A NEW MATCHING APPROACH FOR THREE-LINE SCANNER IMAGERY

C. Wiedemann [1], L. Tang [2], T. Ohlhof [1]

[1] Chair for Photogrammetry and Remote Sensing
Technical University Munich, D-80290 Munich, Germany
Phone: +49-89-2892 2676, Fax: +49-89-280 95 73
E-Mail: wied@photo.verm.tu-muenchen.de

[2] Technical Consulting & Software Development for
Photogrammetry, Remote Sensing and Geoinformatics
Riesstr. 65, D-80993 Munich, Germany
Phone, Fax: +49-89-140 50 34
E-Mail: 101377.3562@compuserve.com

Commision III, Working Group 2

KEY WORDS: Photogrammetry, Matching, CCD, Extraterrestrial, Method, Three-Line Imagery, HRSC, WAOSS

ABSTRACT

This paper deals with the automatic determination of conjugate points in multiple 3-line images of different resolution for the task of image orientation. A program for digital image matching was developed as part of the photogrammetric data processing chain in the context of the planned Mars'96 mission. The matching approach contains three phases: First, a few highly reliable conjugate points are found on the higher levels of image pyramids using feature based matching. In the second phase — also on a higher image pyramid level — a regular distribution of conjugate points is obtained by least squares matching. Finally, the points are tracked down through the image pyramid to the original resolution. The program was tested with terrestrial and extraterrestrial data provided by 3-line scanners as well as by a frame camera. The test results show the applicability of the approach.

KURZFASSUNG

Der vorliegende Beitrag behandelt die automatische Bestimmung homologer Punkte für die Orientierung mehrerer 3-Zeilen-Bilder unterschiedlicher Auflösung. Dazu wurde ein Programm für die digitale Bildzuordnung als Teil der photogrammetrischen Verarbeitungskette im Rahmen der geplanten Mars'96 Mission entwickelt. Der Zuordnungsansatz beinhaltet drei Phasen: Zuerst werden einige sehr zuverlässige homologe Punkte mittels merkmalsbasierter Zuordnung auf einer höheren Bildpyramidenebene gefunden. In der zweiten Phase — ebenfalls auf der höheren Pyramidenebene — wird eine gleichmäßige Punktverteilung durch Kleinste-Quadrate-Zuordnung erreicht. Schließlich werden die Punkte durch die Bildpyramide bis zur Originalauflösung verfolgt. Das Programm wurde mit terrestrischen und extraterrestrischen Bilddaten getestet, die von 3-Zeilen-Scannern sowie einer Flächenkamera stammen. Die Ergebnisse der Tests zeigen die Anwendbarkeit des Ansatzes.

1 INTRODUCTION

This paper deals with the automatic determination of conjugate points in multiple 3-line images of different resolution in the context of the planned Russian Mars'96 mission. In this mission, two different 3-line scanners, the High Resolution Stereo Camera (HRSC) and the Wide-Angle Optoelectronic Stereo Scanner (WAOSS), will be flown on board a Russian spacecraft towards planet Mars, to be launched in November 1996. The quality of the imagery and the stereoscopic coverage of Mars by the combination of HRSC and WAOSS is expected to be superior to the images taken from the former Mariner and Viking missions.

The scientific objectives of the two camera experiments in the field of photogrammetry are concentrated on the acquisition of 3-dimensional information of Mars' topography in local, regional and global scales. For fulfilling these objectives digital image matching is an essential step, as conjugate points are needed for both the reconstruction of the exterior orientation of the images and the generation of Digital Terrain Models (DTM). In this contribution an image matching algorithm is presented for the image orientation task only.

Both HRSC and WAOSS are based on the 3-line CCD concept, in which stereo images are acquired nearly simultaneously (Hofmann et al. 1982). Note that 3 linear CCD arrays are imaging different terrain at the same time, whereas the 3 CCD arrays image the same terrain at different times, as the sensor platform moves. HRSC consists of 9 CCD arrays with 5184 active sensor elements each, and WAOSS contains 3 CCD arrays with also 5184 active sensor elements each. HRSC will operate in the near periapsis region of the orbit around Mars (≈300 km orbital height), whereas WAOSS will work also in more distant orbit segments (up to ≈3,000 km orbital height). The ground track of both cameras in periapsis is depicted in Figure 1. A detailed description of the cameras and its operations is given in Albertz et al. (1993) and Ebner et al. (1994).

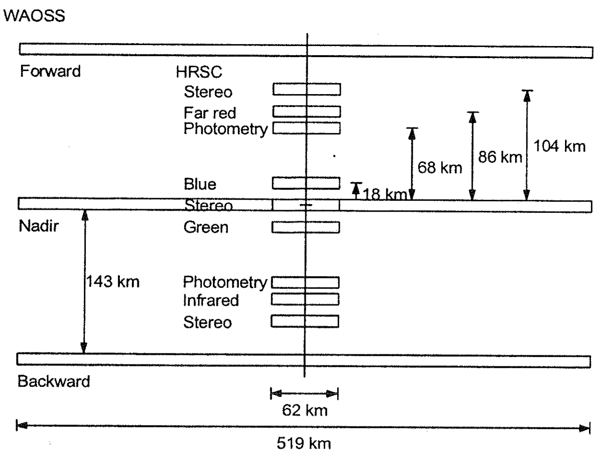

Figure 1: Ground track of HRSC and WAOSS at 300 km orbital height (not true to scale)

The image matching procedure of HRSC and WAOSS data has to consider several factors:

- the highly elliptic orbit, which causes varying ground pixel sizes in the image strips;
- the different ground pixel size of HRSC and WAOSS (normally factor 8);
- the macropixel formation due to the limited onboard storage capacity: the gray values of 4 or 16 pixels are averaged to 1 macropixel;
- changing illumination conditions during the mission;
- poor texture in parts of the image data to be acquired.

In order to improve the accuracy of the subsequent bundle block adjustment, the matching approach has to work with any combination of HRSC and WAOSS imagery taken during the mission. Comprehensive computer simulations on local, regional and global block triangulation have shown, that most accurate results can be achieved, if image strips from many orbital arcs are processed simultaneously in a block of high geometric strength based on a combination of HRSC, WAOSS, orbit, attitude and ground control data (Ohlhof 1996).

The matching approach has to cope with different sets of input parameters. In the most general mode, only a rough estimation of the overlapping area is known. In the nominal case, preprocessed position and attitude parameters and image coordinates of a few ground control points measured interactively are available.

In the next section the matching approach is described in detail. The approach was tested using terrestrial 3-line imagery of the MEOSS and MOMS-02/D2 projects and extraterrestrial frame imagery of the Viking mission. The results of the tests are presented and discussed. Finally, conclusions are drawn.

2 DESCRIPTION OF THE MATCHING APPROACH

In this section we describe the new image matching approach. It mainly consists of a combination of feature based matching and least squares matching. Moreover, image pyramids are incorporated into the strategy. Some special adaptations are necessary to properly deal with several overlapping images recorded by HRSC and WAOSS.

In the first strip[1] one image[1] is selected as the reference image. Then each other image of this strip is matched with the reference image. The resulting pairs of conjugate points receive the number of the point in the reference image. Therefore identification of many-fold points is possible by a simple comparison of the numbers of the pairs.

In case of two or more strips, the concept developed by Heipke et al. (1996) is used. For the subsequent block triangulation, the strips have to be connected by tie points. This task is solved using the concept of point transfer which is well known from analytical photogrammetry. There is one reference image in each strip. The reference image of the first strip is matched with the reference image of the second strip. For points in the reference image of the second strip conjugate points are searched in the other images of this strip. If there are regions with no points transferred from the first reference image, we treat these areas such as in the reference image of the first strip. Then, the reference images of the second and the third strip are matched and so forth. This concept is free regarding the number of strips in the block.

The concept described above starts on a higher level (e.g. 4 or 5) of the image pyramid. If a sufficient number of conjugate points have been found, they are tracked up to the original images. In Figure 2 the general work-flow is shown, the single steps are explained in the following sections.

2.1 Input Data

The input data consists of a set of images, some initial information about their exterior orientation and a set of control parameters.

Images. The images with smaller ground pixel size have to be resampled to the largest common ground pixel size of all images if there is a significant difference between the image scales (factor 2 or more). For our task, this step is necessary if images from both HRSC and WAOSS, or if images with different macropixel formation are to be matched. Starting from the common resolution level, an image pyramid for each image is generated.

Initial Orientation Information. Information about the exterior orientation of the images has to be provided by control points, orbital data or both of them. For our task, control points will be available from the existing ground control net of Mars. Besides the control points orbital information, i.e. information about position and attitude of the scanner for each recorded image line, will be available. According to Montenbruck et al. (1994) this information is expected to be very precise ($\sim$ 10 m, 4″) within one flight

[1] One *strip* is normally acquired during one imaging sequence and consists of at least 3 *images* (image strips) recorded by the fore-, nadir-, and aft-looking CCD arrays.

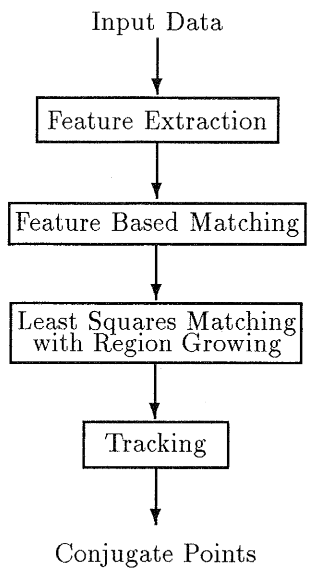

Figure 2: Work-flow of the matching concept

path, i.e. the relative accuracy will be very good. The absolute accuracy, however, will be in the order of 1 km and $2'$ respectively. Consequently, it will be sufficient to use the orbital data solely, if only images of one single strip are matched. In order to connect images of different strips (orbital arcs), tie points should be available.

2.2 Feature Extraction

Feature extraction is performed on the highest level of the image pyramid, i.e. on the level with the lowest resolution. It is carried out for each image independently. Currently the Moravec (1977) interest operator is implemented. This operator do not really locate point features, but a kind of interest areas (Förstner and Gülch 1987). Within these areas significant differences of the gray values exist in each of the four main directions. For this reason conjugate points may be found using an intensity based procedure, e.g. gray value correlation. The position of the areas is calculated with an accuracy of one pixel only. Hence the Moravec operator is not suitable for accurate matching but can provide good initial values for a more accurate method (e.g. least squares matching).

2.3 Feature Based Matching

For each interest point of the reference image, the corresponding interest point of the second image is ascertained by calculating the correlation between the image windows in the surroundings of the two interest points. If the correlation coefficient lies above a certain user-defined threshold, the two points are considered as conjugate points. The choice of this threshold influences number and reliability of the conjugate points. In general, a high threshold value (e.g. 0.95) will provide highly reliable points whereas a lower value (e.g. 0.7) leads to a dense but less reliable point distribution.

This matching procedure would be very time consuming and susceptible to ambiguities if each interest point of the second image would be considered as a candidate for a conjugate point. For that reason, for each interest point in the reference image some coarse information about its estimated position in the other image is utilized to build up search areas. This geometric information is taken either from the control points or from the orbital data, from which affine transformation parameters are calculated. As the scale may vary within one image due to the elliptic Mars'96 orbit, it is necessary to partition the image into transformation cells, each having its own set of transformation parameters.

From feature based matching a set of conjugate points is provided. If the acceptance threshold is chosen high, the resulting pairs of conjugate points are reliable but not very dense. The following method is introduced to receive a dense distribution of conjugate points.

2.4 Least Squares Matching

This method consists of two major steps: First, the conjugate points are checked and their accuracy is improved by means of least squares matching (Ackermann 1983). Second, these re-measured points serve as seed points for *region growing* (Otto and Chau 1989).

The number of resulting points mainly depends on the raster spacing of the region growing and the pyramid level on which it is performed. The raster spacing should not be too large, especially in mountainous regions in order to get good approximations for the next points. The pyramid level should be chosen dependent on the complexity of the image data, e.g. if there are only structures of only a few pixels width which possibly disappears on higher pyramid levels, a lower start level have to be chosen.

To speed up the matching procedure, least squares matching with region growing normally is performed only once on a higher pyramid level (e.g. level 5, where one pixel consist of $32 \cdot 32$ pixel of the original image).

2.5 Tracking

If the parameters (step size, pyramid level) are chosen appropriately, enough conjugate points are generated by least squares matching. To improve the accuracy, the conjugate points are projected on the next lower pyramid level and remeasured using least squares matching. This step is repeated until the lowest level is reached. The number of points decreases because of

- wrongly matched points which are eliminated on different resolution levels
- the non-linear change of texture within the image pyramid

3 PRACTICAL TESTS

In this section we present results of the new matching approach. To this end, three different image sets have been selected. Two of them were taken by 3-line scanners whereas the third was acquired by a frame camera. For all image sets we used six manually measured tie points per image as initial information.

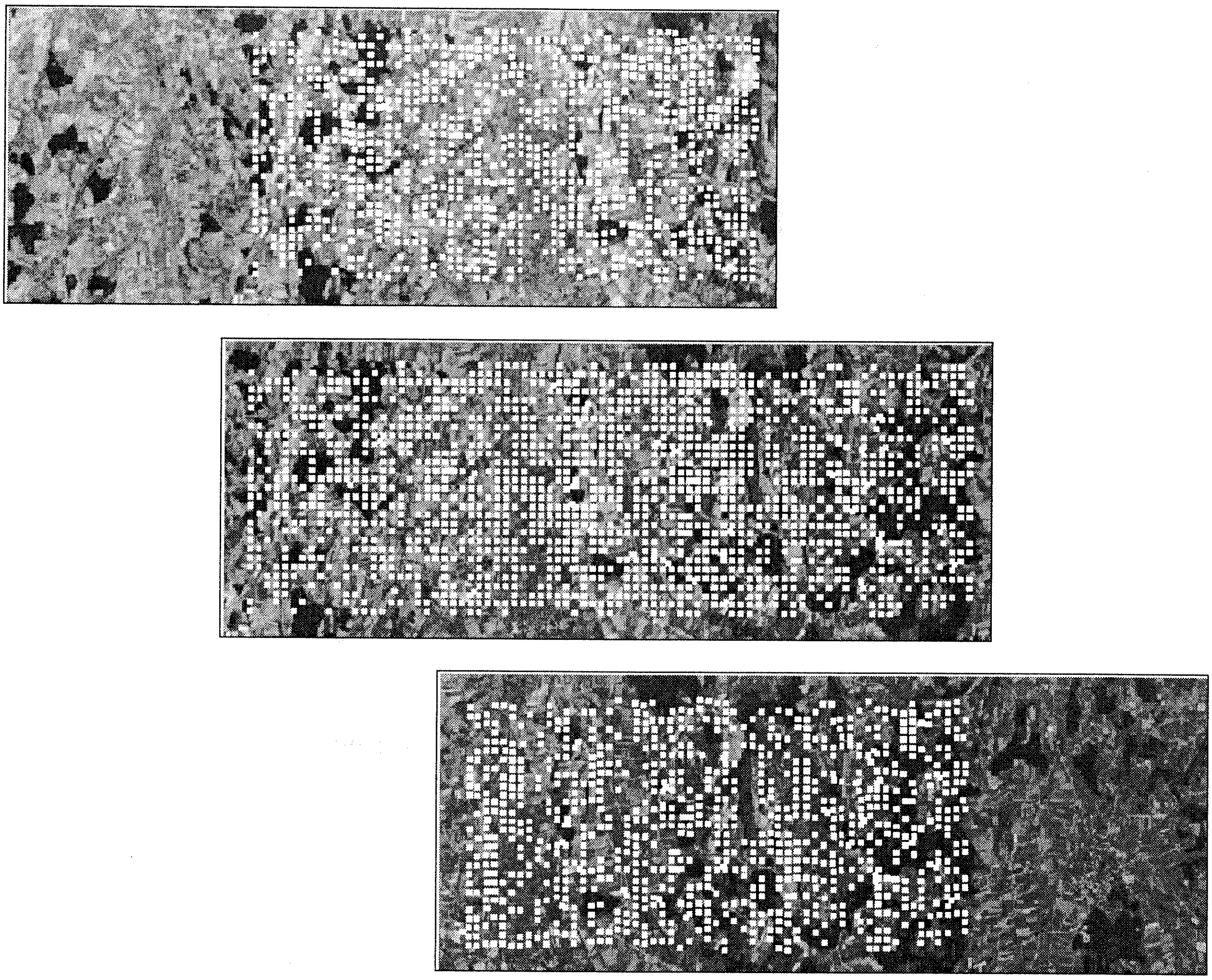

Figure 3: MEOSS images from the forward-looking (upper), nadir-looking (middle), and aft-looking (lower) CCD arrays with conjugate points (flight direction is from left to right)

3.1 MEOSS

In Figure 3 images from a rural scene are displayed. They were taken by MEOSS (Monocular Electro-Optical Stereo Scanner) during an airborne testflight in 1989. Each image has a size of about 8400 × 3200 pixel and a ground pixel size of 2.0 m.

1771 conjugate points — superimposed in white — were found, which are well distributed across the overlapping area. The region growing has been performed at pyramid level 4 with a step size of 6 pixel.

A bundle adjustment was carried out to check the matching accuracy and the number of remaining gross errors. The results indicate an accuracy of the image coordinates of 0.2 pixel, and less than 3% of the image points were detected as gross errors.

3.2 MOMS-02/D2

In Figure 4 two images from the Egyptian desert taken by the 3-line camera MOMS-02 (Modular Optoelectronic Multispectral Stereo Scanner) are depicted. The MOMS-02 scanner was flown on the Space Shuttle during the German D2-Mission in April/May 1993. The images have been acquired from the nadir looking arrays at different orbit arcs with slightly different flight directions ($\sim 5°$). The ground pixel size amounts to 4.5 m in both images. In this example, region growing was performed at level 5 of the image pyramid. Due to poor texture in parts of the images in combination with the high level for the region growing, only a few points could be found.

To improve the result, we started a second region growing at pyramid level 3. This leads to a very dense distribution of conjugate points (Figure 5). In regions with very little texture, however, no points were determined.

To demonstrate the improved performance of the new approach, we applied least squares matching with region growing solely on pyramid level 0, which leads to inadequate results (Figure 6). Note that initial values and control parameters were identical to those of the new approach.

3.3 VIKING

Figure 7 represents a pair of stereo images from planet Mars, taken by a Vidicon frame camera from the VIKING

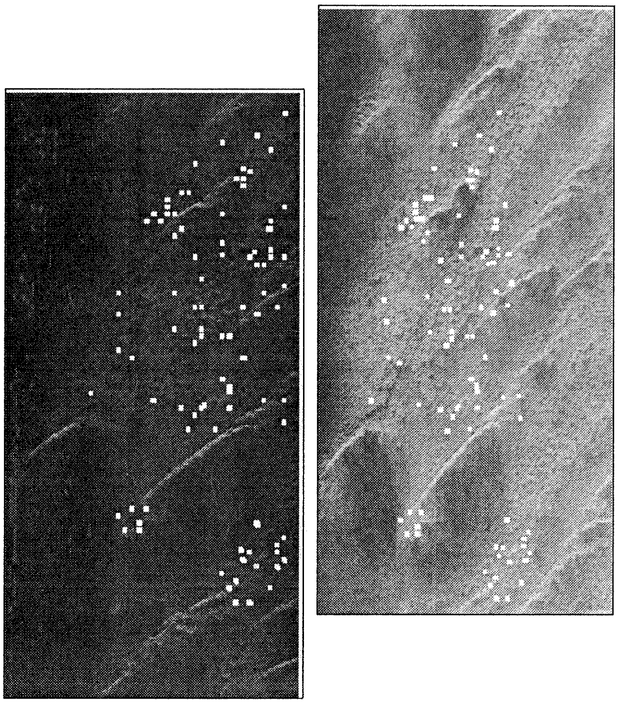

Figure 4: MOMS-02/D2 imagery (flight direction is from top to bottom) from two different orbit arcs with conjugate points (region growing at pyramid level 5)

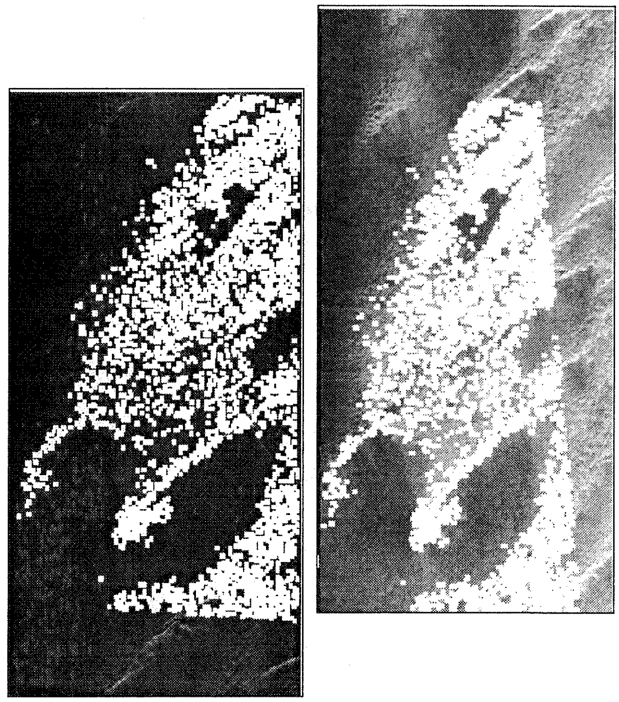

Figure 5: MOMS-02/D2 imagery with conjugate points (additional region growing at pyramid level 3)

spacecraft. Again, the conjugate points are superimposed. In the right part of the images the surface steeply drops away leading to clearly visible texture. The left part shows flat terrain with little texture and some craters.

As could be expected, the distribution of the conjugate points is sufficient in the right part of the images. In the left part, however, only a few points could be found. At first glance one might think that there is enough structure to guaranty conjugate points not only at craters (cf. Figure 8). By comparing the left part of the two images in more detail, it becomes clearly visible that there is almost no direct correspondence between them. The only corresponding features, besides the craters, are some linear structures running from the top left towards the bottom of the images. With regard to the gray values within a local area around them, their appearance is very different in the two images. Therefore, point features based on local interest windows will probably not serve as correct candidates for conjugate points. Lines or other more abstracted features than points may be better suited for this kind of images.

4 CONCLUSIONS

We have proposed a new approach for the matching of 3-line imagery, which is based on a combination of feature based matching and least squares matching. We exploit the fact that feature based matching is less demanding concerning the accuracy of initial values. The least squares region growing algorithm utilizes the initial values determined previously by feature based matching and provides a regular distribution of conjugate points. Least squares matching without region growing is used to improve accuracy and reliability of the final points.

The application of our approach was investigated using 3-line airborne (MEOSS) and spaceborne (MOMS-02) as well as extraterrestrial frame (VIKING) imagery. The results demonstrate the ability of the approach, even for cases where conventional least squares matching fails. By the choice of the region growing start level and the step size, the number of conjugate points can be adapted to different needs. Airborne 3-line imagery, for instance, requires a large amount of conjugate points, whereas spaceborne (satellite) imagery needs only a small number of points.

5 REFERENCES

Ackermann F. (1983): High Precision Digital Image Correlation. Schriftenreihe des Instituts für Photogrammetrie der Universität Stuttgart, Nr. 9, 231–243.

Albertz J., Scholten F., Ebner H., Heipke C., Neukum G. (1993): Two Camera Experiments on the Mars94/96 Missions; GIS **6**(4), 11–16.

Ebner H., Ohlhof T., Tang L. (1994): Eine Studie zur Bildzuordnung und Punktbestimmung im Rahmen der Mars94-Mission; Zeitschrift für Photogrammetrie und Fernerkundung **62**(2), 57–71.

Förstner W. and Gülch E. (1987): A Fast Operator for Detection and Location of Distinct Points, Corners and Centres of Circular Features; ISPRS Intercommission Conference on Fast Processing of Photogrammetric Data, Interlaken, Schweiz.

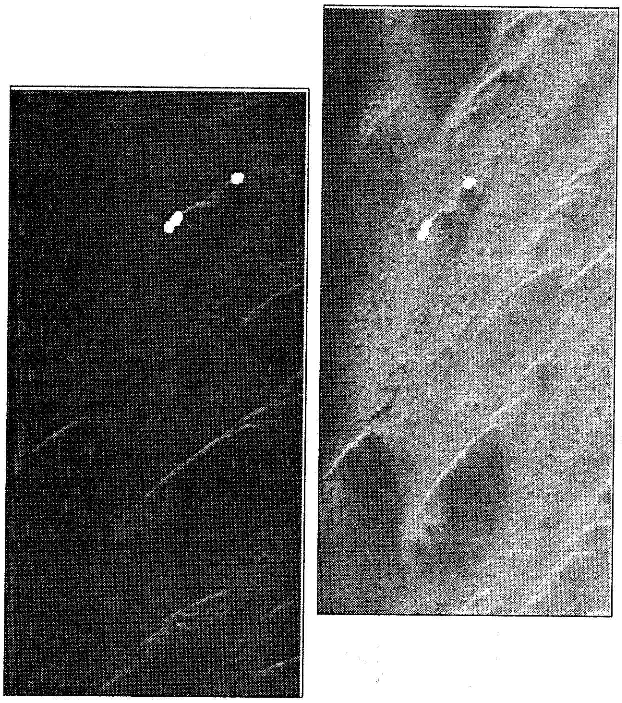

Figure 6: MOMS stereo images with conjugate points (region growing at pyramid level 0)

Heipke C., Kornus W., Pfannenstein A. (1996): The Evaluation of MEOSS Airborne 3-Line Scanner Imagery – Processing Chain and Results; Photogrammetric Engineering & Remote Sensing, **62**(3), 293–299.

Hofmann O., Navé P., Ebner H. (1982): DPS — A Digital Photogrammetric System for Producing Digital Elevation Models (DEM) and Orthophotos by Means of Linear Array Scanner Imagery; International Archives of Photogrammetry and Remote Sensing, **24**(3), 216–227.

Montenbruck O., Gill E., Ohlhof T. (1994): A Combined Approach for Mars-94 Orbit Determination and Photogrammetric Bundle Adjustment; DLR-Forschungsbericht 94-13, 95 p.

Moravec H.P. (1977): Towards Automatic Visual Obstacle Avoidence; 5th International Joint Conference on Artificial Intelligence, 584.

Ohlhof T. (1996): Local, Regional and Global Point Determination Using 3-Line Imagery and Orbital Constraints; Presented paper at the XVIII. ISPRS Congress Vienna, July 9–19, Commission III.

Otto G.P., Chau T.K.W. (1989): "Region growing" Algorithm for Matching of Terrain Images; Image and Vision Computing **7**(2), 83–94.

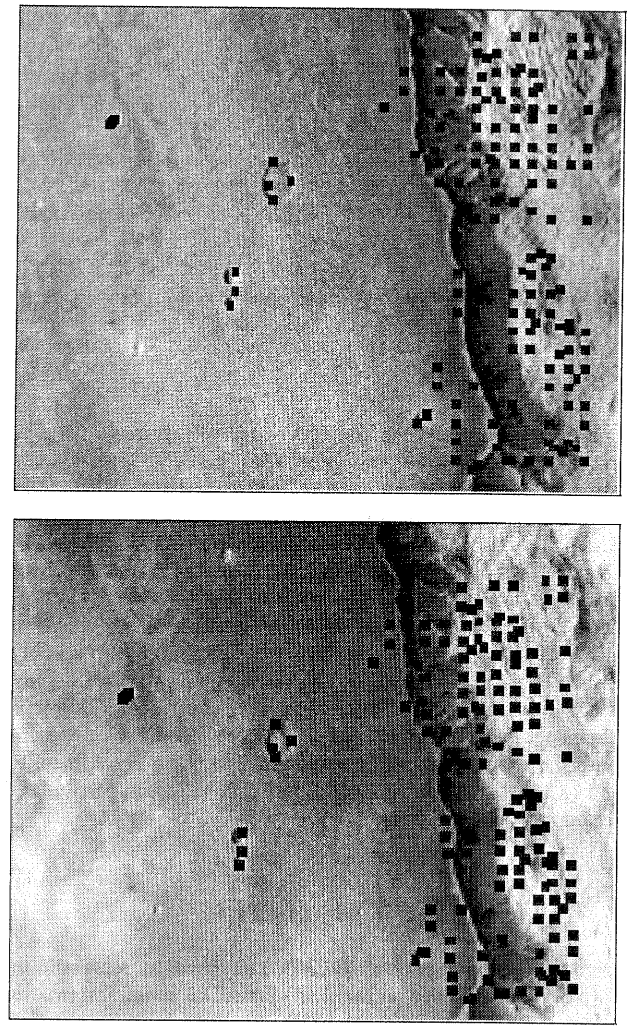

Figure 7: VIKING stereo images from Mars with conjugate points

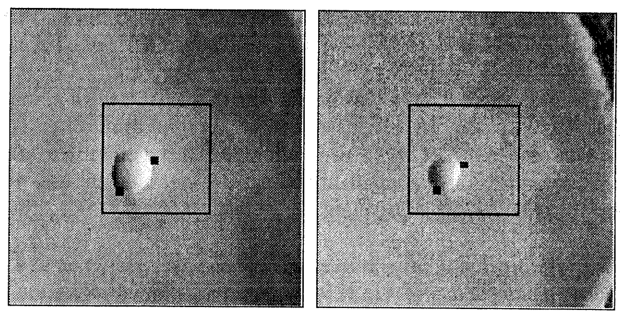

Figure 8: Parts from the VIKING stereo images with conjugate points