IMAGE ORIENTATION EXCLUSIVELY BASED ON FREE-FORM TIE CURVES

Gerald Forkert

University of Technology Vienna, Institute of Photogrammetry and Remote Sensing
Gusshausstraße 27-29 / 122
A - 1040 Vienna, Austria
Tel.: +43 1 58801 3802
Fax: + 43 1 5056268
e-mail: gforkert@fbgeo1.tuwien.ac.at

Commission III, Working Group 2

KEY WORDS: orientation, reconstruction, bundle block adjustment, digital image, free-form curves

ABSTRACT

Recent developments in the field of digital image processing encourage to use line information for image orientation and object reconstruction instead of or in addition to traditional methods based on distinct points. In this paper, image orientation exclusively based on free-form tie curves shall be demonstrated working on a car as real-world test object. Photographs were taken from around the car and scanned in order to obtain digital images. Edges extracted from those digital images provided the input data for bundle block adjustment for the determination of both, the orientational parameters of the images as well as the spatial shape of the tie curves. The results show, that an accuracy in the order of the uncertainty of definition of the object lines could be achieved.

KURZFASSUNG

Die jüngsten Entwicklungen auf dem Gebiete der digitalen Bildverarbeitung legen die Verwertung von Linieninformation für Bildorientierung und Objektrekonstruktion nahe, um traditionelle, auf Punkten basierende, Methoden zu ergänzen oder sogar zu ersetzen. In diesem Beitrag soll mit Hilfe eines Autos als Testobjekt die ausschließlich auf Freiform-Verknüpfungskurven basierende Bildorientierung demonstriert werden. Mehrere rund um dieses Auto angeordnete Photos wurden gescannt, um digitale Bilder zu erhalten. Die von diesen digitalen Bildern extrahierten Kanten dienten als Beobachtungsdaten für die Bündelblockausgleichung zur simultanen Bestimmung sowohl der Bildorientierungen als auch der räumlichen Form der Verknüpfungskurven. Die Ergebnisse zeigen, daß eine Genauigkeit in der Größenordnung der Definitionsunsicherheit der Objektlinien erzielt werden konnte.

1. INTRODUCTION

One of the main tasks in photogrammetry is object reconstruction. As a prerequisite the problems of image orientation must be solved, which usually is done by traditional photogrammetric algorithms based on object points. Many objects can hardly be described by points but by linear features. It is obvious to use that features for image orientation and object reconstruction in addition to point based methods.

Furthermore, line features may be very valuable for the automated orientation of digital images: detecting homologous lines in two or more images appears to be easier in many cases than finding homologous points.

Several methods have been published which use line features represented by a single polynomial (Kager 1980), what, however, is not sufficient for complex object shapes. Spatial free form curves of joined cubic polynomials seemed to be appropriate and have been implemented into the bundle adjustment program ORIENT (Kager 1989).

The basic concept of this method was presented in 1993 for the first time (Forkert 1993): The shape of a joined cubic polynomial curve is completely described by its node points. The positions of these nodes in object space are determined by adjusting the curve either to object points or to image rays of at least two images.

Applying this method, the three basic problems of object reconstruction can be solved using line features only:

1) orientation of at least three images merely by free-form tie curves using an arbitrarily chosen local reference co-ordinate system (alike relative orientation),
2) absolute orientation based on free-form control curves, and
3) reconstruction of free-form object curves from at least two already oriented images.

Absolute orientation based on free-form control curves was presented in 1994 using models from computer tomography (Forkert et al. 1994). The solution of the reconstruction task was demonstrated in 1995 with a car as real world test object (Forkert et al. 1995) So, this paper deals with the orientation of images exclusively based on tie curves working on the same car.

2. THE TEST OBJECT

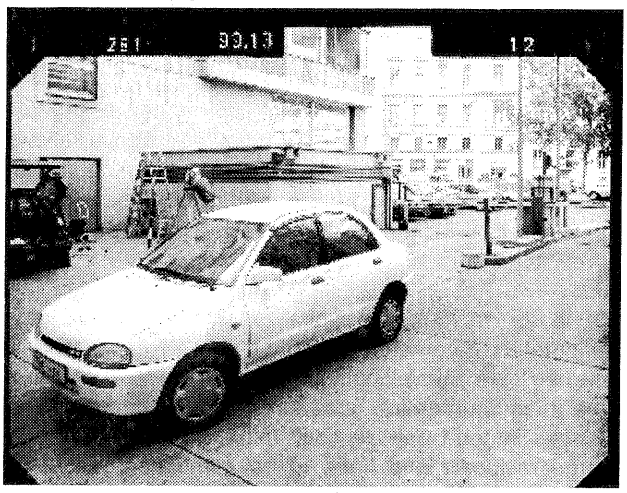

Figure 1: Car image

Twelve images were taken from around the car using a P31 terrestrial metric camera with a principal distance of 100 mm. The camera was focused to 4m, thus achieving an average image scale of 1:40. The image format was 12 cm x 9 cm. Figure 1 shows one of the images; the arrangement of the photographs can be seen in figure 2. It was mainly chosen according to considerations about the depth of field. For control purposes, 116 points were targeted on the car surface using black adhesive paper dots with a diameter of 8 mm.

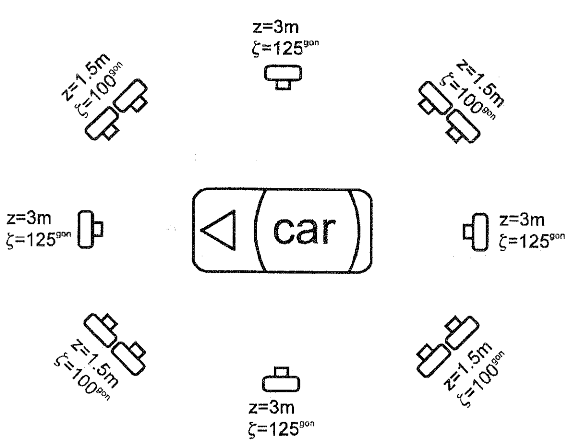

Figure 2: Arrangement of photos

In order to get digital images, the photographs were scanned with a resolution of 15 µm using a Zeiss PhotoScan PS1. Due to the large image format we obtained digital images with 50 MB each.

The measurement of the control targets was done using a "digital mono comparator". The accuracy of the position of the targets was estimated to be about ±1/2 pixels.

For extracting tie curves from the digital images, firstly a line extraction algorithm was applied to the images delivering rather long line segments which are likely to present object curves (see Forkert et al. 1995). Secondly, line segments from different images belonging to the same object curve have to be declared homologous. Though currently done interactively with the help of a graphic line editor, the assignment of homologous lines can possibly run automatically in future, at least for long line segments.

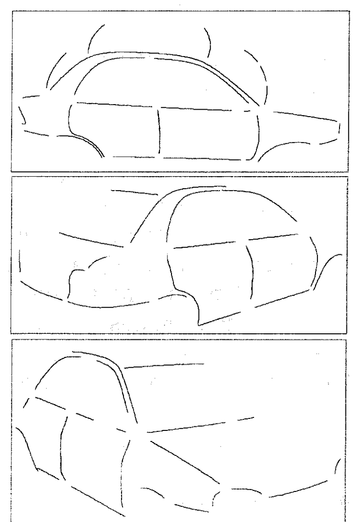

Figure 3: Lines extracted from three images

3. BASIC CONCEPT

Figure 4 shows the basic concept of free-form curves in bundle block adjustment. We have recorded points (for example *P'*) from the images of the original curve in the way described in section 2. Note that in general it is not possible to find homologous edge points in different images. The unknown three dimensional curve point *P* corresponding to the two dimensional image point *P'* is located on its image ray running from the projection centre through the image point. So, a "bundle" can be formed by all relevant rays of an image. Now, the curve *S* can be adjusted to the bundles of rays coming from the images (see figure 4).

The curve *S* that shall be the best possible reconstruction of the original is described by a series of cubic polynomials, each representing one curve segment. These curve segments are joined together at node points with at least the first derivations of the polynomials being continuous. Well-known examples for such "joined cubic polynomial curves" are cubic splines or Akima curves.

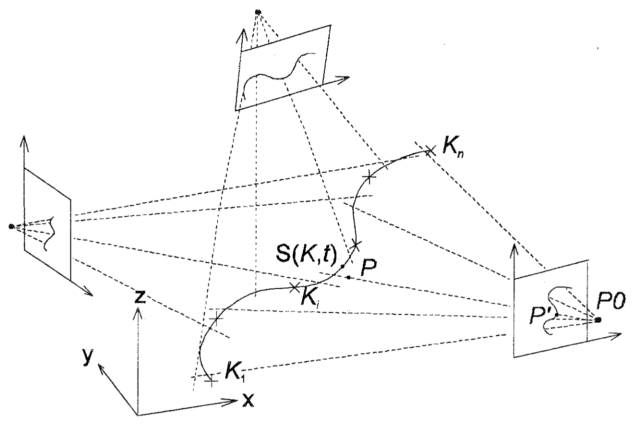

Figure 4: Basic concept of free-form curves in bundle block adjustment

Note that the shape of *S* is completely described by a set of node points *K*. Parameter *t* describes the position of the foot (S(K,t)) of point *P* on *S*.

So, the unknowns of our least squares adjustment problem are the co-ordinates of the node points (*K*), the positions of the points along the curve (*t*) and the object co-ordinates of the curve points (*P*), and the orientation parameters (the rotational parameters and the projection centres) of the images. If the photographs have been taken with a calibrated camera, the elements of the inner orientation are well known.

Considering parameters *t* unknown in the adjustment process enables optimisation of the positions of the nodes both laterally and along the curve (Forkert, 1993, pp. 221-228). If the distance between to consecutive nodes falls below a user specified threshold, one of the nodes will be deactivated automatically.

The problem of "relative orientation" can be solved if object curves exist which are visible in three or more images. For the following considerations let's concentrate on one object curve, only. If the images are not oriented, the bundles of rays running through the image curves do not intersect uniquely. So, the bundles have to be shifted and rotated until they intersect correctly in one spatial curve. At the same time, the shape of this tie curve will be determined. Consequently, the relative orientation of three or more images can be found by using an arrangement of tie curves. Note, that in general it is not possible to find homologous points in different images of the curve. So, our method is based on homologous curves instead of on homologous points.

Questions for the minimum configuration of tie curves can be answered by replacing the curves by their significant tangents. A U-formed curve, for instance, consists of two significant tangents. Every tangent is described by four parameters in object space and by two parameters in image space, respectively. So, for example, the eleven parameters describing the relative orientation of three images can theoretically be determined by at least three U-formed curves.

4 IMAGE ORIENTATION

4.1 Determination of approximate values

In this test project, the local reference co-ordinate system was chosen arbitrarily by fixing seven orientational elements. The scale of this local co-ordinate system was estimated corresponding to the real object dimensions in order to get realistic r.m.s. errors in object space.

An appropriate configuration of provisional tie curves, extracted from the images as described above, allows to determine initial values for the image orientation. The real image orientation will be carried out later on (see section 4.2), using tie curves cutted out from the provisional curves.

In order to get provisional values for the image orientation parameters, the first step of calculation is carried out conventionally with points: the end points of the image curves are used as tie points. End points of curves imaged only partially might cause significantly large residuals and have to be eliminated by robust estimation. The results of the adjustment can be seen in table 1.

No. images	No. tie points	r.m.s. error in image
12	84	5 mm

Table 1

Thereafter, the initial node positions of a provisional tie curve can be obtained through an approximation algorithm: Approximate curve points in object space are found by intersecting their image rays with the cone surface formed by the rays of another image. Afterwards, the algorithm distributes the nodes in regular intervals along the polygon of curve points. In this test project, the initial number of nodes was chosen automatically dependent on the number of curve points (one node per fifty curve points). In order to improve the initial node arrangement, the approximation process is completed by a curve adjustment with the approximated object points assumed to be constant.

For the time being image orientation is quite inaccurate. Nevertheless 29 out of 40 provisional tie curves could be approximated as shown in figure 5.

Experience shows, that it is advisable to refine the tie curve´s shape before starting image orientation. The unknowns of this "curve reconstruction" task are: the co-ordinates of the node points, the positions of the points along the curve and the object co-ordinates of the curve points. The actual values of the orientational parameters are assumed to be constant. The automated iterative process of curve reconstruction consists of two main steps alternately applied:

1) adjustment with a given number of nodes

2) insertion of additional nodes in the intervals containing points with the greatest mean residuals

So, the flexibility of the adjusting curve is improved step by step by inserting additional nodes. If the insertion of additional nodes does not result in significantly reduced residuals, the optimum reconstructing curve has obviously been found. The refinement of the provisional tie curve at the right back door is shown in figure 6.

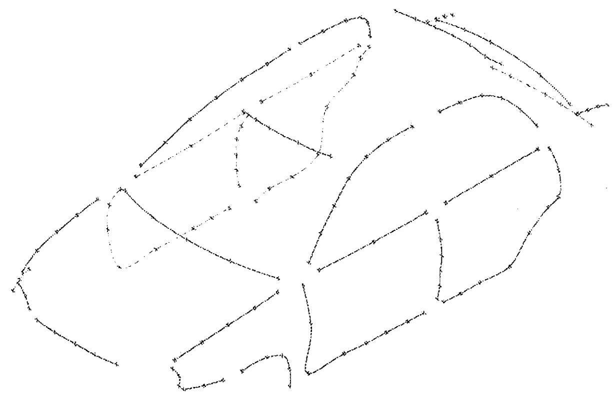

Figure 5: Approximated provisional tie curves

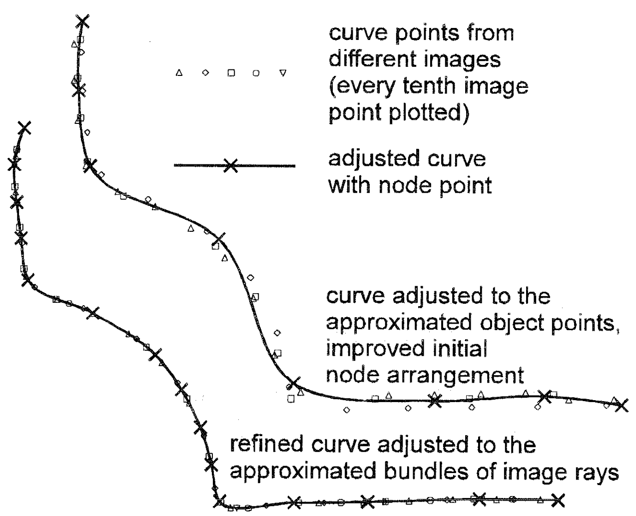

Figure 6: Refinement of a provisional tie curve

Up to now, 29 provisional tie curves are available. In order to get initial values for the remaining 11 curves, the provisional values for the image orientational parameters have to be improved by a further step of adjustment. In addition to the orientational parameters, the object co-ordinates of the nodes and the curve points are assumed to be unknown during this step. The positions of the curve points along the curve are considered to be constant in order to save computational time. The result, obtained after five iterations, can be seen in table 2.

No. tie curves	No. nodes	No. curve points	r.m.s. error in image
29	104	5380	55 µm

Table 2

Using the improved image orientation, the remaining 11 provisional tie curves can be obtained by the approximation algorithm as described above.

4.2 Image Orientation using short tie curves

After having determined all provisional tie curves the real image orientation can commence. At the same time, the real shape of the tie curves is reconstructed in object space. Unfortunately, long complex tie curves, as obtained from the line extraction procedure described above, are not optimally suited for image orientation: a high number of nodes might be necessary to build up a curve which is flexible enough for the spatial reconstruction of the tie curve. However, a very flexible curve would fit to the bundles of rays even if the relative orientation is weak. Consequently, the shape of the tie curve has to be rather simple, for instance U- or S-formed, in order to force an accurate image orientation. So, short tie curves have to be extracted from the provisional tie curves in object space.

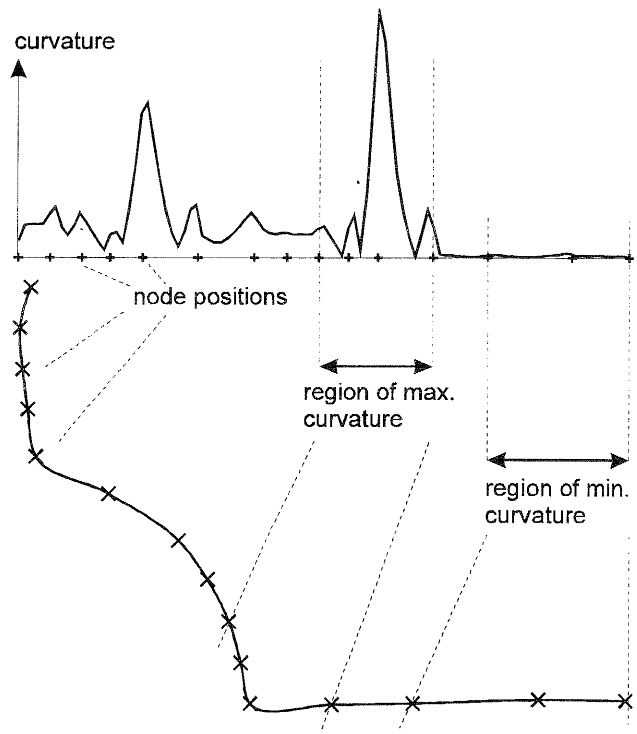

Figure 7: Extraction of tie curves from a provisional curve

Two different configurations of tie curves have been examined in the course of this test project:
a) low bent tie curves extracted from regions of minimum curvature of the provisional curve, and,
b) highly bent tie curves extracted from regions of maximum curvature.
The tie curves of configuration a) are initially built up by 3 nodes (thus describing a parabola), those of configuration b) by 4 nodes (see figure 7).

The image orientation based on free-form tie curves consists of two steps alternately applied until the expected accuracy is achieved.

The first step is the simultaneous adjustment of the image orientation and the tie curves. The unknowns of this adjustment are: the projection centres and the rotational parameters of the images, the object co-ordinates of the curve points, the positions of the points along the curve and the nodes representing the tie curves. The number of nodes remains unchanged during this first step.

The second step is the improvement of the node arrangement of every tie curve with significantly high residuals by applying the curve reconstruction task as described in section 4.1. The orientational parameters are assumed to be constant during this step.

The refinement of a tie curve´s shape during the process of image orientation can be seen in figure 8. At the end of this process, the shown curve is built up by a rather high number (nine) of node points. Using even more nodes did not improve the reconstruction of the tie curve (second step) nor did it improve image orientation (first step).

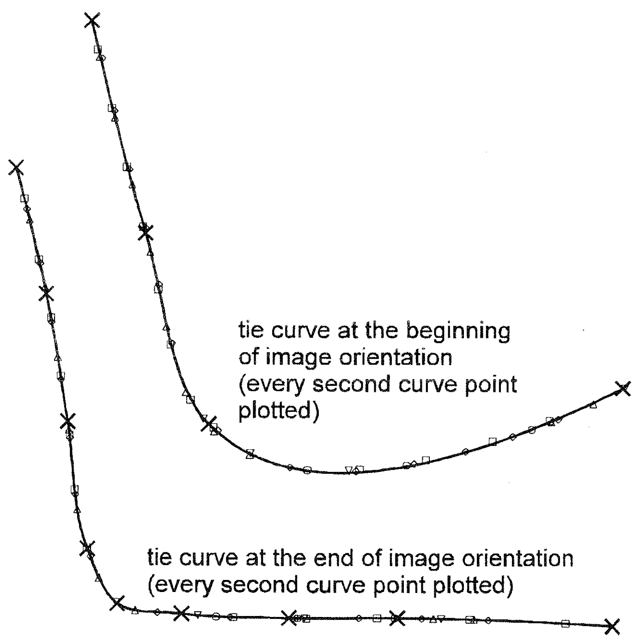

Figure 8: The tie curve at the right back door at the beginning and at the end of image orientation.

4.3 The result

The final results (see figure 9 and 10) were achieved by twice repeating the process of image orientation and curve reconstruction as described in section 4.2. Every step of image orientation took among 20 (configuration a)) and 30 (configuration b)) iterations; every iteration took about seven minutes computational time on a PC-486. The accuracies of both configurations are quite similar: The finally adjusted tie curves fit to the oriented bundles of rays with an accuracy of about 4 µm or ¼ pixel, respectively (see table 3 and 4).

However, inspecting the control points, reveals that the real r.m.s error is in the order of about ±35 µm (2 pixels) in the image or ±1.5 mm in object space. Regarding the residual vectors of the control points, it can be concluded that a small deformation remained in the adjusted object points. This deformation is caused by the weak tie information between the left and the right side of the car, with all the tie curves available being nearly parallel (e.g. the lower and upper borderlines of the front and rear windows).

Adjusting the images of the left and the right side separately results in r.m.s. errors at the control points in the order of 20 µm (1.5 pixel) or 0.8 mm in object space. This corresponds to the uncertainty of definition of the original object curves.

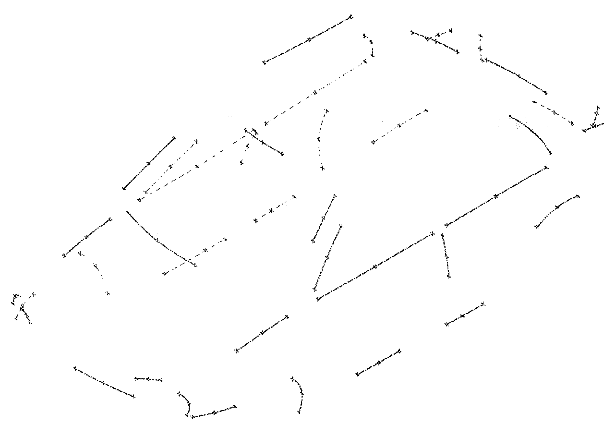

Figure 9: Finally adjusted tie curves of configuration a) (low bent tie curves)

No. tie curves	No. nodes	No. curve points	r.m.s. error in image
40	183	5529	3.8 µm

Table 3: Adjustment results of configuration a)

Figure 10: Finally adjusted tie curves of configuration b) (highly bent tie curves)

No. tie curves	No. nodes	No. curve points	r.m.s. error in image
40	224	6554	4.3 µm

Table 4: Adjustment results of configuration b)

As mentioned above, the accuracies achieved with configurations a) and b) are quite similar; however, configuration a) has some advantages regarding the computational effort. Thus, in practice, it is advisable to use rather low bent tie curves.

Having a configuration of low bent tie curves one might be attempted to represent the curves by parabolas instead of joined cubic polynomials. As mentioned above, the tie curves of configuration a) initially have been described by parabolas. Adjusting this initial configuration resulted in r.m.s. errors at the control points in the order of 44 µm or 3 pixels. As described, this result has been improved decisively (see table 3) by inserting additional nodes in order to refine the tie curve´s shape. So, even low bent lines of the car are better represented by free-form curves than by parabolas.

After having finished image orientation a model of the car can be reconstructed. The object curves are obtained by spatial intersection of free-form curves. Image orientation is regarded to be constant during this process, so that long and flexible object curves can be modelled (see figure 11).

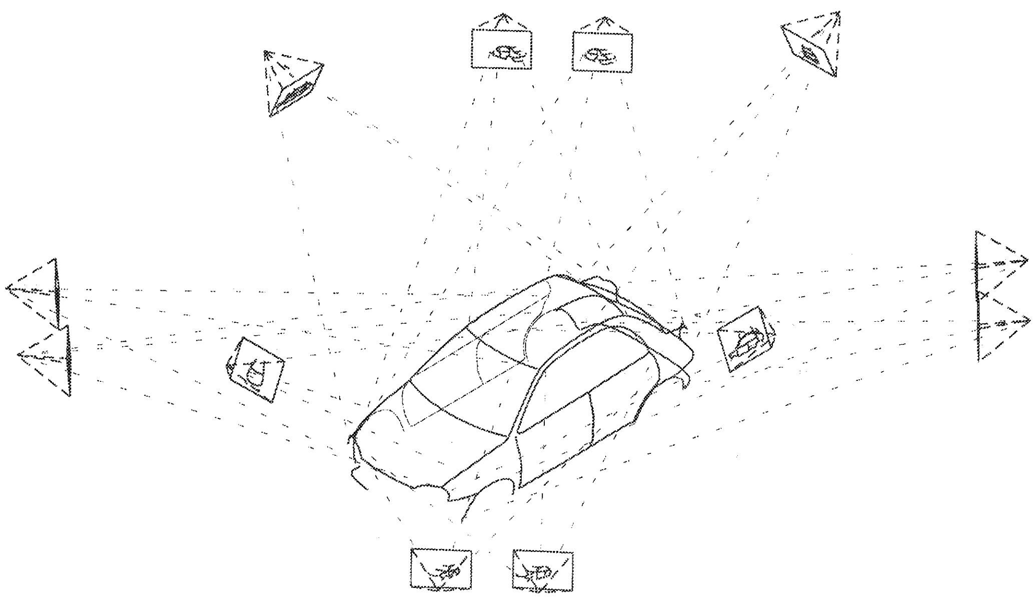

Figure 11: Object curves reconstructed from the finally oriented images

5 CONCLUSION

Applying photogrammetric object reconstruction techniques we can build models from spatial objects using images as source of information exclusively. By means of the method presented in this paper, real world objects having no or hardly any point information but enough line features can be dealt with. This could be advantageous, for instance, if targeting is not possible. Additionally, complex free-form object curves extracted from digital images might be a valuable support for automated detection of homologous features, thus increasing the level of automation in digital photogrammetry.

References

Forkert, G., 1993. Photogrammetric Object Reconstruction using Free-Formed Spatial Curves. In: Gruen, A. and Kahmen, H. (editors.): Optical 3-D Measurement Techniques II. Herbert Wichmann Verlag, Karlsruhe, 1993, pp. 221-228.

Forkert, G., Dorffner, L., Klimpfinger, H., Rusch, W., 1994: The Application of Visualization Techniques for Diagnosis and Quality Control. ISPRS Comission III Symposium, Munich 1994, pp. 194-200.

Forkert, G., Kerschner, M., Prinz, R., Rottensteiner, F., 1995: Reconstruction of Free-Formed Spatial Curves from Digital Images. In: IAPRS, Vol. 30, Part 5W1, ISPRS Intercomission Workshop "From Pixels to Sequences", Zurich 1995, pp. 163-168.

Kager, H., 1980: Das interaktive Programmsystem ORIENT im Einsatz. International Archives of Photogrammetry and Remote Sensing XXIII/B5, Hamburg 1980, pp. 390-401..

Kager, H., 1989: ORIENT: A Universal Photogrammetric Adjustment System. In: Gruen, A. and Kahmen, H. (editors.): Optical 3-D Measurement Techniques. Herbert Wichmann Verlag, Karlsruhe, 1989, pp. 447-455.