Simultaneous Calibration of Digital Aerial Survey Cameras

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Abstract: To create digital aerial images of high resolution and large format, frames from several CCD sensors have to be combined to one image, because of limited resolution of commercially available CCD sensor elements. The most popular examples of those cameras are the DMC und the UltraCamD. Despite of high efforts in factory calibration, systematic image errors are found in practical applications, showing clearly different effects of rotations, scalings and/or displacements for every CCD sensor element. As known from traditional aerial survey film cameras, a simultaneous calibration has to be done, because of different environmental conditions between laboratory and application in the airplane.

New methods have been introduced into the bundle triangulation software package BINGO for precise analysis and presentation of those remaining systematic effects. Based on the analysis and experience with several practical projects new algorithms have been developed and applied in BINGO to completely eliminate these systematic image errors. After simultaneous calibration no more systematic effects have been detected in current projects. In one of these test projects the accuracy of ground points has been improved by a factor of two – proven by many independent check points. Calibration parameters from one project can be applied as corrections for further projects.

Zusammenfassung: Großflächige digitale Luftbildkameras wie DMC und UltraCamD sind derzeit wegen begrenzter Größe verfügbarer Flächensensoren darauf angewiesen, das Bild einer Aufnahme jeweils aus mehreren Einzelbildern zusammenzusetzen. Im praktischen Einsatz dieser Kameras zeigen sich trotz guter Laborkalibrierungen systematische Restfehler in der Bildgeometrie, die deutlich die einzelnen Sensorflächen erkennen lassen. Wie von herkömmlichen Filmkameras bekannt, ist eine Nachkalibrierung erforderlich, weil die Verhältnisse im Flugzeugeinsatz anders sind als im Labor.

In das Softwarepaket BINGO sind Methoden integriert, die eine genaue Analyse solcher systematischen Restfehler erlauben. Aufgrund dieser Analysen wurden Algorithmen zur Beseitigung dieser systematischen Effekte entwickelt und in BINGO integriert. Nach simultaner Kalibrierung konnten bei allen bisher durchgeführten Projekten alle systematischen Effekte beseitigt werden. In einem der Testprojekte konnte die Genauigkeit am Boden nachweislich um den Faktor Zwei gesteigert werden. Der Nachweis dieser Genauigkeitsverbesserung erfolgte mit unabhängigen Kontrollpunkten. Die einmal gewonnenen Kalibrierdaten sind als Korrekturdaten für weitere Projekte verwendbar.

1. Introduction

This article does not touch the manufacturer calibration of digital cameras. It’s known that this calibration checks and corrects beside the geometrical calibration as well radiometry of sensors and adjusts every single pixel of a CCD array. Here we present an enhanced algorithm for the widely introduced self-calibration, which is adapted to the special geometry of new digital aerial survey cameras. These cameras combine every photo from various numbers of pictures of several CCD sensor elements.

As for Z/I’s DMC there are two by two sensors. Each sensor has its own optical system. Because of convergent exposure directions of the four systems relative to each other, the overlap in the covert ground area is small and a wide ground space will be recorded. All cameras will be released synchronously.

The UltraCamD from Vexcel has as well four optical systems for panchromatic exposures. Behind every lens system there are four, two ore one CCD sensors. The four systems are positioned in one line. The release is a little time shifted to record every photo at the some position (syntopically). The so-called master-cone has four CCD elements positioned in the corners of the photo. The sensors of the further cameras are positioned to fill all gapes of the master cone. All cameras are mounted parallel for vertical view.

Of course the precise relative positions of the photos of the single sensors have a central rule in combining the single photos are of crucial importance and they are finally responsible for the geometric quality of the images. This process is done by the software belonging to the camera. In practical use however, small systematic errors have been detected, which have to be considered to fulfil high precision quality requirements. Therefore a new extended calibration method has been introduced into the bundle triangulation software BINGO and proven in several practical projects. The achieved results are excellent. This is the reason why this method can be a base for further considerations and developments of standard methods for camera calibration.

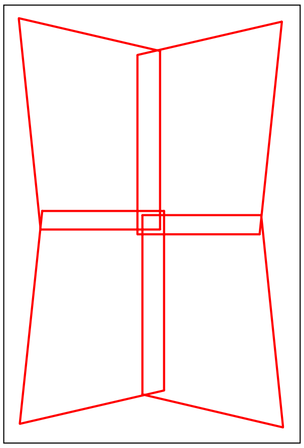

Fig.1 Partial photos of a DMC

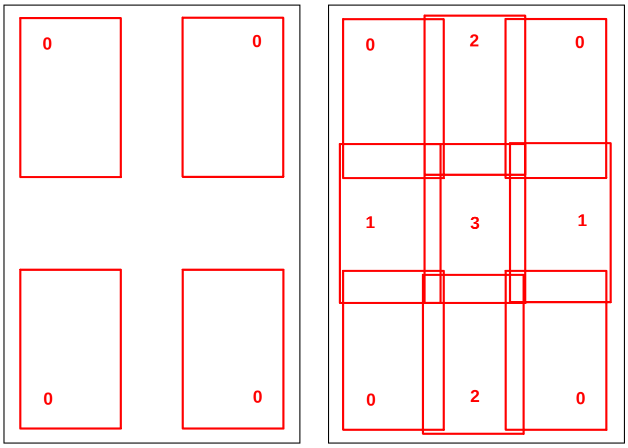

Fig.2 Master cone and partial photos of an UltraCamD

2. Calibration Approach

Before developing a new calibration approach, we have to find out if there is a further specific demand. I.e., we have to check if the existing parameters of self-calibration are still appropriate and sufficient. Because all cameras have been calibrated by the manufacturers in the laboratory, a new check of the calibration in a laboratory seems to be completely pointless. Furthermore it is known from experience with aerial survey film cameras, that self-calibration is required for practical applications because of systematic image deformation. This is as well true after a brand new camera calibration. For film cameras these effects are based on various influences like temperature gradients inside the camera and in the air, different film magazines, film development, refraction, earth curvature, map projection etc. Different effects are to be expected for the new digital cameras.

The results of a bundle triangulation provide an ideal base for estimating systematic image deformation, if a big data set from practical application with high redundancy is processed. For this purpose a big number of photos with high overlap and many tie-points is requested. Otherwise it is not possible to receive reliable significant results. However, having those data sets, possibly included systematic image deformations can be evaluated by viewing and checking all residuals of photo measurements.

Displaying the residuals of the photo measurements of all photos in one single photo frame, systematic effects mustn't be visible. However, this method fails if the requested number of photo measurements is really available, because nothing can be differentiated anymore because of too many visible vectors. Therefore it makes sense to cover this photo frame with a regular grid and to display just mean residuals for each grid cell. Of course this restitution could be done as well mathematically by correlation analysis, but in this case a necessary figure of the geometric corrections isn't available.

Several example data sets have been analysed this way for systematic effects. Typical results for both cameras are shown below. As for the DMC small rotations inside the CCD areas and scale effects are visible (Fig. 3), the UltraCamD shows slightly different scales and displacements for the CCD sensors (Fig. 4).

The requirements of simultaneous calibrations can be seen clearly. The CCD arrays have to be rotated, shifted and scaled. Special rotation and scaling parameters are needed for the DMC. To do these calibrations, the edges of the CCD arrays have to be known precisely inside the bundle triangulation. A new class "sensortype" in BINGO allows integration of this information.

Practical tests have shown different effects for the two camera types DMC and UltraCamD, which require individual calibration approaches. The UltraCamD needs beside the usual global parameters of self-calibration five new special calibration parameters for each CCD array for rotation, translations, and scales in x´ and y´. Effects of non-perpendicular axis have not been detected. Therefore these additional five parameters per CCD array should be able to remove all systematic influences completely. For the DMC these parameters were not sufficient in these projects, and new adapted additional parameters had to be developed.

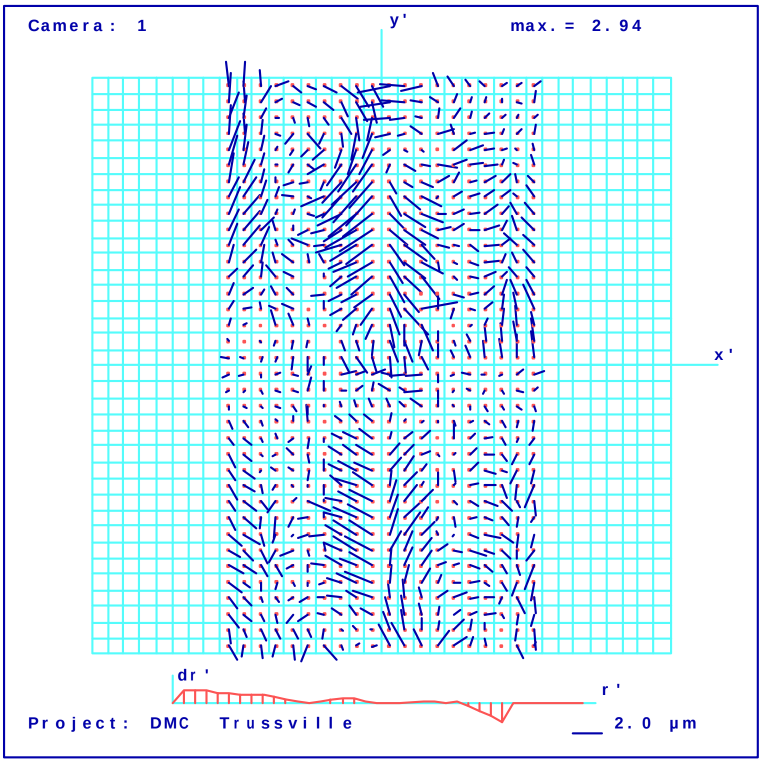

Fig.3 Remaining systematic image errors in the DMC project "Trussville"

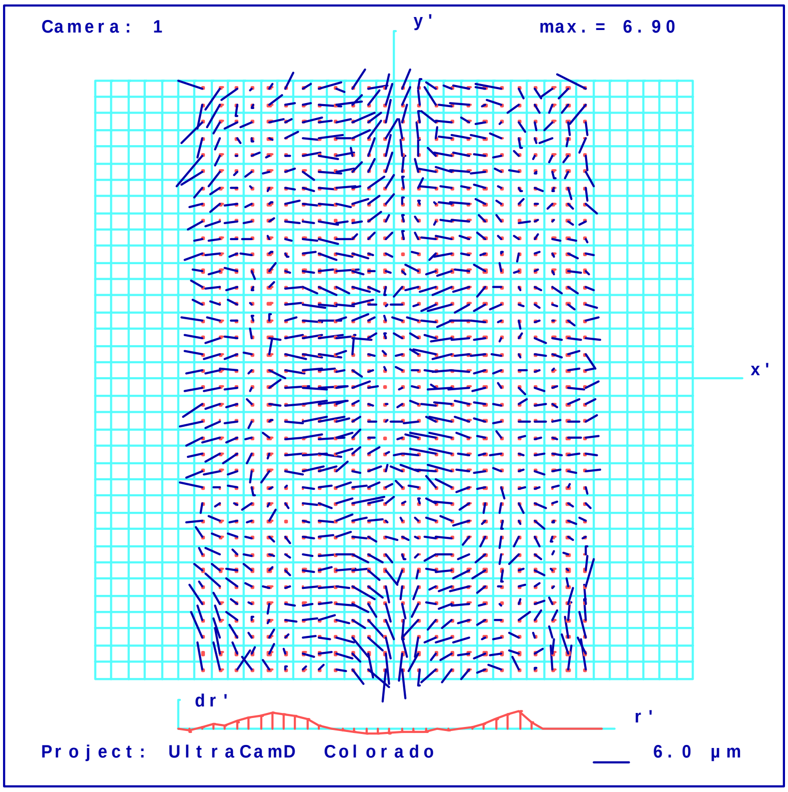

Fig.4 Remaining systematic image errors in the UltraCamD project "Colorado"

3. Practical Results

Indeed, these new parameters have been sufficient for all tested UltraCamD example data sets. After bundle triangulation using these extended self-calibration parameters no remaining systematic effectswere visible in any of the projects, even no small ones. Another important question is the influence of the self-calibration to the accuracy of the ground coordinates. Unfortunately only for the data set ″Colorado″ independent check points had been available. In this data set we can see an increase of the accuracy by a factor of Two (Table 1). Table 2 shows the layout data for both blocks ″Colorado″ und ″Trussville″.

Tab. 1 Results of Bundle Adjustment in the Block ″Colorado″

	σ_0 [µm]	RMS residuals of independent check points in X [feet]	in Y [feet]	in Z [feet]
Without Calibration	3.0	0.18	0.22	0.29
New Calibration	1.7	0.09	0.13	0.14

This pleasant result confirms the diagnosis made by visual review that a considerable enhancement has been done by means of this new calibration approach. Fig. 5 demonstrates the remaining (not systematic) photo residuals after self-calibration.

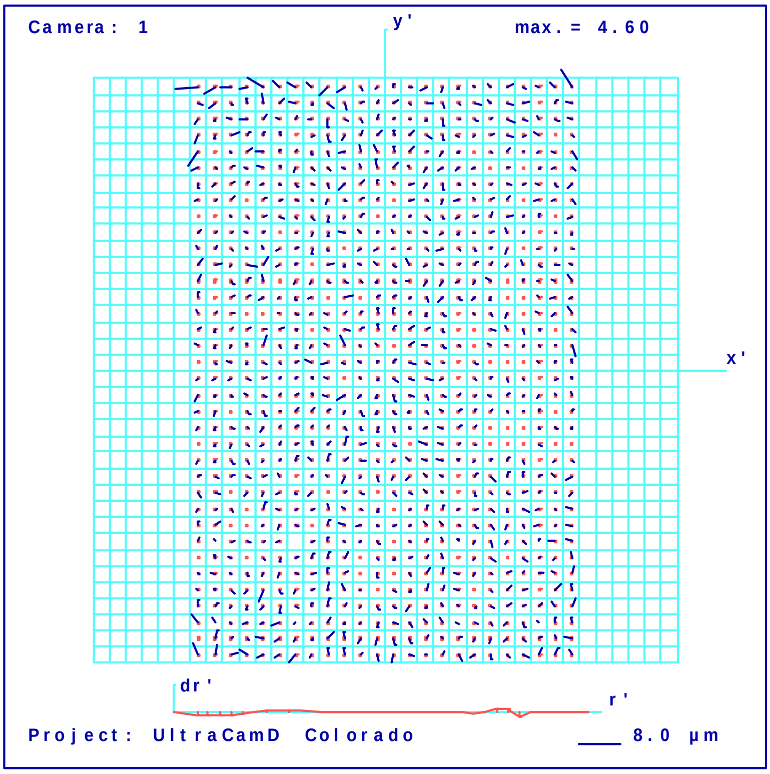

Fig.5 Systematic photo residuals after new self-calibration

Fig. 6 presents this ″Colorado″ block in 3D perspective with confidence ellipsoids. The green colour is used for points measured in at least two flight lines (tie points), magenta points are seen only within one flight line (bridging points). The geometry of this block with high overlap and cross strips is well equipped for camera calibration. It is to expect that really all systematic effects can be detected. Fig. 7 presents the distribution of control and check points. The black points with numbers are the control points and the magenta points with vectors are the independent check points.

Tab 2. Layout Data of the Blocks ″Colorado″ and ″Trussville″		
Photos	276	1037
Adjustment points	2212	12934
Points per photo	36 to 89, mean 53	11 to 53, mean 44
Flight lines	7 with 29 photos each	18
Cross flight lines	2	
Overlap	80%	60%
Side lap	30%	25%
Control points	20 along the block edges	36
GPS/IMU data		for all photos
Independent check points	81	
Flying height	1400 feet	4500 feet
Terrain height differences	148 feet	1000 feet

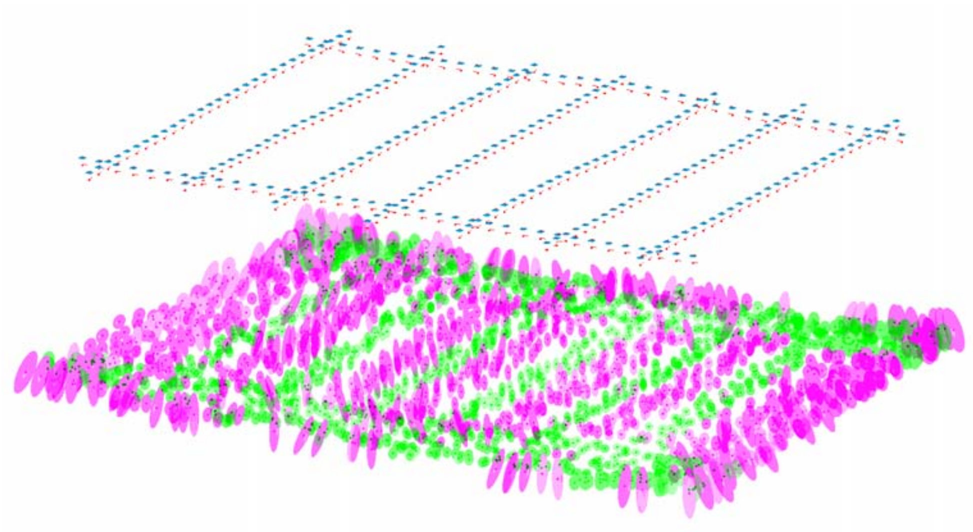

Fig.6 Block ″Colorado″ in 3D perspective with confidence ellipsoids

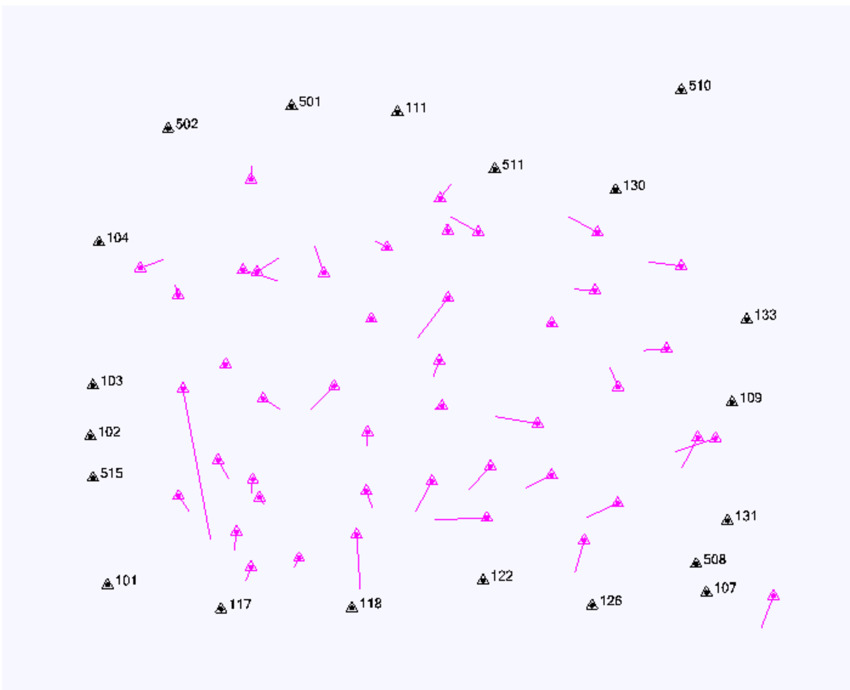

Fig.7 Control points and independent check points in Block ″Colorado″

Fig. 8 presents the layout of block "Trussville". As well in this block all systematic effects have been removed using the new calibration approach. 15 additional parameters have been used. Sigma naught decreased from 2.1 to 1.8 µm. The effect of these additional parameters to the image geometry is shown in Fig. 9.

An exemplary parameter data set of additional parameters has been collected for both cameras, which is sufficient to remove all typical systematic effects. This set has 22 parameters for the DMC and 35 for the UltraCamD. The reason for these different numbers is the different number of CCD arrays in these cameras. The bundle triangulation can test these additional parameters and remove those ones, which are not necessary for a given project.

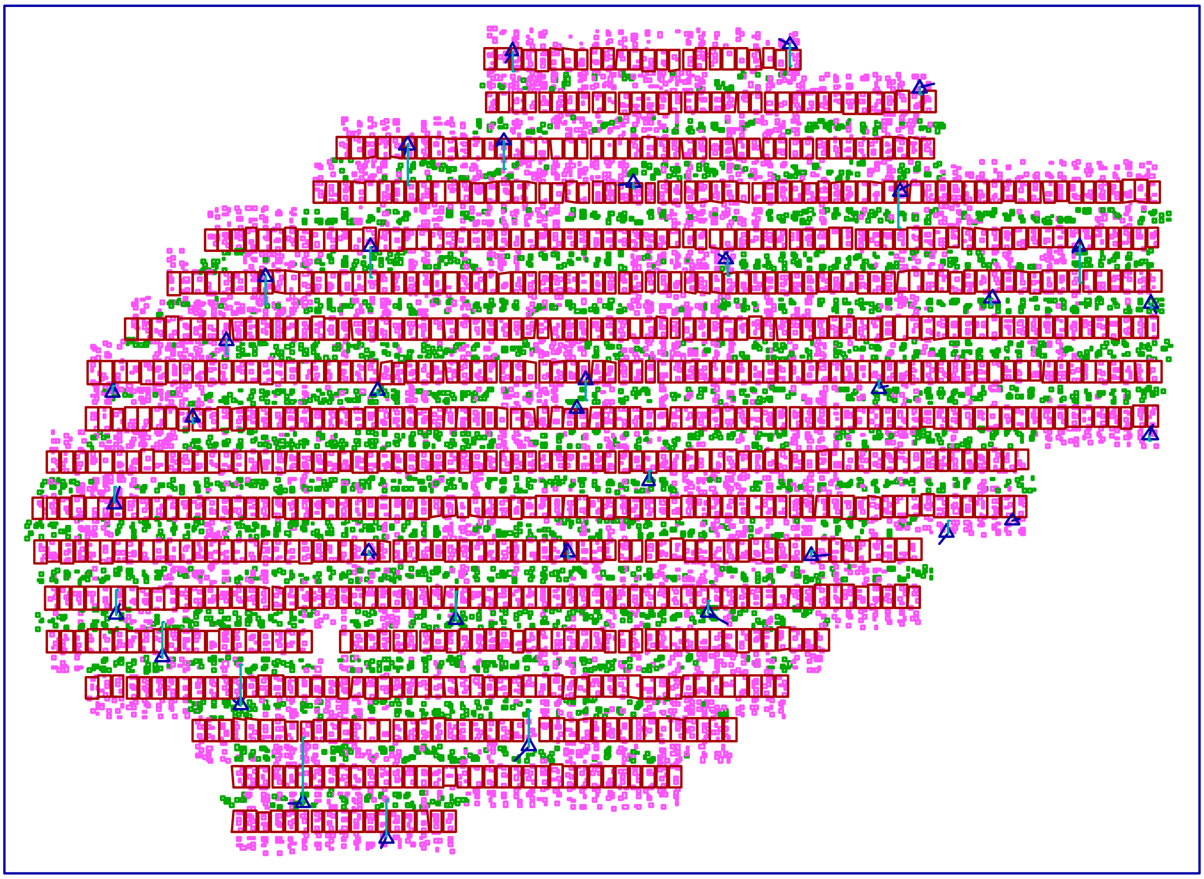

Fig.8 Layout for block "Trussville"

Like in fig. 6 the green colour is used for tie points and magenta for bridging points. The foot prints (red) are reduced to 1/3 of their original size to provide a better overview. Control points are presented in blue.

4. Conclusions and Outlook

This small research has proven clearly that new digital aerial survey cameras have remaining systematic effects of camera calibration. These effects can be detected, displayed and eliminated by BINGO. There are principally two ways to apply the achieved correction results for further processing in digital photogrammetric workstations:

- A look-up table with these corrections will be introduced into the photogrammetric system and applied for all further processes.
- The look-up table will be used to enhance the calibration table of the camera, and the resampling from the single photos to complete photos will be repeated. The stability of the camera systems over a certain time can be assumed. It is not necessary for all projects to repeat this time consuming process.

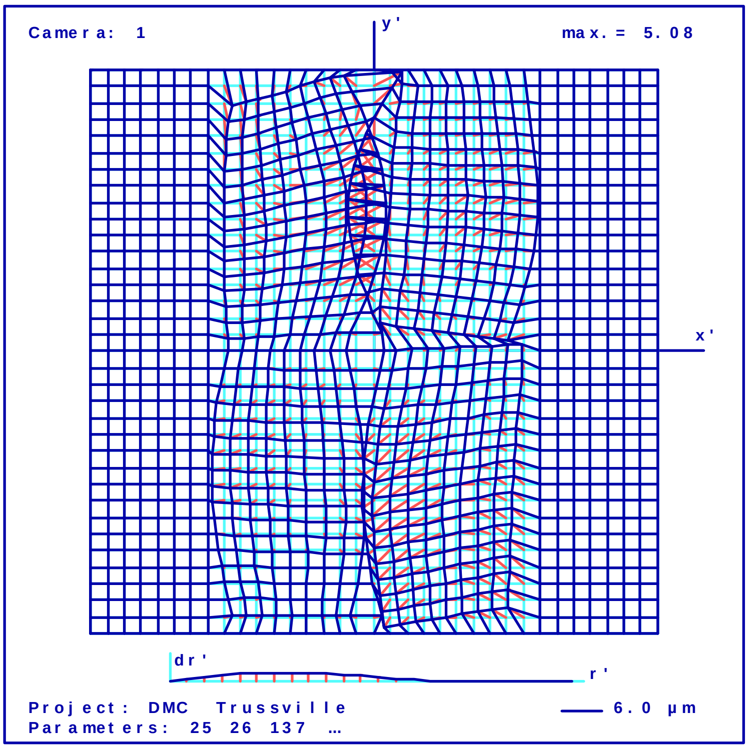

Fig.9 Image geometry correction grid for block ″Trussville″

I would like to point out the need of checking the geometry of other photogrammetric equipment. Arial photo film scanners of manufacturers well positioned in the marked show a high demand for better calibration. Unfortunately these deformations cannot be removed easily in using additional parameters.

5. Literature

A lot of publications about both cameras have been provided during the last few years. Therefore I intend to provide here only the source to read about the regular factory calibration of the UltraCamD using the BINGO software.

KRÖPFL, K:, KRUCK, E., GRUBER, M., 2004: Geometric calibration of the digital large format aerial camera UltraCamD, ISPRS Symposium Istanbul Comm. I, WG I/2.