A new solution for the automatic orientation of arbitrary arranged images

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Abstract. The paper presents a new solution allowing to substitute tie points by tie objects. The use of tie objects avoids problems being inevitable, when planar tie points are projected under oblique views into an image or when the view angles are differing strongly for different images. Spatial tie objects however, are visible from any viewing direction and allow a sure identification. Algorithms for an automatic detection and localisation of such spatial tie objects have been developed and will be presented here. The principal functionality will be shown and practical examples demonstrate the correctness of the conception.

Key words. Image orientation, image analysis, colour image data, spatial tie objects

1 Introduction

Within most photogrammetric applications several images are used for the determination of objects in order to get an acceptable accuracy (cf. fig.1). The images are usually tied together by a varying number of identical object points measured in the image space. In case of object points being marked by special signals, this measurement can be done automatically using computer algorithms. Mostly, these algorithms are designed to find special signals with a predefined and well known shape. These algorithms have to take into account, that the projective geometry of the imaging process introduces varying deformations onto the targets to be searched for. In spite of this modelling functionality, there are limits for the amount of deformations acceptable. The degree of deformation depends on the angle between target plane and image plane resulting in invisibility of a signal when the angle approaches 90 degree. Such object points are no longer usable, although the corresponding image rays would be of value for intersections with rays originating from other images. This diminishes the amount of connections between images and reduces the geometric stability of the whole image block. In dependence of the angle between the viewing directions of images this even might result in a failure of an orientation.

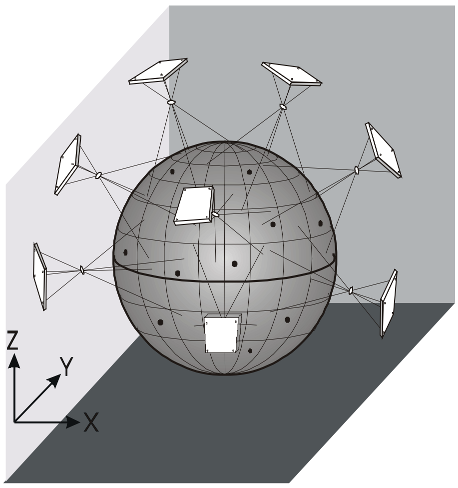


Fig. 1: Any 3D-object with images arranged around

All these problems will be are avoided, when the targets used are not of planar shape but have spatial shape. The presented solution shows a way how to use spatial targets for the connection of arbitrary arranged images. The conception is based on cubes, which are automatically detected within images by means of image analysis techniques. The principle of the solution will be shown, together with some first practical results.

2 Conventional solution

2.1 Technique

The determination of object co-ordinates and orientations is based on homologeous image rays, which are represented by their corresponding image points. In most cases, these are collected by means of algorithms, allowing to detect the imaged object points. These algorithms don't provide human interpreting intelligence, they simply identify predefined patterns within the images. The patterns are very simple, thus providing the robustness needed for practical applications (cf. Fig. 2).

Fig. 2: Sample pattern

Physically, they mostly consist of reflective foils being glued onto the object surface. Accordingly, they represent small planes stacking on the object surface.

2.2 Practical Aspects

Meanwhile metric digital camera systems (Leica, Imetric) are delivered with software packages providing tools for target detection and they are in permanent use in several industrial application fields (e.g. airplane or automobile industry).

However, two aspects have to be observed, possibly reducing the success of a project. They arise from the fact, that the algorithms are sensitive to brightness and contrast and to the geometry of the targets.

The radiometric problems are almost eliminated by use of flashlights. They significantly reduce the impact of background light and give the image contrast needed. Variations in the geometric appearance of targets, however, cannot be avoided, because of the different viewing directions of the images and the effect of the projective geometry within images.

2.3 Consequence

Although simple patterns are used for targets and, in addition, feature based algorithms are able to model geometric changes a certain number of targets will not be detected if the geometry varies too much.

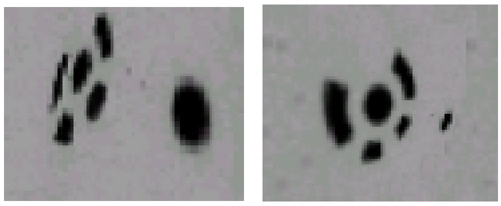


Fig. 3: Variations of geometry within planar targets

One therefore has to be conscious of a reduced number of links between the images of a block. This might not be a problem, if the absence of the connections would happen in the central part of images, where in general most of the images rays will be found. But in many cases the links are reduced in the outer parts of the images, where the value of a ray is high.

Correspondingly, targets not being found may end in a

- weakening of the geometry within the block
- problems with the establishment of a complete block
- higher effort for calculations

These problems can only be diminished by a higher effort in the preparation of the object with a greater number of signals and by use of more images. Both actions are cost sensitive and don't avoid, that images with a greater difference in the viewing direction will not be connected directly.

3 The new conception

3.1 Key problem

The problem exists, because of the planar shape of the signals and its interaction with the images and their projective geometry. There exists only one constellation without geometric deformations for a central perspective. That is, when image and object plane are parallel, or optical axis and surface normal are parallel, respectively. Accordingly, deformations rise with increasing angle (β) between optical axis and surface normal (cf. Fig.4). In addition to this deformation with respect to the original appearance of the object one has a second one, relating to the differences in the appearance of an object in two images. This one is a function of the angle between the two optical axes (α). Both angles may have large values within close range applications.

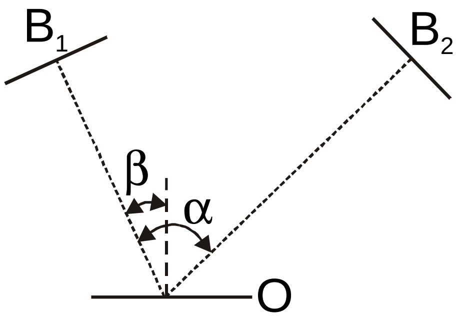


Fig. 4: Angular relationships

3.2 Idea

The angular relations as they exist to a target surface cannot be avoided, this is why increasing angles between images result in increasing deformations. But why not splitting the angles by means of multiple target surfaces (cf. fig. 5)? In case of feature based detection there is no direct comparison of target appearance in different image, wherefore it is not necessary to have comparable appearances for a targets. One simply has to assure, that the detection algorithm is able to identify different surfaces as they belong to the same target.

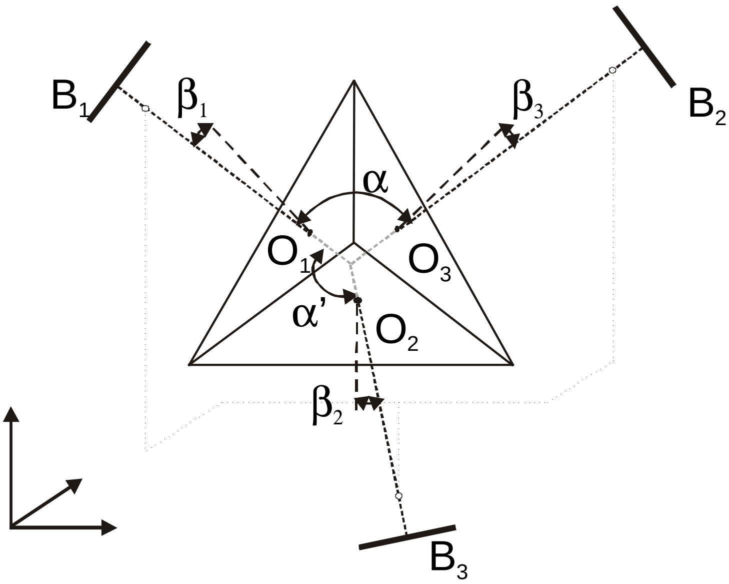


Fig. 5: Angular relationships for cubic signals

3.3 Advantages

The use of three dimensional signals with several tied surfaces has various advantages:

- multiple surfaces are useable
  As in case of the pyramid shown in fig.5 one has four surfaces (O_1, O_2, O_3, O_4) which are exposed to the images. Each of them serves as target surface, allowing to have at least one optimal angular constellation between image and target.

- smaller angle with respect to the best surface
  As each target surface has its own surface normal the angular difference between two optical axes is reduced by the angle between the surface normals. In case of Image 1 and 2 (B_1, B_2) the angular difference (α) is reduced to the sum of β_1 and β_2. This reduces the individual deformation of a target surface and improves the detection.

- allows completely new constellations

With increasing angular difference between images the risk of connection failures rises. In case of Image 1 and 3 (B_1, B_3), for example, a connection won't be possible using planar targets. Taking the pyramid shown, this would be easily achieved, what gives much more flexibility in the arrangement of images.

3.4 Requirements

The use of cubic tie objects results in some additional efforts having to be invested, because of their higher complexity compared to planar targets.

- multiple surfaces have to be detected
  As the whole tie object has to be known for the orientation procedure the algorithm has to detect all surfaces of the object, being projected into a particular image.
- each surfaces has to be uniquely identified
  Giving the freedom of connecting arbitrarily arranged images the images may observe completely different parts of the object. This has to be recognised, because otherwise wrong constellations would be assumed.
- The tie objects need to have a fix and known topology, which has to be observed and used, because they might be arbitrarily oriented within space. This has impact onto the sides presented to the different images and must be handled by the algorithm.

These are the most important elementary requirements having to be met, in order to achieve principal functioning. Some further aspects arise from the practical side and from the operational view, which will not be mentioned in detail here.

4 Aspects of Solution

4.1 Target

In principle, manifold spatial objects could serve as targets, they only need to have planar faces. From the practical side, however, an optimum has to be found with respect to the size of each individual side and the number of sides existing. The size is of importance for the process of detection, as each side has to be uniquely identified and the number of sides determines the amount of different angular relations to each image. As ideal object we therefore chose a cube (cf. fig. 6), because of its

- symmetry
- size of faces
- number of faces
- angular difference of adjacent faces

The later one allows to have angular relations between an image and the best face (β, cf. fig.5) of 45^o or better.

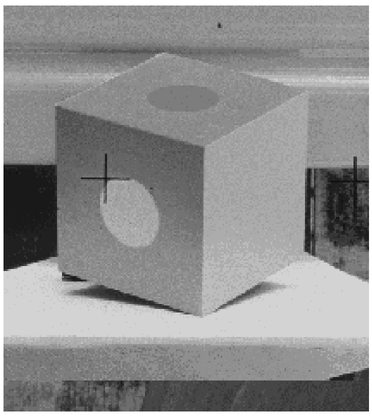


Fig. 6: sample cube

4.2 Mode of discrimination

As already mentioned, each face of the spatial target has to be unique. Uniqueness has to be sufficiently significant, so the algorithm can produce reliable results. This might be achieved by use of different textured faces. But a robust detection of a texture needs to have a sufficient large image area. Under practical conditions, however, this cannot be assured.

We therefore chose colour as coding information. The use of colour information is up to now not very common within metric applications and at the moment the majority of digital metric camera systems simply provides one b/w channel. But for the future the use of colour will not produce practical problems. The development goes on and the first metric colour cameras with high resolution sensors are already announced (e.g. Nikon D1).

In addition, a cube is a good object for a unique coding with colour. Its six sides give a good separation using the base and complementary colours (R,G,B,C,M,Y). In this way, the required uniqueness and amount of difference can be assured.

4.3 Cubic geometry

Finally, cubes offer further information useful within different stages of the algorithm. They have a simple geometry with the benefit that the edges are perpendicular to each other and represent all three axes of the space. This is of value for the calculations, because their shape can easily be modelled within 2D or 3D spaces and used for different purposes.

Another aspect of the spatial geometry comes from the fact, that size and shape are exactly known in advance. This is especially useful for all photogrammetric calculations, using the cubes as spatial reference objects, which provide an exactly known 3D co-ordinate system.

5 Method

5.1 In general

The overall procedure has three different steps, which are applied sequentially. First, all images of a block are individually analysed, looking for the occurrence of targets. This is the most important part of all steps, because it has to assure, that the targets distributed in the object space will be successfully detected.
The second part analyses the correspondence of the images and calculates first estimates for the orientation values and the object co-ordinates.
Finally, a conventional orientation procedure on the base of image bundles will be applied.

5.2 Image processing

Purpose of the image processing is the detection and location of coloured cubes within colour images. As criterion for a separation from other imaged details can be used the

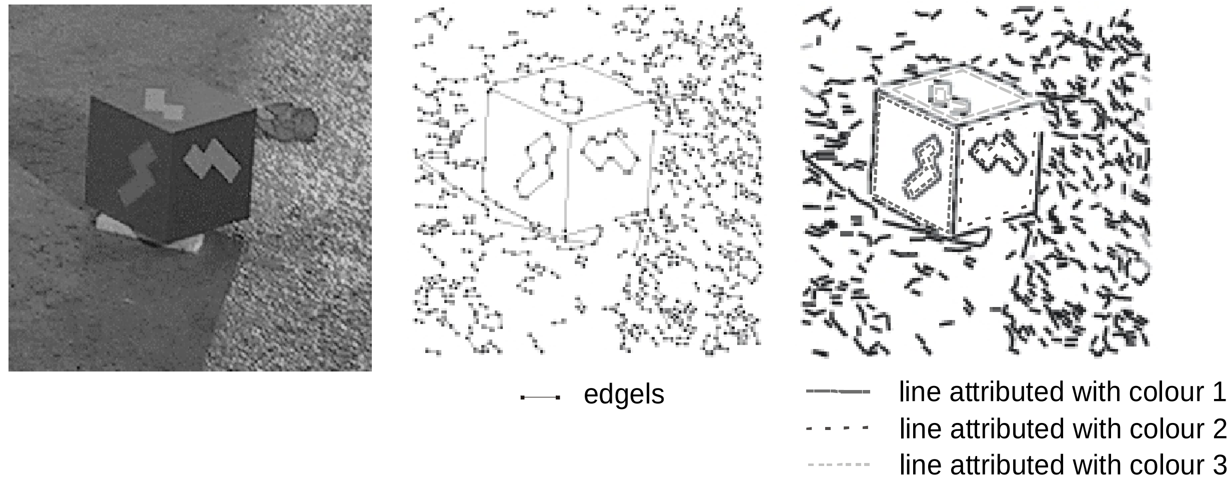
- colour value
- shape
- neighbourhood of colours

Intuitively one might choose a processing first looking for areas with a homogeneous colour distribution having values matching to the colour values corresponding to the target sides. However, a robust estimation of homogeneity needs a greater amount of pixels. As consequence, this might lead to overlook targets, when they appear a bit too small.

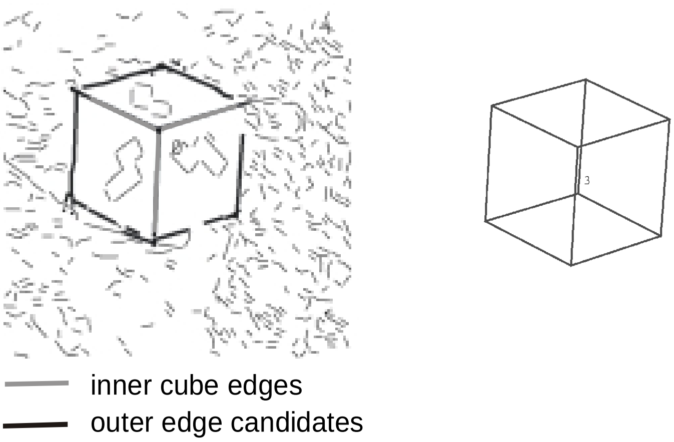
We therefore chose a strategy combining shape and colour information within the first search step. As specific shape component of cubes we use the existence of edges and their special geometric constellation. Accordingly, the processing starts with the detection of colour edges, continues with a check of their geometry, is followed by first assumptions about target candidates and will be terminated by final tests onto the exact shape.

An example with results of some of the processing steps is shown in fig. 7. The image part shown there has a size of about 80 by 80 pixel.

5.3 Correspondence analysis



part of original colour image line image accepted colour lines



cube hypothesis final cube object

Fig. 7: examples for results of processing steps

The image analysis produces a list of cube objects for each image, from which the correspondence of all images has to be derived. Each cubes comes with 8 image points and an ID if it was prepared as special tie object. Fig. 7 shows a cube with ID code.

The task of checking the correspondence between the images and their data sets is in principle identical to the general problem known from the literature. However, there are some simplifications existing, allowing to reduce the amount of calculations and to introduce some rigorous controls. They originate from the cubes themselves. Due to the fact, that all corner points are used, each cube object contributes 8 image points. These points can be treated as a group in two respects.

First, due to the unique and known topology of the faces, each point of a cube can be assigned a fix ID. For the correspondence analysis follows, that the search can be restricted to the comparison of whole cubes, because the points at each cube are fix. This reduces the amount of search steps due to less combinations possible. Second, the geometry of the cubes is well known. Accordingly one has the opportunity to rigorously control the hypotheses for stereo models, because the produced model geometry has exactly to correspond with the cube geometry. By this, systematic deformations will de detected immediately.

5.4 Triangulation

The triangulation is not a feature especially developed for this solution. There are existing several powerful software packages, being well-tried in the field of industrial or terrestrial applications, which can be used for the purpose of finding optimal results for the orientation values. At the moment, we have implemented an interface for CAP. An integrated solution will be prepared.

5.5 Practical Aspects

The example (cf. fig. 7) shows the general working of the new solution. But with respect to an operational use, some further considerations have to be made. It would be misleading to state, that the development has already reached the perfection of a human operator. The reliability of a human, who is able to detect such objects under any conditions with any kind of degradations cannot be achieved by an algorithm simply relying on a geometric and colourmetric image analysis. However, the actual results are already very encouraging, especially, when some practical aspects are observed:

Role of colour. Colour is inevitable for the actual processing structure. Especially colour is necessary for the discrimination of the targets from other objects. This discrimination has to be founded on the colour values of the target faces (R,G,B,C,M,Y) and their corresponding values within colour space. Unfortunately, a colour value registered within an image may considerably vary compared to the value directly measured at the face itself. There are countless influences onto the imaging process (direction, composition and intensity of illumination, sensor characteristics etc.) not being controllable. For proper practical working it is therefore necessary to check the colour distribution within the images and to assign appropriate boundary values for the colour intervals.

Size of targets. Colour has been chosen as optical characteristic for the faces, because it needs less image data to be identified compared to texture, for example. Nevertheless, targets have to be imaged with a certain area too. At the moment, the length of those edges belonging to the largest face should be longer than 10 pixel. Otherwise the influence of colour mixing would avoid a reliable detection.

Role of the spatial characteristic. The fact of having tie objects possessing a spatial structure opens up completely new possibilities. As already mentioned for the correspondence analysis, the known shape is useful for control purposes. But furthermore, these targets provide reference data for the final photogrammetric triangulation process. Every target contributes 4 precisely given distances in each direction of space. This allows to control and support the geometry of the whole image block, as this substantial information comes with each cube and is therefore scattered over the whole object space.

Role of corner points. Each cube has 8 corner points, which are located directly if imaged or calculated from the edges otherwise. Together with the corresponding edges, these points are representing a three dimensional co-ordinate system. This might be used in different ways:

- definition of a local co-ordinate system in a selected target without any other efforts for the preparation of the object
- calculation of orientations (relative, exterior) already with one target
- control of local image geometry by the proximity of the corner points
- high redundancy for each target, allowing to check the correctness of each individual corner point

Accuracy. An acceptable accuracy is a very important precondition for a practical use. Although further extensive tests still have to be conducted actual results are very encouraging. For example, a block of 2 * 8 images in two height levels circular arranged around an artificial object has been imaged using a conventional CCD-camera with 2000 * 1600 pixel. The new technique allowed with the used arrangement a connectivity of up to 10 images per target. Without any deep investigation into possible camera errors, a triangulation using 27 distances from cube edges ended up with a standard deviation for image co-ordinates of about 3 µm. For object points the standard deviations scattered around 3.5 mm, what is in correspondence with the image scale of about 1:1100. Considering the non optimal image quality due to degradations introduced by the image compression used in the camera and the fact of not having used a metric imaging system these results are satisfying.

6 Conclusion

The presented technique shows a way to improve the connectivity within image blocks by means of spatial tie objects instead of conventional tie points. It has been outlined, that the chosen way of detection works properly and allows an automated processing without manual measurements. Additionally, the spatial characteristic of the objects provides information which cannot be contributed by planar targets. As consequence this technique cannot only be used for an improvement of connectivity but could serve other aims too, like

- Combination of separated image blocks (inner and outer part of buildings)
- Use of targets as reference bodies
- Use of targets for orientations within a local co-ordinate system
- Simplification of triangulations.

Further operational tests will be carried out in the next future, what might allow to offer the corresponding software package (IMPACT) for practical use soon. Moreover, there is potential for additional developments like the direct use of the detected edges as measurements within the triangulation process, what stimulates further efforts.

7 References

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