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Calibration and Georeferencing of Aerial Digital Cameras

OTTO HOFMANN, Brunnthal

ABSTRACT

The conventional determination of the orientation parameters of photogrammetric images by aero-triangulation is increasingly complemented or even replaced by direct observations obtained from GPS and inertial (IMU) systems. For including these measurements in the image data processing a procedure was developed as well as the design principles of a calibration equipment formulated with the aim of op-timally accomplishing these tasks with a minimum of costs.

The orientation parameters directly observed with IMU and GPS sensors are corrupted by systematic er-rors that are caused by error parameters of these sensors. In order to detect the sources of the errors and to eliminate the ensuing errors from the sensor data, homologous image points of object points of the terrain are determined that are recorded during a mission from at least three different camera positions. These camera coordinates together with IMU and GPS data are subjected to a least squares adjustment, which yields the following results:

- the orientation parameters at every recorded instant during the mission;
- offset data;
- systematic errors of the measurement equipment;
- precision of these data.

The algorithms of this procedure have been generated and coded both for model simulations and for rou-tine services. Calibration in the field is not necessary. The procedure may be applied to both film-based and digital area or line sensor cameras on board of aircraft and space vehicles as well as to on-line proc-essing. It functions also without GPS data.

1. THE SCOPE OF THE TASK

Georeferencing of photogrammetric recordings by the direct observation of the orientation parameters is accomplished with inertial and GPS systems. The inertial measurement system IMU senses angular rates and linear accelerations from which the orientation parameters of the camera – positions and angular orientations – are calculated. The IMU system is rigidly connected with the camera. The distance between the camera and the IMU is irrelevant but their coordinate systems must be mutually aligned. Angular deviations are called bore sight angles. The GPS receiver is mounted rigidly on the aircraft; its distance to the external perspective center of the camera may amount to meters. Due to the stabilizing movements of the camera during the flight the eccentricity coordinates of the GPS receiver change continuously with respect to the camera coordinate system. The IMU and GPS data are corrupted by stochastic and systematic errors. These facts pose problems for both the calibration and the determination of the orientation parameters.

M. CRAMER published in PFG-Geoinformation 4/2003 results and experiences gathered during comprehensive investigations into georeferencing and field calibrations of photogrammetric cameras. There he reports, among other observations, that „internal system errors of the IMU could not be completely eliminated“ and that they varied with time. As a possible explanation the suspicion was voiced that „the GPS and inertial data had not been processed with sufficient care“. Furthermore, the author found that systematic errors could not be detected without control points and that offsets vary with time and are not reproducible.

Determining the bore sight angles requires „optimum processing of the GPS and inertial data“ and the author concludes that the errors can be compensated only by „adjustments of the system calibration on every day of the mission“ and by „integrated sensor orientation“ over the actual terrain.

TEMPELMANN, HINSKEN and RECKE (2003) published a field calibration method for line cameras dispensing with geometric calibration of the line sensors in the laboratory: a „flat“ test terrain with-out control points is bidirectionally flown over on crossed paths at two different flight altitudes. The camera coordinates of the sensor pixels are determined with the aid of about 4000 rays from 3000 to 3500 homologous image points on three line sensors to which polynomials are fitted by a least squares method.

The results, experiences and facts published in these papers are technologically and economically problematical.

2. CALIBRATION

A precise and economically acceptable geometric calibration of photogrammetric sensing systems is optimally feasible only with suitable equipment and procedures in the laboratory. The precision of the results depends exclusively on the suitability and quality of the calibration equipment and is not affected by other processes, observations or circumstances.

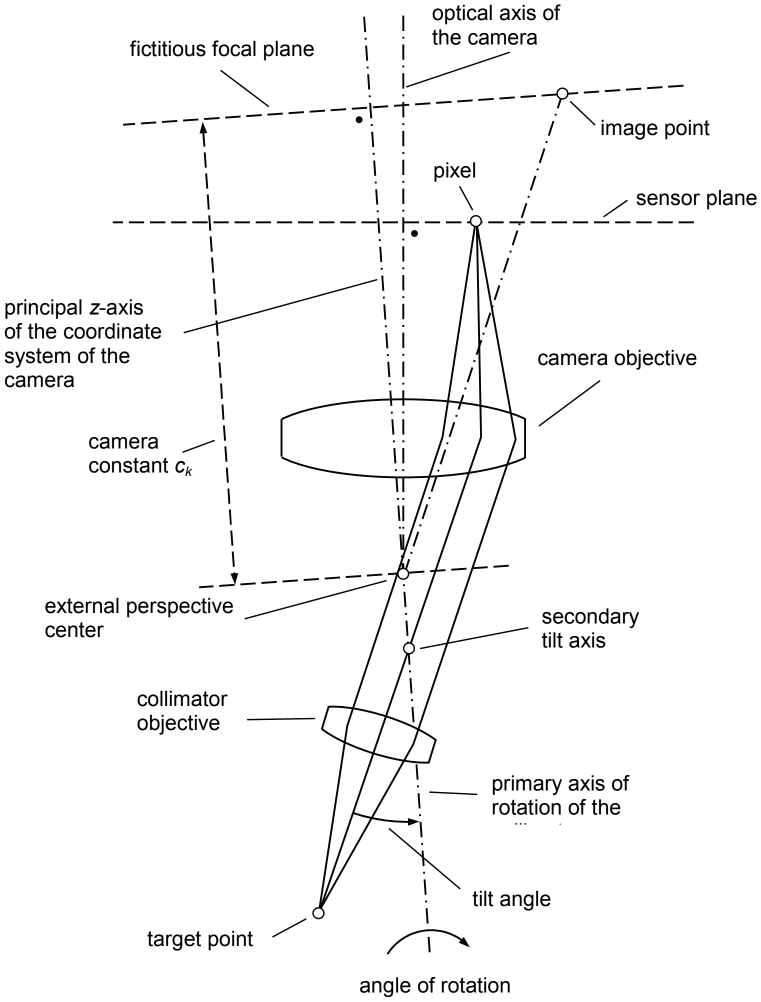

Fig. 1: Calibration of the camera

For the calibration of the camera, i. e. the determination of the coordinates of the pixels of a digital camera or the fiducial marks of a photographic camera a collimator is used, i. e. with the target marker of a telescope focused on infinity. The telescope can rotate about two mutually perpendicular axes. For eliminating the axis error of the equipment the collimator must be tiltable by 180° so that the sensor pixels can be observed from two positions of the telescope, Fig. 1.

The external perspective center of the objective is the origin of the camera coordinates and therefore the projection center of the whole sensor system.

The z-axis oft the camera coordinate system represents the zero direction of the collimator; it is nearly parallel with the optical axis of the camera objective but need not coincide with it. The measurement of the angles about both collimator axes furnish the pixel coordinates in a fictitious focal plane that lies perpendicularly to the principal axis at the arbitrary distance ck, the camera constant, from the projection center.

Some aerial and satellite cameras have large objective apertures and digital cameras may have several objectives. Strictly speaking these optics must be calibrated separately and the eccentricities of their external perspective centers must be included in the data processing. This complicates the computations considerably. The situation can be avoided by arranging the objectives in such a way that their projection centers nearly coincide. They are calibrated simultaneously and the pixel coordinates are projected into a common focal plane. It follows that cameras with only one objective module are advantageous over systems with several objectives.

Bore sight angles cause scale errors of the observed positions and orientations, which are eliminated within the scope of an all-encompassing least squares adjustment procedure.

At ordinary straight flights only stochastic errors arise whose magnitude depends on the amplitudes of the attitude and speed variations of the platform. In flight turns, however, bore sight angles have substantial effects. They cannot be removed by analytical methods. Therefore the coordinate systems of the camera and the IMU must be aligned parallel to each other as precisely as possible.

The requirements listed above are optimally fulfilled by a calibration equipment that has been conceived by the author. It is characterized by the following features:

- observation of the pixels from two telescope positions;
- relatively small aperture of the collimator, which does not depend on the size and the number of objectives;
- precise parallel alignment of the IMU with the camera coordinate system;
- low technical complexity and low costs.

3. GEOREFERENCING

The observed variables used for georeferencing are corrupted by stochastic and systematic errors. To minimize or even eliminate them they are subjected to a least squares adjustment procedure. Only the original observed data from the camera, the IMU and the GPS sensors shall be entered into the least squares adjustment procedure. Otherwise the systematic errors of the sensors and the data they generate and the precision of the data can not be determined. Preprocessed data and data mixes from GPS and IMU sensors are unsuitable to solve the problem.
The following observed data are entered into the least squares adjustment procedure.

3.1. Observed data

The image points, the IMU and the GPS data are observed. It must be emphasized that, in contrast to conventional aero-triangulation, in the context of the presented procedure of direct georeferencing the observed image points are first used to determine the error parameters of the sensors. With these the systematic errors of the observations are then eliminated.

3.1.1. Camera coordinates

Homologous image points are determined of arbitrarily selectable object points along the flight strip. They are recorded from at least three platform positions. If area sensors are employed the object points are situated only in zones of triple coverage. In contrast to this, recordings in the push-broom mode with line sensors A, B and C contain all object points seen from all three camera positions.

The image rays intersecting in the object point obey the collinearity equations. These contain the approximate orientation parameters at the instant of recording that correspond to the data observed by the IMU and GPS sensors.

For matching the calculated coordinates to the local geodetic coordinate system control points are used, preferably two each at the beginning and at the end of the flight strip.

3.1.2. Computing the raw orientation parameters using the IMU observations

The IMU provides data of rotation rates p, measured in rad/s, and linear accelerations b, m/s2, that refer to inertial space. They are samples obtained at intervals of Δt seconds and yield

- angular increments Δp rad = p rad/s • Δt s and
- speed increments Δv m/s = b m/s2 • Δt s.

These are the original observations provided by the IMU. From them the raw photogrammetric orientation parameters are to be computed, i. e. coordinates and attitude angles of the camera position at each sampling instant of the IMU. They are not mutually independent but are correlated and contain stochastic and systematic errors and offsets.

3.1.3. GPS data

The position data that are recorded by the GPS receiver and subsequently transformed to the local coordinate system are to be transformed to the camera coordinate system. The eccentricity coordinates of the GPS receiver vary due to the stabilizing movements of the camera platform. They are calculated off-line with the aid of the angular parameters of the platform. The eccentricity coordinates by themselves can be determined only with uncertainty. Therefore they are corrected together with the offset and quasi drift errors of the GPS inside the least squares adjustment procedure.

3.2. The least squares adjustment procedure

The error equation matrix and the normal equation system are set up by using the error equations of the collinearity equations, the raw IMU data and the GPS data. Iterative computation and inversion yield the following results:

- the orientation parameters at each IMU sample;
- the coordinates of selected object points;
- offset parameters;
- IMU and GPS drift parameters;
- the eccentricity coordinates of the GPS receiver;
- the stochastic errors of all results.

The algorithms used in the procedures for model simulations and operational applications were developed by the author and coded by P. NAVÉ[1] .

4. APPLICATIONS AND ADVANTAGES OF THE PROCEDURE

The procedure is suitable for imagery from aircraft and space vehicles with both film-based and digital area and line cameras.

The orientation parameters of an image-taking flight and the systematic errors of the sensor system are determined with optimum quality at a minimum of costs. Field calibrations are unnecessary.

The systematic error parameters of the camera system are constant by they nature. They are determined for every mission and updated if, according to section 3.1., homologous image points of object points along the flight track are included in the least squares adjustment. For lesser demands on the precision this may be dispensed with, only the recording of control points is required. In this case homologous image points of object points need not be determined. The procedure is thus simplified and the amount of data of observations and for the least squares adjustment is significantly reduced.

The procedure works also without GPS data and is in principle applicable to online processing

5. REFERENCES

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[1] Dr. Peter M. W. Navé, Hubertusstrasse 5, D-85662 Hohenbrunn, e-mail: pmwnave@yahoo.de