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METHODS AND POSSIBILITIES OF DIGITAL IMAGE PROCESSING FOR APPLICATION IN PHOTOGRAMMETRY

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1. Introduction

1.1 Historical Roots: Digital processing of images has several historical roots: artifical intelligence with robot vision systems, medical imaging, processing of telemetered space images. A broader breakthrough was stimulated with space remote sensing since 1972 since it led to a wide availability of digital data and to acceptance of the new technology.

1.2 Classical Photogrammetry: In classical (metric-camera) photogrammetry or photogrammetry proper, the methods of digital image processing were first applied to stereo correlation (Correlation-Papers, 1983). Current work extends, however, to orthophotogeneration, digital cameras and entirely new concepts of image analysis to be described as "automated photo-interpretation" (McKeown, 1983).

1.3 Photogrammetry and Remote Sensing: Generally any discussion of image processing in photogrammetry centers around remote sensing and satellite data. However, this paper should stress photogrammetry in the classical sense dealing with metric photographs and geometric image analysis. It does not concentrate on non-topographic remote sensing images, nor does it address imaging techniques in medicine or industrial quality control.

1.4 Topographic Applications: One topic is to review the role of digital image processing in the context of topographic applications of photogrammetry. This will be achieved by a discussion of available processing techniques and development trends, applications to single images and to stereo pairs, and by an outlook to expected future techniques of image analysis.

1.5 Metric vs other Imaging Techniques; Geometric vs Thematic Processing: Although it is of course perfectly legitimate to discuss only one aspect of image processing, it does not seem meaningful to many workers in the field, including this author, to continue to sharply separate between metric camera photogrammetry and other imaging methods in remote sensing, industry and medicine, or to think of geometric and thematic (?) processing as of two different areas. Such differences are rapidly loosing their significance.

2. On Methods of Digital Image Processing

2.1 Classification Scheme of Goetz et al.(1975): Various classification schemes exist to describe image processing methods. Goetz et al.(1975) use the following:

- rectification - elimination of systematic errors of geometry and radiometry;
- cosmetics - elimination of random noise;
- analysis - information extraction;
- display .

2.2 Classification Scheme of Pratt (1978): Pratt (1978) uses another typical grouping:

- restoration - to create an image with defects removed;
- enhancement - to prepare an image for analysis to bring out specific features;
- analysis;
- coding - a concept that includes display.

Photogrammetrische Woche 1983
Institut für Photogrammetrie
Schriftenreihe, Heft 9, 1984

2.3 Classification according to Algorithms: Kazmierczak (1980) differentiates according to algorithmic concepts, such as pixel-oriented local versus global processing methods, linear and non-linear transformations, change detection, object tracking in image sequences, multispectral analysis, texture analysis, line-following, edge and contour finding etc.

2.4 Types of Image Analysis Methods: Within image analysis it is common to differentiate between a statistical and a syntactic or structural approach (see e.g. Fu, 1974). The former typically refers to the widely discussed classification of feature vectors. The latter relates to the sequential and cascaded use of context, strategy and a-priori knowledge.

2.5 Processing for Interpretation: Image interpreters tend to see two broad categories (Anuta, 1977):

- preprocessing for subsequent visual or automated interpretation of optimized images;
- automated analysis

Another grouping of relevance to photogrammetry would be methods for

- single images;
- multiple images (mulitspectral, -spatial, -temporal, -positional).

This latter sub-division conforms with photogrammetric traditions of single image photogrammetry, stereo and image blocks.

2.6 Processing as Part of a Larger System: A somewhat different view at image processing is obtained if one does not only consider data or algorithms, but machines as well. Image processing then includes very prominently the topics of image acquisition, analog-to-digital conversion, processing systems with conventional computers, parallel-, pipeline- and array-processors and with bit-slice technology.

2.7 Photogrammetry vs Digital Processing: It should be clear that the methods of digital image processing are both extremely varied and nearly impossible to categorize in some universally meaningful manner. Classical photogrammetry has its metric camera, its central perspective and a rather limited range of products; in comparison digital image processing is an enormously much broader field.

For classical photogrammetric tasks the scope of relevant image processing techniques may seem today to be rather limited, due to hardware limitations. It will be shown, however, that the full range of image analysis concepts has great relevance also for classical photogrammetry.

2.8 Existing Text-Books: Any systematic description of methods of image processing would have to be beyond the scope of a paper. Numerous text books are available today on the various computer methods to process digital images. Prominent examples include Pratt (1978), Huang (1975), Fu (1974), Pavlidis (1977), Rosenfeld (1969), Rosenfeld and Kak (1976), Kazmierczak (1980), Niemann (1983) an many others. Several international journals are available for presentation of research results and an entire image processing industry is rapidly developing that represents a multiple of the photogrammetric one.

2.9 Emphasis of Discussion: Of particular relevance to photogrammetry is the use of image processing for geometric manipulation of single and stereo images. Of interest is also a view on the significance of image analysis research for automated photo interpretation.

3. Geometric Processing of Single Images

3.1 Uses of Single Images: Photogrammetric uses of single images are in flat terrain for the generation of planimetric maps, for rectification and to a limited extent for point positioning. With known elevations or object shapes one can generate orthophotos and use the method of digital mono-plotting as proposed by Makarovic (1973).

Photogrammetrische Woche 1983
Institut für Photogrammetrie
Schriftenreihe, Heft 9, 1984

3.2 Digital Processing: Digital image processing largely results in the same products as in conventional photogrammetry: this includes globally or differentially rectified images, and location of image coordinates (Konecny, 1979); radiometric manipulations, however, are a domain of digital processing. A geometric application of radiometric processing with single images is so-called photoclinometry as used in planetary exploration (Nathan, 1966).

3.3 Geometric Rectification of Photographs: Several examples exist for rectification of photographs by digital image processing. This was demonstrated e.g. by Bähr (1980) in a close-range photogrammetry context and by Göpfert (1981). Digital processing can achieve a result that is at least equivalent or superior in quality to differential rectification in an orthophoto-machine.

3.4 Computational Speed: A general purpose computer today is too slow to produce an orthophoto in a competitive manner. Therefore digital rectification of analog photographs has so far not been considered economical. One may expect that a specifically designed rectifying scanner and film writer with a hard-wired processor could be an economic alternative to conventional orthophoto-instruments. Specialized systems have been demonstrated in the past in other contexts and with only a limited digital component. Examples are with panoramic photographs such as the RPIE-instrument of Bendix, and radar image rectification (Yoritomo, 1972).

3.5 Digital Cameras: Images produced by a digital camera should be processed digitally (Hofmann et al., 1982). However, digital cameras are currently not yet a common photogrammetric image acquisition device. Sensor and processing systems must come into existence alongside one another. It would seem, however, that no technological breakthrouhgs are required to achieve competitive digital rectification systems.

3.6 Radiometric Processing: There is a range of radiometric manipulations one can perform in the digital domain. This has hardly been considered in a photogrammetric mapping context, but has been treated in studies for quality assessment and photo-interpretation (see for example Schneider and Plank, 1980). A much greater body of work exists with remote sensing images, e.g. radiometric rectification for Landsat-MSS (Holben et al., 1982) or radar (Domik et al., in print).

3.7 Image Simulation: The use of a given terrain model for rectification is well understood in classical photogrammetry. Digital image processing adds another dimension by image simulation. Synthetic images allow one, through comparisons, to study the real image of a given area for enhanced photo-interpretation.

3.8 Use of Simulation for Geometric Processing: Discussion of image simulation is beyond the scope of this paper. However, it should be understood that image simulation is only of interest in geometrically less predictable image data such as scanning. For geometric and radiometric analysis of classical photographs this is not of relevance.

3.9 Defining Image Points: Digital processing of single images can serve in the refined centering on pricked or signalized photogrammetric image points (Förstner, 1982; Thurgood and Mikhail, 1982). This application can be developed with conventional computers and with small data sets; one does not, in this problem, digitize an entire analog image but one just uses small image segments in an image area of interest. Digital image processing can help to center on the image feature and to objectively define its image coordinate pair.

3.10 Accuracy of Image Point Definition: Thurgood and Mikhail (1982) and Förstner (1982) are among those who have examined the achievable pointing accuracy in digital data sets; one conclusion is that an accuracy of ± 0.1 of a pixel diameter can be obtained. Earlier studies with analog images have produced pointing accuracies of 5 percent of a target diameter.

4. Geometric Processing of Overlapping Images

4.1 Types of Overlapping Images: Nasu (1976) differentiates between multispectral, -temporal, -spatial, -positional and -sensor images. Photogrammetry commonly deals with multi-positional image pairs or blocks: a single sensor produces a set of overlapping images.

Photogrammetrische Woche 1983
Institut für Photogrammetrie
Schriftenreihe, Heft 9, 1984

4.2 Multi-Positional: The typical photogrammetric task with overlapping images is image correlation for either parallax detection and object shape reconstruction, or for relative rectification or registration of one image with respect to the other. This deals with multi-positional data.

4.3 Multi-Temporal: The problem of working with multi-temporal data is reduced to relative rectification. An added difficulty arises from thematic differences of images.

4.4 Multi-Spatial and Multi-Sensor: Multi-spatial data are commonly available in remote sensing when different geometric resolutions exist. It presents itself also with images from different sensors. Schowengerdt (1980) coined the name. This type of data has so far been uncommon in photogrammetry. However, remote sensing workers have combined scanner and radar images and similar such data (Harris and Graham, 1974; Anuta, 1977; Daily et al., 1978; Rebillard and Evans, 1982).

4.5 Parallax Detection: Parallax detection is well understood and documented in photogrammetry and does not need to be discussed here. One should stress, however, that robot vision work is influencing the classical photogrammetric approaches to stereo correlation: there is a tradition of using brute-force and epipolar line correlation. Robot vision is based, however, on so-called syntactic methods of analysis of overlapping images. An image is first segmented; then an optimum understanding of the contents of an image is acquired using a-priori knowledge about a scene. It is only then that the two images are compared for parallax detection (Baker, 1982).

4.6 Multiple Image Clinometry: Reconstruction of the object space could rely on multiple images from various positions using image brightnesses in addition to or instead of image geometry. This is a theoretical concept in planetary mapping; industrial "shape from shading" or moving target methods employ it (so-called "motion-stereo"). Use of multiple images has the advantage that several brightness values exist per object point. To obtain a result fewer assumptions must be made than in single image clinometry.

4.7 Definition of Image Registration: Relating pixels from overlapping images to one another is called "registration" if it serves to obtain a combined data set. Wiesel (1981) uses the expression of "relative rectification". The problem is solved with methods also in use for brute-force stereo correlation.

4.8 Tie-Points: Commonly registration is by manually defined tie-points that result in a defined transformation function. However, this is followed by an automated prodecure to generate a dense set of correspondence points. This is standard procedure with multipositional and -temporal images.

4.9 Multi-Sensor Data: The problem of registering dissimilar sensor data, e.g. radar and satellite-MSS (thus so-called multi-sensor data) cannot use automated correlation. The images are not sufficiently similar and the best visual definition of homologue features is required. A successful approach to automation would have to include a syntactic image analysis component.

4.10 Merging an Image with a DTM: Recent remote sensing work has taken note of the fact that topography not only effects image geometry but also radiometry. Any approach to remove these effects is based on the requirement that digital elevation data must be related to the image.

4.11 Metric Photographs and DTM: In metric cameras the relationship between image and DTM is rigorous; it can be defined by 3 control points.

4.12 Non-Conventional Images and DTM: With the kinematic geometries of scanners and radar images there is no minimum number of control points to relate the image geometry to a DTM. Therefore several authors have begun to simulate an image from a given DTM. The resulting synthetic image is then correlated with the real one (Seidel et al., 1982, Domik et al., in print). Once the real image and a DTM relate one can apply several geometric and radiometric correction techniques.

Photogrammetrische Woche 1983
Institut für Photogrammetrie
Schriftenreihe, Heft 9, 1984

5. Automation of Photo-Interpretation

5.1 Classification of Multi-Spectral Image: Digital image processing has enabled photogrammetrists to do their traditional geometric work with both conventional and new types of images. However, a new task was added to automate certain aspects of photo-interpreters. During early agricultural aircraft remote sensing and LANDSAT-MSS analysis segments of the scientific community developed great expectations that multi-spectral classification and texture analysis would greatly reduce the problems and work load of image interpreters and mapping workers. These expectations were disappointed. Multiple coverage with remote sensing data has not caused significant automation of image analysis.

5.2 Photo-Interpretation "Experts": New concepts are evolving that address the same goal of automating image analysis. A different perspective is based on so-called "photo-interpretation experts".

In the field of artifical intelligence human knowledge is used by computerizing expert knowledge; this knowledge is used in dealing with the data. Expert knowledge in the mapping field is contained in a map; this is a set of data, better yet a "model" of the image contents. Additionally, of course, one can formulate "rules" about the image contents: e.g. a freeway must be a line with certain maximum curvatures etc. Digital map data together with decision rules can therefore serve to automate aspects of the analysis of an image. Essentially this can lead to understand the contents of the image and to compare it with a given scene description (map). This is the result of a process of "image understanding" (Image Understanding Workshops, undated).

5.3 Application to Automated Interpretation: Expert systems may develop into the most significant long range perspective of photogrammetric and remote sensing research. In its broadest sense any image interpretation task would be preceded by a machine analysis of the image combining all available data on the area and all known rules or expert knowledge. Instead of mere multispectral classification of an image one would employ the existing maps and images jointly in an analysis that is specific for the purpose. This would then not only be data-driven but a knowlegde-based analysis, much like conventional photo-interpretation.

5.4 Monitoring: Map revision and environmental thematic mapping will increasingly have to face the need of timely information. Modern imaging techniques seem to indicate that it will soon be feasible to create the needed data stream for extraction of timely information. However, processing methods are not available. The solution of the dilemma may be in the concept of image understanding. At an initial time the scene of interest is analyzed in detail and results in a product suitable for subsequent "monitoring". The symbolic description of the scene is a digital map. This is the basis of merely detecting and flagging changes in subsequent images using a data-driven, knowledge-based approach. Changes serve to update the symbolic description of the scene and to release action where required.

5.5 Automated Rectification: Matching an image with a given map or symbolic scene description can be called "rectification". Control points from the map can be found in the image by automated methods. This can serve as the heart of a system of fully automated rectification, much as if the sensor orientation were sufficiently well known (Leberl and Kropatsch, 1980; Tenenbaum et al., 1978).

6. Conclusions and Outlook

Remote Sensing is merely widening the range of image acquisition methods to be used by photogrammetrists. Digital image processing, however, not only enlarges his tool-kit; it potentially changes the entire purpose and application of the field.

This paper gives a view on geometric processing with digital single and overlapping images. From this classical photogrammetric task the attention was directed towards the broad ideas of so-called "expert systems", data-driven and knowledge-based image analysis. Their relevance to mapping, map revision and scene monitoring was discussed.

Photogrammetrische Woche 1983
Institut für Photogrammetrie
Schriftenreihe, Heft 9, 1984

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Photogrammetrische Woche 1983
Institut für Photogrammetrie
Schriftenreihe, Heft 9, 1984

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Abstract

Digital images consistently acquire their role in the work of photogrammetric users. They serve to solve classical applications of geometric measurements from images and also to satisfy new, previously untreated problems.
The first category contains the definition of object surface heights from stereo correlation and from other height generating concepts. This includes also the definition of control points by image correlation, the geometric rectification with digital orthophotos, and image analysis to support mapping of thematic information.

New tasks are in the area of "monitoring" by maintaining the level of actuality in an existing data set. This is being achieved by an ongoing image analysis. The application will only be meaningful if digital methods can cut back in a sufficient manner on the required effort.

The scope of new concepts offers applications in the area of topography with aerial and satellite images, in industrial imaging for process control and for geometric as well as thematic mapping of changes, and in the area of medical imaging.

METHODEN UND MÖGLICHKEITEN DER DIGITALEN BILDVERARBEITUNG
FÜR DIE ANWENDUNG IN DER PHOTOGRAMMETRIE

Zusammenfassung

Das digitale Bild rückt zunehmend in den Arbeitsbereich des photogrammetrischen Anwenders. Einerseits dient dies den klassischen Aufgaben geometrischer Vermessungen aus Bildern, andererseits der Erfüllung neuer, bisher nicht bearbeiteter Aufgaben.

Zu ersterem Problemkreis zählt die Höhenermittlung aus der Stereokorrelation und aus anderen Bildanalysemethoden der Ein- und Mehrbildmessung. Weiters zählt hierzu die Bestimmung von Paßpunktlagen im Bild durch Bildkorrelation, die geometrische Entzerrung mit Erstellung von digitalen Orthophotos und die Bildauswertung durch Unterstützung zur Erfassung thematischer Information.

Neue Aufgaben liegen im Bereich der "Überwachung" oder des Monitoring durch Laufendhaltung eines Datenbestandes, welcher durch oftmalige Bildanalyse ständig auf seine Aktualität überprüft werden muß. Dies ist erst durch die Anwendung moderner Methoden auf digitale Bilder mit einem wirtschaftlich vertretbaren Aufwand machbar geworden.

Die Fülle dieser neuen Konzepte bietet Anwendungen im topographischen Bereich mit Luft- und Satellitenbildern, mit industriellen Daten zur Prozeßsteuerung und Wahrnehmung geometrischer und thematischer Veränderungen, sowie in der Medizin bei der Anwendung bildgebender Analysedaten.

Photogrammetrische Woche 1983
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METHODES ET POSSIBILITES D'APPLICATION DE TRAITEMENT NUMERIQUE DES IMAGES EN PHOTOGRAMMETRIE

Résumé

Le traitement numérique des images prend une place de plus en plus importante en photogrammétrie, d'une part dans les tâches classiques pour l'analyse géométrique des clichés et d'autre part dans de nouvelles applications restées jusque là intraitées.

Dans la première catégorie de ces problèmes, on range la définition altimétrique d'un objet sur la base de la stéréo-corrélation et d'autres méthodes d'analyse d'image, ainsi que la détermination des points d'appui par la méthode de corrélation des images, le redressement géométrique avec la réalisation d'orthophotos digitalisées et l'analyse des clichés pour l'acquisition d'informations thématiques.

Les nouvelles applications du traitement numérique des images appartiennent aux domaines de la surveillance régulière d'un ensemble d'informations dans un but d'actualisation continue. Les méthodes modernes de numérisation des images ont rendu ces opérations économiques et rentables.

La diversité de ces nouveaux concepts offre de nombreuses applications topographiques: télédétection aérospatiale avec les images prises par avion ou par satellite, imagerie industrielle avec les systèmes de contrôle automatique, reconnaissance de modifications géométriques ou thématiques et imagerie médicale.

METODOS Y POSIBILIDADES DEL PROCESAMIENTO DIGITAL DE IMAGENES, CON DESTINO A SU APLICACION EN FOTOGRAMETRIA

Resumen

La imagen digital está adquiriendo importancia siempre creciente en las aplicaciones fotogramétricas. Por una parte sirve para las mediciones geométricas de tipo clásico realizadas a base de imágenes y por otra para resolver problemas de índole nueva, no abordados hasta la fecha.

Pertenece al primer conjunto temático la determinación de cotas altimétricas a partir de la estereocorrelación y con ayuda de otros métodos de análisis de imagen, aplicados en la medición de imágenes sueltas y múltiples, así como la determinación de la situación de puntos de apoyo en la imagen por correlación de imagenes, la rectificación geométrica con obtención de ortofotos digitales y el análisis de imagen para apoyar el trazado de mapas temáticos.

Las nuevas tareas se presentan en el campo del "monitoring" para el mantenimiento al día de datos existentes, cuja actualidad tendrá que controlarse en forma continua por análisis repetidos de imagen. Sólo la aplicación de métodos modernos a imágenes digitales ha permitido realizar este control de manera económicamente aceptable.

Esta multitud de conceptos innovativos ofrece aplicaciones en topografía con fotografías aéreas y de satélites, en la industria para el mando de procesos y la detección de modificaciones geométricas y temáticas y en medicina para el análisis de imágenes.

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