

# RG-DW IMAGE MATCHING SCHEME AND ITS APPLICATION

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## Abstract

*In this article we report on research performed at the Ohio State University to automatically extract digital elevation models and orthophotos from satellite images and digital aerial photographs to implement the integration of digital data into GIS. The focus of this research was to develop an operational image matching technique to automate the whole process for acquiring digital elevations. In contrast to many others, our RG-DW (Recursive Grid—Dynamic Window) matching scheme does not need any a priori knowledge about image orientation nor any information of object space, it takes advantage of the parallelism of the matching scheme and makes a comprehensive utilization of a series of simple concepts as elementary tools, such as pyramid images, geometric transformation, multiple dynamic window size, cross-correlation and least squares matching. The only approximations needed can be taken from four corresponding points of the overlapping area of a stereo model. Matches are obtained over the whole area of interest by recursively densifying a regular grid through scale space. This matching scheme was applied to develop the package MATCH for automatic image matching for both SPOT and aerial photos, which is the key part of the Digital Ortho Module, the new commercial digital photogrammetric module recently released by ERDAS Inc. MATCH has been fully integrated in a raster GIS, together with a variety of functions to compute the orientation of satellite and aerial images, to perform the matching, to interpolate a grid DEM, and to create digital orthophotos. Thus, digital image data can be directly analyzed in the GIS.*

**Key words:** Image Matching, Digital Photogrammetry, GIS, SPOT Image, Aerial Photo

## 1. INTRODUCTION

Image matching, one of the central problems for automating photogrammetry, is the key to simulating the function of human vision to replace a human to do stereo observation and measurements by computer. An overwhelming diversity of approaches proposed by many researchers who tried to tackle the matching problem shows its very high complexity and difficulty. It seems that the proposed methods are getting more and more complicated. However, whether area-based/signal matching (cross-correlation or least squares correlation), feature-based matching, relational or global matching approaches, and whether simple or complex, the real goal of matching is to utilize a computer to collect a mass of corresponding points from a stereo pair of images, just like a human operator observes the stereo pair on a plotter. Once the successful matching results are available, the reconstruction of the 3-D object space can be done more easily by using traditional photogrammetric concepts and techniques. The Recursive Grid—Dynamic Window (RG-DW) technique introduced in this paper is such a matching technique which simulates the function of a human operator to do matching without involving any other processes. The only difference is that with the RG-DW technique, computers find matched points much easier, faster and more cost-effective than human operators do.

The RG-DW utilizes a series of simple concepts as elementary tools, such as pyramid images, geometric transformation, multiple dynamic window size, cross-correlation and least squares matching to perform a successful matching for both SPOT and aerial photos. The RG-DW matching scheme, unlike many other matching approaches, is free of any ground approximations or image orientation, and achieves rather high success rates. Especially, if array processors or parallel computers are available, it will be easy to implement this technique, and match hundreds or even thousands of points in a second.

The RG-DW matching scheme was proposed by the authors at the beginning of 1991 (Lue and Novak 1991). At

the ASPRS Annual Convention in March, 1991, in Baltimore, the first matching results for SPOT images with the RG-DW technique were exhibited and provoked interest there. At the GIS/LIS and ASPRS Fall Convention in October, 1991, in Atlanta full matching progress and successive products—DEM and orthophotos—were demonstrated by ERDAS Inc., our commercial partner in this joint research project, again drew interest. This was followed by the sophisticated process of multiple experiments to optimize the software and finally make it operational and user friendly. MATCH, based on the RG-DW technique, as the key component of the new commercial digital photogrammetry module Digital Ortho Module, was released by ERDAS Inc. at the beginning of this year (ERDAS, 1992, Lue and Novak, 1992).

In the following chapter, the concept of RG-DW is briefly outlined, and then some characteristics of RG-DW are discussed. The final part gives some matching results of Digital Ortho Module. The images used to get matching results in this paper include three types: SPOT images, digitized normal aerial photographs and digital aerial photos taken by the MapCam System developed by the Center for Mapping of the Ohio State University (Novak, 1992). The other parts of digital photogrammetry, such as aerotriangulation, intersection, DEM interpolation, orthophoto generation are not described.

## 2. THE RG-DW MATCHING SCHEME

In the early research stage of image matching, area-based matching with simple concepts was predominantly used. The normal area-based matching methods have a rather small pull-in range, and the required approximations are usually taken from previous matching results or existing data. As long as the images to be matched, however, have a good quality, contain enough information, and are free of water or clouds, reasonable results can be expected. Otherwise systematic matching errors or even failure to match may occur due to inaccurate or even wrong approximations. Theoretically, least squares matching (LSM) and its variants such as multi-point LSM or LSM with geometric constraints,

which belong to area-based matching, can reach subpixel accuracies, its pull-in range, unfortunately, is even smaller, that is to say, very precise approximations have to be provided.

It is evident that the approximation problem is critical for area-based matching. In recent years results of feature matching are often used as approximations for area-based matching. Although the complexity of matching increases in this way, the results are still not always satisfactory, especially in areas without any features. On the other hand, global approaches to perform matching in object space have been studied intensively to utilize additional information to strengthen matching results. Some global approaches like MATCH-T (Ackermann and Hahn, 1991), no longer need precise approximations, at the price of a very high complexity.

The RG-DW scheme described in this paper is one kind of area-based matching based on some simple and common concepts and methods. The strategies employed in the scheme, however, are unique, and aim at both performing good matching and keeping the procedure relatively simple.

### 2.1 RG — Recursive Grid

Usually, the relative geometric distortion between two images, which form a stereo pair, is not too great. Suppose, using a simple geometric transformation, e.g., bilinear or affine transformation, to approximately describe this distortion. Once the conjugate image coordinates of four points at the four corners of the overlapping area of a stereo pair are known, the transformation parameters between the two images and rough positions of any corresponding points, can be easily calculated. Although using these coordinates as approximations may be too rough to be accepted by general area-based matching, the situation is certainly changed if pyramid images are used. The Recursive Grid is just based on this idea.

As shown in figures 1 and figure 2, at first we use the approximate conjugate coordinates of the four corner points to calculate the geometric transformation parameters between two images of the level 3 of pyramid images and to derive an irregular grid on the right image, which is correspondent to the regular grid on the left image (figure 2). Using the rough conjugate grid as approximations, the accurate corresponding points can be obtained by using the Dynamic Window method, which will be explained below, and then transmitted through scale space to the next pyramid level. Finally a sparse grid with rather high reliability is available in the original images. By recursively using the sparse conjugate grid points as anchor points to calculate new geometric transformation parameters for each conjugate square, a dense set of corresponding grid points can be obtained. It is clear that the smaller the interval between two anchor points, the better the approximations of points in between will be. If the interval between anchors is small enough, the final dense conjugate points can be directly acquired on the original images instead of through pyramid images by using the Dynamic Window method. This case, in which we proceed, from anchor points directly to a final dense grid, is called *two-stage* RG-DW; if we move from anchor points to the next level of anchor points and then to densification, it is called *three-stage* RG-DW. Two or three stages can be chosen depending on the images and the applications as well as user preference. Someday soon parallel processing with the RG-DW scheme will allow simultaneous calculation of all required corresponding as anchor points, that will be called *one-stage*, of course.

Obviously, the determination of each anchor point is done by searching from the top level of pyramid images down to the original image, and on each level of the pyramid a set of windows with different sizes is used, so that a reliability index, based on the searching and matching status can be labeled to each anchor point. The higher the index, the better the reliability. For a few anchor points with index values less than a threshold, a measure such as automatic shifting of the point position, interpolation, or an interactive

editing mode can be easily used to improve the reliability of the matching results. In the interactive editing mode the matching results are overlaid on top of the original images with different colors representing the matching reliability indices, so that the user can delete or correct wrong matches.

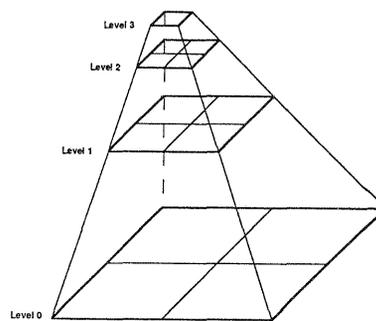


Figure.1 The pyramid image for pyramid matching

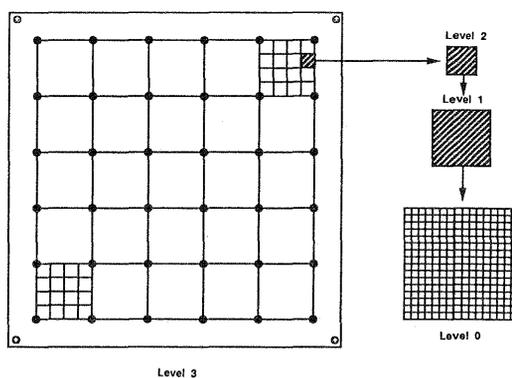


Fig. 2 The concept of the recursive grid method

### 2.2 DW — Dynamic Window

Different window sizes often result in different matching results. The question is, if there is an optimal window size for matching? If so, is the optimal window size applicable to different images? This question is hard to answer, actually. In general, the reliability of matching increases with enlarging the window size. In the case of using a larger window size, however, the matching accuracy decreases, or even lost matching may happen, if there is a major geometric distortion between the two images to be matched. In addition, computing expense rises quickly with enlarging the window size. On the other hand, with a smaller window size the computing effort is smaller, but wrong matches may occur frequently, if there is not enough feature information or there exist repeating patterns in the area to be matched.

In order to take advantage of both large and small windows and to increase the reliability of matching, a dynamic windows is adopted in the RG-DW scheme. For each pair of points to be matched a set of at least three windows from small to large are used for each pyramid image level. Only if matching results of different windows are similar, is the matching considered successful. Otherwise the window size is enlarged until the correct match is found or the window size reaches a certain threshold. In most cases, the matching quality of all windows, such as a cumulation of all correlation coefficients as an index, indicates the reliability of the matching quite well. The indices range from 1 to 12 in our case. If we overlay matching points over the original images and represent the reliability indices with different colors, the matching quality can be visualized and corrected.

It should be pointed out, that during matching the searching range on the right image is changed for each

matching window and for different levels of the pyramid images. If the approximate range of elevations in the overlapping area is already known, it is easy to derive a searching range for different cases. Otherwise approximate geometric transformation parameters can be used to derive it. The searching range should decrease with increasing the level of pyramid images when we consider image resolution. On the other hand, when we consider the matching strategy from the top level down to the original image, i.e., acquired approximations are getting better from the top level down, does the searching range decrease with decreasing the level. Generally, we define the searching range as large as possible on the top level of the pyramid images to avoid the possibility of losing matching.

### 3. DISCUSSION

In this section some characteristics of the RG-DW matching scheme are discussed.

#### 3.1 Simplicity

As described above, the RG-DW scheme combines the advantages of very simple elementary tools. Without introducing any complicated concepts and algorithms, and without any a priori knowledge about images and object space, the RG-DW can be easily programmed and applied to match satellite images and aerial photos.

#### 3.2 Reliability

For each anchor point a total of at least 12 windows of different sizes are used to do the matching. They are compared to each other, so that the percentage of wrong or lost matches drops dramatically compared to the case where only a single window is used to do the matching.

#### 3.3 Accuracy

Many experiments with the RG-DW show that the matching accuracy is very satisfactory, therefore the results can certainly be used as very good approximations of a successive least squares matching to get subpixel accuracy.

#### 3.4 Independence

As mentioned before, the RG-DW does not rely on any a priori knowledge about image orientation or information about object space. The only thing to do before performing matching is to very roughly determine the four corner points at the overlapping area of the stereopair of images. The whole matching process can be completed independent of other processes such as image orientation. In other words, once a stereopair of digital images is on hand, matching with MATCH can be implemented. On the other hand, approximations for all points to be matched can be derived from the first geometric transformation parameters, i.e., each point can be processed independently.

#### 3.5 Parallelism

It is clear that this characteristic directly comes from the independence of the RG-DW noted above. Because the required initial values for cross-correlation of each point are directly derived from the geometric transformation parameters between the two images, it is very convenient to perform a parallel processing, i.e., all points to be matched can be derived at the same time, if array processors or parallel computers are available.

On the other hand due to this parallelism, systematic matching errors are greatly eliminated.

### 4. RESULTS

The software package MATCH based on the RG-DW is the kernel of a new commercial digital photogrammetry module, the Digital Ortho Module of ERDAS Inc.. It has been applied for both SPOT images and aerial photos. The success rate of matching results (SRMR) is quite high. For two pairs of full SPOT (1A) success matching was performed at different grid intervals. For the case with an

interval of 240 pixels, 484 (22 x 22) anchor points were matched, which are homogeneously distributed over the whole overlapping area. The point were visually checked on the screen of a Sunsparc 1 workstation with full image resolution. The SRMRs of both pairs are 96 percent. Most wrongly matched points fell into clouds or empty areas without information. Figures 3 and 4 show one of the pairs. Figure 3 is the pair of original images with 6000 x 6000 pixels and figure 4 shows the anchor point matching results. The SRMR for densification is similar as the anchor points according to the visual color examination method mentioned above. If those anchor points with lower reliability indices values had been interactively corrected, the SRMR of successive matching would increase. Figure 5 shows densification matching points in a small area (512 x 512 pixels) of figure 3. It can be seen that even though there exists quite a big geometric distortion, the matching results with the RG-DW are still good. Figure 6 is a DEM created from the matching results of figure 3. Figure 7 is a perspective view derived from figure 6.

Figures 8 to 12 are results of aerial photos digitized with a pixel size of 100 microns. Figure 8 shows a pair of original images and some anchor points. Figure 9 and 10 display two parts of densification matching results (512 x 512 pixels). Figure 11 is the DEM derived from the densification matching results of the overlapping area. Figure 12 is a perspective view of the DEM overlaid with the orthophoto. Figure 13 shows matching results from aerial photos taken by a CCD camera installed in a helicopter.

It should be noted that all results displayed here are direct results without any correction by the human operator, so some inconsistent situations may be found in the figures. For visibility, the sizes of crosses representing matched points in the images were enlarged.

Although the authors did not optimize the program, it is acceptable for current use, for example, the run time of MATCH for the full scene of figure 3 with intervals of five pixels on a Sunsparc 2 was about 24 hours.

### 5. OUTLOOK

The RG-DW scheme with its simplicity, reliability and parallelism, and its practical application shows that it is a promising image matching technique. Further investigations will be concentrated on the following aspects:

1. Postprocessing - make use of some existing conditions to automatically detect and delete wrong matches.
2. Investigate and design parallel algorithms with the RG-DW.

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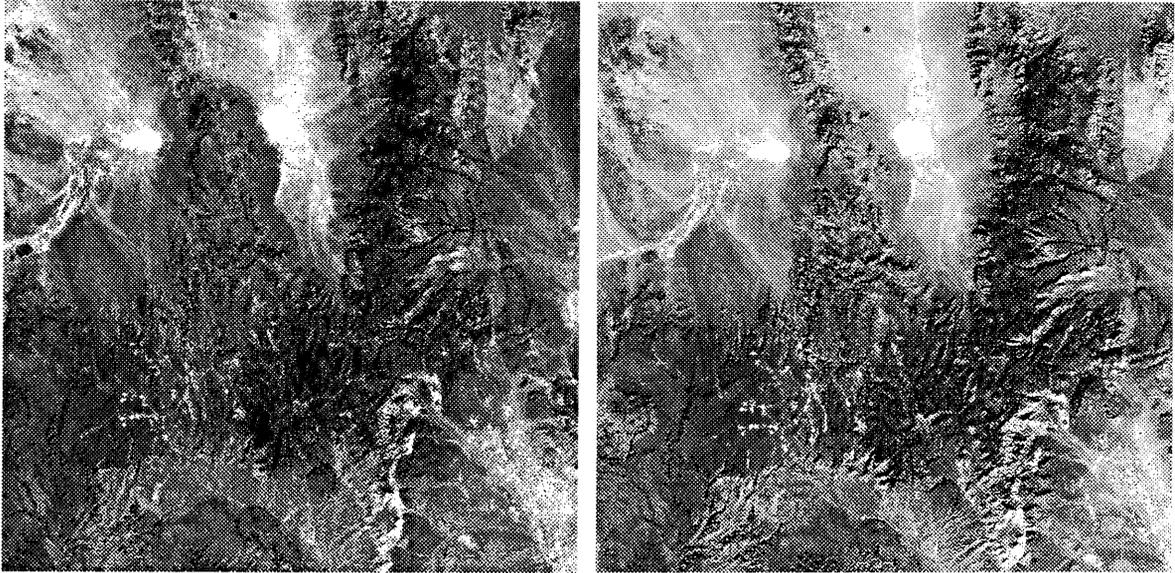


Figure 3: A pair of original SPOT images (6000 x 6000 pixels).

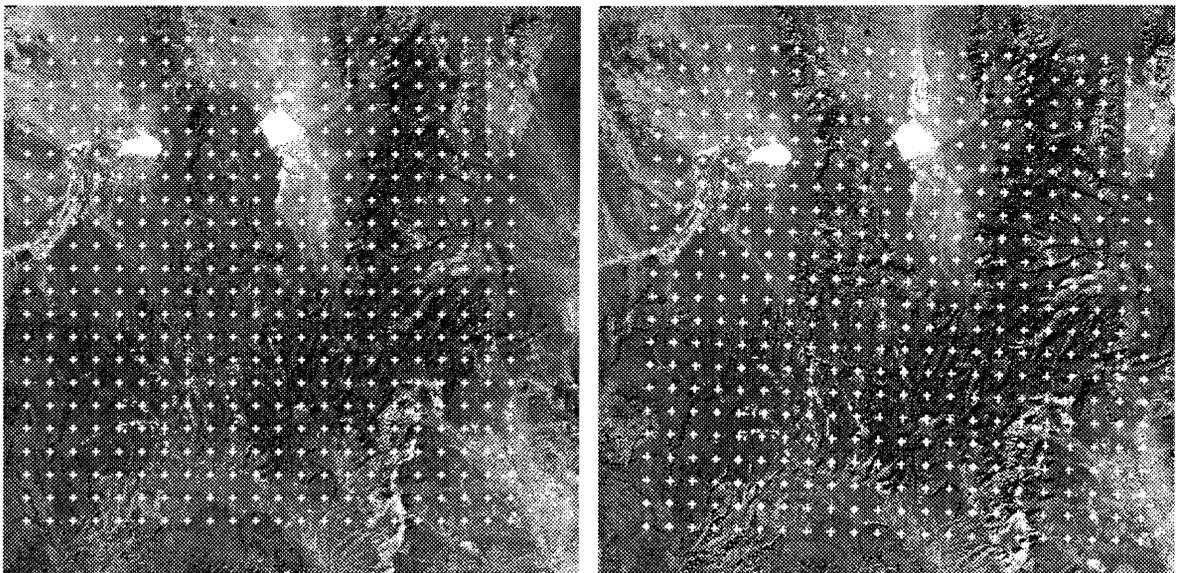


Figure 4: 484 anchor points spaced by a grid interval of 240 pixels derived by MATCH, every four nearest neighbor points can be used for determining approximations for point densification at any desired interval.

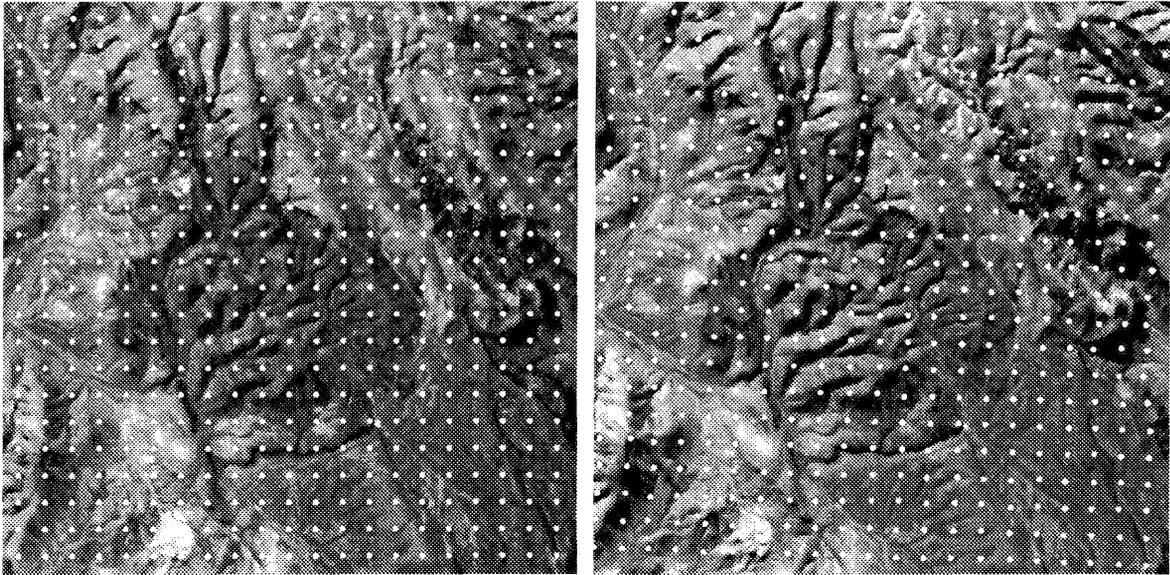


Figure 5: Densification matching results with an interval of 24 pixels in a small area (512 x 512 pixels) of figure 3.

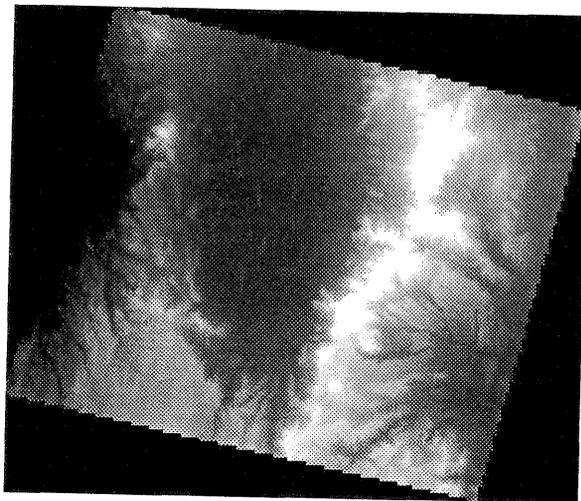


Figure 6: A DEM derived from the matching results of figure 3 using the function MAKEDEM of the Digital Ortho Module.



Figure 7: A perspective view generated with the DEM of figure.6 and overlaid with an orthophoto, which was derived from the DEM and the original images using the function ORTHO of the Digital Ortho Module.

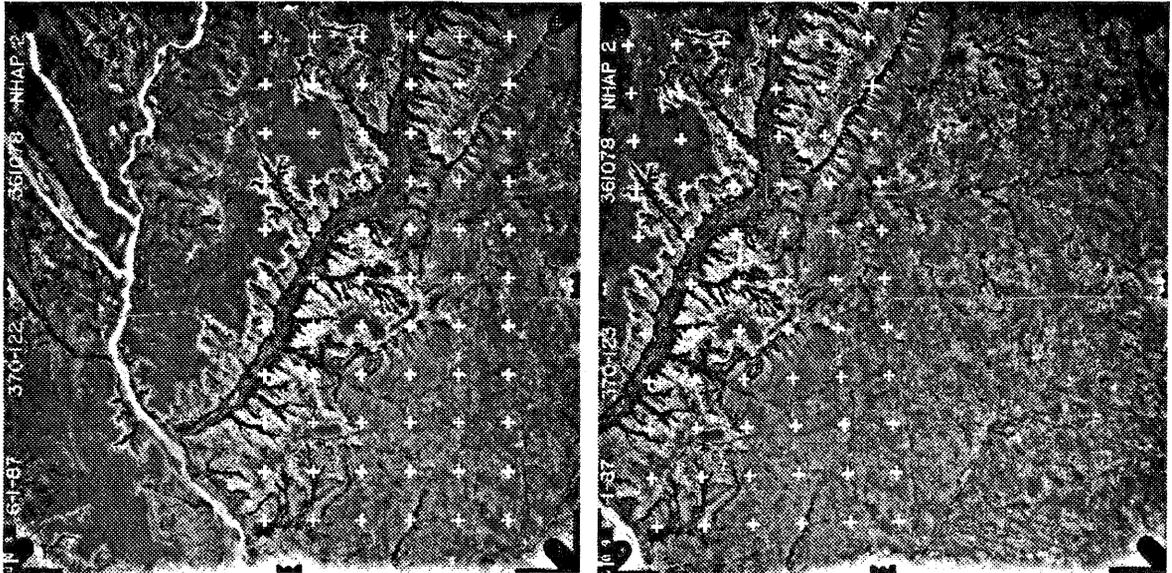


Figure 8: A pair of digitized high altitude aerial images - Left : 2267 x 2272 (pixels) and Right : 2283 x 2256 (pixels) , digitized by an Optronics scanner with a pixel size of 100 microns. 66 anchor points with an interval of 192 pixels were obtained by MATCH.

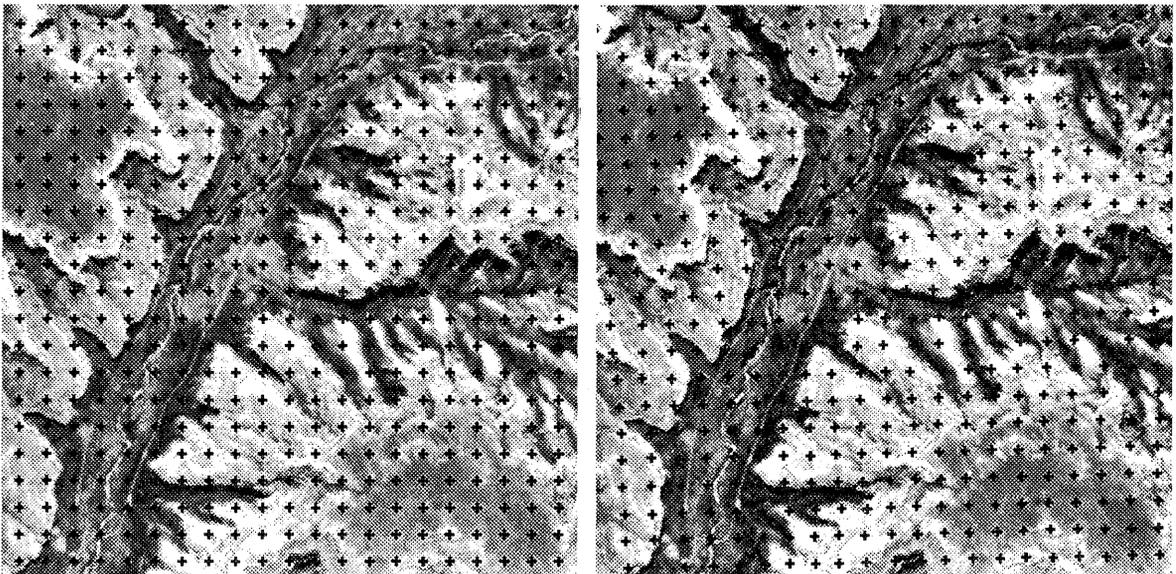


Figure 9: Densification matching results with a 24 pixel interval on the center (512 x 512 pixels) of the overlapping area of figure 8.

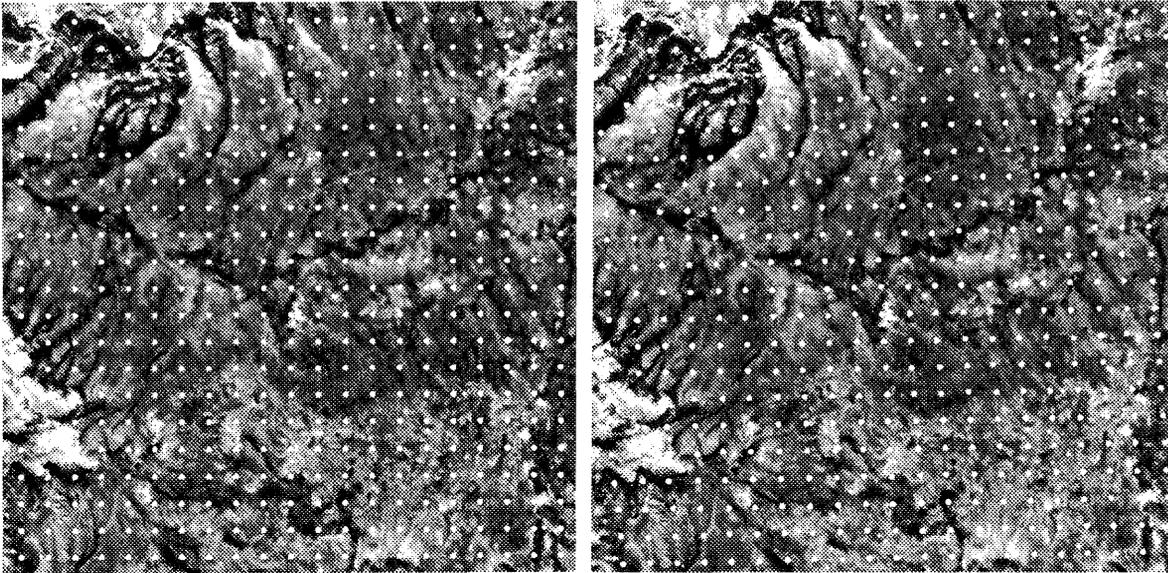


Figure 10: Densification matching results with a 24 pixel interval on the lower right corner (512 x 512 pixels) of the overlapping area of figure 8.



Figure 11: A DEM derived from the densification matching results using the function MAKEDEM of the Digital Ortho Module. The lack of ground control points resulted in a black area at the lower left corner.

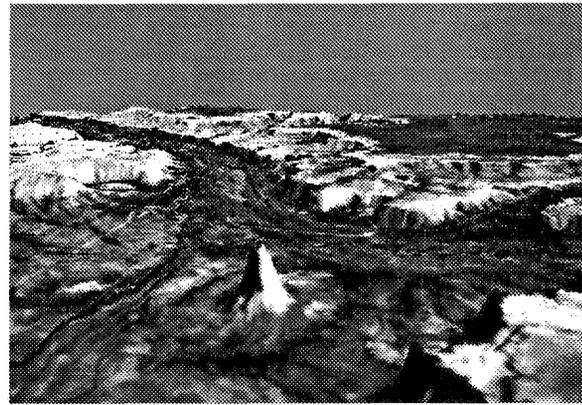


Figure 12: A perspective view generated with the DEM of figure 11 and overlaid with the orthophoto.



Figure 13: Matching results with a 72 pixel interval on a stereo pair captured by a high resolution CCD camera.