A Contribution to Solving the Problems of Geometric Processing of Digital Images

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1. Introduction

Geometrical operations play a significant role in digital processing of remote sensing images. These operations include image correlation, determination of the transformation model, geometrical transformation of digital images and mosaicking. This paper sums up the results of some experiments, carried out at the Geodetic and Cartographic Enterprise in Prague. Paying regard to the results of this research the GETRO program system for the geometrical transformation of digital images has been developed.

2. Some results from the image correlation experiments

The research and related experiments were concentrated on the problems of:

- preprocessing of correlated images
- verification of correlation quality parameters for detection of blunders
- the influence of geometric distortion of window on the correlation quality
- possibility of the interpolation of non-integer location of maximum in the correlation matrix.

Less attention was paid to the question of the choise of correlation measure, which was detailed analysed by Ehlers [3]. In the course of testing the image correlation on experimental image data set /Fig.1/ it was proved that this method gives more accurate results than the definition of coordinates of ground control points /GCP/ by cursor on the graphical display, but with more frequent occurence of blunders [7]. Mean square coordinate error of the image correlation oscillated within the range of 0.3-0.35 pixel when using the cursor it has increased up to 0.7-0.9 pixel. Blunders in GCP must be eliminated before using them for determination of the transformation model. For this purpose three following parameters have been tested, which can be easily computed immediately after computation of the correlation matrix: the signal-to-noise ratio /SNR/, peak-to-sidelobe ratio /PSR/ and the correlation coefficient r. In the course of experiment their dependence on the relative frequency of blunders has been found. The results obtained are illustrated by graphs in the Fig.2. Thanks to this analysis such thresholds /critical values/ of given parameters has been defined, which enable to eliminate corresponding GCP as a blunder with a high probability in the case of their exceeding.
The most suitable way of elimination seems to be the combination of PSR with SNR or with the correlation coefficient r. Two last parameters are strongly correlated and they cannot detect the blunders caused by the worse frequency quality of correlated images /see GCP No 15 and No 24 in Fig.4/.

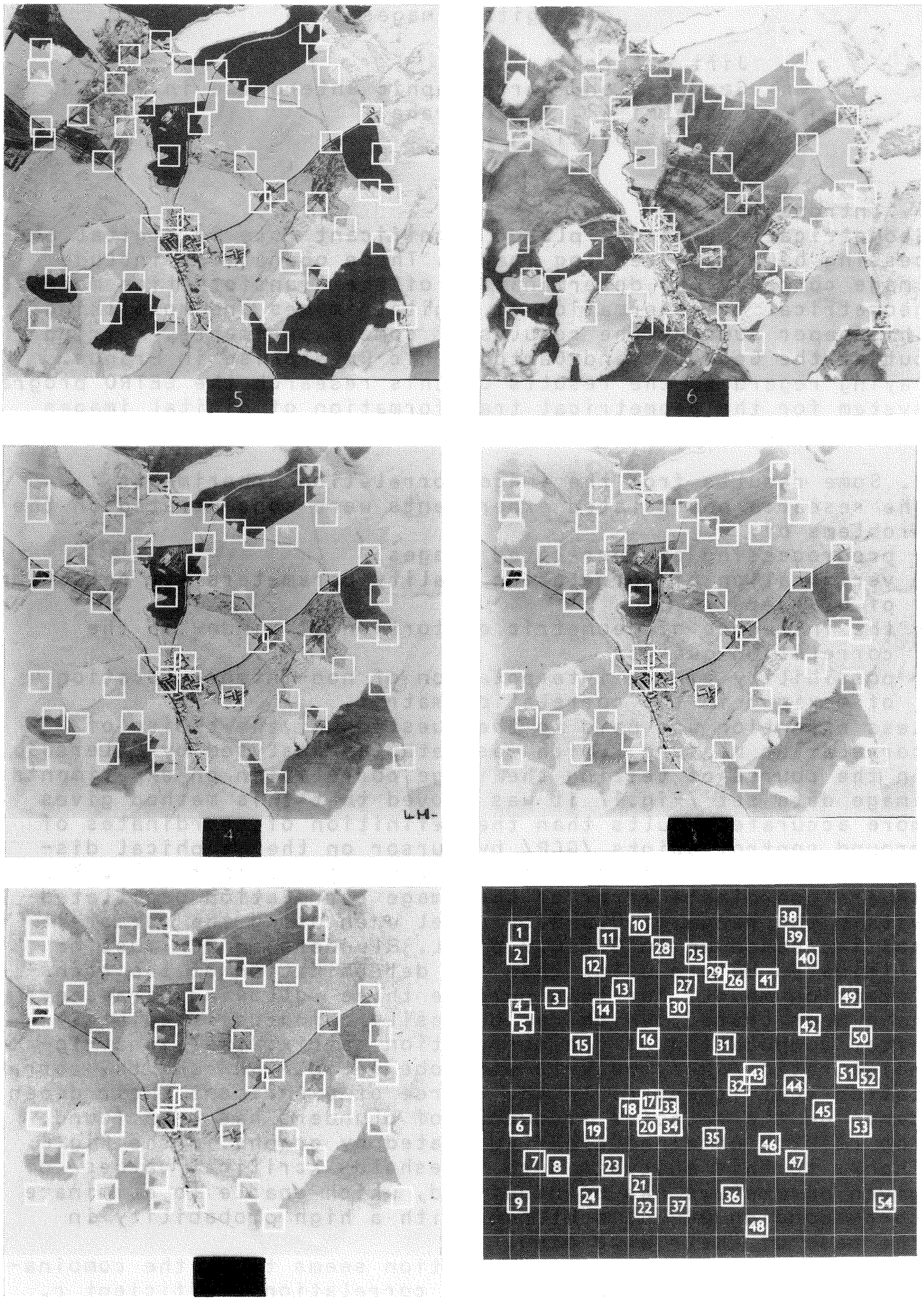

Fig.1: Experimental multispectral aerial scene with the identification of correlated windows. The numbers of spectral bands are given under the photographs, the GCPs are marked right down.

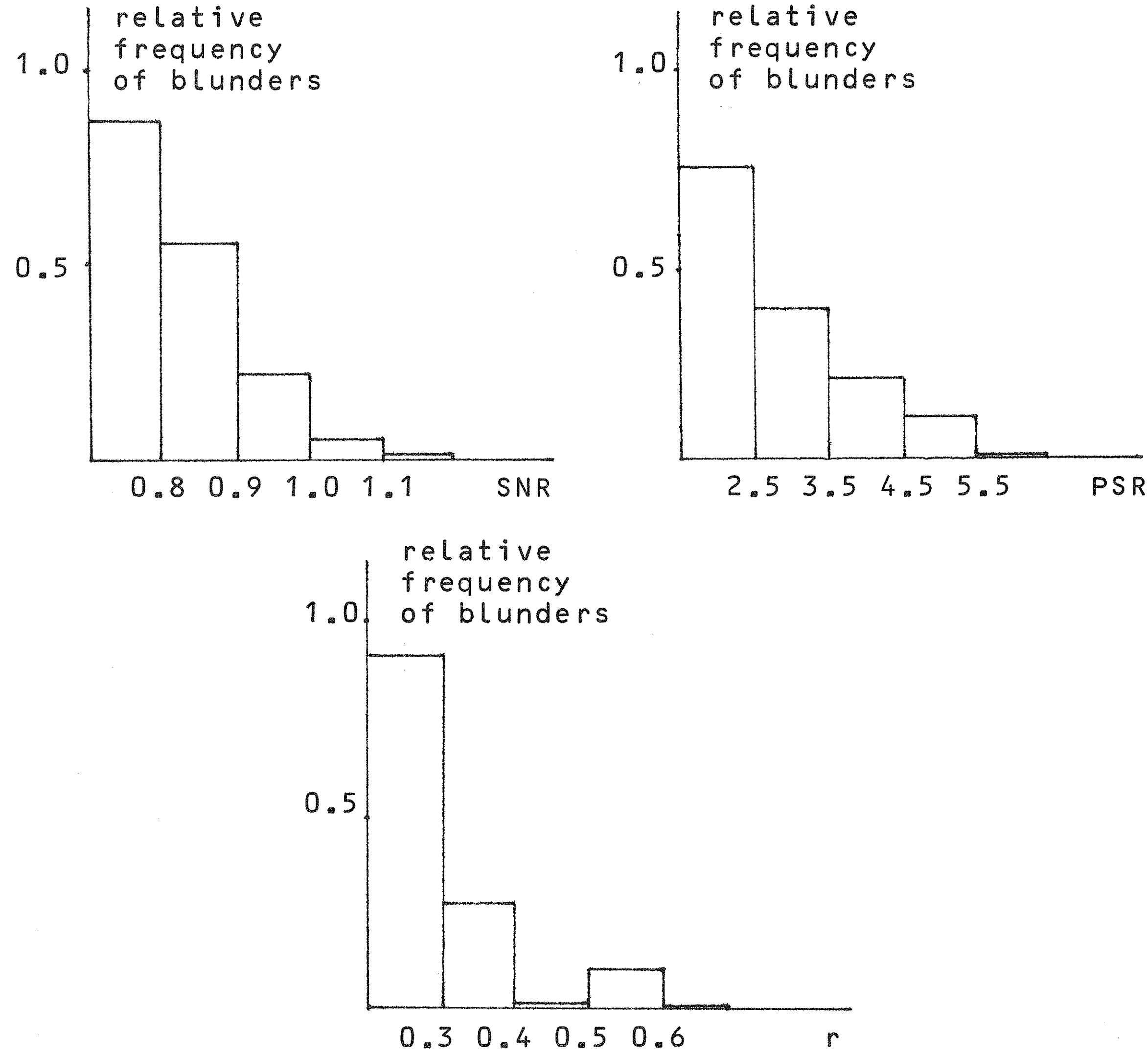

Fig.2: Dependence of the relative frequency of blunders on the quality parameters.

The aim of another axperiment was to study the influence of geometrical distortion of window on the correlation quality /affine geometrical distortion was considered only/. The results agree well with theoretical considerations of Mostafavi and Smith [6], in spite of all their assumptions were not satisfied. The correlation quality decreases abruptly with relatively small distortion and with increasing size of correlated window. This important fact is illustrated by Fig. 3.

The correlation quality depends on the method of preliminary transformation of the window. In case of using the nearest-neighbour transformation method the accuracy /standard deviation of GCP coordinates/ is worse /0.4-0.5 pixel/, than when the transformation method with bilinear interpolation is used /this value fluctuates within the limits 0.28-0.35 pixel/.

The research of the optimal preprocessing method for the image correlation was also started. Some of preliminary tested me-

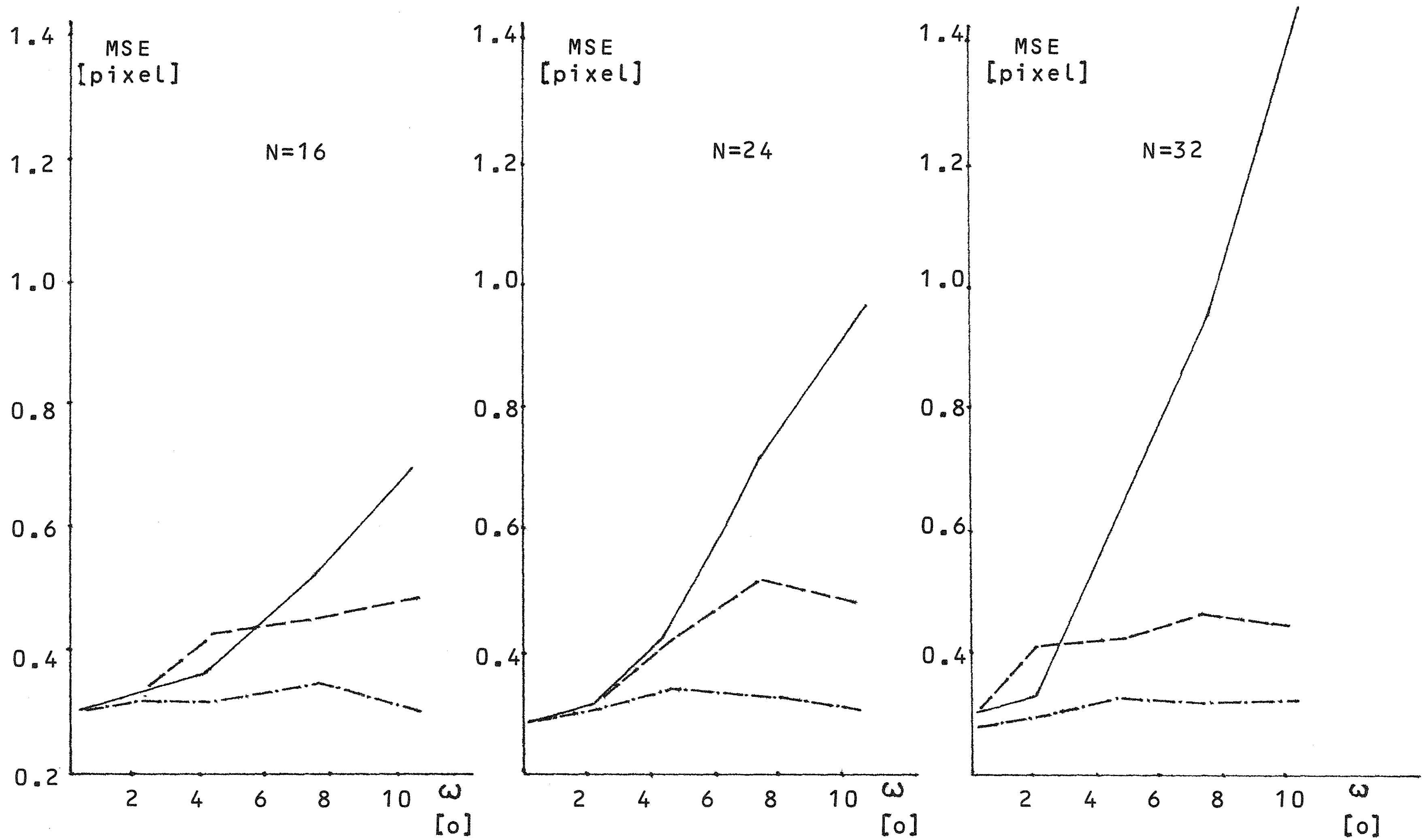

Fig.3: Dependence of the mean-square coordinate error /MSE/ of correlation on the geometric distortion of the window and its size N. Distortion is represented by the rotation angle ω, —— no transformation of the window, ----- nearest-neighbour transformation, -·-·- transformation with bilinear interpolation

thods are introduced in Fig.4. The experiments proved that more universal correlator should use one of the methods of image edge enhancing. As the best result the standard deviation of image function within the 3x3 matrix /method No 3 in Fig.4/ has been found. The correlation can be further improved by preliminary median filtering. Research of this problem is in progress.
The last problem under study was the interpolation of the non-integer maximum location in the correlation matrix. Two following groups of methods were verified: first way was to fit a least-square smooth surface to a certain neighbourhood of the maximum in correlation matrix /2nd and 3rd order polynomials, a cone with a circuit or elliptical base/, the other way was to interpolate the location using some approximate methods /e.g. the weighted average/. This interpolation does not improve correlation accuracy significantly. The best results have been reached in experimental data set with an approximate method fitting to the neighbourhood of maximum of correlation matrix four parabolas /in the main directions/. Their maxima were computed and final non-integer position determined by the weighted average. The accuracy was improved /10-15%/ in this case.

3. A brief characterization of the GETRO system

The GETRO program system was written in Fortran, PL/I and Assembler for the EC 1045 computer. The system enables to perform consequently following operations:

- image correlation
- determination of the transformation model
- geometrical transformation of digital images
- mosaicking.

Computation can start in each of above mentioned stages. The input data can be divided into image data /digital images/ and control parameters /all the data necessary for the program execution/.
The image correlation programs differ from each other only by the type of geometric distortion assumed for the input image data, by preprocessing method and computation of the similarity measure. A two-step algorithm is time-saving in the procedure of multi-level image correlation. In first step an approximate matching position by adapted SSDA method [1],[8] is found, in second step the location is defined more accurate by an exact correlation coefficient using the "hill climbing" technique. The CPU time consumed for the computation of one GCP fluctuates within the range 0.5-5 seconds according to the window size and the search area.
Determination of the transformation model is performed with the knowledge of GCP coordinates - either using the least-square method /affine, projective and polynomial transformation/, or the prediction method described in [4].
There is also a possibility to substitute the polynomial transformation by a set of projective transformations, and to use the DTM for digital differential rectification.
Geometrical transformation is the most time-consuming operation in the GETRO system. However, there are possibilities how to speed it up on the current computer:
- to ensure "sufficiently small" geometric distortion between

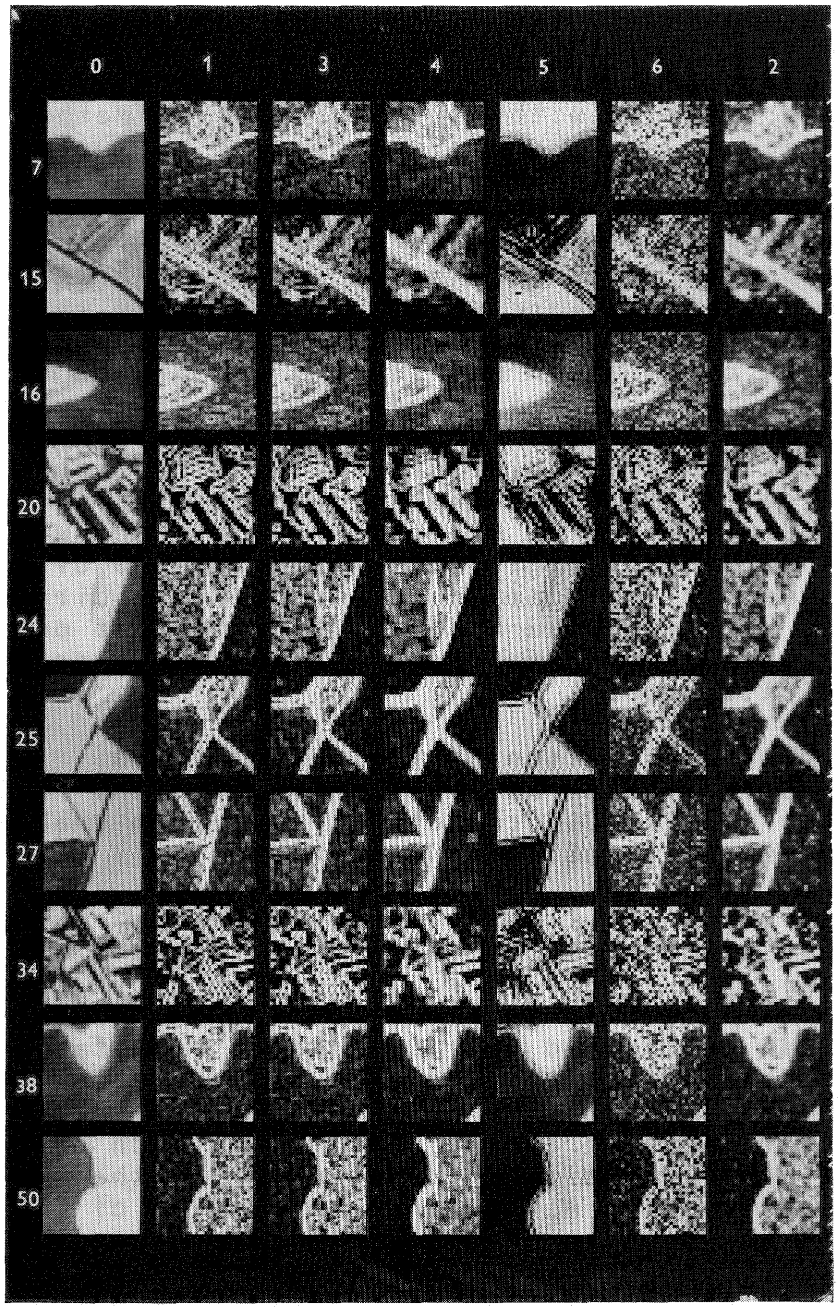

Fig.4: Sample of correlated windows. Left - GCPs numbers according to Fig.1, up - numbers of preprocessing methods used:
0 - original image
1 - Robert's gradient
2 - general gradient /size 3x3 pixels/
3,4 - standard deviation /size 3x3 and 2x2 pixels/
5,6 - linear filtering /with different filter matrixs/

the input image and the output /reference/ system
- to perform the transformation by the nearest-neighbour method /without an interpolation/.

In that case it is not necessary to substitute into the transformation equations "pixel by pixel" /slow method/, but it is possible to transfer the whole blocks of image data from the input to the output file /fast method - [5]/. The speed both of the mentioned methods is automatically compared in the GETRO system and the transformation is performed by the faster one. Speed comparision depended on the geometric distortion /rotation/ is illustrated by Table 1.

Table 1: Comparision of fast and slow transformation method. The geometrical distortion is approximately of rotation character.

Method	Rotation [o]	CPU time [s]		
		Affine	Projective	Projective transformation in parts
fast	0	3	3	7 /x/
	2	15	19	23
	5	35	45	48
	7	50	62	66
	10	74	93	98
slow		118	157	161

/x/ - The image of 750x650 pixels was divided into 5x5 parts

Simultaneously with the geometrical transformation the radiometrical corrections by means of established transfer characteristics /look-up table method/ are performed according to user requirements.

Final operation of the GETRO system is the mosaicking. It arranges transformed digital images into the block similarly as a photomap is prepared in an analog way.

4. Conclusions

The research of the problems, which can be summarised as the geometrical operations with digital images, enabled the implementation of the GETRO program system at the Geodetic and Cartographic Enterprise in Prague since 1985. This system is currently used for transformation of digitized aerial multispectral images /namely for subsequent classification of forrest health-conditions/ and will be extended for the processing of sattelite images in 1988-90.

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