OBJECT SPACE BASED CORRELATION WITH ADDITIONAL INFORMATION

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Abstract:

The conception of a new algorithm will be presented, aimed at the determination of digital elevation models by means of image correlation. Main features of the algorithm are the central managment of all image densities within the object space, the parallelization of the point determinations for individually defined regions with homogeneous morphology, the parametrization of the surface by functionals of greater complexity and the introduction and use of additional informations, used as support for the definition and computation of the surface parameters. Besides a detailed description of the conceptional ideas, some first test result will be shown.

Zusammenfassung:

Es wird das Konzept für ein Verfahren vorgestellt, das auf die automatische Berechnung von digitalen Höhenmodellen abzielt. Charakteristische Merkmale des Verfahrens sind die Übertragung der Bildinformationen in den Objektraum zwecks vereifachter koordinierter Handhabung der verfügbaren Daten, die parallele Abwicklung der Punktbestimmungen innerhalb an die Oberflächenmorpholgie angepaßter Regionen, die Einführung komplexer Parameterisierungen des Oberflächenverlaufes und die Einbeziehung zusätzlicher Informationen, die zur Stabilisierung der Berechnungen und zur Unterstützung der geometrischen Beschreibung der Oberflächen eingesetzt werden können. Neben einer Beschreibung des Konzeptes werden erste Testergebnisse an natürlichem Bildmaterial vorgestellt.

Keywords: Image Correlation, Image Matching, DEM Generation, Surface Modelling

INTRODUCTION

In the last few years photogrammetric procedures and instruments have shown a trend towards the use of purely digital data including the images themselves. This gives the opportunity to transfer most of the photogrammetric tasks to the computer, thus opening up new application fields and acquiring greater flexibility. One of the most important aspects of this scenario for sure is the reduction of time and costs by substitution of the human mensuration activities by equivalent computer algorithms based on digital image data.

One of these mensuration domains is the determination of object surfaces by profiling, contouring or discrete point measurements within a stereo model. This task needs precise visual perception capabilities and extensive, in most cases not explicitly documented interpretative work.

The first task allows the localization of homologeous image points using the density variations within their close vicinity and guarantees an adequate precision under the existing conditions (image quality, image contrast etc.).

The interpretative process assures the recognition of the object or parts of it, supposed the density is of sufficient significance. This information is very useful to get a raw impression of the underlying geometrical and radiometrical relations as long as they are typical for the object in question. In connection with the knowledge about the geometrical and physical rules of the central perspective it then is possible to verify the result of the localization guaranteeing high precision and robustness even in cases of complicate geometric and/or radiometric circumstances.

For the human operator the performance of this task in general seems not to be critical, because of his knowledge about the real world, his perceptual talent and his experience with the mensuration process itself.

The attempt to substitute this work by a computer procedure starts with the perception, meaning to locate similar distributed densities within the images. The scale of algorithmic solutions for this similarity detection task ranges from correlation set ups to least squares algorithms of different complexity and feature based solutions. Each procedure has its advantages and disadvantages but all of them have the lack of beeing unable to solve the interpretation process. This restriction in general is circumvented by the introduction of some simplifying model assumptions what in fact limits the flexibility and partly dramatically reduces the performance. Although these similarity detection algorithms might still be subject to further improvements it seems to be of interest to extend the model assumptions.

On the geometrical side, for example, simplifying constraints ask for smooth surfaces, without steep height variations or discontinuties. This exludes the applicability within urban areas, forests, slopes and so on. Expanding the geometric model to the incorporation of discontinuities therefore would lead to higher flexibility and, hopefully, greater accuracy within these regions.
This expectation might be met, if the information necessary for the consideration of the more complex geometry can be extracted from the image and object data and accordingly is incorporated into the geometric model.
To match that aim the algorithmic performance has to imply

1. a flexible geometrical set up tuned by additional informations extracted from the available data
2. some rudimentary interpretative capability to evaluate the data characteristics and to link them to the shape of the surface.

The presented algorithm will give a contribution in that direction.
First, the geometrical model will be explained, then possibilities to extract additional informations will be sketched and finally, some first test results are shown.

THE ALGORITHMIC CONCEPTION

Some thoughts to the current state of algorithms

The scenario of algorithms, accomplishing the identification and localization of homologeous image areas is as manifold as the scale of possible applications and motivations. In order to keep the considerations transparent they will be restricted here to the determination of topographic surfaces.
With regard to the processing of the image data, the kind of point determination and the assumptions concerning the surface geometry we find three different types of solutions:

1. Image correlation
2. Least squares matching
3. Feature based matching

To characterise the algorithms the following aspects might be useful:

Image correlation: Uses the original image data to calculate a similarity value, has an iterative structure calculating point by point, allows the incorporation of geometric distortions as far as they are known and modelled (piecewise bilinear surface parts, for example)/Boochs 1987/

Least squares matching: Uses the original image data as measurements within a least sqaures adjustment, allows modelling of image radiometry, is a direct solution, considers geometric distortions as part of the deterministic model (in general: piecewiese bilinear surface parts) and allows extended set ups or constraints (combined point determination, regularizations etc.)/Ebner,Heipke 1988, Krzystek 1991, Wrobel 1987/

Feature based matching: Uses the original image data to derive feature values characterising image points and their neighborhood, determines the correspondence between the points in both images, needs no geometric model. /Förstner 1986/

Considering preprocessing and transformation capabilities there are some further, common steps possible (the use of image pyramids, for example).

With respect to functionality and results the solutions have different attributes like:

Image correlation: produces medium to high accuracy, needs not very precise start values, is applicable even in cases of low image contrast, does not provide internal accuracy estimates, does not allow the direct interference of the determination of adjacent points.

Least squares matching: gives results of high accuracy, needs precise start values, is more sensitive to low image contrast, gives internal accuracy estimates, allows the simultaneous determination of a large number of points.

Feature based matching: produces medium accuracy, opperates without start values, needs high and characteristic image contrast, produces irregular distributed points, works even in cases of arbitrary object geometries.

Due to the importance of the accuracy in geodetic applications least squares solutions are preferred in general. Feature based matching may serve as tool for the calculation of approximate values or is very useful if robustness is the most important attribute.
Correlation algorithms range in between. The something lower accuracy and the lack of internal control capability are disadvantegeous. Nevertheless the simplicity of the functional set up, the flexibility in the algorithmic control and the individual calculations for each point are useful for extended geometric models and the incorporation of additional knowledge. The following concept therefore is founded on the image correlation technique.

The concept of object space based correlation

Two essential preconditions have to be met to garantee a succesful similarity measurement. The compared image areas have to be rectified and the albedo variations within the corresponding object area have to provide sufficient image contrast. If one or both conditions are not given the calculation will fail or at least produce incorrect results.
In addition to the attempt to overcome such problems by improving the rectification in order to reduce geometric

distortions, correlation procedures may react by an enlargement of the processed image area. In many cases this has to be proven as successful in that failures might be avoided.
As these precautions take place individually for each object point the considered image areas of adjacent points may overlap thus producing certain interrelations between the computed heights. To avoid these dependencies the size of adjacent image areas has to be harmonized. This might easily be done defining the windows in a common reference system, as the object space for example.
Furthermore, almost all other informations supporting the point determinations (surface shape, object types, exluded areas etc.) are defined in the object space too. It therefore seems to be straightforward, likewise to manage the density values within this environment. In addition, such a common definition allows the combination of multiple image sources, if occlusions or other problems within the calculation makes it necessary.

Point definition and description of the surface shape
In manual driven evaluation procedures the location of points might be done very individually due to the interpretative capability of human operators. Points are defined where necessary to garantee a correct registration of the surface morphology. For computer controlled evaluations this is not feasible and instead, a regular, equidistant point grid of sufficient density has to be selected (cf. Fig. 1).

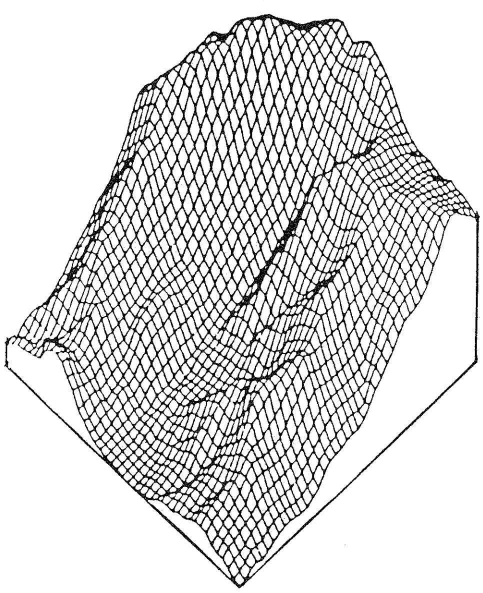
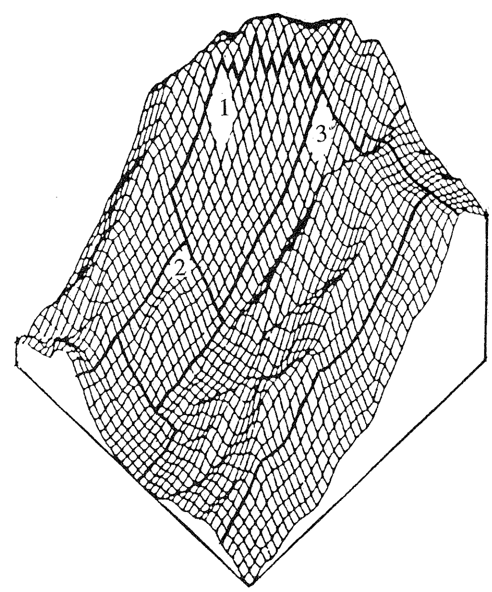


Fig.1 Surface registration by a regular and dense point grid

Supposed, the surface morpholgy is adequately reflected therein, a way has to be found to use this information for the rectification of the images.
To achieve this, the grid is seperated into regions of homogeneous morphology as flat terrain, smooth areas, steep zones, highly varying areas, regions with few or many discontinuities for example. For each region an adequate functional set up has to be selected reflecting the typical surface shape. This might be a plane, a polynomial or seperated functionals as necessary to model discontinuities.
The information needed for the determination of those functional parameters will be extracted from the points lying in the region in consideration. This has to be done iteratively, because there is no or only raw a priori knowledge available.
All points within a region will be determined in parallel. This assures, that at the end of each iteration all points covering the surface in registration are known, allowing for a new calculation of the functional parameters and thus improving the correctness of the surface description.
The dimensions of the regions are strongly interrelated with the functional complexity. Within flat terrain a great number of points may be determined in parallel, whereas with increasing complexity the extension of the region has to be limited in order to describe even frequent surface variations correctly (cf. Fig.2).
Although the actual concept uses closed parameterized functions other functionals might be possible if necessitated to improve the flexibility.



1,2,3 = regions of different morphology

Fig.2 Definition of regions with homogen morphology

Rectification and point determination Between abjacent grid points, a few surface elements will be defined. Within each of them the surface albedo will be calculated as registrated in the images in concern (cf. Fig.3). For that purpose, the location of these surface elements within the images has to be computed. This might be done directly or by interpolation from adjacent anchor points in the images. The latter attempt supposes, that the surface geometry is smooth enough to allow this simplification. Finally, the albedo value is approximated

by the image densities in the neighborhood of the interpolated surface element.
At the end of the rectification process at least two sets (one for each image) of albedo values are available surrounding each grid point. For every grid point these sets are then correlated. As usual the location of the highest similarity value within a 3 by 3 vicinity is calculated. Subsequently, the object height has to be computed from the resulting parallax.
Finally, the residuals between the a priori heights and the new ones are calculated and combined to a mean square value which is checked against a threshold defining the success of the computations.

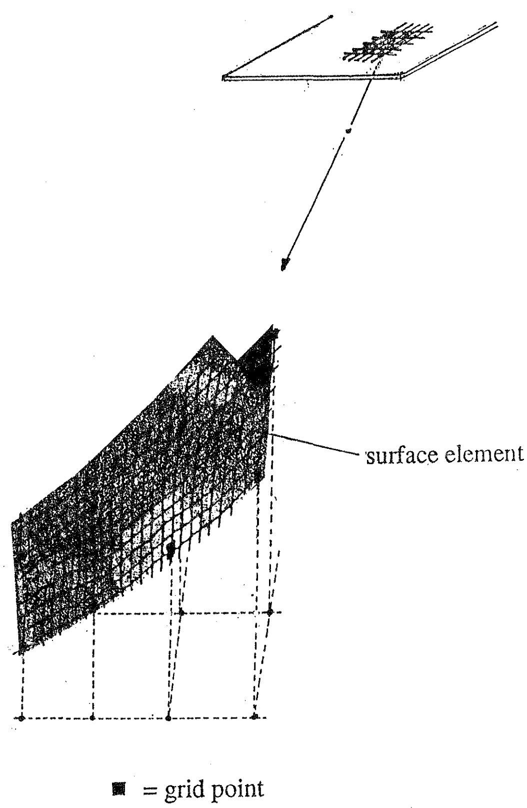


Fig.3 Projection of the image densities onto the surface

Control aspects A flexible and purely automatically operating algorithm needs some internal control to assure satisfying functionality. Out of the numerous features three will be mentioned here.
First, the appearance of failures has to be taken into account. Especially due to the limitation of the window size to a fix value, defined by the grid width and the size of the surface elements, in cases of low contrast failures will be as numereous as with extendable windows. This disadvantage might be compensatable, because all points belonging to a homogeneous structed surface part are calculated in parallel. This allows the substitution of failed calculations by computations from the parametric surface description. Although these substitutes will be reliable, the points affected have to be marked to allow an a posterori assessment of the results.
Secondly, we have to consider those determinations, which will result in blunders. Manifold reasons might be responsible for their occurence which would not be identifiable immediately. However, an algorithm should at least perform the identification of such points. This might be achieved correspondingly to the substitution of failures. As the determination of the functional surface parameters in general will be a redundant process, a blunder detection algorithm might be applied to the results, in order to discover unreliable point heights.
Finally, using a least squares adjustment for the estimation of the surface parameters permits an evaluation of the correctness of the functional set up. This can be used for internal control purposes and for selection of a new functional description, if necessary.

Process tuning Besides the internal algorithmic control some general fixings have to be done. Here are the size of the surface elements and the grid widths or window dimensions rsp. of interest.
The size of the surface elements defines the geometric resolution and therefore affects the accuray attainable. Although no direct interrelation exists, the selection has to account for the desired precision.
Unfortunately, the tendency towards small element sizes will result in a reduction of the image contrast available. As consequence, one has to expect an increasing number of failures and/or blunders, thus diminishing the robustness of the procedure /Faugeras 1992, Boochs,Hartfiel 1989/.
Furthermore, the interrelation of these two factors is superimposed by the image quality and the albedo variations within the object, being responsible for the image contrast. The selection of the element size therefore has to reflect the data quality and the aims of the application.
Regarding at the dimension of the image windows, defined by the grid width and the size of the surface elements, a similar view may be obtained. Small windows result in higher precision /Faugeras 1992/ accompanied by a loss of robustness. Although in general, robustness might be acquired by an adopted increase of the window size, this will not be necessary within the actual concept, because due to the contextual determination of several points within regions of homogeneous shapes the calculations will be stabilised and allow the substitution of incalculable heights, if desired.

Introduction and use of additional informations

Due to the flexible concept some additional knowledge has to be available within the calculations to achieve good results. This are

- the type of functionals to be used
- the average size of the regions
- the run of the region borders
- the location of important object features (breaklines, edges etc.)

These informations might be provided explicitly and in advance by discrete definitions or might be introduced internally within preprocessing algorithms, based on the image data available.
The explicit definition for sure is the simpler solution, because there further investigations might be restricted

to the question to what extend information has to be available to model discontinuities within the object, in order to garantee acceptable results.
The collection of the informations needed might be achieved by visual inspection of the image data or by use of other sources (information systems, maps etc.). The types of functionals as the size of the regions, for example, could be determined by some rough knowledge about the topography. The definition of the region borders will be done by some measurements within the digital images (polynomials, corner points etc.). The same is valuable for the discretization of discontinuities.

Much more demanding but of greater importance for future developments is the attempt to extract these informations automatically from the image data available. The realization of this approach would equip the algorithm with interpretative capability, what for sure is a necessity to attain the required flexibility within fully automated procedures.
One important prerequisite for the success of the preprocessing is the existance of some dependencies between the distribution of the image densities and the geometry of the corresponding surface part. Although there won't exist direct relations, this assumption will hold to a certain degree. This might be illustrated by the effect of illumination with direct solar radiation, which determines the distribution of enlighted and shadowed areas by the geometric disposition of the surface. Further informations like brightness, texture, edges etc. are depending on the underlying objects too. This data allows to differentiate between objects, what in many cases will be equivalent to a discrimination of changes within the surface morphology.
Existing approaches /Besl, Jain 1988; Grimson, Pavlidis 1985; Haralick et al 1983/ document that the interrelations between density values and surface topography might be useful to approximate the surface or to segment the images into homogeneous regions. Furthermore there are trends towards algorithms performing an extraction of complete objects /Förstner 1991/ which likewise could contribute to the evaluation of the required informations.
Once, the additional knowledge is available it will be used within the algorithm to control the calculations. This might be done by selection of those points within a zone of homogeneous morphology which have to be combined to a region, or by evaluation of the results with respect to the type of surface.
In addition the knowledge may be used to segment the surface elements into different groups. This is useful in case of discontinuities, because then the surface elements within a region may belong to different sets of surface parameters. Similarily the grouping is convenient to exclude elements from the calculations or to weight them down, what is necessary to eliminate or reduce the contribution of some surface parts.

FIRST RESULTS

The presented conception has not yet been realized completely, but at least the principle of the object space based correlation is already transformed into a computer algorithm. However, this algorithm does not yet have tuning or control capabilities as they will be necessary to optimize the results. It therefore seems to be likely to expect further improvements with increasing completeness of the algorithm.
The tests have been done with already used material /Boochs 1987/ showing a topographic surface projected into a medium scale (1:12000) image pair. The digital images have a resolution of 50 µm. For control purposes a set of manual height measurements is available.
The tests are performed within three small object areas, each of them exhibiting different morphology (hillside, urban, meadow).
The results are compared with calculations from a different correlation algorithm (ARCOS), which has been proved as valuable for the determination of digital elevation models of smooth topographic surfaces.
Table 1 shows the mean square residuals (m_{qr}) from the differences between correlation results and manual measurements, the mean square residuals after blunder detection ($\hat{m}_{qr}$) and the number of blunders (out).

	obj.sp.cor.			ARCOS		
	m_{qr}	$\hat{m}_{qr}$	out	m_{qr}	$\hat{m}_{qr}$	out
meadow	0.27	0.15	1	0.14	0.14	0
hillside	0.23	0.19	1	0.68	0.53	1
urban	0.99	0.99	0	2.11	0.71	5

Table 1: Mean square residuals [m]

Regarding at the area with the simplest morphology (meadow) we find, that the general accuracy ($\hat{m}_{qr}$) is equivalent to the known one from ARCOS and seems to be acceptable (0.07‰ h_g) for this application. Certainly, a blunder appears within the object space based correlation. However, it will easily be detected and substituted when the internal program control is available.
Considering the results from the hillside, a considerable improvement has to be found. This reflects the advantages of a higher complexity within the functional description of the surface. In this case a polynomial of order 4 has been used.
Finally, even for the urban area some positive aspects may be found. Although $\hat{m}_{qr}$ decreases (0.71m->0.99m) there arise no more blunders leading to an improvement in m_{qr}. Nevertheless, these results are not satisfying. Further enhancements are to be expected, when the discontinuities within urban regions will be modelled correctly. In the present stage with the use of polynomials, results can't be better. After all, the use of small and fix image windows seems to be valuable, as the geometric distortions will decrease, what might be an explanation for the disappearence of the blunders.

CONCLUSION

The presented conception has to be seen as contribution towards higher performance and flexibility of automaon towards higher performance and flexibility of automatic procedures aimed at the determination of digital elevation models. To achieve this, a new correlation conception has been developed, allowing for

- the managment of the density values in the object space
- the parallelization of the calculations within small regions, adopted to the surface morphology
- the introduction of complex parametrizations of the surface, up to an introduction of discontinuities
- the incorporation of several additional informations, used for tuning and control purposes and necessary to support the introduced functionals.

As first tests have shown, the concept seems to work, producing results of acceptable precision even in cases of surfaces with some higher morphologic complexity.
In the next future the algorithm has to be completed followed by extensive tests to get an impression of the overall performance.

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