

A NEW APPROACH FOR RELATIVE ORIENTATION OF NON- CALIBRATED HISTORICAL PHOTOS OF BAALBEK/LIBANON

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Commission V, WG V/2

KEY WORDS: Photogrammetry, Calibration, Bundle, Camera, Identification, Distortion, Adjust, combining

ABSTRACT:

Within this paper the combination of the different classes of Baalbek's historical photos for the documentation of heritage sites is discussed. We propose an effective approach in order to perform this combination which is based on an optimal orientation of the photos and the calibration of the different cameras which were used. The photos of Baalbek have poor properties (such as: different cameras used and no primary data of the cameras' parameters, different image scales, different altitudes of the flight, the contrast of the gray values and the image noise are relative great, in addition the images were taken in different dates). The posed problem in this work is: *it is not a priori clear by which combination and order of the images orientation process the optimal results could be produced*. Therefore, different steps of the combination between the images were investigated (e.g. orientation of vertical and oblique images together, orientation of all images etc.). Additionally, the camera calibration was achieved using the bundle block adjustment method. The computation flow in the bundle block adjustment consists of four phases. First consistency and plausibility check of input data is performed. In the second step the functional model of the calculation is derived from the collinearity equations and changed in that way that it converges well. In the third and the last phases an optimal bundle adjustment including parameters for modelling of the lens distortions is achieved. Through this method a model coordinate system was created and the errors of the image points were eliminated. As results of this work; the internal geometric configuration of the different cameras used and the lens systems were determined, furthermore the photos were oriented; so that the measurement of additional 3D points is possible, in order to use them to create a 3D City model of Baalbek which provides on one hand an important document for the city and on the other hand to understand the historical development of Baalbek's building remains from the prehistoric date until 20th century.

1. INTRODUCTION

Baalbek is located on the Beqaa Plain in Libanon, which was settled in the beginning of 3 millenniums B. C. and the old preserved dwellings validate the importance of this city. Additionally, constructions as the temples: Jupiter, Bacchus and Venus are witnesses of Baalbek's wonderful constructions. As source graphical materials of Baalbek there are historical aerial photographs (vertical and oblique images), which had been taken in the years 1933-1937. Moreover there are the terrestrial photos which were taken in the year 1904. These images were taken by different cameras and different directions. The problem of the graphical materials of Baalbek is the images' properties; such as: no a priori data about the cameras used, different scales of images, different altitudes of flight, the contrast of the gray values, in addition the images were taken in different dates. Therefore the objective of this work is the performance of an optimal calibration of the different cameras used. In order to obtain an optimal orientation process of Baalbek's photos, the combination of the different types of the graphical materials has to be achieved. This combination was investigated insufficiently up to now; in addition, the faulty parts of the objects can be derived using the combination between the different data sources of Baalbek. That leads to create an optimal 3D model of the city. The 3D model will provide on the one hand an important document for this city and its temples and monuments (Jupiter, Bacchus and Venus), on the other hand to help us to understand the historical changes of Baalbek's urban heritage from the prehistoric date up to 20th century. A powerful tool for the orientation process is the employment of the bundle block adjustment to estimate a priori values for the orientation parameters (Luhmann, 2003):

- Interior parameters x' , y' and c
- Coordinates of the projection centres
- Elements of rotation matrices
- Distortion parameters of the Lenses

This way was selected because it offers the possibility to model the direct relationship between the photo system and the object space (Kraus, 1994). Due to the mathematic model in our project is highly non-linear, a special emphasis has to be put on the solving this problem.

The orientation process was divided in three steps; the first one is the orientation of each image type in one block with its special properties (for example, for each type a special camera was assumed) then the bundle block adjustment was implemented. The second one is the performance of the orientation process only for the vertical and oblique photos together. The last one is that all different types of Baalbek's photos were assembled in the same block then the triangulation process was enforced.

The work results are: the internal geometric configuration of the different cameras used was achieved, the lens systems were described and furthermore the photos were oriented. By using the oriented model of the images the 3D features could be derived and implemented to generate a 3D City model of Baalbek either in (Level of Detail one) LOD1 or LOD2 according to the City Geography Markup Language, City GML; the international standard for 3D City models (Gröger et al., 2007).

2. AVAILABLE MATERIALS

2.1 Historical photos

The historical photographs are classed into three types; aerial vertical photos, oblique and terrestrial images.

2.1.1 Vertical aerial photos

These photos were taken in the year 1937 through the French mandate and located in the institute of *Francais du Proche Orient* (IFPO) in Damascus as celluloid photographic film (Figure 1). They were performed on glass sheets with the size 18×13 cm with four fiducial points. These images were scanned and sent to technical university of Cottbus in Germany. Unfortunately the resolution of the scanner used is unknown, but by using the program *Adobe Photoshop CS2* can be displayed that the photo's resolution is 96 dpi (dot per inch) that means the size of the pixel is approx. 0.25×0.25 mm and the size of the digital aerial vertical images is approx. 6250×4750 pixel, in other words the image size is about 165×125 cm. Actually these values don't reflect the reality, but it could be assumed that the images' resolution corresponds the monitor resolution, therefore the pixel size must be multiplied with the factor ε which is computed as follow:

$$\varepsilon = \frac{18}{165} \approx \frac{13}{125} \approx 0.1 \quad (1)$$

Hence, the new assumed pixel size, which was taken into the consideration, is approx. (29) μm and the resolution about (880) dpi. The camera used for this type was considered as a metric camera, due to the four fiducial points on the photos. It could be observed the following informations on the photos' borders:

(Mission vertical 29 12/4/37 3 cmc experience, GB'39/2 ES M30 CL66 F.O. 26 C-C, CL85, ALT 2100)

By the interpretation of these data, it could be accepted that the focal length of the camera used was 260 mm (F.O. 26 C-C). ALT2100 could be the absolute altitude over the sea's level. The mean altitude of Baalbek's ground is approximately 1156 m (the mean value of the z-coordinates of the control points which were measured in Baalbek's coordinates system), that drives to the flying altitude approx. 945 m. Eventually we accepted the following criterion as primary assumption: the aerial vertical photos were taken through the same metric camera, moreover they cover a maximal area of Baalbek. The properties of the vertical images are presented in the Table 1.

Flying year	1937
Number of images used	14
Image size cm	18×13
Scan resolution dpi	96
Flying direction	SW-NE
Focal length mm	200
Flying altitude m	945

Table 1. The properties of the vertical images

In the thirties the cameras used, which produced by the French, were as following (Carlier, 1942):

- Camera Gallus G20: 13×18 cm; f = 20 cm, 24 Plates
- Poivilliers precision camera: image size 13×18 cm; the focal length: f = 20, 15, 12 cm; 12 Plates
- Aviophote: picture size 13×18; f = 20, 30 cm; 12 Plates
- Altiphote (Richard): image size 13×18; f = 20, 26 cm;
- Toporex Krauss: 18×24; f = 30, 50 and 70 cm

Therefore, the focal length of the camera used in the vertical photos was considered 200 mm in the bundle block adjustment depending on the glass sheet with the image size 18×13 cm.



Figure 1. Baalbek's vertical image 1937

2.1.2 Oblique aerial images

The oblique images were taken in the year 1933 (Figure 2). They were scanned with the photo scanner (Epson 4870) and the resolution 600 dpi that means the pixel size is round 42 μm . Through the scan process there were two problems; the first one is no complete existing of the fiducial points on the images, whereas the area of the transmitted light of the scanner was around 6×9 inch, so that the negative film was not complete collected, thus these photos have only two or three fiducial points. The other one is the resolution; due to the poor properties of the images the high resolution doesn't take an important role in order to obtain more details from the images. For the properties of the oblique images, see Table 2.

Photograph year	1933
Number of the images used	8
Image size cm	18×13
Scan resolution dpi	600
Focal length mm	260

Table 2. The properties of the oblique photos

The focal length was considered (260) mm based on the informations which were noted on the images borders.



Figure 2. Baalbek's oblique image 1933

2.1.3 Terrestrial photographs

The third part of the Baalbek's images is the terrestrial images which refer to the first German researches in the beginning of the 20th century AD (Fig. 3). These photos are stored in the regional authority of Brandenburg (Meydenbauer's archive). There are about 23 terrestrial images of Baalbek which were taken in the year 1904. The probable photograph distance was considered approx. 100 m. The resolution of the scanner used is 1000 dpi that leads to the pixel size about 25 μm (See Table 3).



Figure 3. Baalbek's terrestrial image 1904

Photograph year	Beginning of 20 century
Number of the images used	3
Image size cm	20 × 30
Scan resolution dpi	1000
Focal length mm	350

Table 3. The properties of the terrestrial images

According to the Meyer's classification of the cameras produced by Albrecht Meydenbauer, the camera constant was regarded 350 mm as primary value in the computation (Meyer, 1985). The cameras used for the oblique and terrestrial photos were considered as a non-metric camera, because of no existing of a special referenced frame of the image area; no existing of fiducial marks (Luhmann, 2003).

2.2 Additional informations

- In the years 2003 and 2004 the control points' coordinates were measured tachymetric and reflectorless in the Baalbek's local system. The accuracy of the measurements is in the range [5-10] cm. The control points were drawn in 27 sketches.
- There are two digital topographic maps. They both cover the whole studied area of Baalbek and have the scale 1: 20 000.
- The coordinates of the control points were measured by using the Tachymeter Leica TCRM 1102.

3. DETERMINATION OF IMAGES' SCALES AND GROUND RESOLUTION

As mentioned in the chapter 1, the images of Baalbek have different image scales. In order to determine the scales of the images of Baalbek, some distances (s_i') between the control points were measured in the images using the program *Adobe Photoshop CS2*. Through the natural coordinates (X_i, Y_i and Z_i) of the control points, the distances (S_i) were calculated. The ratio $m_{bi} = S_i/s_i'$ represents the image scale numbers; then the image scales can be given by:

$$m_i = \frac{1}{m_{bi}} \quad (2)$$

The ground resolution R_g can be expressed as following:

$$R_g = P_s \cdot \bar{m}_b \quad (3)$$

Where: P_s the pixel size and \bar{m}_b the mean image scale number

The mean image scale numbers and the ground resolutions regarded in the orientation process are presented in the Table 4.

Image type	\bar{m}_b	R_g
vertical	4000	[11-12] cm
oblique	4000	[13-22] cm
terrestrial	2500	[4 -10] cm

Table 4. The mean image scale numbers of the graphical materials and the ground resolutions

4. RELATED WORK

The first excavations and studies in Baalbek were performed by the first German researchers 1900-1904. In the next decades, French colleagues undertook conservation measurements and intensified research on the theological problems of the *Heliopolitaeen trias* round of the three Temples. The French revealed that there was a stairway leading up *Sheikh Abdullah* area. In the 1920s the Department of the Antiquities of the French mandatory government continued the researches and restorative work; since 1945 the Lebanese *Direction Generale des Antiquites* (DGA) has continued this work. For further informations, see (Th. Wiegand, 1925, Van Ess 1998).

Current fieldworks are being conducted in different areas of the Roman town of Baalbek. An important aim of the processes concentrates the further documentation, drawing and stratigraphic analysis of the areas and the buildings. The fieldwork projects are as following (Van Ess et al. 2003):

- *Bustan el Khan* in the 1960s, 1970s and 2001-2004
- Area of the so-called *Venus temple* in 2002
- *Qala'a* in 1960s and *Sheikh Abdullah* since 2002
- In the years 2005 and 2006 A. Klotz and M. Gessner worked only with the aerial vertical images of Baalbek to create orthophotos

The results of these mentioned works based on the town history and geodesy led to new assumptions concerning the chronological sequences of the wonderful constructions of the temples and their interrelationships.

Although the scientific works and researches in Baalbek started in 18th century, many unexplained questions are posed concerning the town planning and its urban progress. These questions display additional motives for this work especially with using the oblique and terrestrial photos of Baalbek, which could be given more information about the city.

5. THE ORIENTATION PROCESS

The orientation process was achieved using the bundle block adjustment because it allows achieving a simultaneous and mathematical adjustment of the photos. This adjustment is performed in the images space. The image points, geodetic observations and a superposed coordinates system are considered in the computations. The single images are tied through identical (correspondent) points and transformed into one model; in it the object points can be reconstructed.

Through a determined system of the calculations the 3D object coordinates, the orientation parameters of the photos and the other unknowns (radial and decentring distortions etc.) can be calculated. Furthermore, the statistic indications of the results' accuracy and confidence could be estimated. The bundle block adjustment is considered an effective and highly productive way for the image orientation in photogrammetry because all observations and unknowns parameters are regarded in one calculation process. An important geometric constraint, which has to be mentioned, is that all image point correspondent rays must intersect optimal in their object point (Epipolar lines).

The software used to perform the orientation process was *Pictran*, which was selected due to the following reasons (Pictran, 2000):

- It is possible to perform the orientation process without primary values of the unknowns; that means a system of coordinates' model will be created through the relative orientation of the photos (this corresponds to our project's case).
- Due to the relative orientation, this software has the advantage, that the images errors could be detected, because these errors relative will not be taken into the consideration through the orientation process of the other photos. That leads to elimination of the gross failures in the orientation process.
- By using the special image format: *BT-format*, *Pictran* provides fast operation of the image data; which is necessary in our project, because the graphical materials of Baalbek have high memory sizes.

The vertical images of Baalbek were oriented at the first step of the orientation process because of:

- existing of a spatial reference system in the images; that means existing of the fiducial points on the image area leads to a stable model of the oriented images, which offers good results (e.g.: the measurements of 3D object points).
- The photogrammetric evaluation of the vertical photos is more accessible than the oblique or the terrestrial images, so that the Nadir distance (Nadir angle) is smaller or equals 3° (Hildbrandet, 1996).

The computation flow through the program *Pictran* consists of four steps. First consistency and plausibility check of input data is performed. In the second step the functional model of the calculation is derived from the collinearity equations (formulas 4 and 5) and changed in that way that it converges well and there is a common scale unknown for each image in order to transform the problem into a linear one. In the third step there is a scale per image point and an orthogonal rotation matrix is enforced. For the last step an optimal bundle block adjustment

including parameters for modelling of the lens distortions is achieved. By this method the errors of the image points were eliminated and the model coordinates systems were created, which will be finally transformed through the similarity transformation into uniform system (based on the control points coordinates). The results are: the parameters of interior and exterior orientation, lens distortion parameters (radial, shear and decentring), the 3D coordinates of tie points and object points.

$$x' = x'_0 + z' \frac{r_{11} \cdot (X - X_0) + r_{21} \cdot (Y - Y_0) + r_{31} \cdot (Z - Z_0)}{r_{13} \cdot (X - X_0) + r_{23} \cdot (Y - Y_0) + r_{33} \cdot (Z - Z_0)} + \Delta x' \quad (4)$$

$$y' = y'_0 + z' \frac{r_{12} \cdot (X - X_0) + r_{22} \cdot (Y - Y_0) + r_{32} \cdot (Z - Z_0)}{r_{13} \cdot (X - X_0) + r_{23} \cdot (Y - Y_0) + r_{33} \cdot (Z - Z_0)} + \Delta y' \quad (5)$$

where X, Y, Z = object coordinates in ground
 X_0, Y_0, Z_0 = coordinates of projection center
 x'_0, y'_0 = coordinates of principle point
 x', y' = image point coordinates
 r_{ii} = elements of the rotation matrix
 $z' = -c_k$ = focal length
 $\Delta x'$ and $\Delta y'$ = correction parameters

The strategy of the orientation process was divided into three steps; the first one is the orientation of the photos using independent blocks that means each type of the images was taken in one block with its special properties and then the bundle block adjustment was implemented. The second one is the orientation procedure based on the combination between the two images classes; the vertical and oblique photos. The last one is the combination between all images classes; that means all different types of Baalbek's photos were assembled in one block then the triangulation process was used. The results of the unknown parameters, which were estimated through the calculations of the first step, were applied into the bundle block adjustment as approximate values (observations) for the unknowns in the second and third steps.

Figure (4.a) shows an illustration of the first orientation step, where fourteen vertical aerial, eight oblique and three terrestrial images were imported to the block (1), block (2) and block (3), respectively. The redundancy depends on the number of the observations and the unknowns associated with each image types. The results of this orientation step are the estimated values of the interior and exterior orientation parameters, moreover the determination of other unknowns (e.g. radial and decentring distortion parameters).

As mentioned in the chapter 1, the combined evaluation of the different types of Baalbek's images is an important goal of this work to suggest a suitable approach to orient the different images together optimally and on the other hand to improve and control the results calculated from the 1st step. Therefore, the orientation of the vertical and oblique photos displays the first effort of the combined images evaluation.

The Figure (4.b) illustrates the image orientation process based on the combination between the vertical and oblique photos, whereas the best six vertical images from the fourteen images (block 1) were selected depending on the image quality (for e.g. low image noise etc.). In addition the best six oblique photos (from the eight images existing in block 2) were implemented.

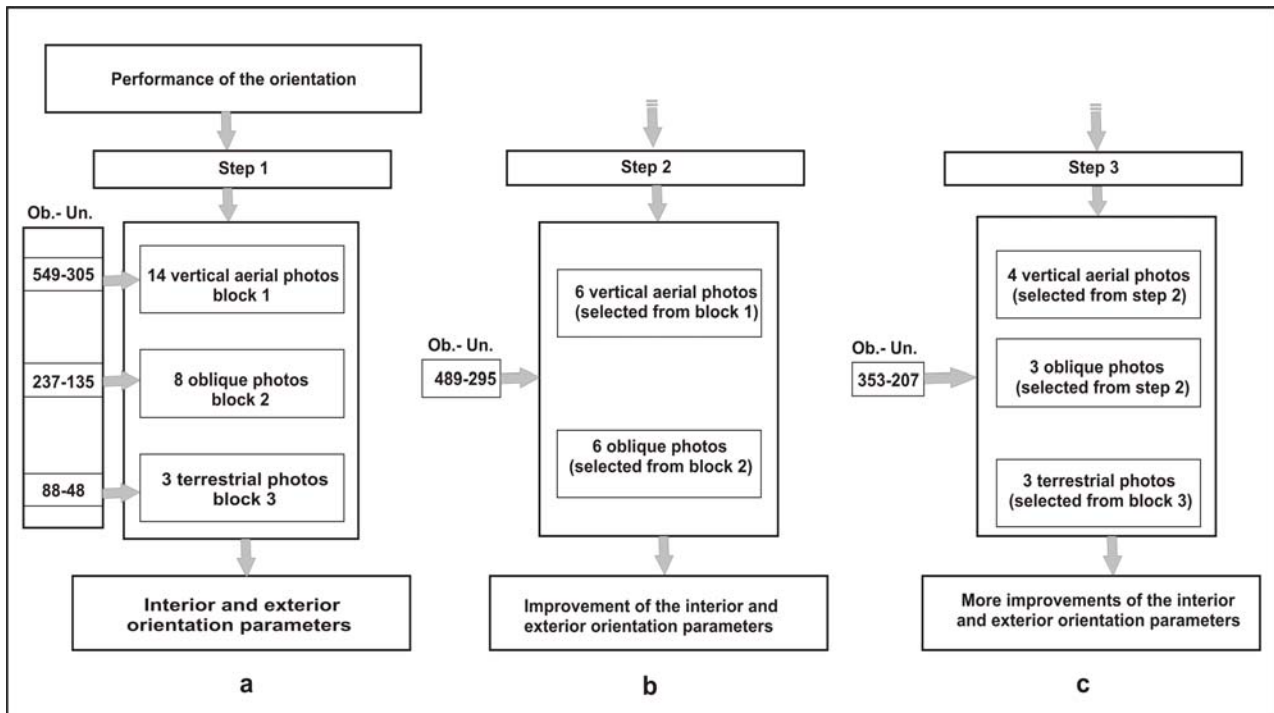


Figure 4. The orientation process steps; Ob.: number of the observations, Un: number of the unknowns

This step was performed using the orientation results obtained from the first step of the orientation process. The 2nd step results are improvement of the interior and exterior orientation parameters calculated from the 1st step of the orientation process.

In order to create an optimal 3D model of Baalbek, it is important to have more features about the objects derived from the images. Although there are different methods to obtain the object details (for e.g.: photos, laser scanning etc.) there are defective objects.

Only through the combination between the different data sources the faulty parts might be detected, therefore, the orientation process of Baalbek's photos was enforced building on the combination between the three classes of the images; vertical, oblique and terrestrial photos. In this step of the image orientation four vertical images, three oblique and three terrestrial photos (with respect of the images quality) were used and together oriented. The numbers of the observations and unknowns in this case are 353 and 207, respectively (Fig. 4.c).

Building on the orientation results calculated from the first and second orientation steps, the third one was performed, that means the results calculated from the 1st and 2nd steps (for e.g. interior and exterior orientation parameters) were considered as new initial approximations for the interior and exterior orientation parameters in the last one. In this step the unknowns were more improved.

The major problems of the calculations were:

- On the one hand no fiducial points' coordinates were available; this means that a mathematic model will be integrated to calibrate the photos and to enable to use them optimally.

- On the other hand the identification of the projection centres depends on the angles of the intersected triangles which are configured from the image points. These image points correspond to known object points which were measured by the tachymetric survey.

Hence, the image points must be determined exactly in the correct positions to determine correct triangles but that was not possible, because of the contrast and noise in the photos.

6. ANALYSIS AND INTERPRETATION OF RESULTS

The results calculated were checked based on the following criteria (Baumann, 1995 & Gründig, 2003):

- Due to the *estimated standard deviation of the unit weight after the adjustment* ($SIGMA_0$) is approximately in the range [0.7-1.3], the image blocks are accepted and were not regarded to contain gross errors visible.
- *The estimated standard deviations after the adjustment* (M) of the principle point coordinates and the focal length of the cameras used are between [0.25-3.84] mm. Additionally, the values of (M) confirmed the assumed mean error of the observations before the adjustment (MFV is between [0.5-8] mm), that means the interior orientation parameters were determined geometrically well.
- An important criterion of the result quality is *the part of redundancy*, which is a measure for the observation control in the adjustment. The relative influence on the residuals is defined by the percentage of the part of redundancy (EV). If the observation has the EV between [10%-70%] that means this observation is well controlled. In our project the

percentage of the part of redundancy (EV) for the most of the observations is in the request range.

- The last criterion of the result quality is the *Data-Snooping-test value (Normalized residuals NV)*. The normalized residual can be expressed by the formula:

$$NV_i = \frac{|v_i|}{\sigma_{vi}} = \frac{|v_i|}{m_0 \sqrt{q_{vivi}}} \quad (6)$$

where:

- v_i : residual
- σ_{vi} : mean error of the residual
- m_0 : assumed mean error of the unit weight (it is set 1)
- q_{vivi} : diagonal elements of the cofactormatrix of the residuals

Depending on the *Normal Distribution*; $N(0, 1)$ the following category could be considered:

$NV < 2.5$	no gross error shown
$2.5 < NV < 4$	gross error possible
$4.0 < NV$	gross error visible

On one hand if the NV is greater than (4) that means the corresponding observation is to the largest value of NV with the probability 95% incorrect with respect of the basic accuracy. On the other hand if the NV is less than 2.5 (probability 80%) that means that there is no gross error shown in the calculations. The NV values in our case are approximately less than 2.5 which reveal that the observations didn't have gross errors visible.

Additionally, based on the values of Z_0 coordinates calculated, it could be evaluated that there were different flying altitudes of the vertical images which can be divided into three flying phases as following:

- Phase₁: $h_g \approx 1765$ m
- phase₂: $h_g \approx 1935$ m
- phase₃: $h_g \approx 2030$ m

These different flights caused the differences of the image scales. Moreover, the rotation elements ω and φ indicate that the flying plane was approximately horizontal.

In comparing between the results of the orientation parameters which were calculated we can find that the results of the last orientation step validate approximately the other one calculated from the 1st and 2nd orientation steps. Moreover, the achievable accuracy of the parameters especially for the coordinates of the applicable 3D object points and centers of projection was plausible and smaller than 2/2 m (position and height); therefore, it will be possible to use the 3D features derived from the oriented model of the images to create a 3D city model of Baalbek in LOD2 (according to Gröger et al., 2007).

7. CONCLUSION

The graphical materials of Baalbek were oriented successfully in Baalbek's local system. Baalbek's photographs have poor properties (such as: no informations about the cameras used, the determination of the image points was unconfident due to the image contrast and the stark noise). The orientation process was divided into three steps; the first one each type of Baalbek's photographs (vertical, oblique and terrestrial) was oriented in an independent block, the second one only the vertical and oblique images were oriented in the same block. The last one is all different photographs were oriented together. The work results are: on one hand an optimal performance of the images orientation so that the 3D point measurement is possible to use it for creation of a 3D city model of Baalbek in the LOD1 or LOD2 depending on City GML, on the other hand suggestion of an effective method in which the combination between the different images were performed, moreover the parameters of the orientation process could be optimal estimated.

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