ADVANCED INFORMATION EXTRACTION FROM NON-METRIC IMAGES USING ADAPTABLE ALGORITHMS EMBEDDED IN A HYBRID ADJUSTMENT

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KEY WORDS: Photogrammetry, Adjustment, Calibration, Parameters, Accuracy, Close Range, Feature, Reliability

ABSTRACT:

During the past decades many computer programs have been developed for solving standardized problems in the field of close-range photogrammetry. Most of these software packages are designed for common tasks and hence algorithmically not very flexible. When facing the problem of dealing with very special, individual cases in photogrammetry, programs with very versatile mathematical background and the ability to adopt to very specific situations are needed, e.g. for evaluating a complex traffic accident scene as described in this paper. At a street intersection a car was hit sidewards by a motorcycle. The task was to calculate the deformation angle between the upper and the lower section of the fork of the front wheel as precise as possible where a sharp bend occurred through the crash. This information would be valuable for the technical expert in order to compute the motorcycle's collision speed. Considering that only four of the available non-metric images were useful and that no calibration, control, or interior orientation parameters were available, this task became rather complex and scientific. Unfortunately, the image-configuration was very weak (bad intersection quality of the rays of tie points) and finding of useable homologous points was restricted to few limited small areas in the images. That is also why geometric tying features had to be introduced. Furthermore, to solve and stabilize the block one had to employ advanced tools of photogrammetry: shapes (features) in form of planes as well as second order surfaces were introduced. In addition, some of the unknowns had to be fictitiously observed.

ZUSAMMENFASSUNG:

Während der letzten Jahre wurden viele Computerprogramme entwickelt, um standardisierte Probleme im Gebiet der terrestrischen Photogrammetrie zu lösen. Die meisten dieser Software-Pakete wurden für Alltagsapplikationen erzeugt und sind deswegen algorithmisch nicht besonders flexibel. Wenn man sich mit sehr speziellen, individuellen Problemen auseinandersetzen muss, braucht man Programme mit einem sehr wendigen und vielseitigen mathematischen Hintergrund, die die Möglichkeit besitzen sich an bestimmte Situationen anzupassen, z.B. um ungewöhnliche Fragestellungen bei einem Verkehrsunfall zu beantworten (wie in dieser Arbeit beschrieben). Bei einer Kreuzung wurde ein Auto seitlich von einem Motorrad gerammt. Die Aufgabe bestand darin, den Deformationswinkel eines Knicks der vorderen Motorradgabel zu berechnen, der während dem Unfall aufgetreten war. Aus dieser Information konnte ein Gutachter anschließend die Kollisionsgeschwindigkeit berechnen.
Es waren vier Amateuraufnahmen vorhanden, aber keine Kalibrierungs- oder Einpassinformation oder Informationen bezüglich der inneren Orientierung, daher wurde diese Aufgabe relativ komplex und wissenschaftlich. Leider war auch die Bildkonfiguration ziemlich schwach (schlechte Schnittqualität der Strahlen) und das Auffinden homologer Verknüpfungspunkte reduzierte sich auf wenige, kleine Regionen in den Bildern. Deshalb mussten geometrische Verknüpfungs- und Passgestalten eingeführt werden. Um den Block zu lösen und zu stabilisieren, wurden außerdem erweiterte photogrammetrische Methoden angewandt: Gestalten in Form von Ebenen und Flächen zweiten Grades. Zusätzlich wurden manche der Unbekannten fiktiv beobachtet.

1. INTRODUCTION

When facing the problem of evaluating a traffic accident, close-range photogrammetry was and is the most commonly used solution, since it is a well established, proven and accurate method. Most of the times the demands are limited and consist of the determination (location, extents and orientation) of skid marks, the exact location of wreckage, or in computing the final positions of the involved vehicles. In general, a number of control points (that are visible in the imagery) are accurately measured by means of various surveying techniques and are needed for the orientation process of the images. Some times these images are taken with a metric camera, hence the interior orientation parameters (and distortion coefficients) are known, which simplifies further processing steps.

The normal procedure begins with the scanning of the developed film of the images (if not acquired with a digital camera), measuring the coordinates of the fiducial marks (metric camera) or the corners of the images (non-metric camera) in order to calculate a common interior orientation describing the relationship between camera-space and image-space.

Next task would be to measure tie points. These homologous points must be visible in at least two images and are important for 'tying' the block. Control points can also be used as tie points. Before performing the first adjustment it is important to define approximate values for the exterior orientation parameters, this can either be done by a manual process, or by using control point information. E.g. if four (or more) control points are visible in one image the method of Mueller-Killian (Kraus 1996) could be applied to get the approximate position and orientation of the new image under investigation. When the results of the adjustment are accepted, we consider the image-block as oriented (relation between object and image space established), which means that we easily can digitise a point in two (or more) images in order to get its coordinates in the

global object coordinate system (object reconstruction). This system is usually the same as the one in which the control points are defined.

In the project described in this paper we were dealing with non-metric images. We did not even know the camera type. No control points were measured and very limited information was given for scaling the image block. Also the texture information in the overlapping areas was not sufficient to measure an adequate amount of tie points. And finally, there was no information available about the position from which the pictures had been taken.

Thus the usual workflow of traffic accident evaluation could not be directly applied and was therefore modified (Figure 1).
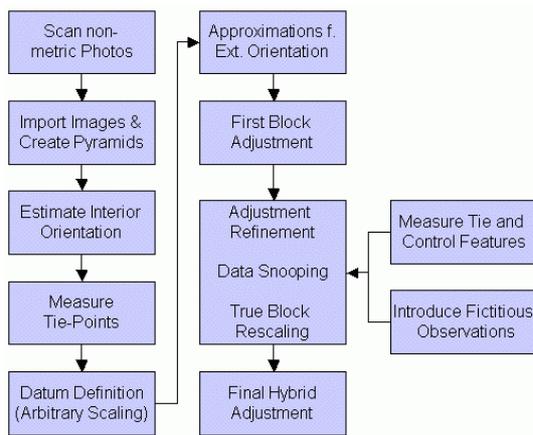

Figure 1: Project Flow

2. PROJECT DEFINITION

Four non-metric images depicting a motorcycle with a deformed front wheel fork were given (Figure 2a and Figure 2b). No control information (control points or orientation approximations of the camera positions) were available and there was no data available regarding the camera with which the images had been taken.

Figure 2a: Non-metric image (a)

Figure 2b: Non-metric image (b)

The depicted motorcycle was involved in an accident. It had crashed frontally into a car's side. The assessor needed to know with what speed the motorcycle had been driving in the moment of the collision. The only clues to derive such information were:

- angle α (see Figure 3) of a sharp bend that arose in the upper right front fork during the accident.
- exact range between the front and rear wheel axes of the deformed motorcycle!

If this angle and/or range could be precisely computed, a technical specialist would be in position to derive the force needed to emerge such a break and thus calculate the unknown driving speed.
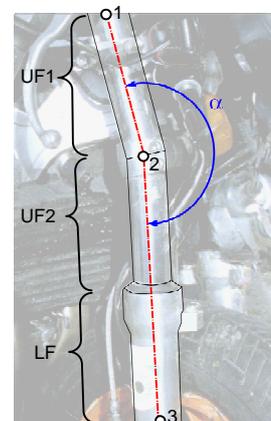

Figure 3: Bent off wheel fork

Due to the complexity of the project and the limited information that was provided, a program with a very versatile mathematical background was needed, hence common off-the-shelf software products for close range photogrammetry did not seem suitable. The employed package should be able to handle hybrid adjustment techniques (including fictitious observation implementation). So, the project was carried out by using the program system ORPHEUS (Kager et al. 2002), which is based on the photogrammetric adjustment system ORIENT (Kager 1995).

2.1 Data Preparation

The small-size negatives (24mmx36mm) were digitised in color at 5µm with the VEXCEL ULTRASCAN 5000 scanner. The digital images were imported into ORPHEUS and image pyramids were computed for faster visualization purposes.

When dealing with non-metric images there are no fiducial marks available that can be measured in order to create the relation between camera space and image space. Therefore the four corners of each image had to be digitised carefully and would serve as fiducials. Unfortunately, in most of the images the texture and contrast was very poor at the corner regions, thus the corner fiducials were measured indirectly. A thorough description of this procedure is given in Waldhauesl and Kager (1984).
A three-parameter-model was employed for the transformation between camera space and image space since fictitious fiducials were used.

At this point the images had been assigned the same interior orientation (assuming no refocusing of the camera), which still was unknown. So, the next step comprised the initialisation of the focal length. It was set to 43mm (= diagonal of the images) for the time being, and would be corrected later on through self-calibration adjustment techniques. The distortion parameters were disregarded for the time being and initialised to zero. They would also be precisely computed once the whole image block had been preliminarily triangulated and an adjustment with self-calibration could be carried out!

2.2 Datum Definition

Due to the fact that no control point information was given, two major problems appeared in the orientation procedure. Firstly, the definition of a global coordinate system (Cartesian XYZ-system) in which the image block should be defined and the object be reconstructed in.

For defining this system (seven degrees of freedom) one tie-point lying close to the motorcycle on the ground was chosen as origin (X=Y=Z=0). This way the three translation components of the system were defined. A second point was fixed on the X-axis of the local system (Y=Z=0). Thus, two rotations were defined. Finally, a third point was chosen to be fixed, lying in the horizontal XY-plane (Z=0) in order to define the third rotation, respectively. It was paid attention that the three points defining the datum were chosen in such a way, that the Y-axis was approximately parallel to the motorcycle's symmetric plane,
The scale - being the seventh degree of freedom - could unfortunately at this step not really be defined. The only valuable information regarding the scale, were the distance between the front and the rear wheel and the brake disks diameters that were taken from the motorcycle's specifications sheet. Unfortunately, no homologous points could be found on the brake disks or at the wheel axes or centres. Hence it was decided to define a fixed arbitrary distance between two points provisorily to achieve first adjustment results. A precise scaling procedure would be carried out later on using fictitious observations!

Since the image configuration was very weak, it was necessary to measure a great number of tie points in the overlapping image areas, but the finding of useable homologous points was restricted to few limited small areas in the images. Hence

additional 'tie-features' had to be employed to stabilise the block and were integrated into a hybrid adjustment (Figure 1).

3. HYBRID ADJUSTMENT AND FICTITIOUS OBSERVATIONS

When talking of hybrid adjustment, it is meant that the incorporated input data (observations) can come from widely different origins (Kraus, 1996). For example, polar points measured with a tachymeter, spatial directions between pairs of points measured with an electronic distance-measuring instrument, GPS measurements, or the well-known image points. Observations can also be provided by so-called shape or feature information. Features are (usually) not observed with an instrument, but are defined by the human senses and accumulated knowledge. Typical feature information can be:

- Horizontal or vertical planes: one or more points needed
- Straight lines: two or more points needed
- Arbitrary planes: three or more points needed
- Parallel straight lines: three or more points needed
- Parallel planes: four or more points needed

Also, spatial curves can be used instead of straight lines and spatial surfaces can be used instead of planes. Such spatial curves and surfaces can allow general relations between (object) points to be taken into account. Observations (done in the mind) leading to feature information are called fictitious observations (Kraus, 1996).

Every such feature is described in an individual local coordinate system. In these local systems the observations are mathematically defined. For example, for image point observations, that local coordinate system is defined through the exterior orientation parameters of the image. The observed values would be the image point coordinates. But also polar point measurements are defined in local coordinate systems. Here the unknowns would be the translation and orientation of the local system, and the observations the azimuth and horizontal angle, as well as the observed range to a specific point. Hence all observations types are described in individual local coordinate systems and are equally treated in the hybrid adjustment process.

3.1 Lines and Circles as Tie-Features

For nearly all projects in photogrammetry points are used for tying and controlling the image block. But in some cases no uniquely identifiable points can be found on the three-dimensional object, mainly due to lack of texture information. Nevertheless, often certain identifiable features appear in multiple images and can be used as tie or control information (see Figure 1). These features can be lines, curves or circles for example, or any other analytically describable feature, e.g. polynomial curves (Kager, 1980) or even splines (Forkert, 1994). If such features cannot be described in a mathematical way, the problem becomes insolvable.

Figure 4 and Figure 5 should give an impression on the idea of using non-homologous points to reconstruct features in object space.
The task is to find the three dimensional objects (L, a line, and C, a circle)! Considering that the elements of the exterior and interior orientation are known and no homologous points can be found on the tie or control element, we measure image

coordinates of some feature points (L', L", C', C") in each image.

In Figure 4 two planes can be seen: each containing the projection rays of all points of L producing the images L' and L''. Some of these rays are used for the reconstruction of L by measuring the corresponding image point. Fictitious observations state the fact that the object point – which is non-uniquely defined by the image ray – lies on the straight line L.
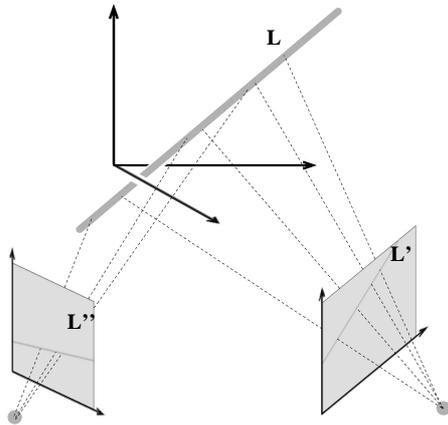

Figure 4: Line reconstruction with non-homologous points

In Figure 5 the shape to be reconstructed is a circle (C) in object space. On the images of this circle (C' and C'') non-homologous points are observed through a cone of rays.
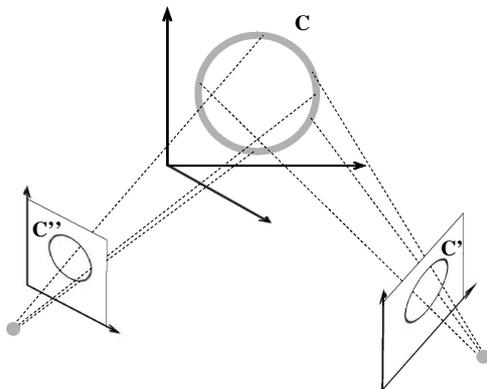

Figure 5: Circle reconstruction with non-homologous points

3.1.1 The Similarity Transformation

The mathematical implementation of such ideas in ORIENT is based on the spatial similarity transformation (Figure 6).

This transformation describes the relation of points in two different Cartesian coordinate systems, labelled 'local' and 'global' coordinate systems (Eq. 1 and 2).

$$\begin{pmatrix} x - x_0 \\ y - y_0 \\ z - z_0 \end{pmatrix} = \lambda \cdot R^T \begin{pmatrix} X - X_0 \\ Y - Y_0 \\ Z - Z_0 \end{pmatrix} \tag{1}$$

or $\qquad (\vec{x} - \vec{x}_0) = \lambda \cdot R^T (\vec{X} - \vec{X}_0) \tag{2}$

where $\qquad$ R is the spatial Rotation Matrix,

p_0 holds the coordinates (x_0, y_0, z_0) of the inner reference point (i.e. in the local system),
P_0 holds the coordinates (X_0, Y_0, Z_0) of the exterior reference point (i.e. in the global system),
λ is the scale factor that converts the length $\left\| (\vec{P} - \vec{P}_0) \right\|$ to $\left\| (\vec{p} - \vec{p}_0) \right\|$.
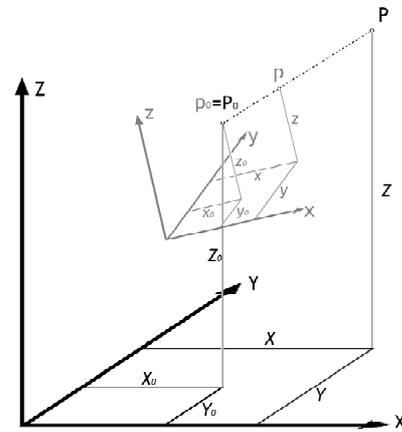

Figure 6: Similarity transformation

When assuming that the local coordinate system is the image space coordinate system, equation (1) (Kraus, 1996) can be rewritten as follows:

$$\begin{pmatrix} x - x_0 \\ y - y_0 \\ -c_0 \end{pmatrix} = \lambda \cdot \begin{pmatrix} r_{11}(X - X_0) + r_{21}(Y - Y_0) + r_{31}(Z - Z_0) \\ r_{12}(X - X_0) + r_{22}(Y - Y_0) + r_{32}(Z - Z_0) \\ r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0) \end{pmatrix} \tag{3}$$

where $\quad r_{ij}$ are the elements of the rotation matrix, which is parameterised by three angles (Kraus, 1996).

This (Eq. 3) is the well-known collinearity equation describing the image to object space relation in central perspective geometry.

After elimination of λ, the observable image coordinates can be expressed through:

$$x = x_0 - c \cdot \frac{r_{11}(X - X_0) + r_{21}(Y - Y_0) + r_{31}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)} \tag{4}$$

$$y = y_0 - c \cdot \frac{r_{12}(X - X_0) + r_{22}(Y - Y_0) + r_{32}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)} \tag{5}$$

3.1.2 Observed Planes

A local coordinate system is considered in which the plane is mathematically easily describable (e.g. xy-plane). The local coordinate system is linked to the global coordinate system through an arbitrarily chosen reference point P_0 and its rotation parameters (see Figure 7).

The observations are the zero-z-coordinates of the points lying in the xy-plane.

X_0, Y_0 and Z_0 can have any value in the global coordinate system. In this particular case only z_0 of the interior reference point P_0 is of interest, while x_0 and y_0 are equal to zero. The scale between the two coordinate systems is usually taken as one. The values of the rotation matrix R describe the attitude of

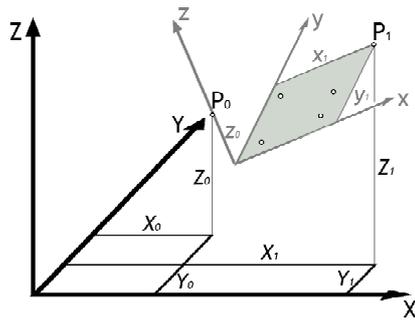the local coordinate system with respect to the global coordinate system.

Figure 7: Observed points in a plane

The equation for the fictitious observation of the z-coordinates follows directly from (1) and is given below:

$$z = 0 = z_0 + r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0) \qquad (6)$$

The unknowns are: the object point coordinates X,Y,Z and the orientation of the local coordinate system: the latter comprises 2 rotations (the rotation around the z-axis can be chosen arbitrarily). Further unknowns are: z_0 and the global coordinates of object points lying in the plane.
Observations are: z-coordinates (=0) of the points lying in the plane and the observations needed to determine these unknowns.

In case the fictitious observations are straight lines, the strategy would be to define two planes in that local coordinate system, which intersect in the desired straight line!
The observed points lying on this line need not to be homologous. A thorough description is given in Kraus (1996) and will not be discussed here.

3.1.3   Observed circles
A circle in object space can either be described through an intersection of a sphere or a cylinder with a plane. This means that feature points have to lie both in the plane and on the surface of the sphere or cylinder. Here the advantage of using local and global coordinate systems for these observations becomes clear. The cylinder or sphere as well as the plane are analytically described in a common local coordinate system (Figure 8 and Figure 9).
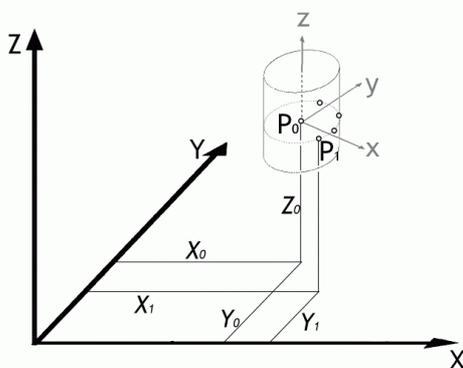

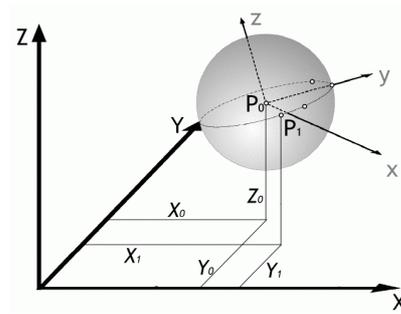Figure 8: Fictitiously observed circle using a cylinder

Figure 9: Fictitiously observed circle using a sphere

Implicit function of a sphere: $S = 0 = x^2 + y^2 + z^2 - r^2$ (7)

Implicit function of a cylinder: $C = 0 = x^2 + y^2 - r^2$ (8)

Explicit function of a plane: $z = 0$ (9)

x,y and z are the coordinates of the adjusted point P after a spatial congruancy transformation from the global coordinate system into the local coordinate system:

$$\vec{x} = R^T (\vec{X} - \vec{X}_0) \qquad (10)$$

x, y and z in the observation equations (7)-(9) must be substituted by the quantities $\vec{X}$, $\vec{X}_0$ and R in relationship (10).

The unknowns are the three translation parameters and the two rotation parameters of the local coordinate system, as well as the radius of the cylinder. The rotation around the z-axis can – and has to be chosen arbitrarily.
Observations are the z-coordinates (z=0) of the points of the plane and the zero-distance of the points from the sphere or cylinder which is subject to adjustment as the algebraical or normalized residuals (Kager, 2000), as well as the image coordinates of the observed points.

4.   BLOCK SCALING

As mentioned before, the only scaling information available were the brake disk diameters. In order to use this information, the brake disks had to be modelled (see chapter 3.1.3). Again, no homologous points could be found on the brake disk circumferences, hence fictitious observations had to be introduced. Two geometric features were described for each disk: a sphere and a plane (see Figure 9).
The plane was defined through all the observed points on the brake disk. The sphere was defined through points lying on the brake disk circumferences. The intersection of these two features lead to the circles in space that corresponded to the outer brake disk brink.
The radius r (Eq. 7) was not considered as unknown, but it was given a fixed value: the brake disk's radius from the motorcycle's specification sheet. It was important to set the previously defined range (chapter 2.2) between the two arbitrarily chosen points free; so there would be no scale-over-parameterisation of the block. After the final adjustment the block got its final, correct scale.

5.   FORK MODELLING

Now, that the image block was properly oriented and scaled, the actual work for computing the angle of the break of the front fork could begin.

The general idea was to model the axes of the fork tubes and then to calculate the wanted angle. Again, no homologous points were visible on the fork cylinders, hence fictitious observations in form of planes had to be introduced. In each image, unique points were digitised on the visible silhouettes of the cylinders.
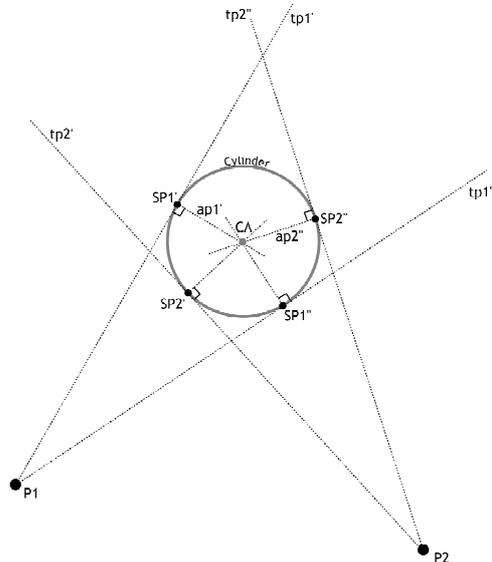

Figure 10: Modelling the fork cylinder axes

In Figure 10 the SP represent some silhouette points that were digitised in the images. P1 and P2 are the perspective centres of two images. The planes that were defined through silhouette points and the perspective centres were called tangential planes (tp). For each tangential plane a perpendicular axis plane (ap) was defined, going through the corresponding silhouette points (SP). All these axis planes (ap) intersect in one line: the cylinder axis, on which two points were defined and fictitiously observed on all axis planes (ap) (see Figure 10).

An additional restriction was set, stating that the axis of one part of the upper-fork (Figure 3: UF2) is equal to the axis of the lower fork (Figure 3: LF).

This procedure of deriving the cylinder axis from observed silhouette points in the images was carried out for all three cylinder parts of the front fork.

Finally, angle α ($\angle 1,2,3$) could be calculated, since the axis exact orientation of the two parts of the upper fork (UF1, UF2) were known.

6. DISCUSSION

This paper gives an insight on the advantage of employing fictitious observations in a hybrid adjustment. These observations seem to be the only solution when not enough tie-point- or control-information is available or when no homologous points can be found on certain features. Of course, the redundancy of the system increases much less with every observed non-homologous point than with a homologue one, but as shown in this example, many times there is no other solution available e.g. for the fork modelling!

The effort of camera calibration was not negligible, since the distortion effects arising from the non-metric camera had to be modelled precisely to achieve the wanted accuracies in the final results (σ_0=0,0315 with and σ_0=0,0384 without distortion modelling, with a $\sigma_{a\text{-}priori}$=0,03mm for an observed image coordinate). The standard deviations of image measurements when applying a distortion model ranged from ±24μm to ±38μm, compared to a range from ±24μm to ±44μm when not modelling the distortion effects.

After the final adjustment, which was carried out with self-calibration, the accuracies of the interior orientation parameters were: ±0.073mm and ±0.173mm for the principal point coordinates. The principal point distance shrunk to 27.511mm (initial value 43mm) with a standard deviation of ±0.112mm. This indicated that the pictures had been most probably taken by using a 28mm lens.

The wanted angle α resulted: $213.6^{\text{g}} \pm 1.3^{\text{g}}$.

During the adjustment process data-snooping techniques were used to trace gross errors and to get a feedback regarding the measurement process. This was very important, since it is difficult to define exact a-priori accuracies for fictitious observations. Thus the a-priori accuracies of especially these observations were revised during the adjustment process using a Variance Component Analysis (VCA)!

The whole adjustment system comprised 2212 observations (986 fictitious), 1677 unknowns and hence had a redundancy of 535. Altogether 99 geometric features were introduced in form of planes, straight lines, cylinders and spheres.

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