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Performance and state-of-the-art of digital stereo processing

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ABSTRACT

This paper presents the state-of-the-art of digital stereo processing. The different subtasks of digital photogrammetry are addressed and compared to those of analytical photogrammetry. While the tasks essentially remain the same, the employed methods vary considerably. Whereas in analytical photogrammetry the human operator must capture all the data manually, in the digital domain he becomes more and more a supervisor of a semi-automatic identification and measurement process. The possibilities of automation are illustrated using examples from automatic relative orientation and DTM generation.

Automating the whole process of extracting 3D information from digital imagery is not possible in the foreseeable future. Therefore, processing needs to be implemented in an interactive environment such as a digital photogrammetric workstation (DPWS). Several DPWS are already available on the market. While they were at first only seen as an extrapolation of the analytical plotter using digital imagery, the achieved degree of automation is slowly increasing. The full potential of DPWS is, however, not reached yet, and therefore, the rapid development in this area is assumed to continue within the next years.

1. INTRODUCTION

Digital or softcopy photogrammetry is an information technology to derive geometric, radiometric, and semantic information of objects in the 3D world from 2D digital images of these objects. It has become a major focus of research in the last decade, although first activities date back nearly 40 years (Rosenberg 1955). A number of reasons can be stated for this increasing interest. The most important ones are probably that digital imagery has become available on a routine basis since the seventies, that due to revolutionary progress in computer science the possibility to process these data has become reality, and that digital imagery offers the potential for automatic processing.

Traditionally the main task of photogrammetry as a whole always was creation and updating of topographic information. Stereo processing has been employed for this task for a long time, since it offers the best results in terms of accuracy and completeness. With the advent of digital photogrammetry the need of such information has of course not changed. What has changed and will continue to change are the methods used to process the imagery. Whereas in analytical photogrammetry the human operator must capture all the data manually, in the digital domain he becomes more and more a supervisor of a semi-automatic identification and measurement process. Also the results are stored in data bases of Geo-Information Systems (GIS) rather than in analog form on paper or film.

In this paper the present situation in digital photogrammetric stereo processing for topographic applications is described. After a presentation of the different subtasks two examples illustrate the possibilities of automation. They deal with relative orientation and DTM generation. Some conclusions are given in the last chapter.

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2. PHOTOGRAMMETRIC PROCESSING OF STEREO IMAGERY AND ITS POTENTIAL FOR AUTOMATION

2.1 Analytical stereo processing

In order to set the scene for the digital domain first the analytical photogrammetric processing chain is briefly addressed. For two images the following list shows the necessary subtasks. (Note that the numerical calculations have long been carried out automatically and are listed for the sakes of completeness only. They will not be considered any further in this paper.)

- selection of ground control points (GCP) in the area to be mapped, visible in the images and geometrically well distributed,
- measurement of photo carrier coordinates of the fiducials in order to establish a relationship between photo carrier and image coordinates, and calculation of the related parameters (often called interior orientation, although the parameters of interior orientation are not computed here),
- selection and image coordinate measurement of geometrically well distributed tie points and calculation of parameters of relative orientation,
- identification and image coordinate measurement of GCP and calculation of parameters of absolute orientation,
- data acquisition for and generation of digital terrain models (DTM),
- orthoprojection,
- vector data acquisition.

In most applications the area to be mapped extends beyond the coverage of only two images. Therefore, aerotriangulation with some additional subtasks comes into play:

- selection of images to be used from a given photo flight,
- point transfer and marking of GCP and tie points in the different images,
- bundle adjustment to compute the parameters of exterior orientation.

2.2 Digital stereo processing

In the digital domain there exist a number of technical advantages over analytical processing (Grün 1989; Dowman 1990; 1991; Helava 1991; Leberl 1992). Moreover substantial subtasks of the given list can be automated. Automation can take the form of completely automatic batch processes or semi-automatic interactive processes. The benefits of automation are results which are not biased by the human operator, faster turn-around times, and thus, more cost-effective solutions. We will next take a closer look at the different subtasks and discuss where automation is possible (see also Heipke, Kornus 1991).

First of all some preprocessing subtasks must be added to the list:

- scanning of the images, if they are only available in analogue form (this is and will continue to be the case for aerial imagery for the time being),
- radiometric calibration including elimination of possible sensor errors (this step is necessary for images acquired directly in digital format only, since otherwise radiometric calibration can be combined with scanning),

- image compression (and decompression prior to processing) in order to reduce the large amount of data (care has to be taken to minimize geometric and radiometric errors, if lossy image compression is used).

2.2.1 Completely automatic processing

From today's perspective automatic batch processes which can be applied in practical working conditions, can only be designed for subtasks not involving semantic information (semantic information is needed eg for the identification of a GCP, or of an extracted linear structure as being a state highway). Thus, batch processes are possible for image preprocessing, interior and relative orientation, DTM data acquisition, orthoprojection, and point transfer. These processes rely either on radiometric and geometric image processing transformations or on digital image matching. In the next chapter two examples involving digital image matching (automatic relative orientation and DTM data acquisition) are treated in more detail.

Digital image matching is subject to blunders, especially in areas of low or repetitive texture. Additional problems can occur in large scale imagery due to occlusions, height discontinuities in built-up areas or forests. Thus, a verification step is required after the batch process. While it is desirable and in some cases also feasible to add a self diagnosis module to the matching algorithm, the verification step normally needs to be carried out by the human operator. This step will be examined for DTM generation in more detail as an example.

Manual pointwise quality control can be performed, if the cursor is locked onto the derived DTM, while the operator inspects the images stereoscopically. If available, a colour coded index of the matching quality (figure of merit), superimposed onto the imagery, gives clues for detecting areas of matching success and failure. The DTM grid or contours derived from the DTM can also be superimposed onto the images in stereo. At the request of the operator orthoimage stereo mates can be generated (locally and in near real time) to give an even better impression of the quality of the results. Using these stereo mates a difference image can be calculated or simple correlation measures derived to identify problematic areas.

2.2.2 Semi-automatic processing

It is of course not only necessary to identify but also to correct areas of bad matching. Here semi-automatic processes come into play. Again the example of DTM generation is used. After selecting points, profiles or areas to be corrected manually, the operator can provide a Z coordinate close to the actual terrain, and then the system generates a new result. This result in turn is visualized, verified and corrected if necessary. If enough computer power is available, it is even feasible to implement pointwise interactive real-time matching. In this case, while the operator moves the measuring mark, it always sits on the terrain and a Z coordinate is automatically and instantaneously provided for every XY position.

Another example of semi-automatic processes is the measurement of the image coordinates of a point with given coordinates in one image. This procedure can be applied when measuring image coordinates of GCP. In one image the exact position is provided by the operator, the image coordinates of the point in the other image(s) are found automatically.

Semi-automatic processes are also used in vector data acquisition. The operator can provide attributes for the desired feature along with an initial position or shape, the system then suggests the exact location of the feature. Road following algorithms have been designed along these lines (Quam, Strat 1991); the use of snakes for the extraction of house contours is another example (Kaas et al. 1987; Gülch 1989). The suggestions are verified and further processed by the human operator.

The selection of images, GCP and tie points for aerotriangulation can also be turned into a semi-automatic process. Approximate overlapping areas can be computed by image matching from coarse resolution images generated from original ones. The GCP can be transformed into image space using approximate exterior orientation parameters available from the photo flight. From this information the system can then suggest the photos, the GCP, and the position of the tie points to be used.

More advanced techniques of object detection, localisation, recognition and reconstruction are currently under investigation at numerous research institutes within photogrammetry and in other areas like computer vision (eg Huertas, Nevatia 1988; Venkateswar, Chellappa 1990; Förstner1991; McKeown 1991; Strat, Fischler 1991; Gülch 1992; Haala, Vosselman 1992; Price, Huertas 1992; Sester 1992). The approaches have in common that models of the desired objects must be constructed and compared to extracted image features. Therefore, they can be regarded as general matching approaches, in which one representation of the object is compared to another one. The differences between the two representations are then minimised using various optimisation techniques. In special cases like the reconstruction of the exterior orientation parameters from 3D location and size information of houses (Schickler 1992) practical use has been demonstrated. In general the results are encouraging, but still need to be robustified in order to be applicable to a wide variety of images.

3. EXAMPLES FOR AUTOMATION IN DIGITAL STEREO PROCESSING

In this chapter two examples from ongoing research work are presented in order to illustrate in more detail the possibilities of automation in digital stereo processing reached today. Both examples are based on digital image matching. Semi-automatic processing as outlined in the previous chapter is not dealt with in the examples.

Two black-and-white images from the Lohja area in Finland forming a stereopair were used. The scale of the images was approximately 1:15.000 and the flying height 3.200 m above the terrain. The images were scanned using the Zeiss Photoscan PS1 with 8 bit and 15 μm (approximately 22 cm in object space) per pixel. The stereomodel covered an agricultural area, with some forest and houses (see figure 1). The surface was mostly smooth with some breaklines. There were height differences of about 50 m in the terrain.

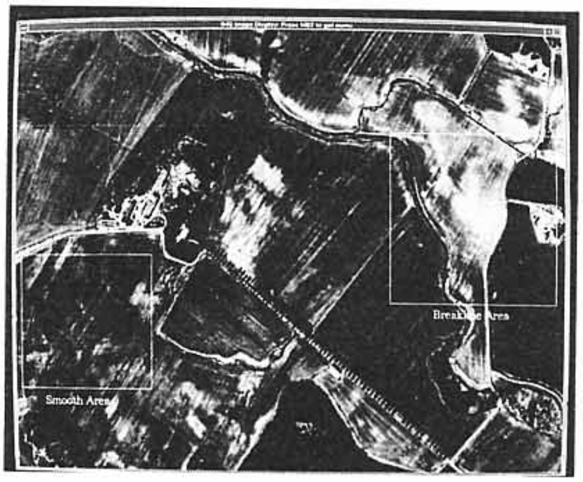

Figure 1: The model area of the images used for the examples.
(for the meaning of smooth and breakline area see chapter 3.2)

3.1 Relative orientation

The first example deals with the automatic extraction of the parameters of relative orientation of two aerial images. This topic has been dealt with by various authors in the past and a number of working solutions are available (eg Schenk et al. 1991; Haala et al. 1993). This subtask is especially suited for automation, because a very small number of parameters, namely 5, need to be computed and a large amount of input data is available, namely about 235 Mega Bytes per aerial image (assuming a pixel size of 15 μm). Instead of only using a limited number of conjugate points with coordinates known to a few μm as in analytical photogrammetry (usually 6 to 8 points), it is possible to use a large number of conjugate points with less accurate coordinates, and still obtain the same accuracy level and in addition a much better confidence level for the results. Thus, it is not necessary to try to reach the very limit of accuracy potential of image matching, and a larger number of false matches can be tolerated.

Our approach is only briefly described in the following and only preliminary results are given. More details can be found in (Tang, Heipke 1993). We assume the following information to be given:

- two overlapping aerial images in digital format,
- approximate values for the amount of overlap, and the relative differences in scale and rotation of the two images,
- interior orientation parameters and the relationship between pixel and image coordinates.

We use a hierarchical feature based matching approach. From the original resolution the following levels of the image pyramid are computed using a weighted 3x3 average filter and subsequently reducing the number of pixels by a factor of 2 in each coordinate direction. In every level the following algorithms are employed:

- Extract point features separately in each of the images using the Förstner operator (Förstner 1986). Non maximum suppression is achieved by only retaining the best feature of each cell of a predefined grid in image space.
- Set up a preliminary list of candidates of conjugate points. This is done by establishing a transformation between the left and the right image. The parameters of this transformation are derived from the results of the previous level. In the uppermost pyramid level a 2D Helmert transformation with parameters derived from the approximate values for overlap, scale, and rotation is used.

  Next each feature of the left image is transformed into the right image. The resulting point is called the predicted position, and the neighbourhood is searched for features. If features are found, the resulting pair is considered a candidate pair of conjugate points. According to the values of the interest operator and the distance between the predicted and the actual position of the feature in the right image a weight is assigned to the pair. More details on setting up this preliminary list can be found in Holm (1992).
- Calculate the correlation coefficient of the windows surrounding the candidate pairs. A threshold is used to eliminate probable mismatches.
- Calculate the parameters of relative orientation using robust least squares estimation (Klein, Förstner 1984; Strunz 1993).
- Improve the accuracy of the results using least squares matching (Förstner 1982) in the bottom level of the pyramid if necessary.

Using this approach the parameters of relative orientation of the described stereo pair were computed. The levels 5 to 0 of the image pyramid were processed. Only points with a cross correlation coefficient larger than 0.8 were used, least squares matching was not employed.
The results are presented in table 1. For each pyramid level the number of pixels for the images, the corresponding pixel size, the number of extracted features per image, and the y-parallax p_y in μm and in pixel units are given.

Pyramid level	**No. of pixels per image**	**Pixel size [μm]**	**No. of extracted features per image**	**y -parallax p_y**	
				[μm]	[pixel]
5	480^2	480	2220	40.7	0.08
4	960^2	240	3744	64.5	0.27
3	1920^2	120	3600	27.3	0.23
2	3840^2	60	5400	15.8	0.26
1	7680^2	30	5370	8.7	0.29
0	15360^2	15	5400	4.6	0.31

Table 1: Results of automatic relative orientation.

During the matching a large amount of candidate feature pairs was eliminated. The number of retained pairs, however, is still larger than in analytical photogrammetry. With the exception of pyramid level 5 the y-parallax p_y remains nearly constant in pixel units and thus decreases continuously when expressed in μm. The final value of 0.31 pixels and 4.6 μm fulfils the accuracy expectations generally contributed to feature based matching. Thus, it seems that least squares matching does not need to be employed.

3.2 DTM data acquisition in object space

In the second example a part of the earth surface in the form of a digital terrain model is automatically computed. This task has great relevance for practical applications, since the manual measurement of DTM data is a very time consuming process. Automation has been attempted for nearly 3 decades (see Sharp et al. 1965 for early work) and today operational solutions exist for medium and small scale imagery (eg Ackermann, Krzystek 1991).
Since a few years much attention has been paid to automatic DTM generation formulated in object space (see Ebner et al. 1987; Wrobel 1987; Helava 1988 for the first publications of the model). In this way another advantage of the digital domain can be exploited, namely the simultaneous processing of more than two images, which increases the robustness of the approach with respect to occlusions and disturbances in image space (scratches, spot lights, etc.). Furthermore this approach constitutes a general model within digital photogrammetry, incorporating image matching, point determination, DTM generation, and orthoprojection.
In digital image matching in object space, essentially an orthoimage is computed from every available input image using approximate values for the DTM grid and the exterior orientation parameters. The grid heights and the orientation parameters are then iteratively improved in a least squares adjustment by minimising the differences of the orthoimages. The approach has been presented in detail a number of times before. Therefore, it seems sufficient to refer the interested reader to available literature (eg Heipke 1990; 1992; Schneider 1991; Weisensee 1992) and to continue with an example in order to illustrate the approach. The example is drawn from Ebner et

al. (1993). It constitutes the first controlled practical test for digital image matching in object space, and thus proves its applicability for automatic DTM generation.

For two test areas reference DTMs with a 10 m mesh size were measured manually in the stereomodel on a Zeiss Planicomp P1 analytical plotter, first one 240 m * 240 m wide, the second one 320 m * 320 m. The areas were measured twice, the mean values of the two measurements were then used as reference. The standard deviations of the two reference DTMs were 0.22 and 0.16 m.

The first test area showed agricultural use and rich texture. The heights varied smoothly from 22 to 32 m, breaklines were not present. The texture was, however, partly repetitive. It is labelled "smooth area" in the following. The corresponding size in the original images was about 1200 x 1200 pixels. The second test area was hilly and rich in texture with two creeks and a road as breaklines. The heights of this area varied from 5 to 27 m. This area is called "breakline area". It covered about 1520 x 1520 pixels in the original images. Both areas can be seen in figure 1.

As in the previous example image pyramids were used in order to enlarge the convergence radius. The hierarchical structure was also applied to the DTM. Matching was started at the fourth pyramid level, with a horizontal plane at about the average height of the terrain as initial value for the DTM. The exterior orientation parameters used were those from the reference measurement. They were introduced as constant values. The DTM derived at one pyramid level was subsequently used as the initial DTM at the next lower level and so forth.

The results can be seen in figure 2 and 3. For the smooth area the standard deviation of the differences between the derived and the manually measured reference DTM was computed to 0.33 m. The computed standard deviation did not change between the last two pyramid levels. Therefore, the results for the breakline test area were only computed down to the last but one level. A standard deviation of 0.37 m was obtained. These values must be compared to the accuracy of the reference DTM (0.22 and 0.16 m) and to 0.01 % of the flying height, namely 0.32 m, which is generally accepted as the accuracy limit for manual photogrammetric height measurement.

The maximum error occurred near one of the breaklines (see also figure 3) and amounted to 2.4 m. This was not surprising, because the grid data structure of the DTM is not optimal if breaklines are present. They can, however, be extracted, if the resulting orthoimages are analyzed. Figure 4 shows the left and the right orthoimage and in the middle the difference between the two. The breaklines are clearly visible and can be extracted using low level image processing techniques. They can subsequently be introduced into the DTM data structure in order to improve the results. Current work is directed in this direction.

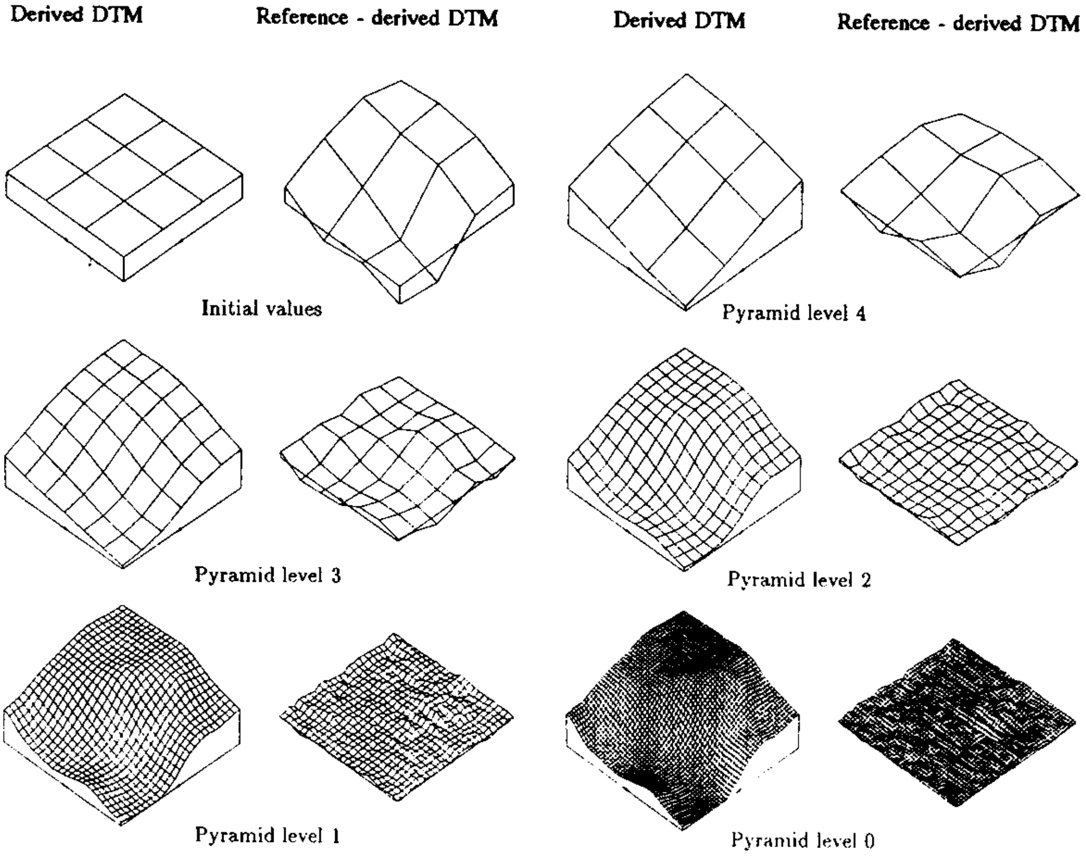

Figure 2: Results of DTM generation in the smooth area.
(pyramid levels 4 to 0)

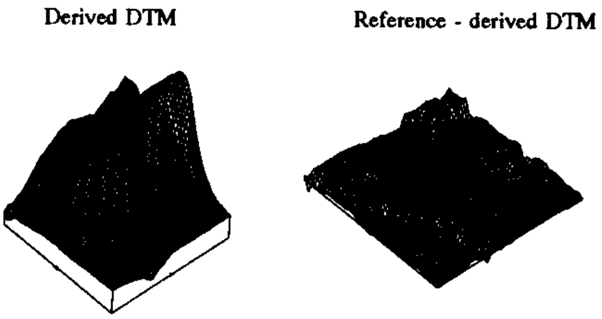

Figure 3: Results of DTM generation in the breakline area.
(pyramid level 1 only)

4. CONCLUSIONS

In this paper the general work flow of digital photogrammetric stereo processing for topographic applications has been presented. It has been shown that it is rather similar to the work flow developed in analytical photogrammetry. In the opinion of the author this is a prerequisite for digital photogrammetry to be successful in practice, because only under these circumstances is it possible for an organisation involved in photogrammetry to incrementally upgrade existing hard- and software and to introduce this new technique.

New products such as (digital) orthoimages and fully orientated stereo imagery resampled to epipolar geometry (Sarjakoski 1990) are available in addition to products offered so far: 3D point

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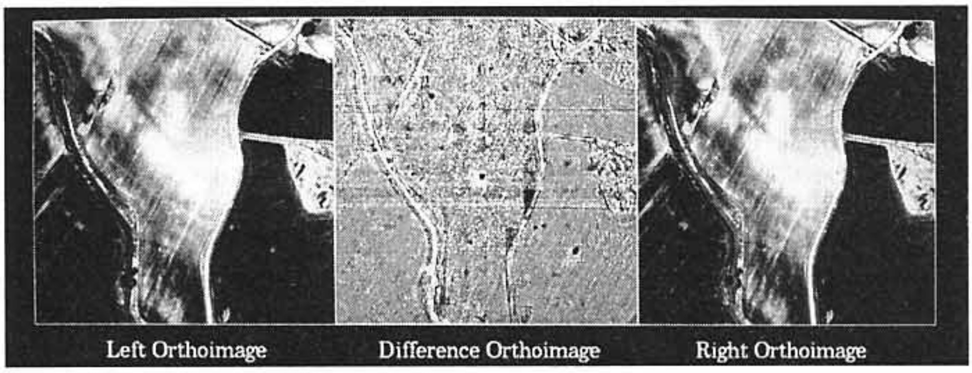

Figure 4: Computed orthoimages, which can be used to automatically detect breaklines.

coordinates, DTM including follow up products, vector data, and (analogue) orthophotos. The orthoimages are increasingly incorporated into GIS and can also be used to derive and update vector data information in mono, if the accuracy demands are not as high as in topographic mapping. Stereo imagery resampled to epipolar geometry allows the image interpretation specialists from fields outside photogrammetry to have access to accurate 3D information without having to cope with the often unfamiliar and thus, complicated orientation process.

Automation of parts of the photogrammetric processing chain has made substantial progress in the last years. Two examples for this development are given in this paper. However, automating the whole process is not possible in the foreseeable future. Therefore, the whole process must be implemented in an interactive environment such as a DPWS. Such DPWS are already available on the market and are slowly being introduced into large government organisation (for a survey see Heipke 1993). At first they were only conceived as an extrapolation of the analytical plotter using digital imagery. In the meantime some automation eg for DTM generation has been introduced into DPWS. Other tasks such as automatic interior and relative orientation are starting to be available. In order for the DPWS to be more successful also solutions for more practical problems must be offered, eg an increase in data transfer rates, a means for handling and archiving a very large amount of data (in the order of 100 Giga Bytes for one photogrammetric block). Also a multiwindow environment offering faster image display, online image roam, zoom, and rotation, and any desired number of mono and stereo windows needs to be developed. These requirements put high demands on the available hardware. The hardware in turn, should not play an essential role in DPWS development, because it changes too quickly. Thus, it seems save to predict that DPWS will continue to be an important issue for research and development in digital photogrammetry in the years to come.

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6. REFERENCES

DPS '91	Ebner H., Fritsch D., Heipke C. (Eds.), Digital Photogrammetric Systems, Wichmann, Karlsruhe
IntArchPhRS	International Archives of Photogrammetry and Remote Sensing
PE&RS	Photogrammetric Engineering and Remote Sensing

Ackermann F., Krzystek P., 1991: MATCH-T: Automatic mensuration of digital elevation models, Proceedings, "Sistemas Fotogramétr. Analíticos Dig.: Una nueva generación emergente", Soc. Esp. de Cart., Fotogram. y Teledetección, Barcelona, 67-74.

Dowman I., 1990: Progress and potential of digital photogrammetric workstations, IntArchPhRS (28) 2, 239-246.

Dowman I., 1991: Design of digital photogrammetric workstations, DPS '91, 28-38.

Ebner H., Fritsch D., Gillessen W., Heipke C., 1987: Integration von Bildzuordnung und Objektrekonstruktion innerhalb der digitalen Photogrammetrie, BuL (55) 5, 194-203.

Ebner H., Heipke C., Holm M., 1993: Global image matching and surface reconstruction in object space using aerial images, SPIE (1944).

Förstner W., 1982: On the geometric precision of digital correlation, IntArchPhRS (24) 3, 176-189.

Förstner W., 1986: A feature based correspondence algorithm for image matching, IntArchPhRS (26) 3/3, 150-166.

Förstner W., 1991: Concepts and algorithms for digital photogrammetric systems, ZPF (59) 5, 140-151.

Grün A., 1989: Digital photogrammetric processing systems: current status and prospects, PE&RS (55) 5, 581-586.

Gülch E., 1989: Active contour models for semi-automatic extraction of features in digital images, Schriftenreihe Institut für Photogrammetrie, Universität Stuttgart 14, 55-68.

Gülch E., 1992: A knowledge based approach to reconstruct buildings in digital aerial imagery, IntArchPhRS (29) B3, 410-417.

Haala B., Hahn M., Schmidt D., 1993: Quality and performance analysis of automatic relative orientation, SPIE (1944).

Haala N., Vosselman G., 1992: Recognition of road and river patterns by relational matching, IntArchPhRS (29) B3, 969-975; German version in ZPF (60) 6, 170-176.

Heipke C., 1990: Integration von digitaler Bildzuordnung, Punktbestimmung, Oberflächenrekonstruktion und Orthoprojektion in der digitalen Photogrammetrie, DGK-C 366.

Heipke C., 1992: A global approach for least squares image matching and surface reconstruction in object space, PE&RS (58) 3, 317-323.

Heipke C., 1993: State-of-the-art of digital photogrammetric workstations for topographic applications, SPIE (1944).

Heipke C., Kornus W., 1991: Nonsemantic photogrammetric processing of digital imagery - the example of SPOT stereo scenes, DPS '91, 86-102.

Helava U.V., 1988: Object-space least-squares correlation, PE&RS (54) 6, 711-714.

Helava U.V., 1991: Prospects in digital photogrammetry, The photogrammetric journal of Finland (12) 2, 57-64.

Holm M., 1992: Automatic rectification of satellite images into a GIS, 4th Scandinavian Research Conference on GIS, Helsinki University of Technology, 255-269.

Huertas A, Nevatia R., 1988: Detecting buildings in aerial images, Computer Vision, Graphics and Image Processing (41), 131-152.

Kaas M., Witkin A., Terzopoulos D., 1987: Snakes: Active contour models, International Journal of Computer Vision (1) 4, 321-331.

Klein H., Förstner W., 1984: Realization of automatic gross error detection in the block adjustment program PAT-M43 using robust estimation, IntArchPhRS (25) 3, 234-241.

Leberl F., 1992: Design alternatives for digital photogrammetric systems, IntArchPhRS (29) B2, 384-389.

McKeown D.M., 1991: Information fusion in cartographic feature extraction from aerial imagery, DPS '91, 103-110.

Price K, Huertas A., 1992: Using perceptual grouping to detect objects in aerial scenes, IntArchPhRS (29) B3, 842-855.

Quam L.H., Strat T.M., 1991: SRI image understanding research in cartographic feature extraction, DPS '91, 111-122.

Rosenberg P., 1955: Information theory and electronic photogrammetry, PE&RS (21) 4, 543-555.

Sarjakoski T., 1990: Digital stereo imagery - a map product in the future?, IntArchPhRS (28) 4, 200-210.

Schenk T., Li J.C., Toth C., 1991: Towards an autonomous system for orienting digital stereopairs, PE&RS (57) 8, 1057-1064.

Schickler W., 1992: Feature matching for outer orientation of single images using 3-D wireframe controlpoints, IntArchPhRS (29) B3, 591-598.

Schneider C.-T., 1991: Objektgestützte Mehrbildzuordnung, DGK-C 375.

Sester M., 1992: Automatic model acquisition by learning, IntArchPhRS (29) B3, 856-863.

Sharp J.V., Christensen R.L., Gilman W.L., Schulman F.D., 1965: Automatic map compilation using digital techniques, PE&RS (31) 3, 223-239.

Strat T.M., Fischler M.A., 1991: Context-based vision, IEEE Transactions on Pattern Recognition and Machine Intelligence (13) 10, 1050-1059.

Strunz G., 1993: Automatische relative Orientierung - Berechnug der Orientierungsparameter, Internal Report, Chair for Photogrammetry and Remote Sensing, Technical University Munich.

Tang L., Heipke C., 1993: An approach for automatic relative orientation, Second conference on Optical 3-D Measurement Techniques, ETH Zürich, October '93, in preparation.

Venkateswar V., Chellappa R., 1990: A framework for interpretation of aerial images, IEEE, 10th International Conference on Pattern Recognition 1, 204-206.

Weisensee M., 1992: Modelle und Algorithmen für das Facetten-Stereosehen, DGK C 374.

Wrobel B., 1987: Digitale Bildzuordnung durch Facetten mit Hilfe von Objektraummodellen, BuL (55) 3, 93-101.