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# Detection of spatial orientation objects for automatic orientation of arbitrary arranged metric images

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## Abstract

The paper presents a new solution for the automatic orientation of metric images using spatial 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 have been developed allowing to detect and localise such spatial tie objects automatically and will be presented here. The principal functionality will be shown and practical examples demonstrate the correctness of the conception.



## Key Words

Pattern recognition, image orientation, image analysis, colour image data, spatial tie objects


## 1. Introduction

Within most photogrammetric applications several images are necessary for the determination of objects in order to get an acceptable accuracy (cf. fig.1). The images have to be tied together by a varying number of identical object points measured in the image space. This measurement should be performed automatically.

Algorithms actually available work properly if only two images have to be tied together or if the object has been prepared with artificial signals. Those algorithms which are designed to find special signals must 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: A 3D-object to be surveyed by means of images

All these problems will be are avoided, when the targets used are not of planar shape but have spatial shape [1]. The presented solution shows a way how to use spatial targets for the connection of arbitrary arranged images and how to detect them by means of pattern recognition. The principle of the solution will be shown, together with some first practical results.

## 2. Identification of planar targets

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 simply identify predefined patterns within the images and don't provide human interpreting intelligence. The patterns have to be simple, thus providing the robustness needed for practical applications (cf. Fig. 2).

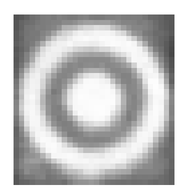


Fig. 2: Simple pattern

Physically, they mostly consist of reflective foils being glued onto the object surface. Accordingly, they represent small planes stacking on the object surface. Most 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) [2].

However, radiometric and geometric degradations exist in the images, possibly reducing the success of the algorithms

The radiometric problems are managed using flashlights. They significantly reduce the impact of background light and provide the S/N ratio needed. Variations in the geometric appearance of targets, however, cannot be reduced, because of the different viewing directions of the images and the effect of the projective geometry within images.

Fig. 3: Impact on geometry due to small change of view

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.

One therefore has to be conscious of a reduced number of links between the images of a block. This might not be a problem for non-metric applications. If accuracy plays an important role, the number of links has to be maximal and the loss of connections has to be kept minimal. Furthermore, the loss occurs often within 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. Use of spatial objects

## 3.1. Impact of viewing direction

The planar shape of the signals and the projective geometry of images results in more or less strong deformations. 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 ($\beta$) 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 ($\alpha$). Both angles may have large values within close range applications.

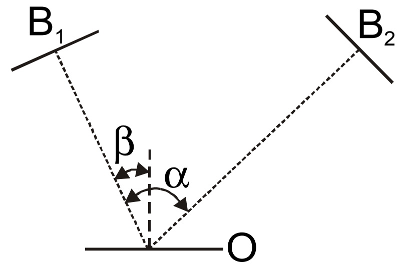



Fig. 4: Angular relationships

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, why 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.

## 3.2. View onto spatial objects

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

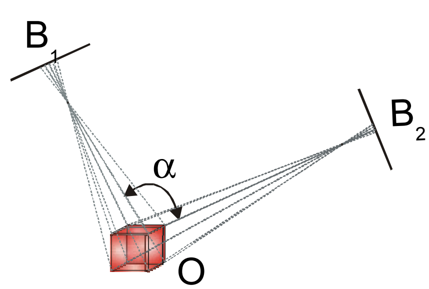



Fig. 5: Angular relationships for cubic signals

  ($\alpha$) is reduced to the sum of $\beta_1$ and $\beta_2$. 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.

## 3.3. Effort for detection

The use of cubic tie objects needs to take some additional aspects into account, 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 ist

- 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 ($\beta$, cf. fig.5) of $45^o$ or better.

## 4.2. Distinction of different faces

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 available.

Fig. 6: sample cubes

In addition, a cube is very suitable 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. Spatial 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. Processing

## 5.1. Related work

In literature manifold algorithms can be found dedicated to the detection of objects. They can be distinguished by the type of information and by the way of modelling used for the discrimination of objects and background. Many use linear features, provided by means of edge detection [3], some use texture, other use colour [4] or a combination of these features [5]. However, they are all far away from the robustness and efficiency of a human interpreter. So, in general, there are always some constraints existing, limiting the variability of the problem to be solved. On the other hand, the solutions show, that the success rate will increase, when the distinctness of the information used can be expanded. This can be achieved by combination of different characteristics within data.

## 5.2. Procedural steps

Correspondingly there are different elements used, characterising the appearance of the spatial tie objects, as colour, edges and a combination of both. Therefore 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.

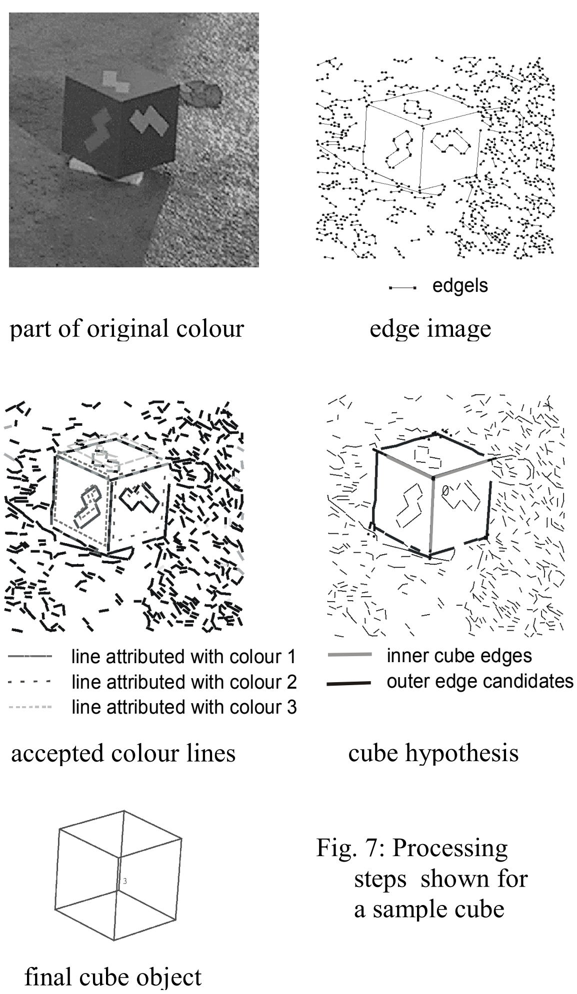



Fig. 7: Processing steps shown for a sample cube

Finally, a conventional orientation procedure on the base of image bundles will be applied.

## 5.3. 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.

## 5.4. Correspondence analysis

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.

## 5.5. 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.

## 5.6. Practical Aspects

Fig. 8 shows the processing results for two images with perpendicular viewing directions. As can be seen, the two images don't have much surface components in common. Simply some floor regions next to the block are represented in both images and would have to be used for the orientation with planar elements. As these parts are covering only a small part of each image the orientation would be poor or impossible.

This is not the case for the orientation based on the cubes scattered on the floor and the top of the block. Not all of them have been correctly identified, but the major part has been detected and assures the orientation of these images. The results are satisfying, because each cube contributes with 8 image rays – one to each corner – thus allowing to get already an orientation, when just one cube in common has been detected.

However, it would be misleading to state, that success rate and robustness have 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:

- 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.

- 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.

- 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.

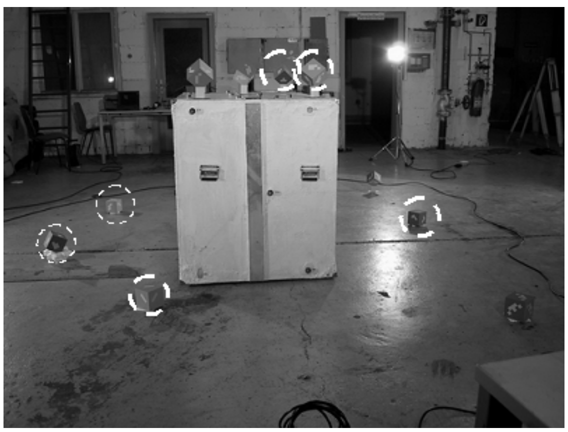
- Each cube has 8 corner points, which are located directly if imaged or calculated from the edges otherwise. Together with the corresponding edges, these points are representing a three dimensional co-ordinate system. This might be used in different ways:
  - definition of a local co-ordinate system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

- 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.



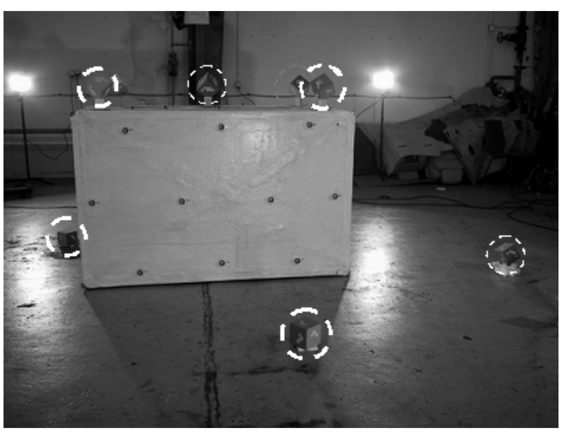


Fig. 8: images with perpendicular viewing directions and detected tie objects

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.

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