Ortho Image Production within an Automatic Processing Chain for hyperspectral Airborne Scanner ARES

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ABSTRACT: The airborne imaging spectrometer ARES (Airborne Reflective Emissive Spectrometer) is a new scanner available for the user community in 2006. The sensor will provide 160 channels in the solar reflective region (0.47 – 2.42 µm) and in the thermal region (8.1 – 12.1 µm) within the thematic focus of agriculture, vegetation, geology and soil science.
An automatic processing system embedded in the Data Information and Management System DIMS of DLR is established, which includes system corrections, radiometric calibration, atmospheric correction and ortho image production. For the ortho image production a kinematic GPS positioning and inertial measurement unit IMU as well as a worldwide digital elevation database is used. Furthermore the stereo sensor ADS40, installed in the aircraft together with the imaging sensor, is foreseen to produce high accuracy digital elevation models in combination with the DEM database. The boresight misalignment angles are calibrated using a ground control point field located at the DLR airbase.
The paper describes the automatic processing chain for the different product levels, especially the direct georeferencing of the airborne data. Results and experiences of the automatic processor for the HyMap line scanner are shown. The long term stability of the boresight misalignment angles are investigated, which is essential for an automatic processing.

1 INTRODUCTION

Hyperspectral earth observation from airborne systems has been established at DLR in the late 1980s, focused on a wide range of applications like agriculture and forestry monitoring, geological mapping and exploration, urban planning, coastal zones and inland water monitoring and more. Several imaging spectrometer campaigns embedded in an European frame have been accomplished. From 2003 to 2004 the ‘HyEurope’ survey campaigns organized by DLR in cooperation with HyVista Corp. have been carried out using the hyperspectral sensor HyMap. The potential of hyperspectral imaging have been demonstrated, but also its limitations. In a joint effort of DLR and GFZ the new, state of the art, instrument ARES will be available in 2006 [A.Müller et al. 2004]. In order to establish a fully automatic processing chain for hyperspectral airborne scanner data, including raw data archiving (Level 0), systematic corrections (Level 1), atmospheric and geometric corrections (Level 2) a complete processing system was designed. Embedded in the environment of the ‘Data Information and Management System’ DIMS of DLR product generation, storage, ordering and delivery is provided.

The paper describes the automatic ortho image production of the processing chain preliminary tested on various airborne scanners especially the hyperspectral sensor HyMap. The demand of an automatic processing must include the access to terrain height information, which is at the moment realized using a worldwide DEM database and also in future a simultaneous installed stereo camera (foreseen ADS40). Additionally the geometric calibration and the stability of the boresight misalignment angles (BMA) are requirements for this task.

2 PROCESSING SYSTEM

DIMS (Data Information and Management System) (figure 1) is an automated processing system for earth observation data of multiple missions [Mikusch et al. 2000]. The user service domain offers browsing, guidance and ordering of earth observation data. The product and order manage-

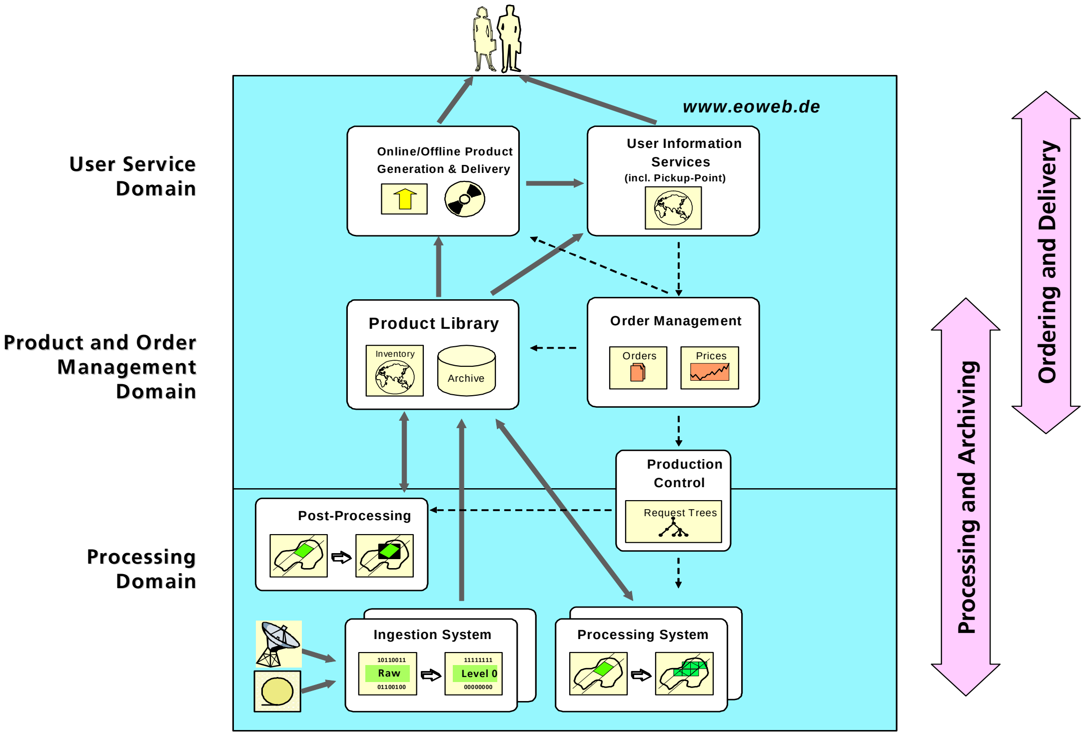

Figure 1: Global scenario of DIMS (Data Information and Management system) [Mikusch et al. 2000, kindly provided by E.Diedrich DLR]

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domain provides long-term storage of the products in a robot archive and handles input/output of the processing system and the external users and facilities. The processing domain provides standardized and flexible interface to DIMS like ingestion, data-driven or requested processing. About 30 automatic processing systems with 150 product types for satellite- and airborne sensors are in operation at DLR. For the hyperspectral sensor ARES an automatic processor up to level 2 has been designed and implemented in the DIMS system. The specific steps of processing are shown in figure 2. After ingestion of the level 0 raw image data together with metadata like radiometric and geometric calibration data, exterior orientation, mission specific data and more into the product library, no further intervention is possible. The specified DIMS workflow for the ARES data processing starts with level 0 data from where the different products are derived:

- Level 1 (System correction): image artifacts due to sensor characteristics are removed, dark current values are subtracted and, applying calibration coefficients, at-sensor-radiances are generated.
- Level 2a (Direct Georeferencing): ortho images are produced using direct georeferencing technique. This part of the processor is discussed in more detail in the following chapter.
- Level 2b (Atmospheric Correction): the radiance values are converted to ground reflectance for the reflective wavelength range and surface emissivity and temperature for the thermal bands. Solar illumination including topographic influences, sun-target-sensor geometry and sensor characteristics are taken into account. A data link to geometric processing is included to obtain sensor viewing geometry and interpolated terrain height information for each image sample.

A full level 2 product consists of system, geometric and atmospheric corrected data building the input to generate value added products.

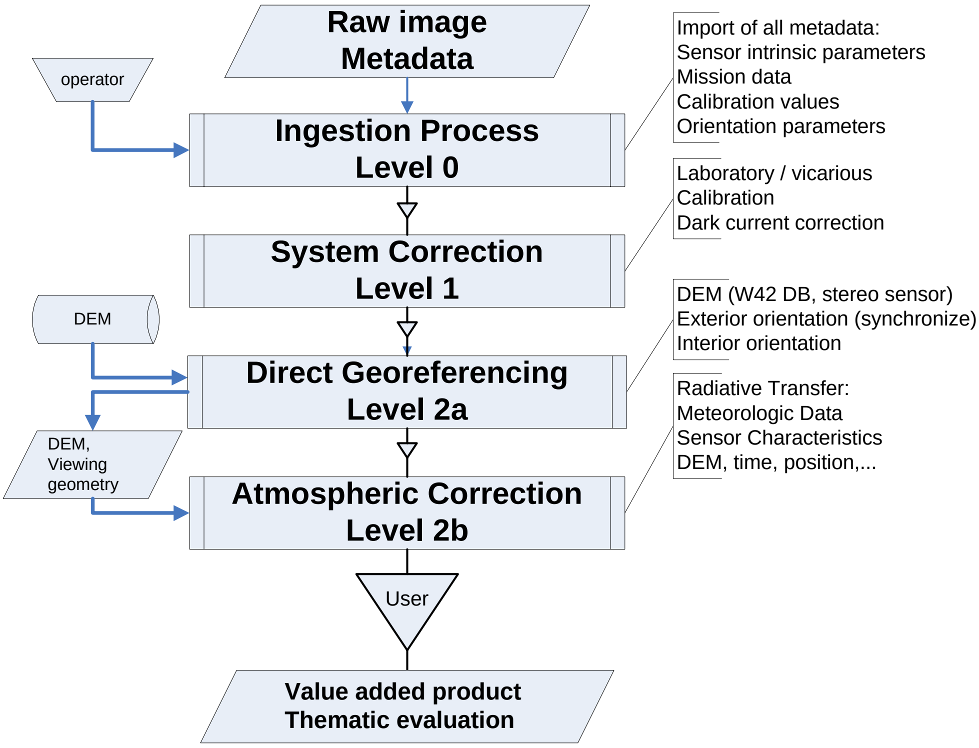


Figure 2: Flow diagram of processing chain

3 PROCESSOR PART: ORTHO IMAGE GENERATION

The hyperspectral sensor ARES will be available in 2006. The processor chain is already implemented in the DIMS system and pre-investigations for performance analysis are carried out using different multi- and hyperspectral sensors especially using the hyperspectral sensor HyMap during the HyEurope campaigns in 2003 and 2004.

The ortho image processor is designed to handle data from airborne and spaceborne sensors based on the dircect georeferencing (DG) technique [Müller et al. 2003, 2005]. The major features in comprehensive form are:

Definitions of coordinate frames:

The model or mapping frame is a local topocentric system (LTS/datum WGS84) with a fundamental point near the centre of the ortho image, with directions x to east, y to north and z perpendicular up to the WGS84 ellipsoid surface. The sensor coordinate frame has its origin at the camera projection center with (roughly spoken) x along track positive to motion direction, z up and y completes right handed triad. Additionally map projections like UTM can serve as mapping frame for airborne imagery.

Transformations of coordinate frames:

In order to transform ephemeris or DEM data to the mapping frame or to produce ortho images in any map projection a collection of 32 coordinate transformations with about 110 predefined as well as free geodetic datum transformations are part of the processor. The undulation w.r.t. WGS84 is taken from the EGM96 (Earth Gravity Model) for conversion from geoid to ellipsoid heights.

Interior orientation:

The interior orientation is described by models for whiskbroom, pushbroom and frame cameras or tables of 3D vectors for each sensor pixel, derived from laboratory or in –flight calibration.

Attitude angles:

The attitude angles can be measured with respect to the local level aircraft navigation frame, ECEF (Earth Centred Earth Fixed) or satellite orbit coordinate frame, where any sequence and direction of rotation is supported. Angles represented in unit quaternion are transformed to Euler angles.

Positions:

The functional model includes the calculation of the position of the sensor projection centre using measured lever arm values. For airborne sensors using integrated GPS/IMU systems the position of the sensor projection centre is normally provided by separate navigation processing software from the manufacturers and for satellite sensors the lever arms are often neglected or already taken into account.

Resampling:

Bilinear or nearest neighbour resampling in irregular grids are supported.

Additional features:

Correction of systematic errors in angular rates during roll movements of optomechanical scanners can be taken into account. For image matching demands in evaluation of stereo data quasi-epipolar images with information on reconstruction of image space coordinates can be produced. A link to the atmospheric correction processor ATCOR, realized by sun-target-sensor geometry data for each pixel of the ortho image is included.

Calibration:

By iterative least squares adjustment the boresight misalignment angles, position and attitude offsets can be determined using ground control information.

Special functions:

The application of an automatic ortho image processor is restricted by coding special, mostly simple pre-processing software for each sensor system to transcribe the metadata into the ortho processor compatible format or to synchronise and interpolate the exterior orientation with imaging elements.

4 DETERMINATION AND STABILITY OF THE BORESIGHT MISALIGNMENT ANGLES

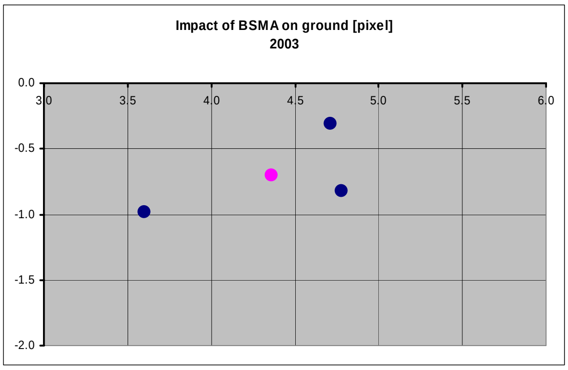
A major requirement for automatic ortho image production is the determination of the boresight misalignment angles, which describe the rotational offsets between sensor coordinate frame and the body coordinate frame defined by the IMU. For this reason a calibration field, located at DLR

Oberpfaffenhofen, Germany, has been established containing 44 ground control points (GCP). The GCPs have been surveyed with differential GPS with an accuracy of <0.1m. For ARES it is foreseen to determine the boresight misalignment angles after each new installation of the equipment in the aircraft or before/after each flight campaign. The IMU is rigidly mounted on the sensor, which itself is installed on a drift frame (for the HyMap sensor the IMU is integrated in the sensor). The boresight misalignment angles are calibrated by iterative least squares adjustment of the calculated points derived from the measurements of the exterior orientation and the GCPs [see also R.Müller et al. 2005]. The time stability of the determined boresight misalignment angles has been investigated for the HyMap sensor in 2003/2004 [Holzwarth et al. 2005]. Table 1 shows the three boresight misalignment angles of rotation sequence first around x-axis (along track), second y-axis (across track) and third z-axis (up) for the two years.

Table 1: Boresight misalignment Euler angles for the years 2003 and 2004 during HyEurope campaigns with the hyperspectral sensor HyMap (Cmigit GPS/IMU system used). For some days before and after flight mission the calibration field has been over flown.

Date	Rotation x [°]	Rotation y [°]	Rotation z [°]	GCP [#]
30.06.2003	-0.114	-0.433	0.460	32
05.08.2003-1	-0.033	-0.574	0.414	37
05.08.2003-2	-0.093	-0.566	0.575	33
20.05.2004	-0.087	-0.715	0.105	32
07.06.2004-1	-0.151	-0.729	-0.104	34
07.06.2004-2	-0.117	-0.703	0.361	33
20.06.2004-1	-0.116	-0.681	0.216	34
20.06.2004-2	-0.072	-0.773	0.696	38

In order to get a better impression of effect of the boresight misalignment angles the deviation on ground with respect to the ideal case of a nadir looking sample in pixel units (therefore adjusted to the flight altitude) is shown in figure 3.



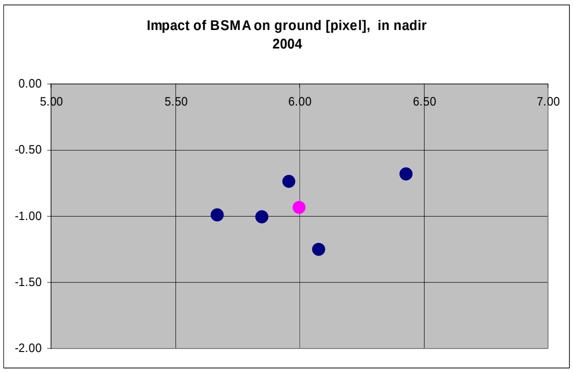


Figure 3: Impact of boresight misalignment angles (BMA) in pixel units (blue dots) on ground for nadir looking case (deviation=0) caused by the boresight misalignment angles for the year 2003 (left graphic) and 2004 (right graphic). The mean value is shown with a red dot.

These values have to be interpreted in the context of the performance accuracy of the GPS/IMU system Cmigit used for the determination of the exterior orientation. For the position accuracy 2.5m planar and 3.0m vertical RMSE, and for the attitude accuracy 0.06° for roll&pitch and 0.09° for heading is specified by the manufacturer. The flight altitudes above ground range from 1800m to 3540m resulting in a footprint ranging from 3.8m to 7.4m. Taken into account the performance of the Cmigit GPS/IMU system a location accuracy in nadir of 4.4m for 1800m flight altitude and 6.3m for 3540m flight altitude can be expected (for the max. scan angle of HyMap 5.0m and 7.9m for the two flight altitudes are calculated). From this considerations a pointing accuracy of about 1 pixel size is reached, which is in line with the variations of the boresight misalignment angles resulting in a accuracy also of about 1 pixel size (see figure 3). For ARES the high performance position and orientation system Applanix POS AV 510 has been purchased with RMSE accuracy specifications of 0.05-0.3m for the position, 0.005° for roll&pitch and 0.008° for heading determination in postprocessed mode. It is noted that temperature infuences can cause torsions of the system resulting in boresight misalignment angle variability, which have to be investigated for ARES.

5 SYSTEMATIC GEOMETRIC CORRECTION OF WHISKBROOM SCANNERS

The rotating scan mirror of whiskbroom scanners, like ARES, should have a constant scan frequency with w.r.t. the sensor body. Therefore systematic errors in angular rates during roll movement can occur due to the moment of inertia of the mirror, which is not fully compensated by the sensor engine. This leads to an under- and overestimation of the measured roll angle depending on the scan direction with respect to the roll direction. The effect on the ortho image for a heavy roll movement (about 6° within 50 scan lines) is shown in figure 4.

Figur 4: Effect of “moment of inertia” of the scan mirror on ortho image accuracy. The left image shows the original data, the middle image the uncorrected ortho image and the right image the corrected ortho image. The uncorrected ortho image (middle) shows undulated roads with respect to the corrected ortho image. This effect can be mainly observed for heavy roll movements and is different for the sensor systems (not all sensors show this effect).

The correction is based on the assumption that this effect is proportional to the roll angle rate, which leads to

$$\omega_{corrected} = \omega_{measured} + c \cdot \frac{d\omega_{measured}}{dt}$$

where $\omega_{measured}$ and $\omega_{corrected}$ are the measured and corrected roll angles at a time t, c is a constant value valid for the sensor, which has to be calibrated, and t the time. The value c can be calibrated by evaluating a series of ortho images produced with varying values of c. Linear image features in

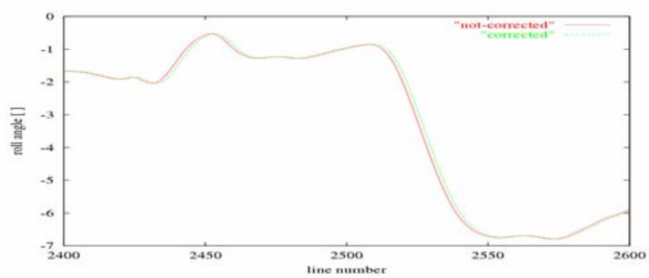


Figure 5: Not corrected and corrected roll angle with c=-1.4

along track in the image, like known straight roads, must become straight in the ortho image for the correct *c* value. An example (corresponding to the above image samples) of the roll correction is shown in figure 5.

6 DEM DATABASE

For DG of single imagery terrain height information is necessary to determine the intersection point of the actual sensor look direction with the earth surface. The demand of automatic ortho image generation requires therefore an already available DEM (DSM/DTM). For the processing of ARES image data the following hierarchical access to DEM data is defined:

1. DEM provided by the user (cooperation partner, employer)
2. simultaneously operated stereo sensor (ADS40 stereo camera foreseen)
3. global DEM database (called: w42) installed at DLR [Roth et al. 2002]

The operational contents of the w42 DEM database are from different sources listed in table 2 with coarse accuracy values (sources from optical sensors are tested).

Table 2: Operational DEM database sources included in w42

Source	Rel. accuracy	Abs. accuracy	resolution	area
SRTM X-Band	6m	16m	1”	+-60° with gaps
SRTM C-Band USGS1	8m	16m	1”	USA
SRTM C-Band USGS3	8m	16m	3”	+-60°
ERS1/2 Tandem	20m	30m	1”	Limited areas
DTED 1	20m	30m	3”	Europe / USA
DTED 2	20m	30m	1”	Limited areas

The accuracy values strongly depend on the terrain characteristic and the location. From a selected subset of these DEM databases the height information within a specified area is extracted by merging and mosaicking of the DEM tiles. Along with the co-registered corresponding height error maps the “best” DEM is generated by weighted averaging of the individual height values from the different sources [Knöpfle et al. 1998]. In every case a DEM for the required area is generated used by the automatic ortho image processor, even though the DEM accuracy not always meets the specified ortho image accuracy requirement especially for scanners having a wide field of view (65° FOV for ARES).

7 ORTHO IMAGE ACCURACY

In preparation for processing ARES imagery the accuracy assessment of ortho images for four different multi- and hyperspectral sensors (see table 3) were investigated. The image data were acquired from the same test site located at DLR Oberpfaffenhofen. The boresight misalignment angles were determined by GCPs.

Table 3: Investigated airborne sensors and mission parameters

Sensor	ROSIS	DAIS	Daedalus	HyMap
Sensor type	pushbroom	whiskbroom	whiskbroom	whiskbroom
FOV [°]	17.37	51.20	85.92	61.3
IFOV [mrad]	0.59	3.3	2.5	2.09
altitude above ground [m]	3230	3230	2030	2370
footprint [m]	1.9	10.7	5.1	4.9
GCPs used for BMA determination	22	5	7	25

For the flight mission with the sensors ROSIS-03, DAIS-7915 and Daeadalus-ATM-1256 the IGI CCNS/AEROcontrol-IIb and for HyMap the Cmigit position and orientation system was used. The performance specifications given by the manufacturers are listed in table 5.

Table 4: Performance (RMSE) of the GPS/inertial systems given by the manufacturers.

	AEROcontrol IIb	Cmigit
Position[m]	0.1–0.3 DGPS mode 1-3 OmniStar	2.5 horizontal 3.0 vertical
roll&pitch[°]	0.01	0.06
Heading[°]	0.1	0.09

A DEM derived from the ERS-1/2 Tandem mission with 25m horizontal resolution served as input for the rectification of the three images. The comparison of this DEM with a DEM (covering only partially the test site) derived from an aerial image stereo pair emphasizes the accuracy of the used DEM with mean height differences less than one meter measured at six corresponding points (as mentioned before the accuracy of the DEM's from the database strongly depends on the location and terrain characteristic; in this case with moderate terrain and multi-pass interferometry high quality DEM's are available; see previous chapter).

The direct comparison of the Daedalus ortho image with manually measured (sub-pixel range) control points leads to a result with mean deviations of < 0.3 pixel (<1.4 m) and standard deviation of about 0.5 pixel (see table 5)

Table 5: Accuracy assessment of Daedalus ortho image using 41 check points

Direction	east	north
Mean [pixel / m]	0.27 / 1.37	-0.16 / -0.81
STDV [pixel / m]	0.53 / 2.68	0.38 / 1.89

Using the estimated boresight misalignment angles ortho images, resampled to a pixel size of 5x5m², are generated from the different sensors. For quality assessment (a major task using DG) the accuracy of co-registration of ortho image pairs are investigated by image matching (table 6).

Table 6: Matching results of pairs of ortho images (1 pixel = 5m)

Combination	DAIS – Daedalus	Daedalus – HyMap	Rosis – Daedalus
Matching Points [#]	63	92	126
Mean [pixel]	0.51 / -0.41	-0.19 / 0.50	-0.12 / -0.50
STDV [pixel]	0.25 / 0.51	0.22 / 0.50	0.12 / 0.25
Minimum [pixel]	0.32 / -1.31	-0.52 / -0.64	-0.36 / -0.99
Maximum [pixel]	1.09 / 0.39	0.30 / 1.56	-0.08 / -0.34

For all matching combinations of the individually corrected ortho images a co-registration in each direction of <0.51 pixel (<2.6m) with a deviation of less than half a pixel size (=2.5m) is found, which is in line with the expected accuracy (table 4). It is noted, that for the interior orientation ideal sensor models are used (also for the CCD camera ROSIS) and the accuracy of the DEM influences the accuracy of the ortho image especially for sensors having a wide FOV. The reached accuracies are in line with the performances of the GPS/inertial systems [see also R.Müller et al. 2005].

8 CONCLUSION

In preparation for automatic processing up to level 2 of data from the new hyperspectral sensor ARES different existing sensor systems were investigated with focus on ortho image generation using direct georeferencing technique.

Preliminary tests show, that the boresight misalignment angles can be calibrated and applied for time intervals of typical flight missions. Remaining geometric distortions in across direction for whiskbroom scanners after ortho image generation can be corrected by a simple model. These distortions are linked to the moment of inertia of the scan mirror not fully compensated by the sensor engine. A DEM database is used to extract height information for the ortho image generation. The ortho image processor has been tested with several airborne scanners reaching location accuracies in subpixel range.

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