NUMERICAL ANALYSIS OF WHISKBROOM TYPE SCANNER IMAGES FOR ASSESSMENT OF OPEN SKIES TEST FLIGHTS

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ABSTRACT:

Nowadays, Open Skies uses mainly whiskbroom type thermal scanners, which provide images in the 3-5μm and 8-12μm ranges. This way of acquiring images introduces commonly known geometrical errors. They result from the „philosophy" of the scanner performance and from the flight parameters. Determination of geometrical errors sources is particularly important for certifying scanners mounted on aircraft. The paper presents a method of determining geometrical errors impacting the quality of images by means of application of calibration targets deployed in the scanned region. The developed method enables to determine both the flight parameters and scanner performance parameters using the acquired images of the target. Computer software developed according to the method enables to determine the basic characteristics of the test flights and hence to eliminate flights that do not comply guidelines.

1. INTRODUCE

This assessment is based on the results of ground and airborne testing of the AAD 5 thermal scanner mounted onboard the German C-160 Transal aircraft. The testing was conducted by an international OPEN SKIES work group in Decimomannu (Italy) on March 27 to April 7, 2006. The aim of the testing was to determine a method for determining Hmin for thermal scanners applied in Open Skies missions.

The participants of the experiment were then provided with tables including results of ground and airborne testing as well as thermo grams and scanned images for further processing. The results of the interpretation concerning geometric distortion are shown in this paper. An international Open Skies work group conducted ground and airborne testing of the AAD 5 thermal scanner mounted onboard the Turkish CASA aircraft in Eskisehir (Turkey) on July 5 to13, 2005. During discussion of the results of the Eskisehir experiment it was noticed that the acquired images were distorted by a geometric deformation.

The Polish State proposed a calibration target for assessment of the geometric deformations to be deployed in the area of testing.

A calibration target composed of four polished aluminium discs 45cm in diameter placed at the corners of a 20m square was applied in the experiment in DECIMOMANNU.

2. WHISKBROOM TYPE THERMAL SCANNERS

Thermal systems of the onboard scanner of an aircraft create two-dimensional images of the terrain along the aircraft flight route. The scanner is a radiometer continuously observing paths of the terrain over which it is carried by an aircraft. Such a path is composed of adjacent scan lines produced perpendicularly to the flight route.

Thermal IR scanner systems (actually all scanning systems) introduce various geometric errors that have to be well understood, because they impact the quality of the imagery processed and analyzed visually or digitally.

Thermal IR images acquired by means of line scanners have different geometric properties than traditional images. The image is a composition of two geometric projections: first being the result of rotation of the projecting beam and the other being the result of the movement of the center of projection.

Additionally, the thermal image includes numerous distortions and errors resulting from the work of the devices' mechanisms and behaviour of the aircraft during flight.

3. IMPACT OF THE SCANNER'S TECHNICAL PARAMETERS ON GEOMETRIC DISTORTIONS IN THERMAL SCANNER IMAGES

Scanners scanning across (multispectral and thermal) are vulnerable to flight level and course changes due to the continuous and dynamic nature of the scanning process and because of the scanning geometry the images include systematic geometric fluctuations.

Images acquired by means of scanning across the flight route have serious scale distortions in the direction perpendicular to the route.

For every increment of time the mirror rotating at a constant speed sees a constant arc $\Delta\theta$ while the distance between the nadir and the observed terrain cell increases – and the linear resolution of the cell increases. Hence the elements of terrain ΔX photographed in a unit of time increase when the distance from the nadir increases. This leads to decreasing scale of the image far from the nadir. This distortion is called tangential distortion of scale and it occurs only across the flight route. The scale along the route is constant.

During the experiments the flights are planned over the thermal calibration targets so that they are placed at nadir.

The spatial resolution is directly related with the instantaneous field of view IFOV of the sensor and it depends on the flight level.

For a specific sensor, the higher the flight level, the lower the spatial resolving power. In case of the whiskbroom type scanners, only terrain at nadir is observed as a circle. It is elliptic when the IFOV moves from the nadir to any of sides.

The real dimension and shape of the cell is not only a function of β, H and θ but also a function of reaction time of the elements in the scanner electronics.

The reaction time is the time necessary for the scanner to provide an electronic response to changes of the reflected or emitted energy. Having this additional limitation in mind we see that the optics impacts the resolution along the flight route while both optics and electronics may impact the size of the cell along the scanning line. Due to limitations concerning the system response time, the resolution along the scanning line may be 3 to 4 times larger than the one along the flight route.

4. IMPACT OF THE FLIGHT PARAMETERS ON THE GEOMETRIC DISTORTIONS OF THE THERMAL SCANNER IMAGES

Since imaging across the flight route is done continuously it lacks a coherent orientation of image points. Scanning across the flight route is a dynamic and continuous process in contrast to sampling as in perspective projection in photography. For this reason distortions of flight trajectory have impact on the relative position of points recorded in the final image.

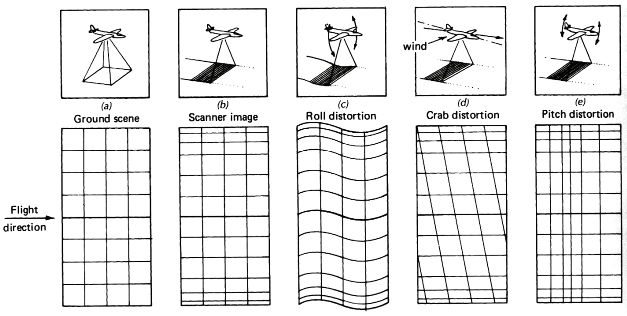

Fig. 1. The variety of deformations related with the aircraft position (angular orientation)

Figure (a) shows an image of an object composed of a grid deployed on the ground for a frame photogrammetric camera. The remaining figures (b-e) show deformations in thermal scanner images depending on the flight parameters.

Figure (b) shows an image draft made by means of scanning across for constant height and course of the flight. This case shows only tangential distortion of the scale.

Figure (c) shows the effects of aircraft swaying to the sides. The image is wavy in this case. The effect may be eliminated by compensation of swaying. It requires application of a gyroscope for monitoring the swaying and delaying or advancing the start of scanning for every line of the image.

During flights in strong cross-winds the axis of the aircraft has to be corrected. This is called side drift and causes that the image is slant (figure d). Side drift may be corrected by means of rotating the scanner in its ring during the flight or using a computer. Most often side drift is avoided by avoiding flights in strong cross-wind.

Finally, figure (e) shows distortions caused by aircraft swaying along its flight route. Local changes of the scale in the direction of flight due to aircraft inclination are usually very small and may be neglected in most analyses.

Compensation system mounted in the ADD5 thermal scanner converts data concerning roll and yaw angles from the gyro of the INS inertial system. It is possible to compensate in the following range:

Roll ± 20°

Yaw ± 10°

5. EXPERIMENTAL PART

Thermal calibration targets are set up in horizontal terrain so it is not necessary to consider distortions related with one-dimensional shifting of the orography.

The Polish calibration target was set up in the area of the thermal calibration targets. Distances between the disks are measured in the acquired thermal images.

To establish unambiguousness of the measurements, the disks were marked by letters as in the figure.

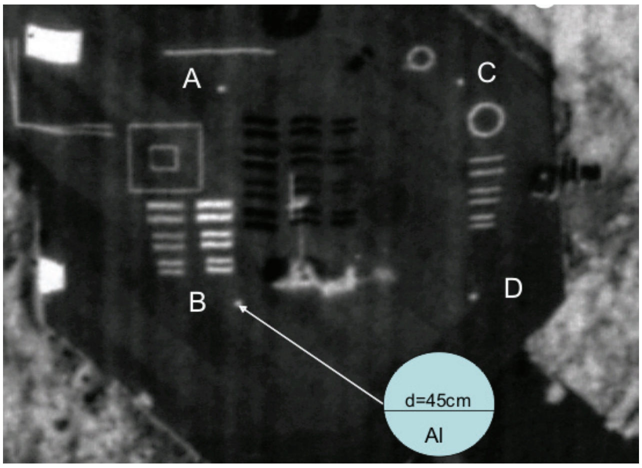

Fig. 2. The arrangement of elements of the polish calibration target

The airborne testing included flights over thermal calibration targets at levels increased by 200ft between 1400 and 3500ft.

The tests were done for narrow scanning angle. The images were recorded on 127mm PAN 200 photosensitive materials and processed in a mobile photochemical laboratory in the DECI airbase. An international group of ten interpreters made visual analyses of the images. Additionally, all images containing elements of calibration targets were scanned at 2400 DPI resolution and pixel dimension of 10.58(3) μm.

The scanned images were rectified using ERDAS software and then measurements were made for determining the geometrical changes of the target. Measurements along and across the target enable the assessment of the flight parameters and performance of the scanner and devices compensating distortion due to the instability of flight.

Information acquired from measurements of the Polish calibration target is used to:

- determine flight level and assess scanning parameters
- determine Vflight and assess scanner performance parameters
- determine distortion related with maintaining the V/H ratio
- determine distortion related with flight realization

5.1. Determination of flight level and assessment of flight parameters

A) distances measurement in the images

To determine flight level two measurements of distances in the target along the scanning line AB and CD in the thermal image are made. The arithmetic mean of the values in {μm} is used for further calculations.

$$(AB+CD)/2 = X \text{ [μm]}$$

B) determination of the image scale
The real distance between the target points in terrain expressed in {μm} is divided by the mean value obtained in paragraph A.

$$AB \text{ [μm]} : X \text{ [μm]}$$

Example
20000000 : X = denominator of the image scale at nadir
20000000 : 2479 = 8068

C) determination of flight level over target
Effective focal length of the objective for wide angle scanning equals 55mm according to the manual. The real flight level at nadir is obtained by multiplying the focal length by the scale denominator.

55mm x denominator of the image scale = H [mm]
Hflight = 0,055m x 8068 = 444 m

D) assessment of flight parameters
The calculated real flight level Hflight (for the distance from the scanner to the target at the moment of imaging) is compared to the planned flight level Hplanned. In this case the flight level error equalled 4%.

E) scanning line width
Whiskbroom type scanning systems geometric resolution at nadir depends on the detector's view angle β and flight level over target which is described by the following formula:

$$D=\beta*H$$

where:
D – scanning line width
β - detector's view angle in mrad
H – flight level over target in [m] or [ft]
The geometric resolution decreases with increasing flight level.

5.2. Determination of flight velocity and assessment of scanner performance parameters

AAD-5 thermal scanner technical parameters used for analyses and calculations during the DECIMOMANNU experiment

A) determination of V/H ratio for assumed flight velocity V=102.89m/s (200knots) and planned flight levels H.
The V/H ratio changes continuously depending on the changes of flight parameters.

B) determination of scanner performance range
The scanner, however, realizes the task for certain predefined values, i.e. V/H ratio value is defined for the middle of each range and it corresponds to the whole range.
V/H [rad/s] ratio value ranges for wide view angle β=0.5mrad

Example
For flight velocity of 102.89m/s (200knots) and level of 1000 m the V/H ratio value equals 0.10289 rad/s which is realized as 0.1 rad/s by the scanner. For the flight level of 500m the V/H ratio value equals 0.20578 rad/s which is realized as 0.2rad/s by the scanner. V/H ratio [rad/s] value has to be appointed to each flight level. In the experiment, from one to four flight levels use the same scanning and recording parameter.

C) What is the V/H [rad/s] ratio value for wide view angle β=0.5mrad
It determines the number of scanned lines per second that the scanner has to process and record. It means that for constant V/H ratio the number of scanned lines per second remains constant independently of flight level changes but the IFOV scanned line width in terrain changes.

Example:
For V/H of 0.1rad/s i.e. 100mrad/s the value has to be divided by 0.5 mrad/s which gives 200 lines/s

D) image recording on film
The film transportation speed changes depending on the V/H [rad/s] ratio value. The film transportation speed is determined for V/H values.
According to the V/H value, the appropriate analogy voltage (V) is supplied to the scanner to realize the process of image signal forming and recording.
A single line width recorded on the photosensitive material is constant and equals 27.5 μm independently of the scanner performance range and flight level.
The film transportation speed controls the number of lines recorded per second. For V/H equal 0.2 rad/s the film shifts 10.988 mm/s and for V/H=0.1125 rad/s it shifts at the speed of 6.172 mm/s independently of the flight level appointed to the V/H value range.

Measurements of the target image

A) The distances AC and BD in the thermal images measured along the aircraft flight route and their arithmetic mean in μm correspond to the distance of 20m in terrain
(AC +BD)/2

B) Calculation of the coefficient of one second flight distance for defined distance between calibration target points in terrain
Example: the aircraft should fly 102.89 m in one second. The distance between the calibration target points along the flight route is 20m or 98m in terrain.
For 20m the coefficient equals 102.89 : 20 = 5.1445, and for 98m 102.89 : 98 = 1.05

C) To increase precision of the film transportation speed V measurement, one of the sides along the flight route was enhanced to 98m by means of an additional Al disk. The position of the disk was selected according to terrain conditions.

D) When the measured value is multiplied by the value of the suitable coefficient obtained, the result corresponds to the real value of the distance of the point in the image in mm after 1s of flight.

E) For the planned flight level, the [V/H] value and the film transportation speed in mm/s are determined. The value in mm corresponds to the distance in the image at which the aircraft should occur after 1s flight i.e. 102.89m in terrain.

F) Comparison of results of the distance on the image in proportion to planned result of distance for flights performed on 04 April 06.
The flight was planned from 1400ft to 3500ft. The planned results were compared with factual result from images for our targets 20 and 98 meters. Generally they were very close to the planned results, but for an altitude of 1400ft and 1600ft the difference was bigger. So, we can presume the IRLS had

worked on V/H=0.225 sub ranges. It's mean for an altitude of 1400 ft instead of 500 lines changed to 450 and for altitude of 1600 ft instead of 400 was 450 lines. The big difference was observed for an altitude of 2100 ft and 2300.
This may be connected with the incorrect functioning of the IRLS (there were two successive flights over the target) or with the speed of the aircraft.

G) Values obtained in paragraph D and E are compared.

H) The real value of the flight velocity during scanning.
The value obtained in paragraph D in mm is divided by the value of the film transportation speed in mm per second for specific parameters of the scanner performance.

5.3. Determination of distortion related with V/H maintaining

The mean values in µm resulting from V/H maintaining i.e. synchronization of the number of lines per second and film transportation speed for each flight level:

(AC + BD) / 2

are divided by the appropriate measured values of distances between points along the scanning line:

(AB + CD) / 2

The big changes of dimensions up to 20% which we observed are connected witch sub ranges of IRLS

planned	0.2 rad/s -	400 lines
realized	0.225 rad/s	450 lines

Noticeable deformation of SIMENS star dimension and ring-shaped targets.
In certain cases we can observe diagonal differences more than 30%.

5.4. Determination of distortion related with flight realization

Measurements of diagonals of the target in the image for all flights. The ratio of the diagonals length with maintained unambiguous data substitution

AD/CB ; CB/AD

5.5. Determination of the drift angle.

Measurement of angle of drift shows us differences up to 15°.

Drift is connected with side wind during experiment.

6. SOFTWARE CREATED BY THE AUTHOR, USED TO EVALUATE THE FULFILMENT OF THE ASSUMPTIONS OF THE TEST FLIGHTS

On the basis of the procedures described in chapter 5 and data acquired during experiments in Decimomannu and Eskisehir, specialized software (DECI) have been created to evaluate the accuracy of the fulfillment of the assumptions of the test flights.

In order to evaluate the images of the calibration targets with the use of the DECI program, one does not have to use the entire image – only the fragment of the image depicting the targets and the bottom edge of the frame are needed. Once the program is running and input data has been entered (fig. 3) one must select all 4 discs of the calibration target on the image as well as two points indicating the beginning of the frame line (fig. 4). Once the first point (A) has been selected, the software assists in the selection of the remaining points. The zoom and snap functions are available when selection of the points is being done.

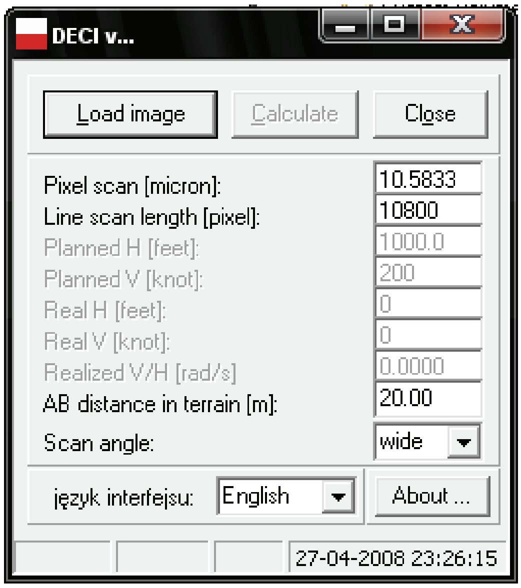

Fig. 3. Input data essential for the application to function

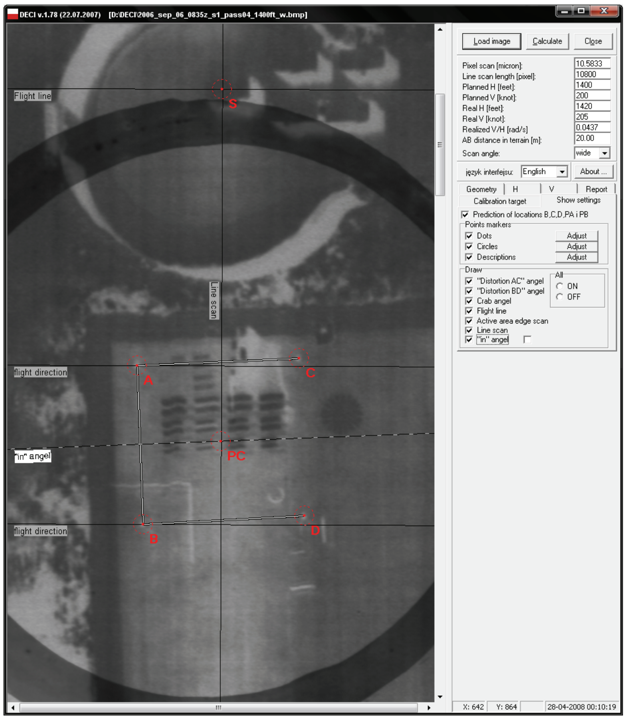

Fig. 4. Points of the calibration target selected on the image

Once the points have been selected, the software automatically calculates all the parameters described in chapter 5. The user can directly browse these within the software. It is however possible to create a database in MS Excel format, which would contain all the accumulated results.

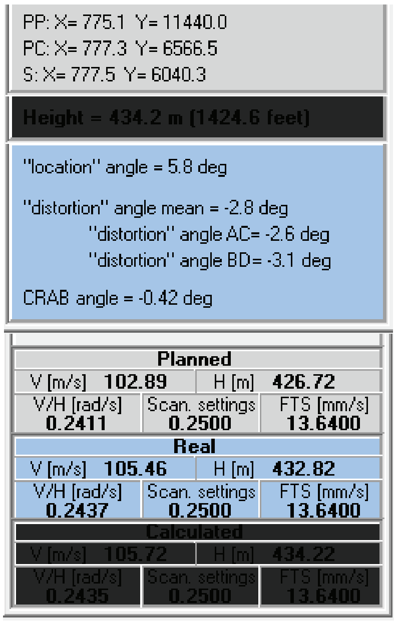

Fig. 5. Basic flight and scanner parameters determined on the basis of the measurements of the polish calibration target.

Computer software developed according to the method enables to determine basic characteristics of the test flights and hence to eliminate flights that do not comply with guidelines.

7. CONCLUSIONS

1. The presented method may be applied during missions related with data acquisition, demonstration and certification flights
2. The proposed target comprised of four polished aluminium disks 45 cm in diameter provides capability of measuring in the conditions of the experiment
3. Deploying the Al disks at corners of a 20x20m square provides appropriate precision
4. Monitoring of the scanner performance, flight parameters (V, H), drift angle, geometric deformations values may constitute a tool for selecting materials for visual analysis and precise interpretation of data acquired from thermal calibration targets.
5. Use of the authors' DECI software significantly speeds up and simplifies the process of selecting the frames used to determine Hmin through visual analysis.

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