CAP

Combined Adjustment Program

software package for a combined adjustment of photogrammetric and geodetic networks

technical overview

K2 - PHOTOGRAMMETRY - Software - Consulting

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What is CAP ?

CAP is an efficient and highly optimised software program packages for a combined adjustment of photogrammetric and geodetic measurements.
CAP is able to process many different observation types justifying the term **COMBINED ADJUSTMENT**.
CAP is regularly used by various institutions to solve the following characteristic tasks:

- 3D-object-reconstruction by spatial point determination
- spatial orientation of photogrammetric images (analogue or digital)
- spatial orientation of geodetic direction bundles (theodolite measurements)
- spatial orientation of models (3D-point fields in local co-ordinate systems)
- calibration of photogrammetric surveying systems (analogue or digital cameras)
- deformation- and moving object analysis.

Since its first release more than 16 years ago CAP has been improved continuously. The use of CAP was considerably simplified by the integration of the intuitive user interface CapMenu. CAP is available for Personal Computers running Windows XP, Windows 2000, Windows NT and Windows 9x.

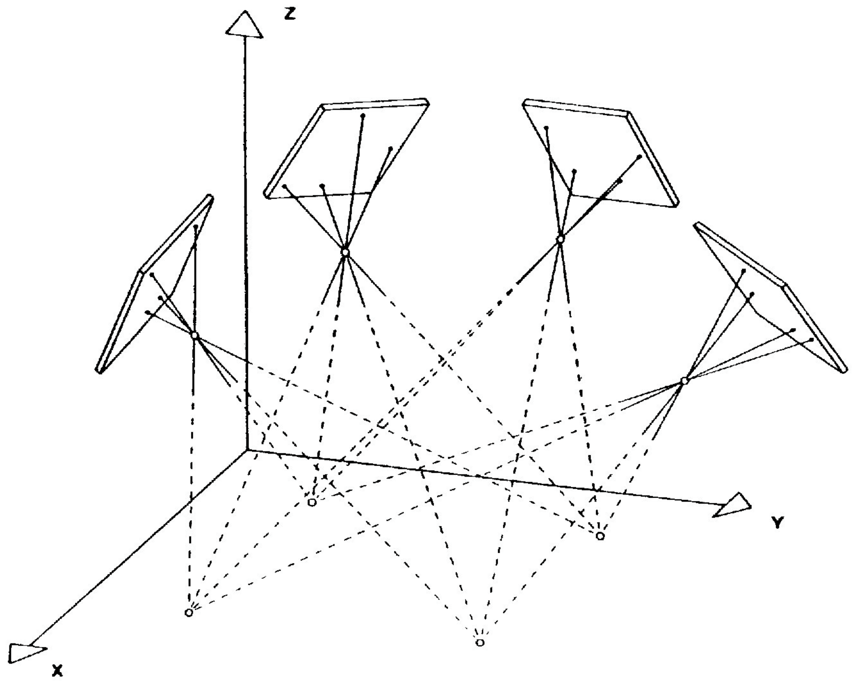

Figure 1: basic principle of bundle triangulation

Fields of application

- 3D geometrical tool inspection in industry (e.g. aeroplane-, car-, ship- and space industry)
- design analysis in the planning phase
- checks for delivered products, internal production checks as well as final quality checks
- security (crash-) tests --> deformation analysis
- as built 3D geometrical analysis and supervision of engineering constructions like bridges, dams, cooling towers, flood gates, etc.
- as built 3D geometrical analysis of industrial plants, e.g. pipeline systems, nuclear power stations, etc.
- geometrical strength tests of materials --> deformation analysis
- motography or motion analysis
- shape analysis in orthopaedics and dental medicine
- surveying of large buildings, architectural photogrammetry
- surveying of archaeological sites
- calibration of photogrammetric and geodetic surveying systems

Program versions

- **CAP-L**: version for large projects with practically no limitations.
- **CAP-S**: version for small projects (e.g. camera calibration) with all features of CAP-L; but limited to 550 unknowns; equivalent to app. 20 images and app. 140 object points.
- **Please see also our package conditions**

Program use

The CAP software is delivered with a hardware security plug to be used on the parallel port (printer port) of your computer to prevent from non-authorised use of the software.

License and warranty

By purchasing the CAP software, you indicate your acceptance of our license and warranty agreements. Maintenance and support services are available on request.

Types of observations

CAP allows the simultaneous adjustment of numerous different observations:

- image co-ordinates
- 3D model co-ordinates
- distances between object points
- distances between projection centres
- distances between object points & projection centres
- distances in co-ordinate planes
- directly observed co-ordinates (e.g. control points)
- co-ordinate differences (e.g. height differences)
- horizontal directions (observed in the object co-ordinate system)
- vertical directions (observed in the object co-ordinate system)
- interior orientation parameters: camera parameters
- exterior orientation parameters : position and rotation of a camera
- relative orientation between two images
- model orientation parameters : position, rotation and scale

Each measurement can participate in the adjustment with its individual weight by assigning a standard deviation a priori to each observation.

Theodolite module

The theodolite module allows the integration of directions observed with a theodolite into the combined adjustment. Each direction bundle is treated like a local co-ordinate system. For the orientation of these direction bundles a set of six parameters is used (three shift and three rotation parameters, comparable to the exterior orientation elements for an image). It is not necessary to presume that the theodolite was perfectly levelled, a general orientation for the direction bundle is possible. Available information about a levelled theodolite can be introduced with additional observations of two rotation parameters. The simultaneous adjustment of observed direction bundles combined with photogrammetric observations is possible, but not a must. The adjustment of a network with pure geodetic observations can also be performed. By this, CAP is well suited for the adjustment of direction bundles in the field of precise point determination for industrial purposes.

Camera calibration

CAP offers the possibility to treat various camera parameters as unknown values. This feature is not only necessary for a test field calibration of a camera, but also for an on-the-job calibration in close range photogrammetry. It should be noted that CAP is well suited for a geometrical calibration of digital cameras (e.g. CCD cameras) as well. The following camera parameters can be determined by CAP:

- principal distance (focal length)
- co-ordinates of principal point
- radial symmetric distortion parameters

- parameters for tangential and radial-asymmetric distortion
- parameters for affinity and non-orthogonality of the image co-ordinate axes
- parameters for unflatness effects of the image plane and
- fine tuning parameters to describe systematic image errors /c.f. Brown 1976/

Several cameras with different numbers of parameters can be introduced simultaneously in one image block.

Adjustment of models

This means the simultaneous adjustment of a general point field with known co-ordinates in a local co-ordinate system. These local co-ordinate systems should be transformable into the object system by a seven-parameter-transformation. Such information is often available and can assist in a combined adjustment with CAP.
Examples:

- observations from photogrammetric models
- point measurements from a 3-D co-ordinate measurement machine
- observations of points in a plane of general position
- observations of points on a straight line

Free adjustment

CAP has the capability for a free or partially free adjustment. This is an important characteristic for many applications especially in industrial photogrammetry. In a free adjustment, the whole network is fitted onto a set of object points without any strength. This feature is an important tool for a deformation analysis that can also be performed with CAP. In a free adjustment, the calculated standard deviations a posteriori become a minimum and a very homogeneous distribution for the point accuracy is obtained, if all object points are used to define the object co-ordinate system (datum definition).
Simultaneously, the (partially-) free adjustment feature is the appropriate tool for a more economic project work. Fieldwork very often becomes time-consuming because of spatial point determination by geodetic means. Frequently, such a set of control points is only derived to define the datum of a photogrammetric bundle block. However, for many applications it is sufficient to define the complete network in a local co-ordinate system that is scaled and levelled correctly. Scaling and levelling information can be obtained by the measurement of distances and height differences around the object of interest. These measurements can be performed much faster than complete spatial geodetic point determination. But, the use of distances and height differences in a network adjustment as the only information from object space -no control points!- leads to an equation system with a rank deficiency, because the datum definition for the object co-ordinate system is still incomplete. The best remedy in these cases is provided by the free adjustment option that allows the determination of the remaining datum parameters (shift in X, Y, Z and the azimuth) without putting any strength on the objects' shape, scale or levelling. The rank deficiency is removed within a partially free adjustment by fitting the network onto a set of object points.
CAP offers various possibilities to define the object co-ordinate system.

Datum definition

a) Control points (error free)
b) Observed control point co-ordinates with its standard deviation a priori
c) Observed exterior orientation with its standard deviation a priori
d) Free or partially free adjustment (any type of rank deficiency), the number of points which participate in the datum definition can be selected.
Appropriate combinations of a), b), c) and d) can be selected.

Statistics

CAP offers the possibility for complete error propagation and sophisticated statistical analysis based on the normal equation inverse. Geometrically weak areas in a network are then easily locatable. It is analytically proven that the implemented inversion algorithm of CAP requires a minimum of computational effort /Hanson,R. 1978/.
The following statistical values are calculated:

- variance of unit weight, estimated sigma naught
- standard deviations for all unknown adjustment parameters like point co-ordinates, exterior orientation parameters (sensor orientation), interior orientation parameters (camera parameters), model parameters
- standard deviations for all non-photogrammetric observations additional observations like distances, directions, observed parameters, etc.

- local redundancy for all image co-ordinates, theodolite observations and model observations
- correlation matrix for correlation between interior orientation parameters
- correlation matrix for correlation between exterior and interior orientation parameters
- internal reliability for each observation
- single object point test statistic for deformation analysis.

Blunder elimination

Gross data errors usually lead to wrong and unacceptable adjustment results and an efficient algorithm for blunder detection becomes necessary. Such a tool is implemented in CAP that is based on a statistical test. A modified data snooping technique is applied. By using the normal equation inverse for the test statistic, the internal accuracy of the network design is fully taken into account /Pope,A. 1976/. The test needs estimated quantities only, no a priori sigma naught is required.
Optionally, gross data errors (blunders) are eliminated automatically by CAP reducing the time of project work. The final result can be achieved in one program run.

Memory management

Computation techniques

Essential parts of CAP are optimised to minimise storage requirements and computing time. Concerning the reduction of storage space for the normal equation system sparse matrix techniques based on profile minimisation are well known in photogrammetry /Jennings,A. 1977; Lucas,J.R. 1985/. However, using profile minimisation still some zero-elements have to be stored. The solution for CAP is more rigorous, because only the non-zero elements of the normal equation system are stored /George,A.; Liu,J.; 1981/. This storage technique combined with adequate algorithms for solving and inverting the equation system leads to a minimum of computing time /Hanson,R. 1978/. The storage requirements is minimised by applying the Bankers algorithm /Snay,R. 1976/. Within a combined adjustment, the structure of connections between the unknowns (adjacency structure) can vary considerably. This is fully taken into account with the computation technique implemented into CAP.
Moreover, CAP uses a special parameterisation of the rotation parameters which is free from singularities /Schut,G.H. 1958/59; Pope,A. 1970; Hinsken,L. 1987/. This characteristic is extremely important for applications in close range photogrammetry. Ill-conditioned equation systems caused by undeterminable rotation parameters /Wrobel,B.; Klemm,D, 1984/ that lead to unreliable adjustment results, are avoided with the parameterisation used in CAP.
Furthermore, this alternative parameterisation needs a minimum of computing time compared to other formulations. The whole iteration process becomes considerably faster. The parameters are used internally only. At the end of the adjustment process, they are always transformed into conventional rotation parameters that are easier to interpret.

CAPMENU

The CAP user-interface

Using CAP on Personal Computers under Windows XP, Windows 2000, Windows NT and Windows 9x the network adjustment with CAP becomes much more comfortable with the project-oriented user interface CAPMENU. Special CAP editors are integrated to increase the user-friendliness. All necessary input data and job control parameters for a specific project with CAP can be easily set up or modified. CAPMENU has been specially designed for the requirements of CAP. CAPMENU is throughout menu-guided and self-explaining; nevertheless, context sensitive on-line-help is available. Numerous routines are included to avoid input of erroneous or non-logical data. The whole preparation procedure for a network adjustment becomes faster and relieves the user from tedious preparation work.
Besides the set-up and modification facilities for all project data CAPMENU allows to run all program components and is completed by user-friendly menu-guided view programs for inspection of all output files.
During program execution, the user is informed about the actual status of the job by displaying important interim results on the monitor. A continuous overview is guaranteed.

GRAV

graphical analysis of CAP adjustment results

By default, CAP provides a printout file (ASCII text file) for each program run with which the quality of the adjustment can be checked. An additional graphical presentation of the adjustment results, however, can be very helpful for the analysis, because usually a huge amount of observations is adjusted simultaneously. An inspection of the network geometry (point distribution, sensor distribution, ray intersection) and the residual analysis becomes more efficient and faster. Therefore, the graphics-assisted analyser GRAV for CAP has been developed. GRAV gives a graphical overview for the most important adjustment results.

Network configuration:

- distribution of object points and sensor locations
- ray intersections (connections between points and sensors)
- multi window option
- zoomoption, etc.

Bundle oriented analysis:

- individual inspection of the image point distribution
- analysis of image point residuals to detect unmodelled systematic errors
- zoomoption, etc.

The GRAV tool is integrated into the user-interface CAPMENU.

CAM_VIEW

graphical analysis of a camera calibration

The estimated camera parameters except focal length and principal point co-ordinates are not suited to show the effect of these parameters. They do not provide a quick overview for geometrical interpretation whether the determination of camera parameters is selected for a field calibration or for an on-the-job camera calibration. The graphical tool CAM_VIEW visualises the effect of these parameters. In addition, the corresponding accuracy derived from the standard deviations a posteriori and the correlation coefficients involved can be visualised.

Graphical features:

- visualisation of radial-symmetric lens distortion
- visualisation of radial-asymmetric and tangential lens distortion
- visualisation of affinity and non-orthogonality effects of the image sensor

A graphical presentation of combined effects is possible. The CAM_VIEW tool is integrated into the user-interface CAPMENU.

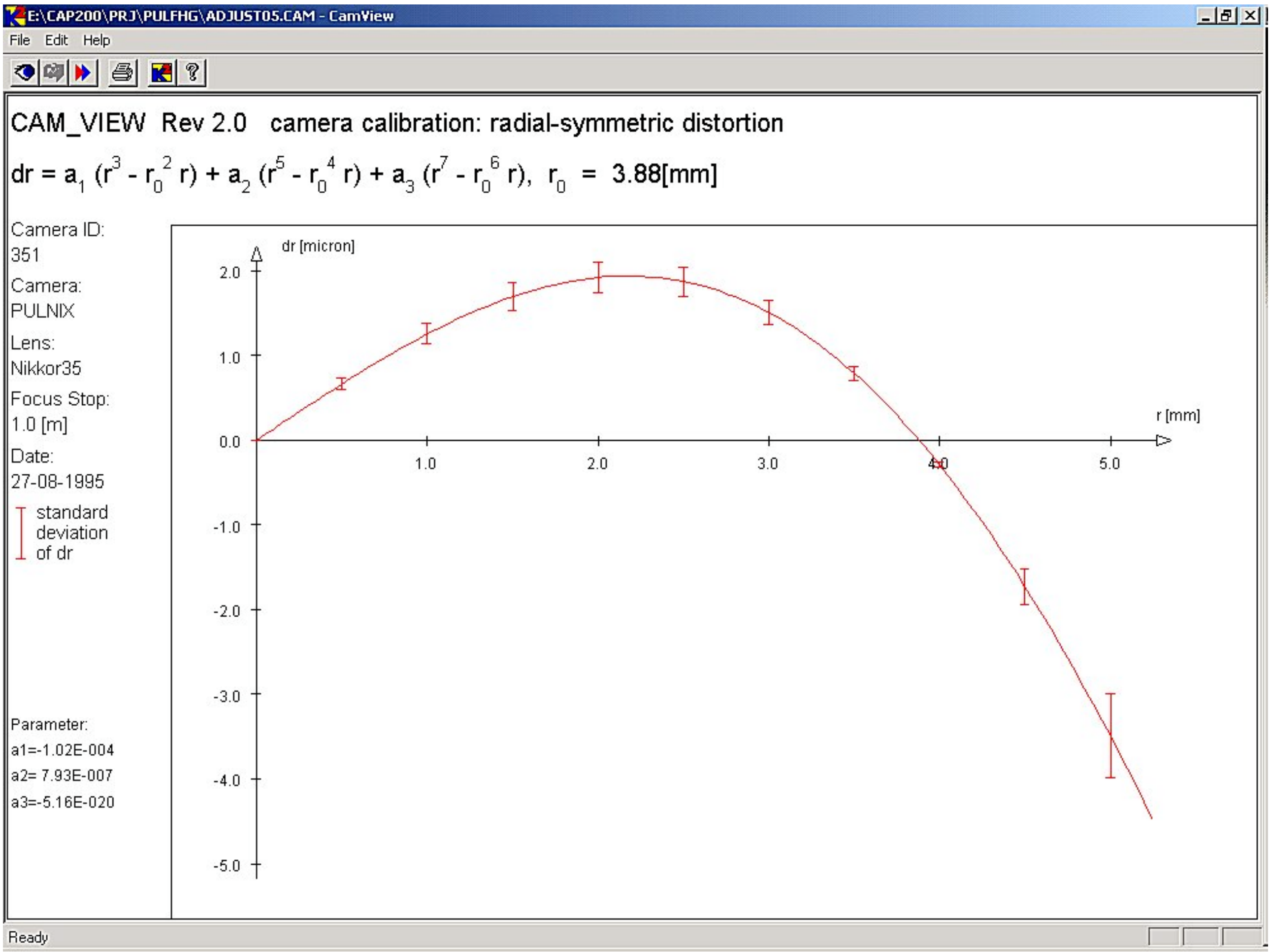

Figure 2: example for radial symmetric lens distortion after camera calibration

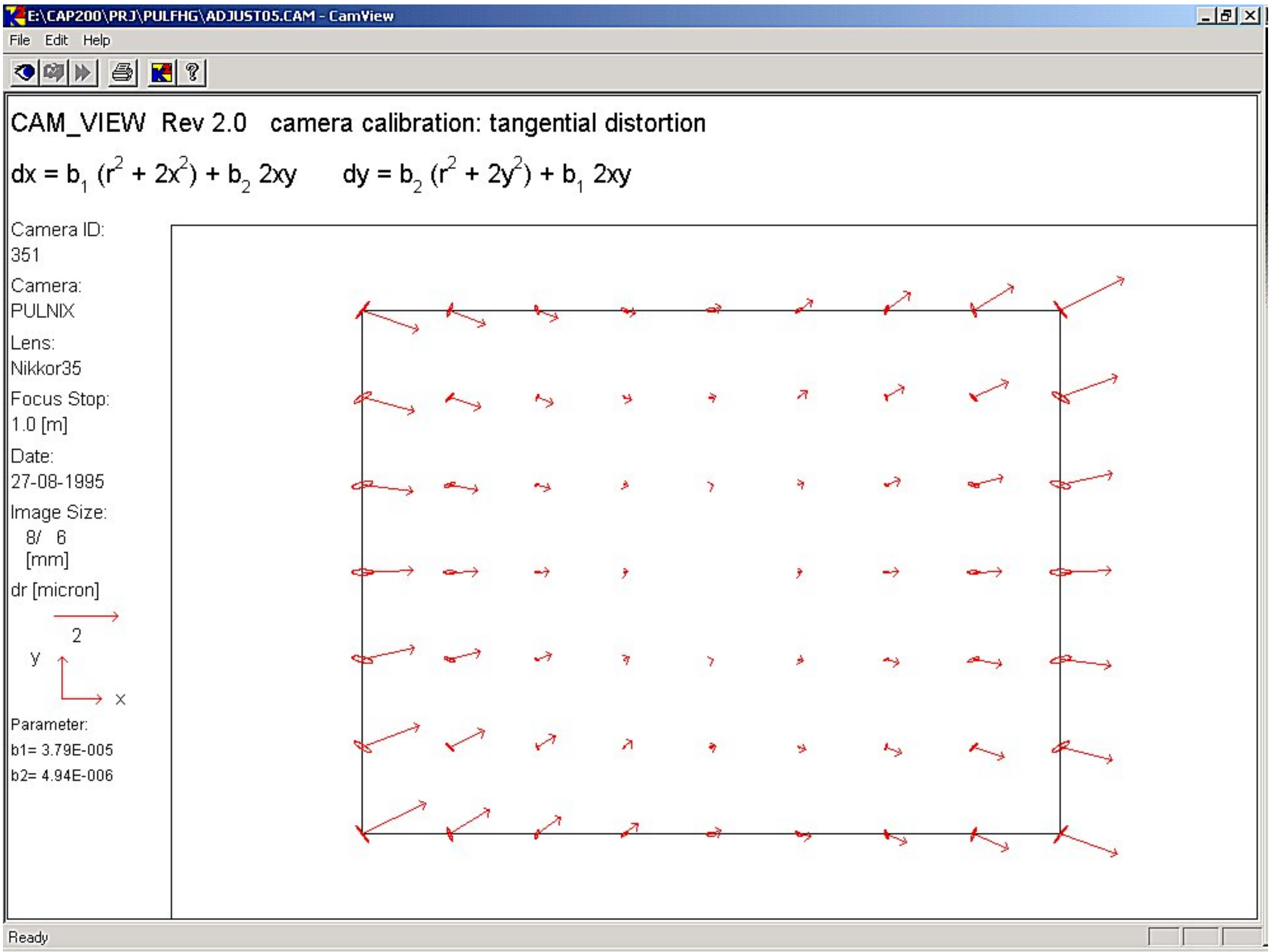

Figure 3: example for tangential lens distortion after camera calibration

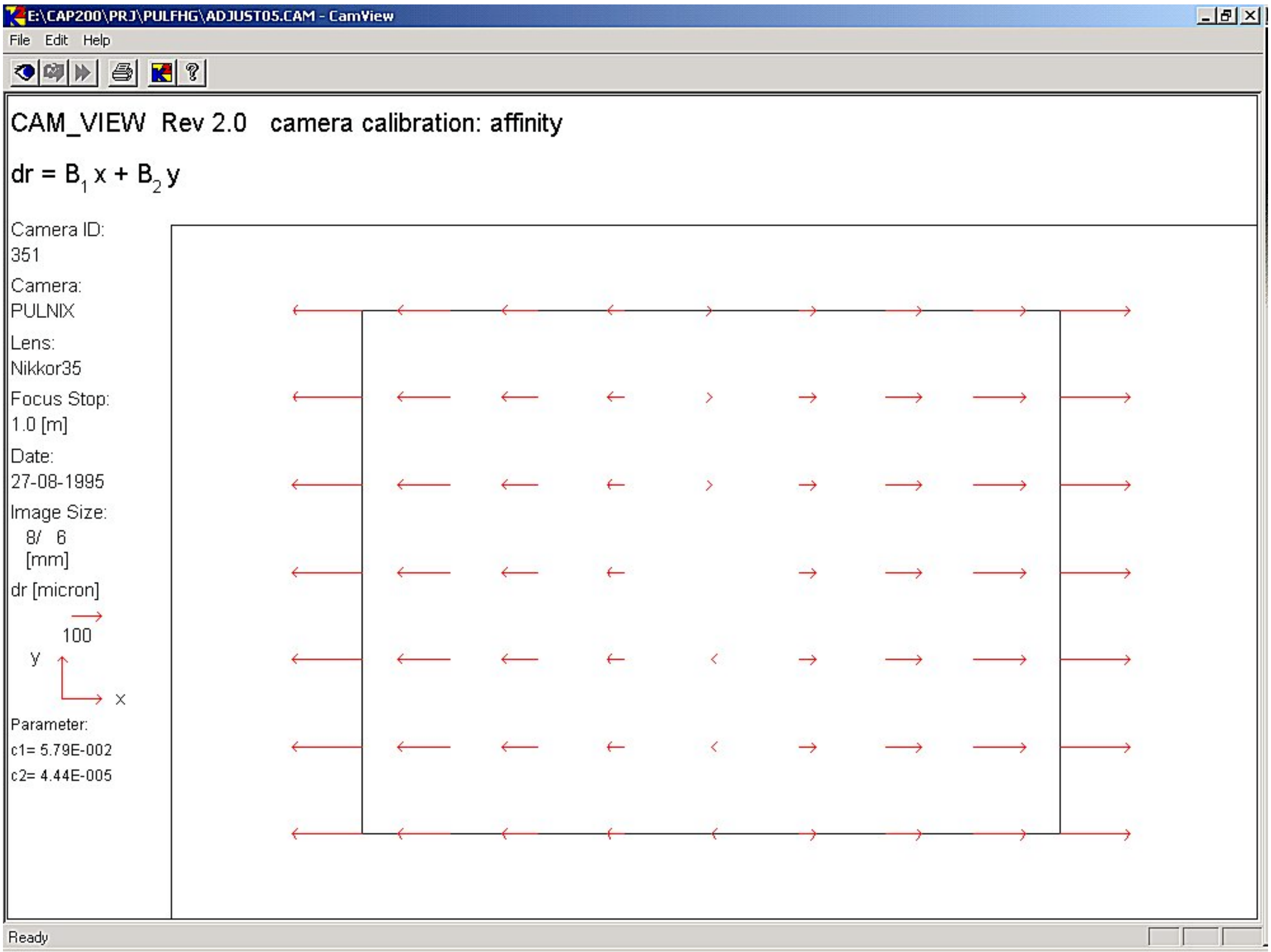

Figure 4: example for affinity effects of the optical sensor after camera calibration

Post processing

The results of CAP are usually needed in application-specific post processing programs (e.g. CAD-programs). In most cases, the adjusted object co-ordinates and sensor orientations are of interest. These data can be written to separate output files in various formats.

Initial values

Bundle block adjustment is a non-linear adjustment problem. Approximate values for all unknowns (object point co-ordinates, parameters of exterior and interior orientation) have to be calculated beforehand. Especially in cases of general photo triangulation this task often becomes a considerable problem and can cause tedious work. Solutions have been proposed based on transformations like relative orientation, absolute orientation and spatial resection /Wester-Ebbinghaus W., 1978, 1981; Kotowski et al. 1983; Gründig et al. 1985/. They provide proper tools for the determination of initial values. Therefore, the programs RELOR (relative orientation), ABSOR (absolute orientation) and RESECT (spatial resection) have been developed and optimised to determine initial values for general photo triangulation. Together with the program CID for correction of image deformations (fiducial mark and reseau transformation) efficient software tools are available to perform all steps for spatial point determination starting from measured plate (comparator-) co-ordinates. Input and output of all these programs are compatible. In general, no additional external editing is necessary to derive all files needed for a bundle block adjustment with CAP.
In addition, it should be mentioned that relative and absolute orientations as well as spatial resection are non-linear adjustment problems and normally initial values must be given beforehand. However, the programs RELOR, ABSOR and RESECT are based on algorithms which guarantee an extremely wide range of convergence for the transformations. Moreover, as realised for CAP as well, the parameterisation for the rotations is numerically very efficient and free from singularities. Independent from the design of the photogrammetric network these programs do not need a manual input of approximate values for the unknowns /Hinsken,L. 1987/. The whole preparation phase for general photo triangulation becomes less time-consuming, easier to handle and more reliable.

Network simulation

Many applications in close range photogrammetry lead to the estimation problem, whether the required accuracy for a project can be achieved. Unlike aerial triangulation, where more or less standardised designs are met, the experience in the field of general photogrammetric networks is only limited up to now. For a lot of projects, especially in cases of ultra-precise close range applications, the simulation of suitable a network design is necessary to estimate the achievable accuracy in advance with a minimum of costs and time. For these purposes the menu guided simulation program CAPSIMU is available. CAPSIMU works interactively and uses the graphical capabilities of the Personal Computer. The simulations can even be performed in situ with a portable PC. CAPSIMU is a helpful tool to derive suitable network designs which fulfil the required accuracy and which are acceptable from the economical point of view.

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