AUTOMATIC DEM GENERATION IN QUARRIES

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ABSTRACT

This paper reports on the application of automatic generation of DEMs in rock quarries, to figure out the excavation volumes by repeated surveys. Accuracies of some percentage of the volume's estimate are acceptable, the ultimate goal being planning and managing the exploitation of the quarries. The aim of the investigation is therefore to check whether automatic DEM generation satisfy this accuracy level and what kind of restrictions should be put on flight planning, image resolution, scanning accuracy, additional terrain information, matching techniques to improve the performance of the DPW in this environment. A stereoscopic model from a 1997 flight over a quarry near Brescia has been processed with two different digital photogrammetric stations and the results compared to those obtained with an analytical plotter as well as by computing DEM errors from the left and right orthophotos of the pair.

1. INTRODUCTION

The automatic generation of digital elevation models by digital photogrammetric techniques is now several years old. Virtually all phogrammetric workstations include such modules and DEM's are routinely generated in production environment. Tests on the accuracy of the technique as well as workshops and meetings on the subject, though, witness that the current level of sophistication of the correlation techniques cannot match the results of analytical plotters in every condition.

Several parameters are relevant trying to asses the behaviour of the algorithms: image resolution, image texture, terrain roughness and slope, vegetation or other terrain superstructures (buildings, vehicles, etc.). As far as image resolution is concerned, empirical tests suggest that this parameter is almost independent of image scale (Baltsavias and Kaeser, 1998) (which is obviously kept at the smallest value for the specific task) and that it may be chosen in the range from 20 to 30 micrometers with just a slight quality decay as resolution decreases. Using larger resolution values, the DEM quality becomes too poor.

Overall DEM accuracy, defined as the RMS of the discrepancies between terrain heights and its interpolated values from the DEM, may be characterized by three factors (Ackermann, 1996):

- the accuracy in elevation $\sigma_z = m_b\ h/B\ \sigma_p$ which depends on image scale, object to baselenght ratio and measurement accuracy in image space;
- DTM grid size: interpolation errors varies with terrain roughness: the denser the grid the smaller the error, for a given terrain;
- detection and filtering of non-terrain features (buildings, trees, etc.).

The accuracy of correlation techniques is normally evaluated in percentage of the pixel size. Therefore, increasing scanning resolution may seem the straightforward way to improve it. In fact, notwithstanding storage and data handling problems, still severe if pixel size goes below 20 μm, empirical studies suggest that the current generation of photogrammetric scanners is affected by significant noise when scanning images at the maximum available optical resolution (below 10 μm). Perhaps more important than resolution is image texture: homogeneous regions or repetitive patterns may lead to wrong identification of conjugate pairs, leading to inaccurate results even if the terrain is not too rough. Steep slopes and terrain breaklines, on the other end, lead to strong perspective differences and occlusions that stereo correlation algorithms cannot cope with. As image scale decreases, their effect is less relevant; the same apply also to non-terrain features.

At large scales, filtering out trees, buildings and so on is automatically performed by some systems, based on appropriate smoothing constraints on the curvature of the interpolating surface or other techniques. This works fine as far as these objects are isolated and there are no terrain breaklines in the vicinity. Forest areas and urban areas are still hard to deal with in large scale.

by correlation. The flight plan can be adjusted to minimize their impact in two ways: modifying the overlap and carefully considering terrain morphology. Quoting Ackermann, in digital photogrammetry "redundancy should replace intelligence": taking and processing several images of the same area rather than a single model is therefore acceptable, if it pays off in terms of better overall accuracy, reducing the number of mismatches. The new flight has therefore been designed with 80% overlap and 60% sidelap, in order to derive models with a less favourable height to base ratio, but with smaller perspective distortions. They will be processed first, to provide an initial DEM to be later refined with the 60% overlap models.
Using sidelap up to 60% yields four-fold model coverage of the same terrain patch. The advantage here is that each model has a different viewing direction, increasing the possibilities that occluded areas are visible in at least one model. Currently, virtually all DEM generation software is stereo-based; thought the use of several images is envisaged and now generally recognized as beneficial, this can be implemented in two significantly different ways: repeating DEM generation in different stereomodels over the same area is not as effective as actually performing DEM generation with all images at the same time, like in MGCM (Gruen and Baltsavias, 1985) or similar approaches. Using several models yields elevation data at nominally coincident grid knots. The question therefore arises what is the best weighting of each elevation value at a given location. A simple averaging, thought optimal in most cases, would certainly fail in problem areas, where more than one value may be grossly falsified. Even more robust estimation methods, with a possible outliers percentage larger than 50%, may give incorrect results.
As far as flight direction is considered, if the excavation front of the quarry is elongated and follows roughly the contour lines, then mimimization of the occlusions may be achieved by using only half image and flying just over the lower edge of the front. Parallel strip may be flown, if necessary, maintaining a 60% side lap, covering the quarry from the lower edge upwards.
Illumination may affect the results, given the strong terrain reflectance, either because of the shadows as well as for the dynamic range of the scene. Minimization of the disturbances is achieved by flying at midday and/or prescribing a flight in a cloudy day. Good image quality make it necessary a FMC system: its effect is nevertheless limited because of the large heigth differences in the model, which leaves a significant residual motion.

2.2 Reference data
The contour lines file of the 1997 map 1:1000 has been made available by the Comune di Botticino. The accuracy of elevation data therein may be assumed to range from 20 to 50 cm. Data have been interpolated either by Kriging and by Delaunay triangulation over a 2m grid, to be used to compute the differences with the elevations estimated by the DPWs. In order to provide a common reference system for the comparison, we used the ground coordinates of the tie points from the analytical AT of the strip, that is just the same points used for the absolute orientation in the map restitution. A topographic survey with a motorized laser scanning theodolite will also provide (sparse but precise) reference data for the second flight.

2.3 Using orthoimages to check a DEM
To provide an additional check of the accuracy of a stereo DEM, a technique may be used which employes two orthophotos, derived from each image of the pair, by using the DEM to be controlled. By comparing the (nominally fully) corresponding images so obtained, errors in the DEM can be traced according to (Baltsavias, 1996). The underlying concept is depicted in Fig. 1: if you select a feature in one orthophoto, its counterpart in the other should show up at the same (X,Y) location in object space. If not, this is because the DEM elevation in the area is wrong. The correct Z value may be determined (and so the error computed) by going back to the image space and intersecting the correct pair of homologous point. In digital photogrammetry this technique is very simple to implement and automate: extensive testing of DEM quality (in principle the whole DEM may be checked) is therefore

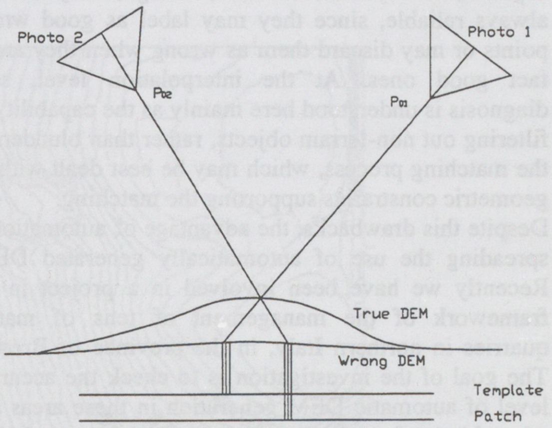

Fig. 1 – DTM check by using two orthophotos

feasible. Once the two orthophotos have been generated, feature points may be selected with an interest operator or on a grid. Image correlation techniques can be employed to find the homologous in the second orthophoto, taking advantage of the nominally coincident initial location and of the smaller perspective distortion that the orthophoto should display, compare to the aerial image. If the discrepancy between the matched positions, converted into object space, are within tolerance, the DEM is correct. Otherwise, each orthophoto point is back projected into the original image and the two rays are intersected, yielding the correct ground coordinates.

2.4 Image scanning
Up today image scanning has been performed only on the 50_51 model of the 1997 flight. Images have been

To be economically acceptable, DEM generation should provide accuracies matching those of manual plotting (i.e. between 0.1-0.2 ‰ of the relative flight height h_r) in a shorter time. Since the point measurement rate is much higher than that of the human operator (and bound to increase further with processing power), large DEMs with hundreds of thousands points may be generated in an hour time or less, depending on hardware and software performance. As far as accuracy is concerned, figures range from 0.1 to 0.8 h_r (Bacher, 1998; Balsavias and Kaeser, 1998, Duperet, 1995), therefore not always matching manually produced DEM. Off-line editing is necessary, clearly pointing out that self-diagnosis tools are not as reliable as they should. Indeed, in large scale photogrammetry and problem areas the percentage of points to edit may be as large as 10% or more, making it a key feature of the system the performance of the editing tools available to the user.

Any DEM generation system has self-diagnosis capabilities at the matching level as well as at the interpolation level. At the former, systems mostly provide a quality index of each matched point which can be as simple as the correlation coefficient (confronted with a terrain and/or image dependent threshold) or may be based on a classification scheme, reporting or providing hints in case of failure, in more sophisticated systems. Overall, though, they are not always reliable, since they may label as good wrong points or may discard them as wrong when they are in fact good ones. At the interpolation level, self-diagnosis is understood here mainly as the capability of filtering out non-terrain objects, rather than blunders in the matching process, which may be best dealt with by geometric constraints supporting the matching.

Despite this drawbacks, the advantage of automation is spreading the use of automatically generated DEM. Recently we have been involved in a project in the framework of the management of tens of marble quarries in northern Italy, in the province of Brescia. The goal of the investigation is to check the accuracy level of automatic DEM generation in these areas and what kind of project parameters (image resolution, scanning accuracy, additional terrain information, matching techniques) are best suited. This paper reports on the results of DEM generation in the repeated survey of a rock quarry, to figure out the volume of material excavated, using aerial images. This information is used in planning the exploitation of the quarries by the authorities in charge; accuracies of some percentage point on the volume's estimate are acceptable. A direct control of the excavation volumes to fix taxes has been for the time being ruled out, since weigthing the lorries in and out of the quarry is more accurate.

2. THE PILOT PROJECT BOTTICINO

The project goals were set as follows:

1) to study which selection of the flight parameters would be the best so that the performance of DEM generation could be improved;
2) to study the accuracy of the DEM and of DEM changes, with respect to DPW system (scanner as well as software) and what gains could be made by first measuring manually a low resolution DEM.

The marble quarry in Botticino, a small village near Brescia, was chosen as a test area, because a recent aerial survey was available and because it is quite representative of the quarries in the area: they are located in steep hills, with height differences from top to bottom up to 400-500 m; their fronts range from several hundreds meters to more than 1 km.

The excavation proceeds in stages, cutting the hill side in banks 10 to 30 m high, slightly inclined downhill; though more or less you may recognize a main front running parallel to the contour lines, large blocks are extracted here and there, leading to a pattern of "holes". Debris is spread around in several areas, depending on which front is currently active. The hills around the quarries are covered by bushes and trees, while the excavation area is rather bright, resulting in a scene with an overall high dynamic range but (though not everywhere) a low contrast within the quarry, in full daylight and clear sky.

The first flight, executed in summer 1997, consists of a single strip with 4 images (numbered 49 to 52) at the average scale 1:5600 and lead to the compilation of a 1:1000 map of the quarry, which is contained in the model 50_51. Although the flight was flown around midday, sharp shadows are projected from the banks, making sometimes difficult to identify the exact location of the base of the walls.

2.1 The new flight plan

As already mentioned, the second part of the project is supposed to complete a new flight over the same area, to highlight volume changes in the time span and to allow an accuracy evaluation thanks to a topographic survey.

The new flight plan has been designed in order to improve the accuracy of automatic DEM generation by proper choice of the flight parameters. Three aspects have been taken into account: flight height and camera focal lenght, endlap and sidelap values along and across strip and finally strip direction versus terrain morphology.

For a constant image scale, a lower flight height means using larger focal lenghts, increasing areas prone to occlusions and perspective distortions. A longer focal lenght would reduce the occlusions and also help image correlation to account for perspective differences; if image scale is taken constant, this would on the other end change the H/B ratio, worsening the elevation accuracy. Larger image scales, compare to the well established standard values adopted in mapping with analytical plotters, would undermine the economies obtained by digital methods, as only for the larger surveying work implied. Based on this reasoning, either image scale and focal lenght have been retained to the values of the preceeding flight.

Though it is hard to figure out their effect in advance, experience shows that occlusions and terrain discontinuities degrade the accuracy of DEM generated digitized with a DWS 100 scanner of the IRIS lab at JRC Ispra at a resolution of 12.5 μm (about 7 cm on the ground). Thought one of the goal of the investigation was to find out the best resolution value to be adopted, no test have been performed at the original resolution: the amount of data (more than 300 MB per image) proved too hard to handle, so images have been resampled to 25 μm. Further test will be executed by using a DTP scanner to check dependency on scanner performance.

3. TEST ON DEM GENERATION

Two digital photogrammetric systems have been used in the test: a high end system (hereafter called system A) and a low cost one (system B). An area of about 320000 square meters has been selected for the test, which encloses most of the quarry and an area mostly covered by trees and bushes (see Fig. 2). After performing a semi-automatic image orientation (automatic relative orientation with operator-assisted check for possible mismatches) System A was set on DEM generation with adaptive strategy: this means the system is capable of adjusting the matching parameters to the terrain and texture characteristics.

Points were determined on a mesh 2 m wide, without supplying any a priori information on the terrain in the form of breakline location and so on. It took less than 5' to provide more than 80000 points on a PII 350 machine.

Fig. 2 – Aerial view of the Botticino quarry

The values have been compared to the interpolated reference data, resulting in a 2m RMS of the discrepancies, with about 50% of the values in the range (-0.5; 0.5m) m and a bias of about 0.7 m.

Figure 3 shows a plot of the DEM errors larger than 1 RMS (10% of the data) with the DEM contour lines in the background. As it could be foreseen, the largest errors occur on terrain breaklines.

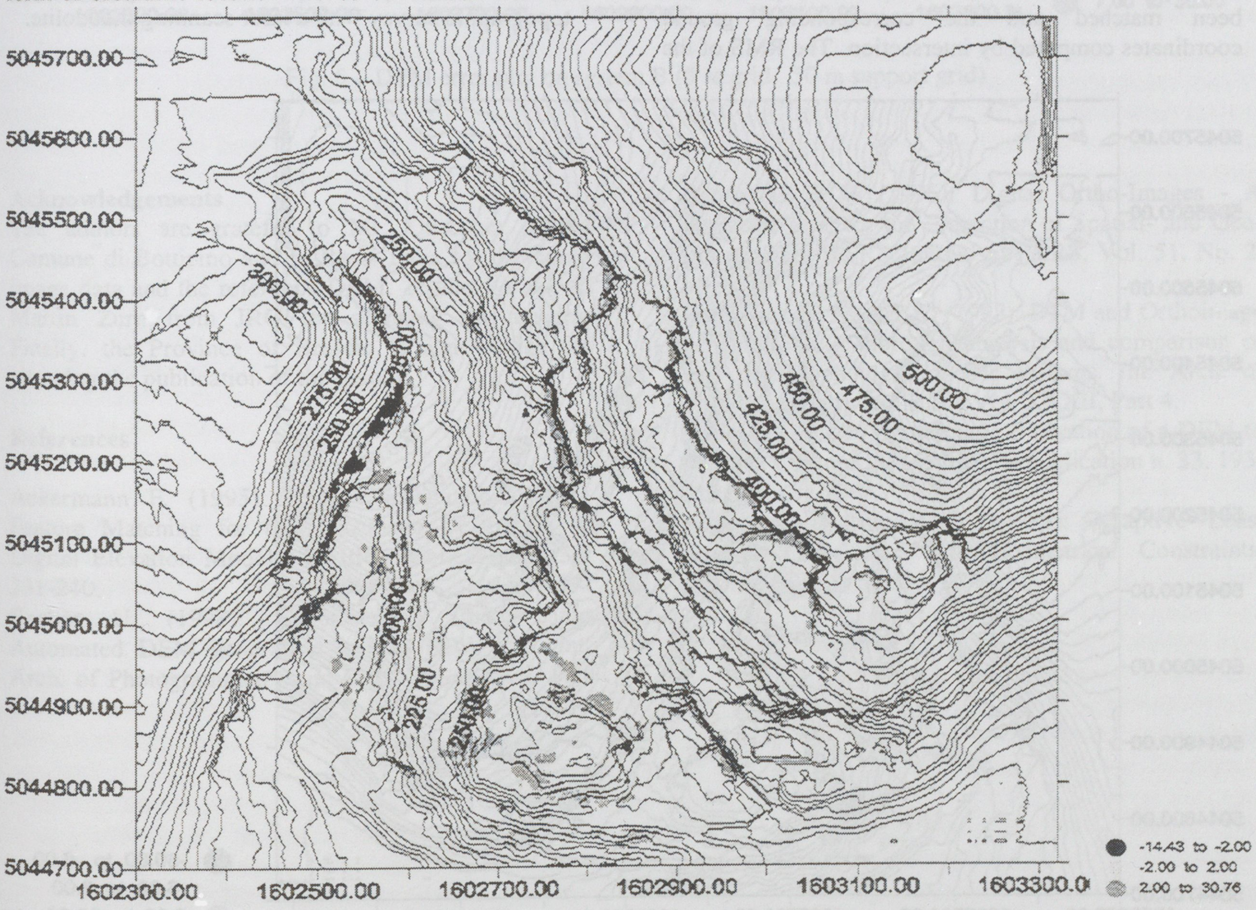

Fig. 3 – DEM error plot for system A (2 m grid)

A close look at the Figure Of Merit (FOM) values, overlapped to the image, indicates that poor matchings are actually concentrated along breaklines showing that the self-diagnosis tool of the system is (on visual evidence) in good agreement with the error plot.
The same area (but with a mesh size of 5 m) was surveyed with system B (which has as available tuning parameters only the correlation window size and correlation coefficient threshold). A low resolution grid (we used a 50 and a 20 m mesh size, which amounts to 130 and 800 points respectivly) taken from the reference data was fed to the program to support it in the search for homologous points. The system output around 13000 points in about 1h 30' on an equivalent machine. The statistics are less satisfactory than in the preceeding case: the RMS of the discrepancies is 7 and 6 m for the 50 m and the 20 m grid respectively; 83% and 87% of the errors are within 1 RMS in both cases. The distribution of DEM errors is shown for the two cases in Fig. 4 and 5. As it is apparent, compare to System A not only errors are larger, but also they extend further from the breaklines. As far as the support given by the grid is concerned, the is a rather small improvement only. This suggest that the system may not be adequate to the task.
The procedure described in Section 2.3 for an independent check based on two orthophotos has been implemented in a software program and applied to the stereo pair, in a smaller area. About 2000 points have been matched and the corresponding ground coordinates computed by intersection. The RMS of the differerences with System A are in the same range as those found from the reference values, but larger. A comparison with the DEM from manual plotting showed a small percentage of outliers, likely due to insufficient robustness of our matching algorithm: no further comparison were therefore performed with this data set.

4. CONCLUSIONS AND PROSPECTS

The work is really still in progress, since the second flight due next summer will provide new, more redundant data, where multi-image techniques will be applied. The preliminary results seems to point out that in such a demanding environment only sophisticated systems do provide acceptable results. It should be stressed, nevertheless, that contour lines do not provide an ideal reference set in breaklines areas, that is, where the largest errors are concentrated: their nominal accuracy along step edges cannot be maintained. Also wooden areas, where it is known that results are unreliable, should be perhaps taken out from the comparison. Besides, a few buildings in the southern area are not taken into account in the reference DEM, so positive discrepancies there are indeed not errors. If this is the case, these preliminary figures would improve and, as far as System A is concerned, it may be proved that it is suited to the taks. A definite answer will be only available after the completion of a topographic survey with a laser scanning theodolite.

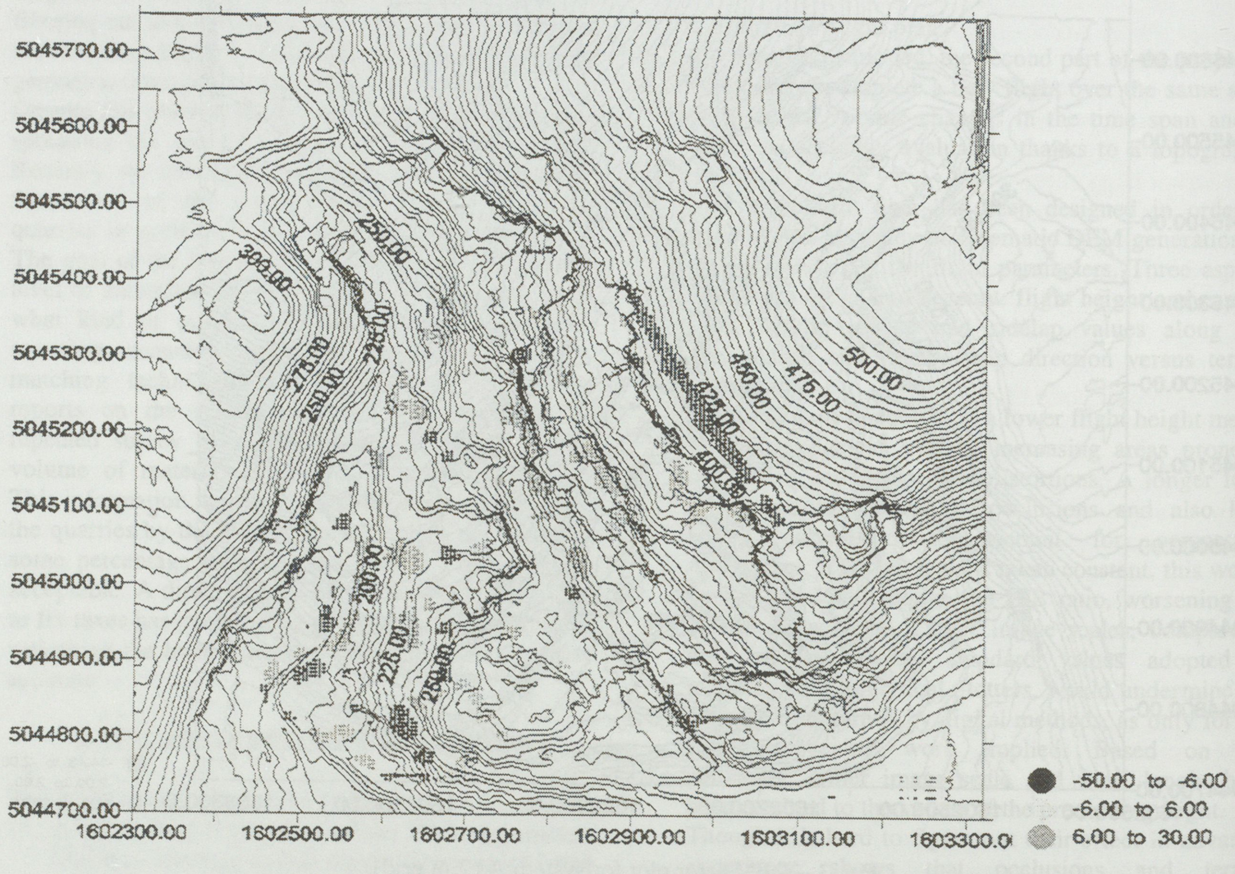

Fig. 4 – DEM error plot on system B (5 m grid, 20m support grid)

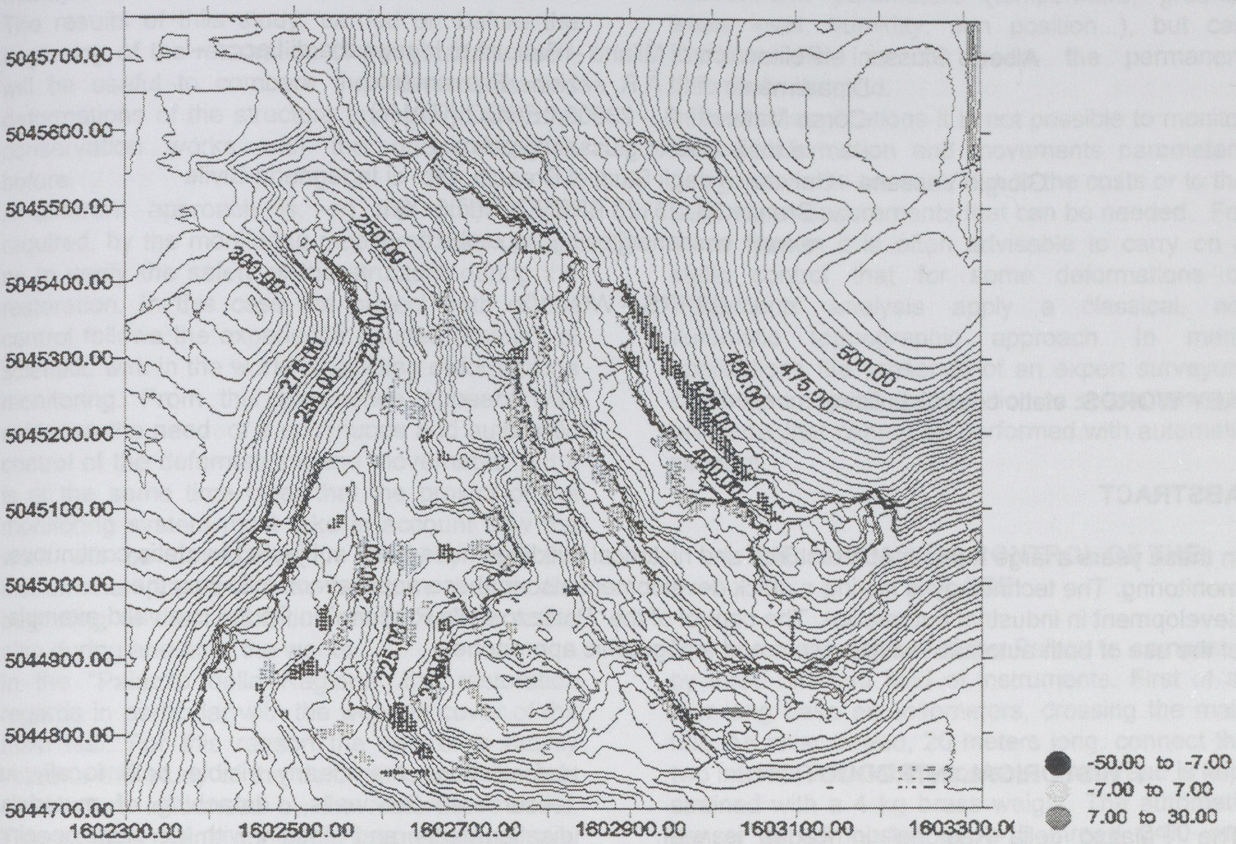

Fig. 5 – DEM error plot on system B (5 m grid, 50 m support grid)

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