined with the IMU measurements in a Kalman Filter in post-processing.

This paper describes the *CCNS4/AEROcontrol* and discusses the advantages and limitations of the system for the use with image sensors like aerial cameras, airborne laserscanners and airborne Synthetic Aperture Radar (SAR).

Introduction

As the sensors for aerial survey, the equipment and procedures used for guidance and positioning of these sensors have undergone a rapid change in the last years. Since the 1980s, the use of Loran-C, DME/Tacan and portable P-DME have improved the ability to survey areas by air, where exact visual navigation was difficult e.g. desert, ice and rain forest. From about 1990 on, GPS based navigation and sensor management systems are widely used. The use of GPS not only improved the precise navigation for aerial survey flight missions, but differential GPS provided additional information for processing the data from airborne sensors. Today, many sensors are equipped with integrated DGPS/IMU systems to enable the calculation of the precise sensor position relative to the GPS antenna (“lever arm correction”) and to obtain the sensor orientation.

Different airborne sensors and project tasks have different requirements for guidance, positioning and sensor management. In this paper, the advantages and limitations of the *CCNS/AEROcontrol* GPS/IMU system of IGI are discussed.

Guidance and sensor management

The requirements for the guidance of a survey aircraft depend mostly on the required flying altitude for the mission. For aerial photography the needed guidance accuracy is mostly in the 10m to 100m range. This accuracy can be achieved with GPS (SA off!). For applications with a very low flying altitude (e.g. some laserscanner applications, very large scale aerial photography, special sensors like thermal imagers or mine sweeping devices) the accuracy has to be improved by using real time differential GPS services. With differential corrections, a positioning accuracy in the 1m range and better is achieved. In this case the final positioning accuracy is limited by the skills of the pilot and the used aircraft only.

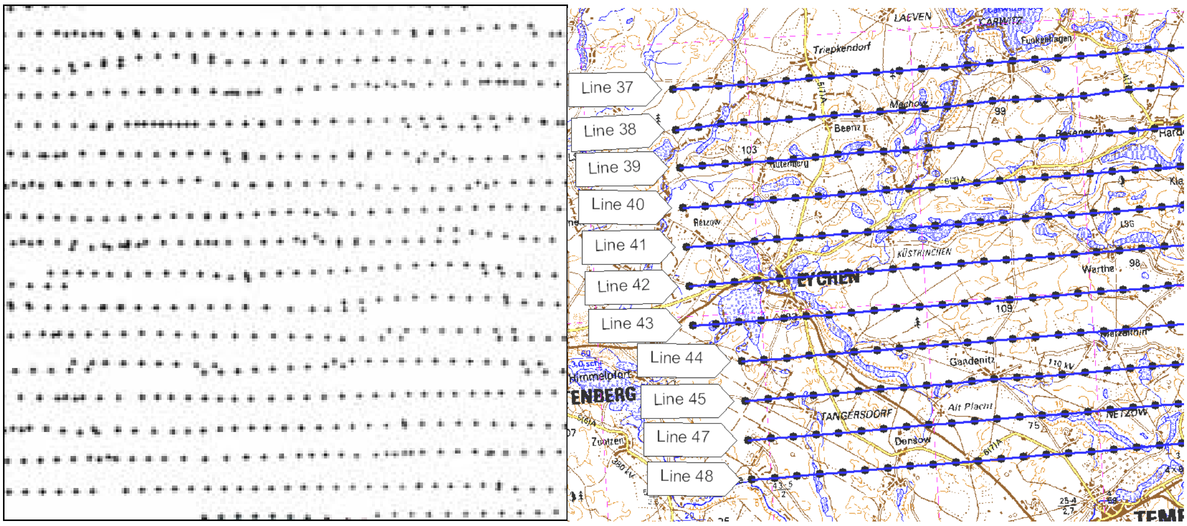

Figure 1: left side: Photoindex of a mission flown with visual navigation
right side: Photoindex of a mission flown with *CCNS4*

To provide the guidance display with the necessary heading information, the determination of the heading angle has to be within an accuracy of about 1 degree. The heading information has to be updated continuously to enable a display that follows the aircraft motion smoothly and with no “jumps”. This heading information is also needed to calculate drift/grab settings for the sensor mount.
With the *CCNS4* system, these goals are reached by integrating GPS with the output of the aircraft directional gyro. The actual position, velocity and heading is calculated

with 10Hz by a Kalman Filter in real time. For guidance tasks this relatively low frequency is sufficient.

The system is equipped with an internal GPS receiver. This receiver is prepared for differential GPS operations according to RTCM-104 format. To provide simple and error free operation by the pilot in the aircraft, the Command and Display Unit (CDU) of the *CCNS4* is designed like an aircraft instrument.

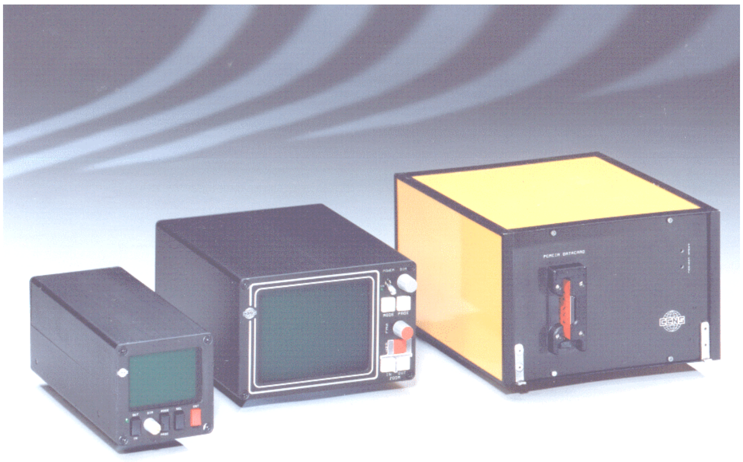

Figure 2: The *CCNS4* airborne computer with 3” and 5” control and display units

The *CCNS4* is able to control two sensors at a time (e.g. a RC30 camera and a RMK-TOP camera). The actual flight data, including the aircraft position, are computed and can be provided for data annotation on film. Waypoint data, flight information and GPS positions are stored on a PC-Card for mission documentation with IGI’s Windows based Mission Planning and Documentation software (*WinMP)*.

Precise positioning and attitude determination

For direct georeferencing of airborne image data the requirements for positioning and attitude determination are typically two orders of magnitude higher than for aircraft guidance. For most applications these Exterior Orientation (EO) parameters are not needed in real time.

As for navigation, the required accuracy for the measurement of the EO parameters for direct georeferencing depends on sensor type and flying height. An estimation of the required accuracy for different sensors is given later.

IGIs GPS/IMU system *AEROcontrol* consists of four components:

- The Inertial Measurement Unit *IMU-IId*:
  The IMU includes three accelerometers, three fiber optic gyroscopes (500m fiber length) and signal pre-processing electronics. The six sensors are attached rigidly to an aluminum frame. Through wholes in the IMU housing, this sensor block is mounted directly to the used airborne sensor. The *IMU-IId* provides a high accuracy measurement of the angular rate and of the acceleration with an update rate of 64Hz or 128Hz.

- The GPS antenna and receiver:
  The system can be operated with different GPS receivers. The default configuration uses the *Z-Xtreme* 12-channel dual frequency receiver (Ashtech/Magellan, USA).

- The airborne computer unit:
  The airborne computer unit collects the raw data of the IMU and of the GPS receiver and stores them on a PC-Card for post-processing. It also provides the time synchronization between the GPS, the IMU and the used sensor. A real-time platform calculation allows to use the information as navigational input for the *CCNS4*. At an IMU rate of 64Hz, the system collects approximately 12MB of data per hour. For the example of a 192MB PC-Card this results in a possible mission time of about 15 hours.

- The post-processing software:
  The *AEROoffice* post-processing software provides all functions necessary for the handling and evaluation of the collected IMU data. Besides the Kalman Filter for the combined inertial navigation/GPS calculation, the software includes tools for the transformation of the EO parameters to the local mapping system. The DGPS calculation can be done with any DGPS post-processing software. The default configuration is the *GrafNav* software package (Waypoint, Canada).

Figure 3: *AEROcontrol* computer with *Z-fly* GPS receiver and IMU

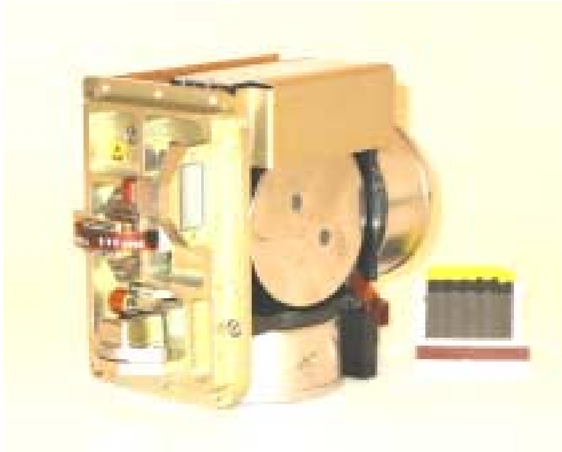

Figure 4: Sensorblock of the *IMU-IId* with three accelerometers and three fiber-optic gyroscopes

The system can read the attitude information of a stabilized camera mount (like Z/I Imaging T-AS or LH Systems PAV30) and store these values for a variable lever-arm correction in post-processing. If it is not possible to read the information from a used stabilized mount, an additional attitude sensor to monitor the mount angles is available from IGI. More detailed information about the *CCNS4/AEROcontrol* is given in [1].

Direct georeferencing for different airborne sensors

The required accuracy for different types of aerial sensors depend on the layout of the sensor, the flying height and the task of the survey mission. Therefore the estimations given here can only be seen as examples. An estimation of the required accuracy should be made prior to every mission.

Aerial photography with analog cameras

To choose the right photo scale for a photo-flight mission is always a tradeoff between the needed accuracy and the resulting costs. To find the optimal photo scale for the production of a topographic map of a certain scale, tables are available that are based mainly on experience e.g. [2]. These tables can be used to estimate the required EO parameter accuracy for aerial photography.
As an example, the required accuracy for the following conditions should be shown:

- An aerial camera with 230×230mm^2 film format and a wide angle lens cone (153 mm) is used.

- Aspired accuracy of an object in the final map: 0.2mm.
- An area of appr. 160×115 mm^2 in the center of the photo is used for mapping.
- The estimated GPS accuracy is 0.1m, 0.5m or 2.0m, respectively.

In a first step the, accuracy in the final map can be transformed to an accuracy in object space by multiplying it with the aspired map scale.

In the second step, the typical photo scale for the production of a map of this scale can be read from the tables mentioned above.

Finally, the effect of the different EO parameter errors on a point in the corner of the used area in a photo can be calculated by simple geometric operations. For the graph in figure 5 the effects of the different EO parameters have been added geometrically.

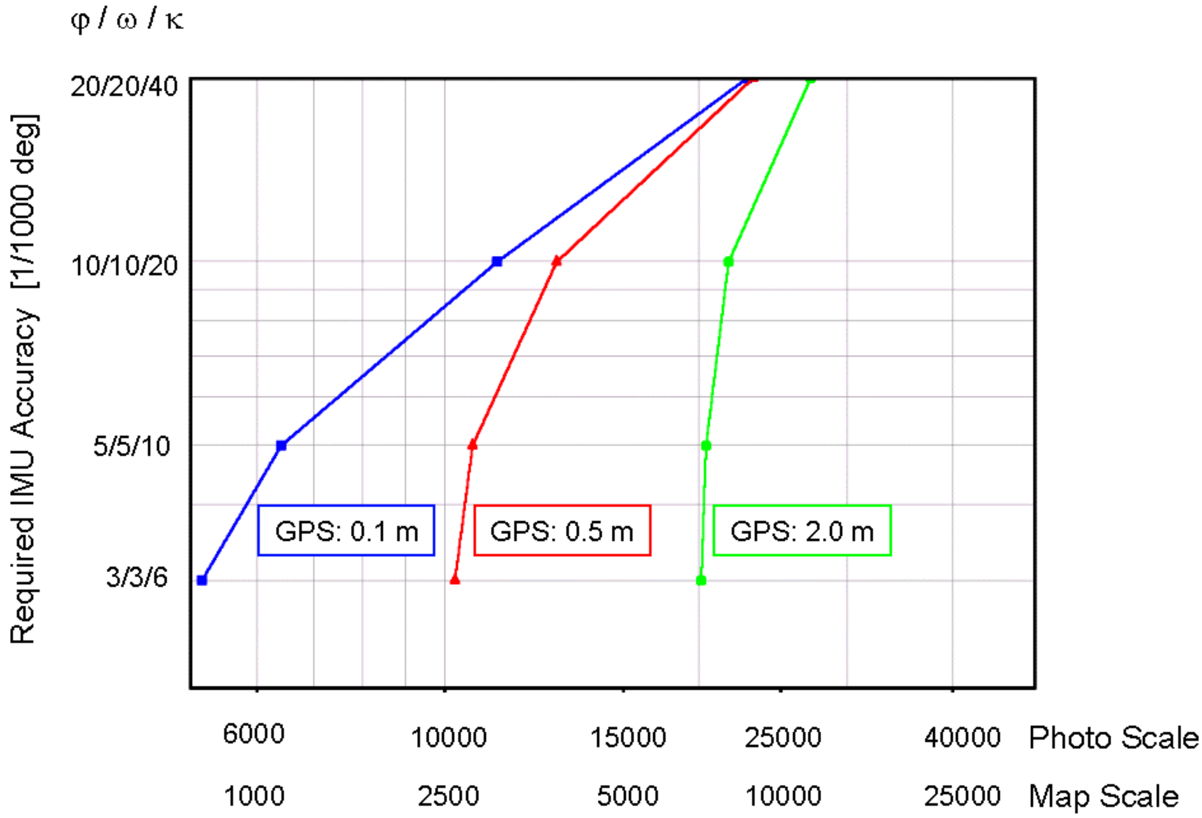

Figure 5: Estimation of the required attitude accuracy for different map scales and positioning accuracy.

Figure 5 might be read in the following way:

1. Choose the aspired map scale in the lower line under the abscissa.
2. Choose the line of the estimated positioning accuracy of your GPS/IMU system.

3. The values at the ordinate at the intersection point of the map scale with the line of estimated positioning accuracy gives the maximum tolerable attitude error. If your GPS/IMU system can fulfill these requirements, the EO parameters might be used for georeferencing directly. If you are not sure that this quality can be reached, the EO parameters should be used as an additional information for a conventional data evaluation, e.g. block adjustment.

Example: For a map scale of 1:5000 a photo scale of 1:15000 would typically be used. With an estimated positioning accuracy of 0.5m an attitude accuracy of about 0.01° for omega and phi and 0.02° for kappa (heading) is required. For a project with these conditions the quality of the attitude measurement of the *AEROcontrol* system (0.005°, 0.005° and 0.01° for omega, phi and kappa) fulfills the requirements for direct georeferencing.

In figure 5 the general tendency can be seen that the requirements for the GPS/IMU system become more strict for larger map-scales. For small scales the requirements can be fulfilled easily.

Please note that figure 5 can only be used as a very rough estimation, because effects on the resulting height in the map are not taken into account. Furthermore all errors have been assumed to have gaussian distribution. The lines are given for a one sigma error.

Airborne laserscanning

For airborne laserscanning, the requirements for the positioning accuracy is mostly much more strict than for the attitude accuracy. The reason is, that compared to aerial photography, the pixel size (or point density on the ground) is much larger.

An example for a laserscanning mission is a project flown by TOPSCAN, Steinfurt, Germany in December 2001. The flying height was 1000 m above ground, the point density on the ground was 1 point per $3m^2$ and the scanning angle was ± 20°.[1]

For these conditions, a roll angle of 0.005° would result in a displacement of the laserpoint on the ground of about 10cm and an altitude error of about 3cm at the maximum scanning angle. Since the internal distance measurement error of the

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[1] For this project, an old scanner type was used. Modern scanners used by TOPSCAN provide a higher performance.

scanner is about 3cm, in this case, the overall error is dominated be the positioning accuracy of the *AEROcontrol*. In this example project, a mean altitude offset of 2cm with a standard deviation of 11cm has been reached.

Aerial photography with digital cameras

From the accuracy point of view, the situation with digital cameras is similar to the situation with analog cameras described above. With the increasing use of digital cameras, the practice of using EO parameters from GPS/IMU systems as an additional information for automatic aerotriangulation might become more important, because both data, the image data and the orientation data is available in digital form without any additional processing steps. If the EO parameters from the GPS/IMU system are refined by an automatic aerotriangulation as a standard procedure for each mission, the effort for a careful GPS/IMU processing decreases, because systematic drift or shift effects in the EO parameters would be eliminated by the AT. An example for the use of *AEROcontrol* in combination with a high-end digital camera can be found in [3].

Airborne SAR

Compared to laserscanning applications, airborne SAR is often employed for digital elevation models (DEM) with a lower altitude accuracy [4],[5]. For a DEM with an accuracy of 0.5m, a positioning accuracy in the same range is sufficient.
An example for the use of SAR with *AEROcontrol* is the Experimental Airborne SAR (E-SAR) of the German Aerospace Center (DLR) [4]. The following accuracy requirements are given for a digital elevation model of 0.5m to 2m:

abs. position:	0.5m
rel. position:	0.8cm inside 160m
velocity:	0.17m/s
roll angle:	0.01°

For special applications of E-SAR, the requirements for the positioning accuracy are more strict.

Multi sensor systems

The accuracy requirements for multi sensor systems have to be derived from the single sub-sensors. If one IMU is used for multiple sensors, a rigid connection between the IMU and the different sensors is essential for an exact attitude determination.

Conclusion

The airborne GPS/IMU system *CCNS/AEROcontrol* of IGI provides attitude information with an accuracy of 0.005° for roll and pitch, 0.01° for heading, and a positioning accuracy of about 0.1m (depending on GPS conditions). In this paper it was shown, that this accuracy is sufficient for many direct georeferencing applications like small and medium scale mapping. Nevertheless, some applications need further refined orientation (e.g. by automatic aerotriangulation) to reach the required accuracy, like in the case of large scale mapping. For airborne laserscanning, the positioning error is the limiting factor for the accuracy of the final product.

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