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EMPIRICAL RESULTS OF AUTOMATIC PARALLAX MEASUREMENT

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1. Introduction

Since the beginning of photogrammetric stereo measurement with Pulfrich's museum stereo comparator stereo plotters have been undergoing constant change due to technological innovations.

By using improved measuring instruments problems of 3d-measurement were mostly able to be solved more precisely or economically. In the age of microelectronics photogrammetric instruments are conceivable, with which, in contrast to present system realisations, 3d-measurements can be carried out, the results of which are completely independent of the spatial facility of vision of the operator or alternatively they are totally independent of the human operator in every aspect. In this way the task of stereoscopic allocation of identical image points can be transferred from the human visual system to the procedures of digital processing of image signals.

This contribution is concerned with the results of empirical investigations of partially automized, highly precise 3d-measurement with an analytical plotter equipped with CCD cameras.

At the present stage of development of the modified Planicomp C100 horizontal and vertical parallaxes can under certain conditions (pgh. 2) be measured by digital image correlation. The approximate setting of the measuring points is taken over by the operator (Pertl 1984).

By means of digital image correlation digitized image windows are tested for similarities with one another. In this case it is primarily used for the measurement of parallaxes of two corresponding image windows. If one replaces one of the two image windows in the case of prominent image structures (e.g. signalized points) by an artificially produced grey-value mask, the parallax measurement gained by digital image correlation then corresponds to a point localization or alternatively a point measurement (Ackermann 1985).

In addition to precision requirements economic demands are also made on the practical usefulness of the analytical system.

In the second part of this contribution the criteria are stated which have to be fulfilled by the correlation areas in order to guarantee high degrees of precision of point correspondence. Furthermore it is shown how much time has to be spent for the automatic parallax measurement.

The third part illustrates by means of three examples taken from photogrammetric practice the functioning ability and efficiency of correlator-aided measurement with the analytical plotter. In addition to a description of the test runs the results of the measurements for point-transfer with regard to aerial triangulation, for surface measurement and for the determination of object deformations or alternatively alterations are interpreted.

2. Empirical Investigations on the Correspondence of Points by Digital Image Correlation

The investigations of this section are devoted to the precision and to the amount of time spent with regard to the method of point-transfer using digital image correlation as described by Ackermann and Pertl (Ackermann, Pertl, 1983).

The investigations are limited to those parameters which can be controlled by the operator in respect of the point selection. These are the size, the initial overlap area and the image content of the correlation areas, the latter being restricted by the given image material.

2.1 Precision

Förstner (Förstner 1982) proves in a theoretical study that the precision of point correspondence by digital image correlation is dependent upon the following parameters

- number of image points
- image contrast
- image noise
- size of the pixels.

The size of the pixels is fixed by the system (CCD sensor) and in this case, therefore, is not subject of further consideration.

The subsequent investigations each relate to the smallest possible pixel size of the system, namely (20 μm)².

Number of Image Points

If one doubles the length of the sides of the correlation windows the theoretical accuracy formula then states (Förstner 1982) that the variance σ_p^2 is improved by a factor of 4.

$$\sigma_p^2 = \frac{1}{n} \cdot \left| \frac{\sigma_n^2}{\sigma_{g_x}^2} + \frac{\sigma_n^2}{\sigma_{g_y}^2} \right| = \frac{1}{n} \cdot \frac{1}{SNR^2} \cdot \left| \frac{\sigma_g^2}{\sigma_{g_x}^2} + \frac{\sigma_g^2}{\sigma_{g_y}^2} \right| \qquad (2.1)$$

The empirical investigations confirm the fact that the precision of point correspondence is dependent upon the number of image points (Fig.2.1.).

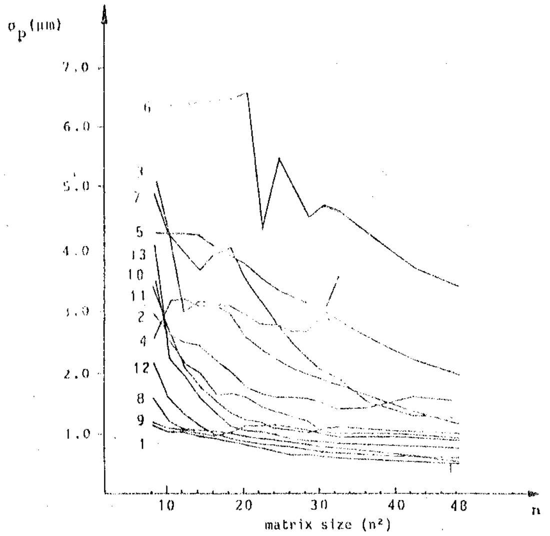

Fig. 2.1: Precision of point correspondence depending on the number of image points

The variance σ_p^2 does not, however, become linearly dependent upon the number of pixels. This can be traced back to the fact that when the size of the correlation areas alters, the image content and thereby the image geometry must also necessarily change. Furthermore, equation 2.1 assumes the isotropy of the image content and the existence of white noise. These assumptions cannot be made for the empirical investigations.

In order to produce the graph (Fig. 2.1) image windows of varying content were used, whereby illustrations of natural points are dealt with exclusively. (aerial photographs m_b = 1 : 4000). (Appendix A1)

Degrees of accuracy for the point correspondence as high as 0,05 pixels (1μm) are already obtained here for a correlation area of the size of (16x16) pixels. The results can be regarded as representative, since equivalent investigations of aerial photographs from other photographic flights yield accuracy values of the same order. The accuracy values are independent of the scale of the photograph. The image structure within the correlation areas is the deciding factor for the quality of the point correspondence.

Image Structure

The image structures differ from one another in their shape, their size and also in the contrast to each of their surroundings. In equation 2.1 these texture parameters are to be found in the quotients.

$$\frac{\sigma_g^2}{\sigma_{gx}^2} \quad \text{und} \quad \frac{\sigma_g^2}{\sigma_{gy}^2}$$

The value σ_{gx}^2 or alternatively σ_{gy}^2 is primarily determined by the steepness of the grey-value gradients (image sharpness). With the correlation algorithm according to the leastsquares method (Ackermann 1984) the characteristics of the grey-value gradients exert an influence on the cofactors. With the aid of the cofactors mean error ellipses can be derived according to Helmert (Wolf 1975), the shape and size of which are characterized by the image texture.

Should the exeptional case arise that the image structures in all directions display the same characteristics, one obtains an error circle instead of an error ellipse.

Image structures with such characteristics are most frequently to be found in large-scale aerial photographs in the form of artificially built constructions (manhole covers, road markings, driving lanes etc.). In the case of aerial photographs on a small-scale one can distinguish above all field corners, street crossings etc. due to similar image structures which lie in directions at right angles to one another.

In addition to the object shape and the contrast and sharpness of the image, the size of the projected objects also exerts an influence on the correlation accuracy because of the finite pixel size of the CCD sensors (20 µm)².

The correlation algorithm presents the possibility of self-diagnosis by the examination of the error ellipses as regards their shape and size. For the correlation procedure unsuitable image structures, e.g. lined objects or objects of poor contrast, are recognized by the algorithm.

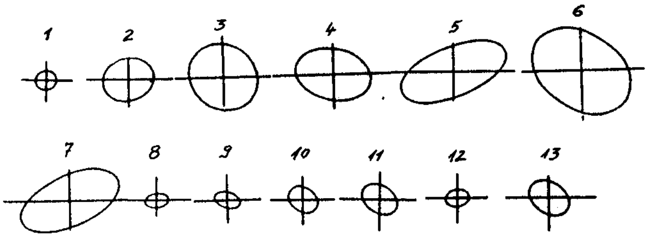

Fig. 2.2: Error ellipsesof correlation examples 1 to 13
Matrix size 16 x 16 image points

2.2 Time Consumption

The initial overlap area (approximate values) and the number of pixels of the correlation areas are deciding factors for the efficiency of the correlation procedure according to the least-squares method.

Convergency

Since the correlation algorithm by least-squares is numerically very complicated, more efficient methods (Ackermann, 1984; Pertl, 1984) are implemented for the determination of the approximate values. The correlation algorithm by least-squares is only then used when the correlation areas differ from one another by less than approximately 1.5 pixels. Under this condition the correlation maximum is arrived at after approximately 3-4 iterations (Fig.2.3).

Area Size

The higher degree of accuracy of point correspondence with large correlation areas (Fig. 2.1) is only to be gained at the cost of time spent. Fig. 2.4 illustrates the time spent with the correlation algorithm by least-squares for various sizes of matrix.

The time data refer to the software realisation with a HP 100 small computer. In Fig. 2.4 the time data are not included for the preparation of the grey-value matrices (scanning, transfer, decoding). In addition to the total times for each of 1-4 iterations the time spent for the resampling and the construction of the system of normal equations is given separately. At present the matrix of normal equations is constructed anew for each iteration. Computing time can still be saved at this point, if after the first or second iteration only the right sides of the system of normal equations are newly constructed and if the matrix of normal equations remains unaltered.

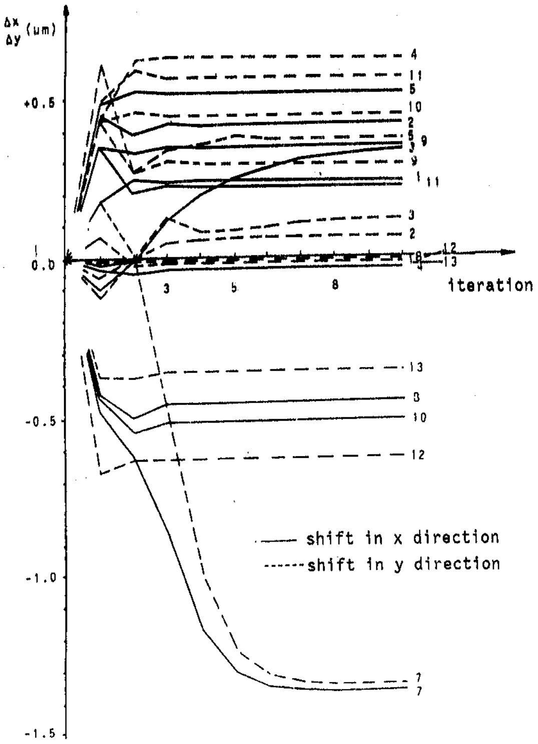

Fig. 2.3: Change of shift parameters of correlation examples 1 to 13 depending on the number of iterations (Change of parallaxes)

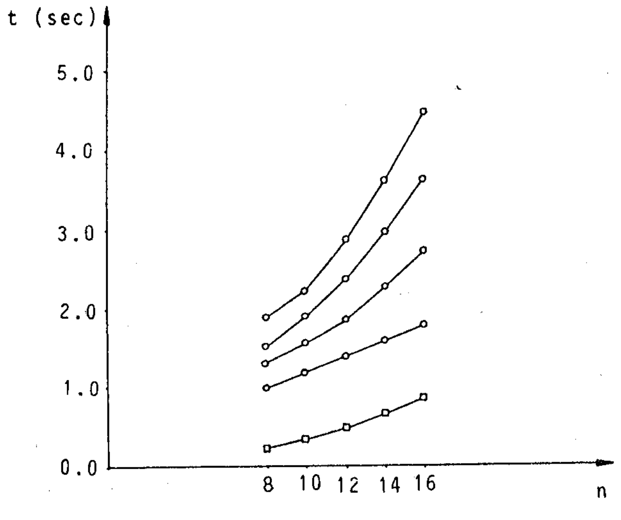

Fig. 2.4: Correlation time with least-squares algorithm

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3. Photogrammetric Standard Tasks - Comparison between Conventional and Correlator-aided measurement

In this section the results of some comparisons between conventional and correlator-aided measurements are presented. The following areas of application were chosen from the photogrammetric practice:

1) aerial triangulation
2) surface measurement and
3) deformation measurement.

3.1 Aerial Triangulation

There are three possibilities at one's disposal (Jordan, Eggert, Kreissl, 1972) for the identification of points in aerial triangulation: a) signalling of the natural points b) artificial marking of the image points and c) the use of natural points.

For reasons of complexity a signalling of the tie-points does not generally come into question. A disadvantage of artificially marking the tie-points is that it causes the photographic emulsion to be locally destroyed. If one uses natural points for the connection of images, this frequently leads with conventional methods of point-transfer to identification errors. The fine adjustment when measuring often becomes problematic if the natural points are not small enough and are not able to be clearly recognized.

In such a case help can be provided by a method of point-transfer which makes use of the possibilities of the analytical plotter and of digital image correlation. This method does not necessitate the artificial marking of the tie-points. As correlation works with image areas, small image structures are not absolutely necessary for the fine adjustment. Moreover, when applying these methods as opposed to conventional methods of point-transfer each image only has to be placed once into the photo-carriage of the plotter.

The following gives a report on an investigation which was carried out to compare the connection accuracies of a conventional measurement with the mono-comparator PK1 with those of a conventional and correlator-aided measurement with the Planicomp C 100. The specific σ_o-value of each measurement obtained from the bundle-block adjustment serves as the unit of comparison.

Photographic Material

The photographic material used originates from a flight over the area of Schnürpflingen (Baden-Württemberg, transition region Swabian Alb - Upper Swabia; image scale 1 : 4000; RMK A 15/23 with FMC; Kodak Panatonic X; p = 60 %, q = 40-80 %; flight direction EW and WE; altitude above ground level 600 m; data of taking photographs: 5.4.1985).

For these investigations a sub-block (Fig. 3.1) was chosen from the block as a whole. The sub-block consists of four strips each with 6 or alternatively 7 photographs in which there are on an average approximately 16 (in total 405) signalized tie-points. In each case these are distributed as single or alternatively double points among the 9 diagram points of the photographs. A prominent natural point was selected in the immediate neighbourhood of each of these signalized tiepoints. A similar block geometry is thus guaranteed when using signalized or alternatively natural tie-points for point-transfer.

An outer boundary with 12 signalized control points in planimetry and height was chosen from the control points at hand.

In order to test the absolute accuracy in planimetry a further 107 signalized check-points are available. These points were not used as tie-points in the block adjustments.

Measurement

The ground control points, the check-points and the signalized tie-points (Version SIG PK1) were measured with the monocomparator Zeiss PK1.

The measurements with the analytical plotter Planicomp C 100 were carried out in the comparator mode (monocomparator - left photo-carriage). The measurements of the operator were again limited to the ground control points, the check-points and the signalized tie-points (SIG C100). The digitization of the image windows for (multi-) image correlation which was carried out later externally took place directly after these measurements with unchanged orientation of the photographs.

Only those image details were digitized which were subsequently used for the connection of the photographs. The digitized image windows were divided into two groups. The first group contains signalized (SIGKORR) points and the second group natural ones (NATKORR). In addition to the image matrices the scanning position (system coordinates) and the calibration data for the assignment of the CCD cameras to the position of the measuring mark (Gülch, 1985) were recorded on magnetic tape.

Correlation

There were between two and nine digitized image windows for each tie-point. Each time one of them was selected (mask) and was correlated with the remaining image matrices. Subsequent to the area adjustments a point was defined within the mask matrix (Ackermann, Pertl, 1983) which was transferred to all other image matrices of the appropriate natural point (Fig. 3.2).

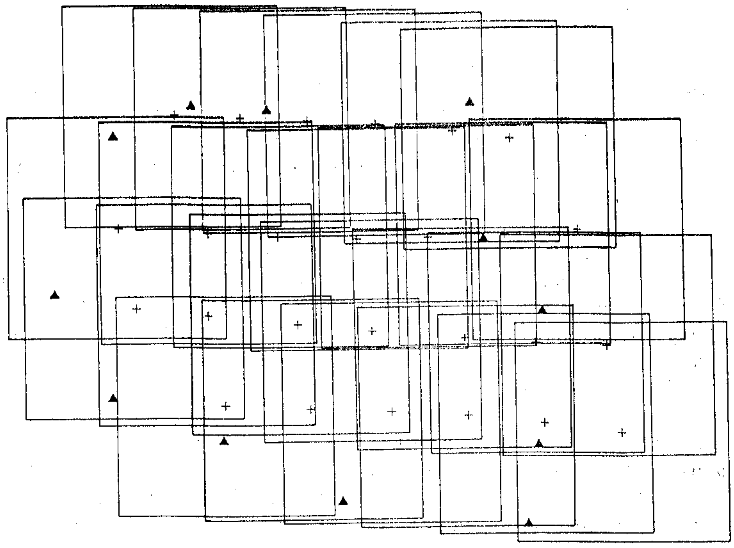

Fig. 3.1: Sub-block Schnürpflingen
(▲ control point, + image center)

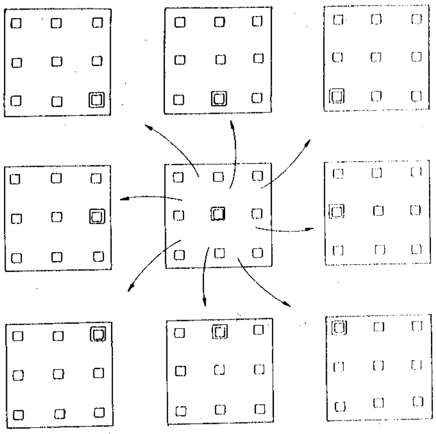

Fig. 3.2: Point transfer

The degrees of precision of point correspondence by correlation are presented separately in Fig. 3.3 and 3.4 for image structures of natural and signalized points respectively. The determined theoretical transfer accuracies are better than 3 µm (2 µm) for 97 % (80 %) of the natural points and 90 % (61 %) of the signalized ones.

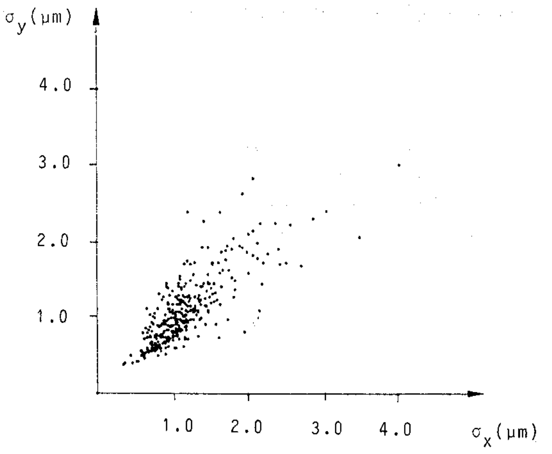

Fig. 3.3: Natural terrain structures

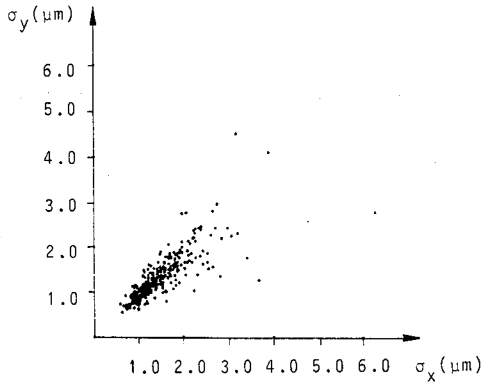

Fig. 3.4: Signalized terrain points

Precision of image point correspondence

Image Coordinates

The coordinates of the transfer points related firstly to local coordinate systems (scanning systems). By means of the scanning position of the image matrices and the assignment values of the measuring mark and the CCD camera these coordinates are transformed into the photo-carriage coordinate system. A subsequent reduction to the main point of the image and a correction of the distortion values carried out symmetrically to the main point of the image provided the image coordinates of the selected tie-points.

Block Adjustment

For each of the four sets of data a bundle-block adjustment was carried out with the PAT-BS programme. 20 measurements had to be eliminated when the version NATKORR was ordered. The corresponding measurements were also eliminated in the other versions for reasons of comparable block geometry. In the version SIGKORR an additional five points were omitted. The number of block points does not alter since one is dealing here with individual tie-points which have been measured several times. For this reason the corresponding points were not eliminated in the other three versions.

The orientation parameters of the images and 12 block-invariant additional parameters were determined for the four different versions by the method of self-calibration (Table 3.1). For each of the block adjustments only the measurements of the tie-points and of the 39 ground control points (12 natural points) were considered.

version	measurement with	type of points	number of		
			tie points	control points	block points
SIG Pk 1	Pk 1	signalized	405	39	104
SIG C 100	Planicomp C 100 with operator	signalized	405	39	104
NAT KORR	Planicomp C 100 plus Korrelator	naturel	405	39	104
SIG KORR		signalized	400	39	104

Tab. 3.1: Versions of block adjustment

The precision values (σ_0-values) of the bundle-block adjustments are thus determined to a considerable extent by the measurement accuracy or alternatively the transfer accuracy of the tie-points.

Version	σ_0 (μm)	μ_x	μ_y (μm)	μ_{xy}	σ_0	μ_x	μ_y (cm)	μ_{xy}
SIG Pk 1	2,4	2,7	3,2	3,0	1,0	1,1	1,3	1,2
SIG C 100	2,7	3,0	3,5	3,3	1,1	1,2	1,4	1,3
NAT KORR	4,0	3,6	3,8	3,7	1,6	1,5	1,5	1,5
SIG KORR	3,9	4,5	3,9	4,2	1,6	1,8	1,6	1,7

Tab. 3.2: Accuracy results

The σ_0-value of 4,0 μm in the NATKORR version can be seen to be the outstanding result of this investigation . For this result makes plain the efficiency of digital image correlation as a method of point-transfer for aerial triangulation .

For each of the four versions the intersection point of the rays of the tie-points were calculated from the respective orientation parameters and also from the 12 block-invariant parameters and the image coordinates . A comparison of these values with the known terrain coordinates leads to the absolute degrees of planimetric accuracy of the sub-block as tabulated in Table 3.2.

One must, however, ,make mention of the restrictive nature of this procedure, in that point measurements can only be carried out with the correlator under certain conditions (Ackermann, 1985). As these conditions were not given for this investigation under consideration the image coordinate measurements of the tie-points for the absolute control of accuracy in planimetry of the version NATKORR and SIGKORR were adopted from the SIGC100 version.

Findings and Conclusions

An essential result can be seen to be that excellent degrees of accuracy can be achieved for point transfer by using the method of digital image correlation. An error distribution for the correlator of 3,0 μm or alternatively 2,8 μm can be derived from the σ_0-values in Table 3.1 (Version SIGC100, NATKORR, SIGKORR). These results agree with the internal precision data of the correlator. It could also not be definitely clarified what influence is then exerted by the temperature-dependent fluctuations according to the time of day of the scanning position of the camera sensors (Gülch, 1985). For the measurements under consideration here a system calibration was only carried out before the first and after the last measurement respectively of each day. For future measurements one should check the scanning position of the camera sensors after each change of image, in order to keep these temperature-dependent influences to a bare minimum.

If one compares the results of the investigations under consideration with those of an investigation of point-transfer equipment and marking equipment (Sigle, 1981), one can clearly see the efficiency of the method of point-transfer presented here.

An absolute comparison of both investigations cannot be drawn here since the conditions (photographic material, block geometry etc.) were not identical.

The results obtained by Sigle are based on measurements with a Zeiss PK1 monocomparator as is the case for the result of the SIGPK1 version (σ_0 = 2,4 μm). A σ_0-value of 2,6 μm, comparable to that of the SIGPK1 version, resulted for signalized tie-points (18 per image) after a bundle-block adjustment with 12 block-invariant parameters had been carried out.

Artificially marked tie-points resulted in a σ_0-value of 6 μm. For the investigations under consideration here σ_0-values of 4,0 μm and 3,9 μm were ascertained for natural tie-points and signalized tie-points respectively. One can thus classify point-transfer by means of digital image correlation as precision aerial triangulation.

When ordering the NATKORR block 20 measurements had to be eliminated. 75 % of these eliminations were already able to be localized during the process of correlation and can be traced back to image defects (scratches in the film emulsion, drying stains, etc.), or alternatively incorrect approximate settings (identification errors).

Four of the additional five measurements eliminated from the SIGKORR version came to notice because of worse correlation values.

This means, therefore, that the rate of self-diagnosis is very high with the process of correlation. Incorrect correlations of similar objects can nevertheless not be be excluded.

3.2 Partially Automatic Surface Measurement

For the process of photogrammetric surface measurement with the Planicomp the operator is assisted by various system programmes of the analytical plotter. The setting of the measuring mark on the object surface depends, however, even with this analytical system on the operator.

The following gives a report on a comparison measurement whereby the stereo measurement was on the one hand carried out by an experienced operator and on the other hand by the correlator.

Image Material

For this test two UMK-photographs of a prepared industrial surface were used ($m_B \cong 1 : 23$, $c = 99{,}18$ mm), $p \cong 60$ %). As there were no data for the external orientation of the pair of images, a free reference system had to be chosen which refers to estimated distances between points within the object area.

Measurement

The measurements were restricted to a sub-section of the photograph measuring approximately 1 cm x 1 cm. This area was measured profile by profile. The placing of the profiles in the case of correlator-aided measurement takes place in one of the two images (here the left one).

After the starting and finishing point of the profile has been fixed the (left) photo-carriage is then moved on step by step with regular distances between measurements. The appropriate position of the second photo-carriage is determined from the preceeding measurements and is finally corrected using the result of the correlation. A step size of 0,1 mm in the direction of the profile was chosen for the investigation under consideration. The distance between the profiles was 0,2 mm. 4 point series of such compactness was necessary because the convergency radius of correlation is relatively small ($<$ 80 m) and because the applied prediction method reacts very sensitively to changes in curvature of the object surface.

36 profiles were measured in total. The average number of points for each profile is 76. During the measurement process correlation errors occurred for various reasons, whereby the operator was able to intervene in the measuring process by means of a control unit. The most frequent correlation errors can be traced back to defective image structure, light reflection, edges and large differences in affinity between the two image windows. As these disturbances only occurred locally the majority of the profiles could be measured without substantial intervention of the operator.

When the measurement is carried out by the operator, the placing of the profiles takes place in the object area. The points to be measured are automatically set (planimetry). The operator only has to readjust the height. For the investigation at hand the distance between points in profile direction was 2,3 mm (0,1 mm in the image) and the distance between profiles 4,6 mm (0,2 mm in the image).

Calculations and Results

Isolines (Fig. 3.5 and 3.6) were derived from the two sets of data by using the programme system SCOP. In addition approximately 3200 coordinate triplets from the measurement of the operator and approximately 2700 from the measurement performed by the correlator were available. The chosen distance between the isolines is 1 mm.

In order to compare the measurements with one another the differences between the DHM derived from the operator's measurement and the DHM from the correlator measurement were calculated. The results are contained in the histogram (Fig. 3.7) and illustrate a systematic deviation of 0.20 mm of the correlator measurement as opposed to the operator measurement. The mean quadratic deviation is 0,37 mm.

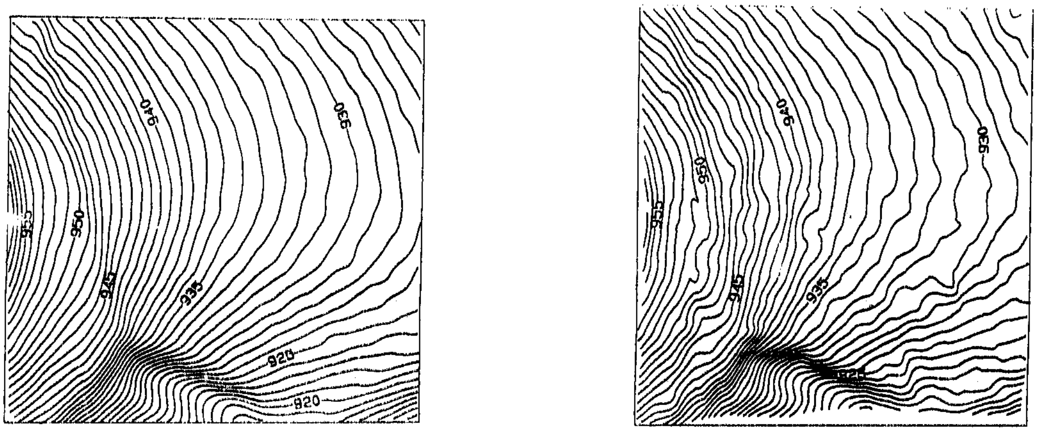

Fig. 3.5 and 3.6: Isolines of a prepared industry survace with 1 mm interval

a) Conventional measurement
b) Correlator assisted measurement

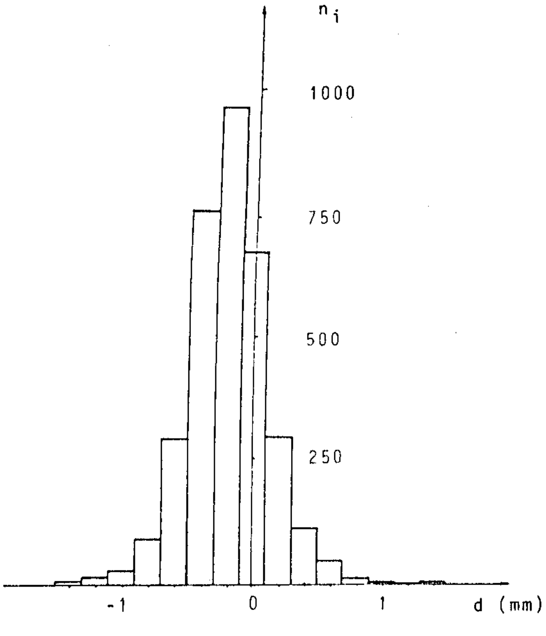

Fig. 3.7: Frequency distribution of discrepancies between conventional and correlator assisted measurement

The smoother course of the isolines of the operator measurement can be explained by the fact that the operator can guide the measuring mark alone the object surface (filter function), whereas the correlator cannot distinguish between the object surface and the colour preparations sprayed onto the object surface.

The comparison measurement showed that the stereoscopic fine adjustment can be taken over by digital image correlation. Nevertheless this is only on the condition that the surface of the object is rich in contrast. The difficulties which occurred during the measurement process affect mainly the determination of the approximate values for image correlation. These can be solved by various methods of image correspondence (Förstner, 1985, Kories, 1985).

3.3 Determination of the Spatial Change of Objects from Measurement Photographs

If photogrammetric measurement methods are applied for the recording of deformed objects or objects which have altered their position, difficulties often occur with the point identification and with the point correspondence of the comparison points in the photographs of the various measurement epochs (different image scales, shift of object position and change of object shape). The correspondence of points or alternatively transfer of points can take place in different ways (Hellmeier, Wendt,1982).

Using the example of a vulcanic region in north-east Iceland a method of point-transfer is presented here, for which the possibilities of the analytical plotter and digital image correlation can be used. The proof of the precision of digital image correlation as a method of point-transfer is not in the foreground of this investigation (see 3.1 in this connection), but the functioning efficiency of the method for obtaining vectors of shift from measurement photographs, which have been taken at different times.

Photographic Material

At our disposal for the investigations were the aerial photographs (original negatives) of three flights over the area (1976, 1980, 1982). From each of the 1976 and 1980 epochs a pair of photographs was selected in which one can see the geodetic profile Gjastykki. The photographs of the 1982 epoch could not be used because the object surface had changed considerably between the photographic flights of 1980 and 1982 (new stream of lava). Apart from the information at the photograph's edge there were no other data available for the interior orientation of the photographs.

Object System

There was not sufficient information available for the fitting-in of the photogrammetric models into the terrain system. Although there are geodetically determined points in the "Spaltengebiet" of Gjastykki, these are, however too difficult to identify due to the lack of signalization. The ground control points (Fig. 3.8) are not suitable for the absolute orientation of the photogrammetric models because of their unfavourable distribution. Moreover, the geodetic point determinations do not coincide with the times of the photographic flights. Therefore, only a relative fitting-in of the photogrammetric models into the terrestrial system took place. The basic information for this was taken from the topographical work map Gjastykki (Weimann, 1979).

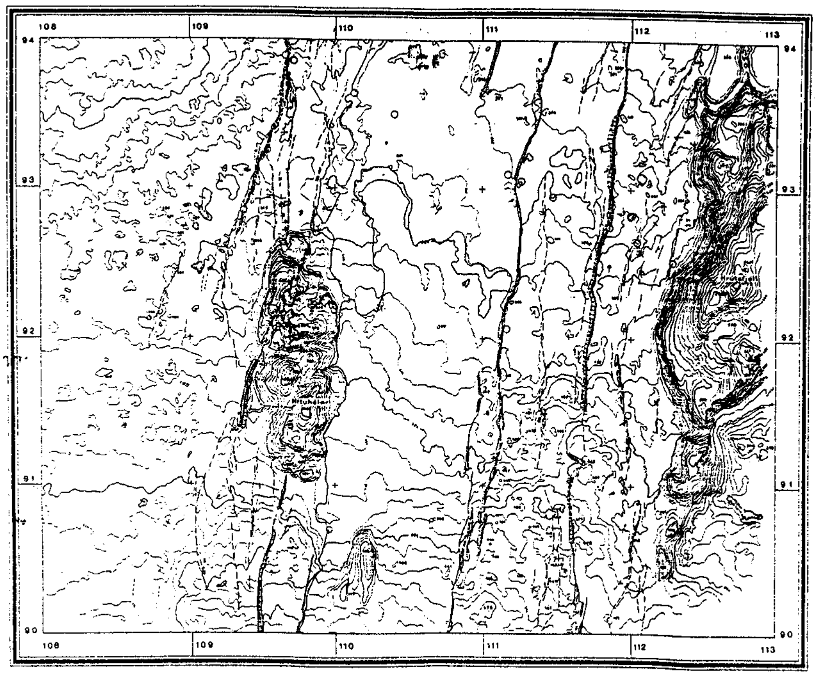

Fig. 3.8: Section of photogrammetric map of Gjästykki (original scale 1 : 20 000)

Point Selection

A total of 111 striking lava formations and the like were selected as check-points within the reference pair of photographs (1976 epoch). The chosen points were irregularly distributed between the terrain elevations Hituholar and Hrutafjöll which lie parallel to the "Spaltenschwarm". The selection of check-points proved to be very difficult because of the partially mediocre photograph quality and the uniform small lava formations.

Correspondence of Points

The 111 check-points of the reference pair of photographs (1976 epoch) were measured conventionally with the analytical plotter. The object coordinates which resulted from this measurement were then used to automatically set the check-points in the photographs of the subsequent epochs. For each image point the scanning position (photo-carriage coordinates) and the transformation parameters for the fixing of the measuring mark position with regard to the CCD cameras were recorded on magnetic tape in addition to the image matrix (0,128 x 128 m^2). The correlation calculations took place in an external computer.

In contrast to the investigation in section 3.1 a method of multi-image correlation was applied in this case, whereby all of the image matrices of a terrain point are simultaneously included in the correlation calculation, as opposed to the method of successive correlation of two images. This is of particular consequence for the estimation of the grey-value gradients.

As for the correlation for two images it is also the case with multi-image correlation that following the area adjustment a point is defined in one of the image matrices under consideration (in this case the left stereo image of the reference epoch) and is then transferred to all other image windows. The coordinates of the check-points determined in this way refer to the local coordinate systems. After transformation into the photo-carriage coordinate system and subsequent reduction to the main point of the image the object coordinates of the check-points were defined using the programme system PAT-B.

Correlation Results

A total of 36 of the 111 originally chosen check-points were eliminated because of poor correlation values. The reasons for elimination originated from various causes. The most frequent errors are to be attributed to 1) the varying light conditions of the two photographic flights. These appeared in the form of altered shadow formations on the extremely rugged surface of the lava, which are then interpreted by the correlation algorithm as object changes. 2) The pronounced tectonic movements between the two photographic flights. These resulted locally in considerable changes in the form of the object structures, which were chosen as check-points. In the correlation calculation such changes can be recognized not only in the large local changes in scale but also in the rotations. 3) The mediocre (poor in contrast) image quality of the photographs of the 1976 photographic flight, primarily at the photograph edges. Minimal variations in contrast lead to low grey-value gradients and thereby to low precision of point correspondence.

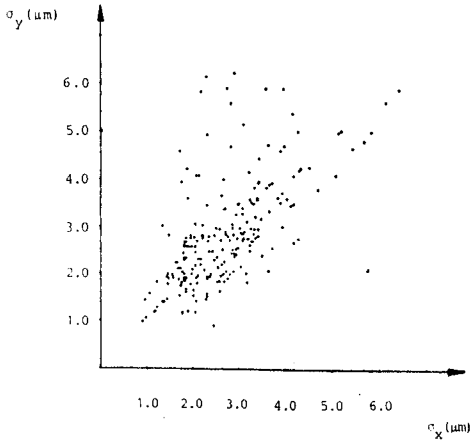

Fig. 3.9: Precision of image point correspondence by digital image correlation

The degrees of precision of point correspondence of the 75 check-points remaining after the ordering process can be seen from Fig. 3.9. The large scattering of the precision values is to be attributed to the differences in image scale and quality of the examined photographs.

Vectors of Shift

Relative horizontal and vertical shifts of the object points were derived from the object coordinates of both comparison epochs. the vectorial field of the relative horizontal shifts (Fig. 3.10) refers to an east-west-oriented shift of the lava surface. The changes in planimetry to the west and east of the "Spaltenschwarm" are oriented in opposite directions. From the vectorial field of the relative changes in altitude (Fig. 3.11) one can recognize a sinking of the region between Hituholar and the "Spaltenschwarm" lying to the east of it and also a rising of the regions north-west of Hituholar and east of the "Spaltenschwarm".

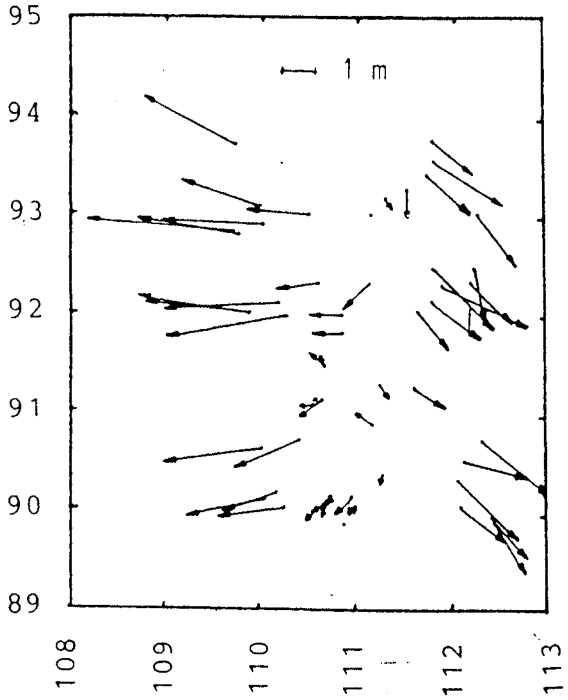

Fig. 3.10: Vectors of relative horizontal shifts

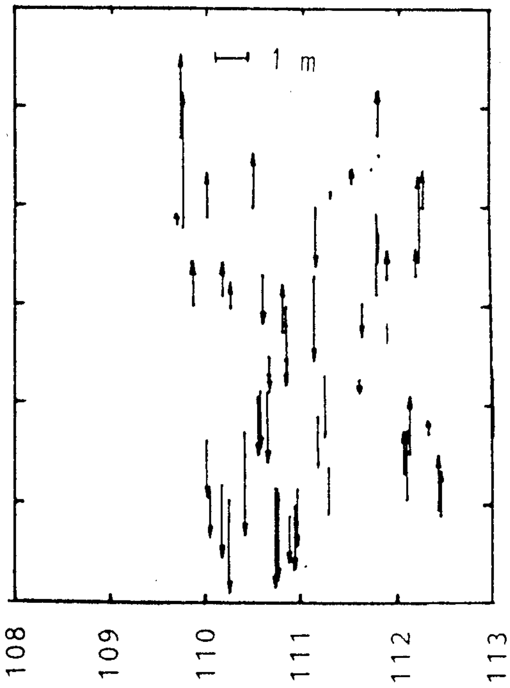

Fig. 3.11: Vectors of relative vertical shifts

Findings

Digital image correlation is suitable as a method of point correspondence for obtaining vectors of shift from photographic series. One can expect reliable results in those cases, in which the observed object structures have undergone only minor changes in form (rotations and changes in size) between the observation times. If the objects do not clearly differ from their surroundings an incorrect correspondence (secondary maximum values) can then not be excluded. The automatic approximate adjustment of the image points is taken over by the analytical plotter. If large changes of shift of the objects occur this can then lead to the exceeding of the functional range of correlation (here < 80 µm in the image). In such cases the operator intervenes in the measurement process. Other solutions are suggested in Förstner (1985).

4. Conclusion

Digital image correlation according to the method of least-squares is an efficient procedure for the correspondence of image points. The procedure can support the visual system of photogrammetric stereo measurement or alternatively replace it. Suitable image textures are a prerequisite for highly precise correspondence of image points. The correlation algorithm yields texture-dependent criteria of quality, by means of which one can recognize incorrect correspondences of various image details and image errors etc. Incorrect correlations of similar objects cannot, however, be excluded.

The software realisation with the Planicomp system of the correlation algorithm by least-squares is at present restricted to a maximum matrix size of 16 x 16 pixels because of the restricted host storage capacity and the desired on-line operation.

An average time consumption of six seconds is required for a single parallax measurement including the recording of data.

The correlation calculations for the pilot studies from the photogrammetric areas of application of aerial triangulation and deformation measurement were not carried out in the system computer of the analytical plotter because of the simpler handling of the large quantities of data. The excellent results of the pilot study for point-transfer in aerial triangulation (σ_0 = 4.0 µm for natural points) are the reason for testing this method of point-transfer in future projects.

Still open is the question of which strategy yields the best solution for the approximate definition when recording object surfaces. In the pilot study the scanning of the object surface took place profile by profile. The advantages or disadvantages presented by arrangements of measuring points either in raster-form or irregular in form are not the theme of this contribution. Förstner (Förstner, 1985) for example and Kories (Kories, 1985) concern themselves with these problems in their individual lectures.

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Abstract

Stereophotogrammetry is based on parallax measurements or on measurements of image coordinates, from which parallaxes can be derived.

In this contribution some results from empirical investigations of the automatic parallax measurement gained by means of a standard system of photogrammetry are presented.

In this case the best match of corresponding image points is found by a least-squares method of digital image correlation.

In a first step it is shown which parameters mainly influence the precision and time consumption of parallax measurement by digital image correlation.

Subsequently the automatic parallax measurement will be tested on three different applications of stereophotogrammetry . In the case of point transfer in aerial triangulation the precision of the image matching algorithm is of greatest importance, whereas, on the other hand, the most important factor when dealing with the examples of partial automatic surface measurement and the measurements for deformation analysis is the proof of functional operation.

EMPIRISCHE ERGEBNISSE DER AUTOMATISCHEN PARALLAXENMESSUNG

Zusammenfassung

Die Stereophotogrammetrie stützt sich auf die Parallaxenmessung oder die Messung von Bildkoordinaten, von denen Parallaxen abgeleitet werden können.

In diesem Beitrag werden die Ergebnisse empirischer Untersuchungen zur automatischen Parallaxenmessung vorgestellt, die mittels eines photogrammetrischen Standardsystems erzielt wurden.

In diesem Fall wird die beste Zuordnung homologer Bildpunkte durch digitale Bildkorrelation nach der Methode der kleinsten Quadrate erreicht.

Zuerst wird gezeigt, welche Parameter hauptsächlich die Genauigkeit und den Zeitaufwand der Parallaxenmessung mit digitaler Bildkorrelation beeinflussen.

Nachfolgend wird die automatische Parallaxenmessung anhand von drei verschiedenen Anwendungen im Bereich der Stereophotogrammetrie überprüft. Im Fall der Punktübertragung für die Aerotriangulation ist die Genauigkeit des Bildzuordnungsalgorithmus von größter Bedeutung. Handelt es sich andererseits um Beispiele der teilautomatischen Oberflächenmessung und der Messung zur Deformationsanalyse, so ist der Nachweis der Funktionstüchtigkeit der wichtigste Faktor.

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precision of point correspondence				error elipses				
image no.	σ_x(µm)	σ_y(µm)	σ_p(µm)	ϕ(gon)	A(µm)	B(µm)	σ_0	ρ
1	0,7	0,6	0,9	14,3	0,7	0,6	4,9	0,981
2	1,7	1,4	2,2	18,9	1,7	1,4	5,5	0,932
3	2,2	2,3	3,1	-42,0	2,4	2,1	6,9	0,891
4	2,5	1,7	3,1	-12,2	2,5	1,7	7,4	0,879
5	3,5	2,1	4,1	24,7	3,7	1,7	16,3	0,870
6	3,0	3,4	4,6	-39,2	3,7	2,6	11,7	0,737
7	3,3	2,1	3,9	26,7	3,5	1,7	17,0	0,908
8	0,8	0,6	1,0	8,1	0,8	0,5	7,8	0,976
9	0,8	0,6	0,9	-13,9	0,8	0,5	4,0	0,987
10	0,8	0,6	1,3	-37,7	1,0	0,8	5,9	0,991
11	1,1	1,0	1,5	-35,0	1,2	0,9	8,3	0,973
12	0,8	0,6	1,0	9,9	0,8	0,6	5,1	0,988
13	1,1	1,3	1,7	-35,7	1,4	0,9	3,0	0,992
14	0,8	0,8	1,1	-14,7	0,8	0,7	6,7	0,955
15	0,6	0,4	0,7	14,4	0,5	0,5	4,3	0,979
16	5,6	4,8	7,4	-1,1	5,6	4,9	18,3	0,678
17	4,0	4,2	5,8	-17,8	4,3	3,9	13,2	0,771
18	1,0	1,0	1,4	46,0	1,2	0,8	4,4	0,991
19	1,0	1,4	1,7	0,8	1,3	1,0	4,3	0,993
20	2,4	1,4	2,8	-23,8	2,6	1,2	11,2	0,976
21	2,0	2,0	2,8	-12,8	2,0	2,0	4,9	0,983
22	0,8	0,8	1,1	37,0	0,9	0,6	4,4	0,989
23	1,8	4,6	4,9	-23,1	4,8	0,8	6,6	0,996

σ_x theoretical accuracy of point transfer in x direction

σ_y .... in y diretion

$\sigma_p = (\sigma_x^2 + \sigma_y^2)^{\frac{1}{2}}$

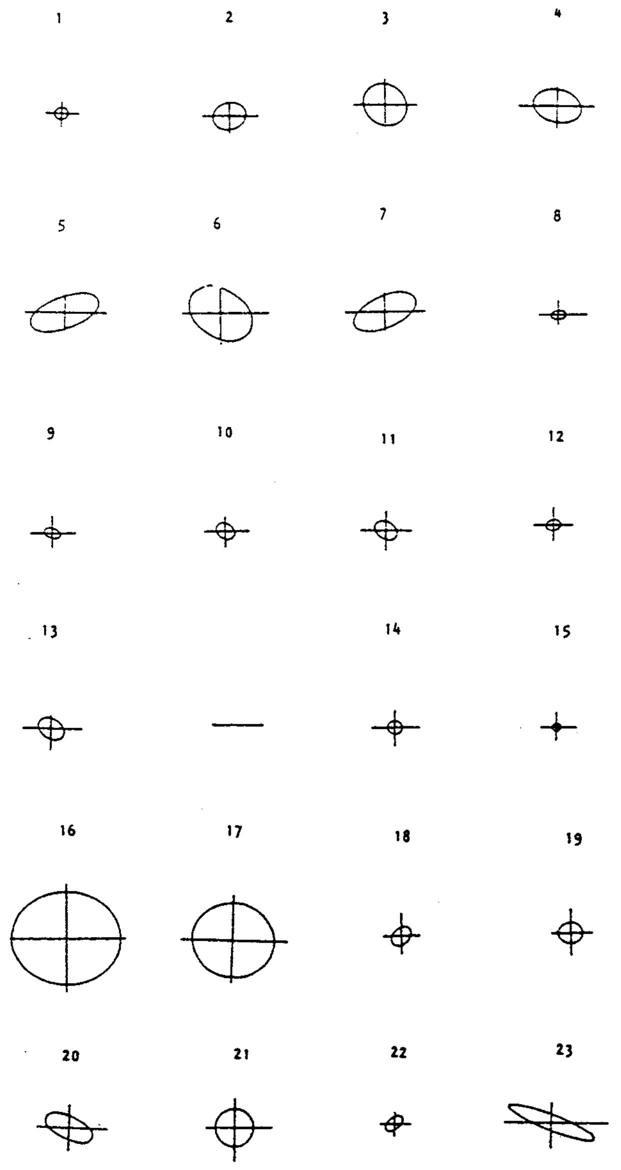
ϕ azimuth of smimajor axe of error ellipse

A semimajor axe of error ellipse

B semiminor axe of error ellipse

ρ correlation coefficient

σ_0 standard deviation of unit weight of grey value differences



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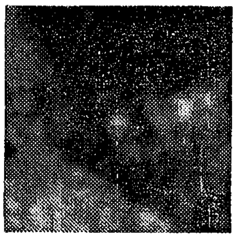

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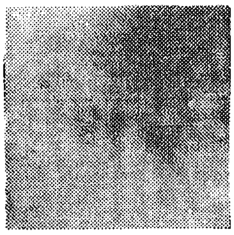

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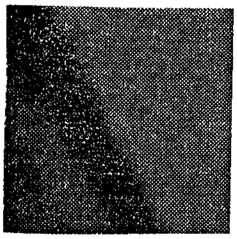

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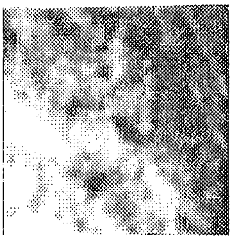

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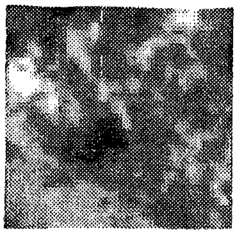

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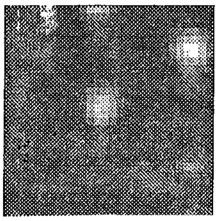

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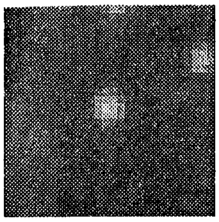

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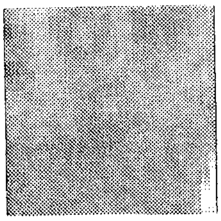

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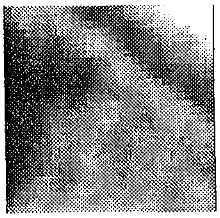

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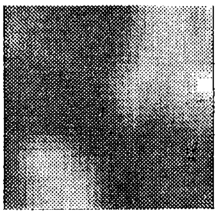

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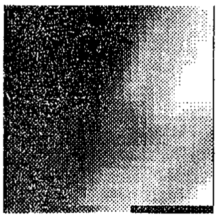

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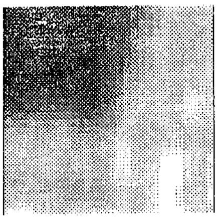

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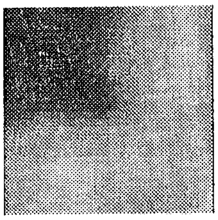

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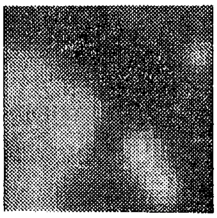

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