

Investigations on Two Methods of DEM Extraction

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Abstract

Digital Elevation Models (DEM) comprise valuable source of data required for many engineering applications. Contour lines, slope - aspect maps are part of their many uses. Moreover, a DEM theme is an essential layer to be included in most GIS analysis operations. Recent scientific achievements aim to automate acquiring DEMs with the most possible speed and accuracy. This paper studies two methods of DEM data extraction from sample aerial stereopairs, the analytical plotter method versus the digital photogrammetric method (DP). The DEM output of the analytical plotter is used as a reference. This is compared to the work performed using the DP method on the sample photos in digital format. Comparison covers various steps of image orientation followed by DEM collection. Numerical outputs of speed and accuracy are presented and discussed. The tests show that errors in automatically extracted DEMs may result from areas representing ground surface of poor texture or contrast conditions, or it may appear due to imperfect photographic processing. Editing time of the product is a major factor especially in urban/ forest areas. Depending on the specified needs of the user, an erroneous DEM output might be accepted as appropriate digital surface model DSM. Statistical tests detect marginal error types in the output. The paper gives conclusions about some problematic sources with recommendations to improve the product.

Keywords: DEM, stereopair, digital photogrammetry

استعراض نتائج طريقتين لتحصيل المناسيب الرقمية لسطح الأرض

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الخلاصة

المناسيب الرقمية لسطح الأرض DEM ذات اهمية كبرى لأغلب الدراسات الهندسية فمن استخداماتها الشائعة هي رسم الخطوط الكنتورية، واعداد خرائط الميل واتجاه الميل وغيرها. كما وتشكل هذه البيانات احدى اهم الطبقات الممكن اضافتها اثناء تحليل نظم المعلومات الجغرافية. يهدف التقدم العلمي الحديث الى الحصول على هذه البيانات بسرعة ودقة عالية. في هذا البحث نقدم مقارنة بين طريقتين للحصول على بيانات المنسوب. حيث تم اولا الحصول عليها من زوج من صور فوتوغرافية مجسمة باستخدام الطريقة التحليلية بجهاز ANALYTICAL PLOTTER وتم اعتبار نتائجها كأساس للمقارنة مع الطريقة الآلية باستخدام برنامج خاص SOFTCOPY حيث تمت دراسة وتحليل النتائج احصائيا وتحديد بعض المؤثرات على الدقة مع مقترحات لتحسين النتائج .

Introduction:

Recently, DEM data is widely used for mapping and engineering related applications. The uses include many fields in civil engineering works, agriculture, navigation, geography and others. Another growing trend recently is the use of this product as an additional layer into GIS projects [1],[2]. DEM data generally comes in the form of X, Y, Z coordinates of ground surface. In many cases, regular grids of points are used where elevation values are stored at the nodes. Other types of data storage are also common.

Field surveying and aerial photogrammetry were the major sources of DEM data. The ease and speed of using photogrammetry is unparalleled and it is established to be the main technique for obtaining 3D data. Analytical photogram metric methods offers relatively reasonable accuracy, speed, and cost against field surveying methods. These methods usually rely on the human ability to interpret surface cover and decide stereoscopic conjugate points. The growing use of aerial photography and other techniques for mapping and monitoring earth resources, together with the fast development of computer hardware and software have urged scientists to automate the process of DEM collection by using digital and/ or digitized aerial stereopairs. These methods try to mimic the human intelligence ability in stereovision.[3]. There is now a great need for this data to be generated in a more cost-effective manner, with less time and without loss in accuracy.

In this problem, a major research field is going on to fix bottleneck areas and provide solutions. Different algorithms have been developed to automate the collection of DEM's. The success of a certain algorithm usually depends on the type of terrain and image quality [4]. Many problems have their effects on the reliability of outputs, including image texture and contents of urban features and forest areas. During the process of automatic DEM generation, the reliability of the system is usually compared with other systems or with the analytical plotter methods taken as a reference.

In this paper, numerical comparisons are made to highlight some findings and problems that were faced while working on DEM extraction using the Planicomp-P3 analytical plotter from Zeiss, and the digital photogram metric (DP) software VirtouZo from Wuhan University [5]. Both systems have been used worldwide for commercial production.

Materials , Data and Methodology:

Two B/W diapositive aerial stereopairs (A,B) were collected for tests (Figure 1). Films were prepared from the originals by contact printing and dodging process. Care was taken to choose samples that were properly handled, stored and geometrically undisturbed. Few ground control points (GCPs) with different shapes of preflight markings are available inside and outside the overlapping regions in both pairs. Quick examination of these films reveals the existence of some defects due to imperfect dodging at the time of printing [6]. Table 1 shows the general photo descriptions used in this work.

Table 1 Parameters of test photos

Year of flight	1990
Camera / lens	RMK 15 / 23
Photo nominal scale	1 / 4800
Focal length	153.21 mm.
Fiducials	4 sides
Photo numbers, Models	21 / 22 First Model (A) 36 / 37 Second Model (B)
Film format	9" = 226 mm. 60 % overlap

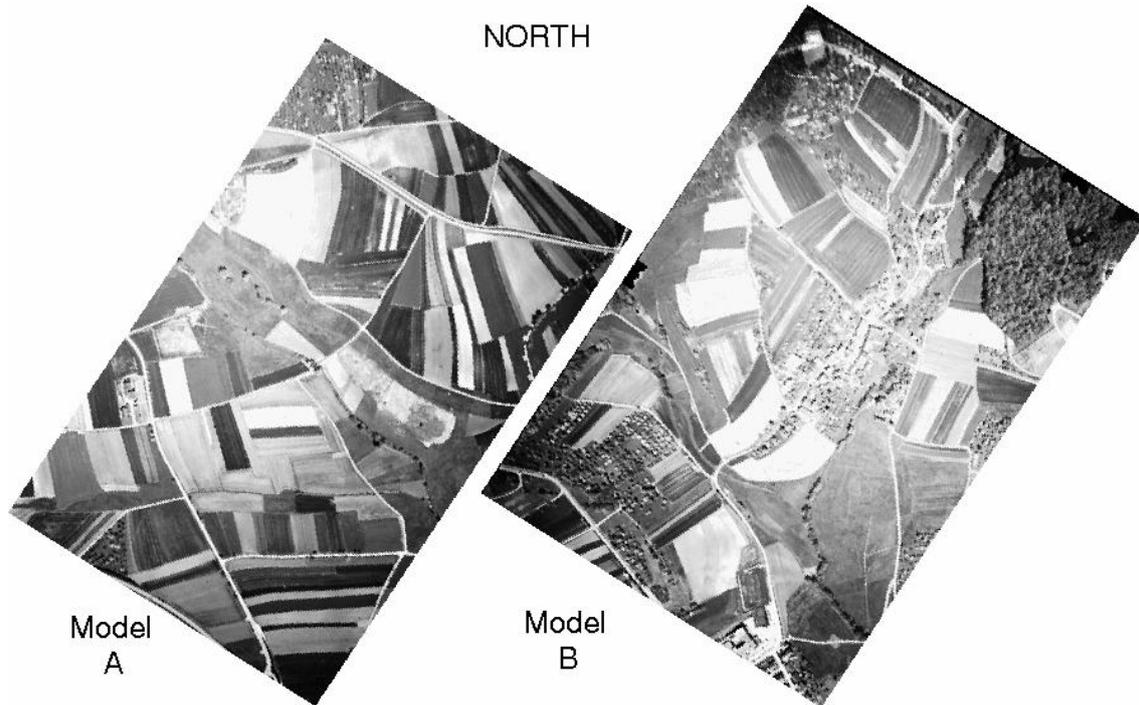


Figure 1 Coverage of the two models used in this study

Both model areas contain considerable portions of cultivated, bare soil, isolated trees, small urban housings and roads. Model (A) has larger cultivated areas compared to that of model (B), while the latter contains dense forests as well. No major water bodies exist. The terrain is moderately hilly with height range of 285-399 m and no abrupt terrain discontinuities. There also exists a topographic map of the region indicating the photographic block extent and strip and photo numbering. Anyhow, this was of limited use due its small scale.

A photogrammetric quality scanner was used to convert these films into digital products ready for computer work. Three resolutions were produced at 21, 56 and 112 μm pixels. The 21 μm is in the acceptable range of resolution widely used for geometric precision keeping reasonable size of image file [7]. The other two resolutions chosen here are mostly being in use for orthoreproduction and possibly for lower precision requirements.

Conventional method of DEM extraction was performed using the analytical plotter PLANICOMP-P3 together with the software PCAP. Results were taken as reference. The digital part used the DP VirtouZo system from Wuhan University. Standard procedures of production were followed in both systems.

Analytical Photogrammetric Approach:

DEM was extracted using the analytical plotter and the film materials. A regular grid with interval of 10 X 10 m. was chosen. This seems sufficient for this terrain having no abrupt changes in heights. Thousands of points were collected and the output DEM files were prepared and exported to SURFER program for regular gridding, analysis and 3D displays. The resulting perspectives of ground surface are shown on Figure 2. Table 2 briefs selected statistics of this part. The output of this work includes files of grid heights used as a basis for comparisons with respect to DP methods. Reported timings of various working activities for model (B) are summarized in Table 3

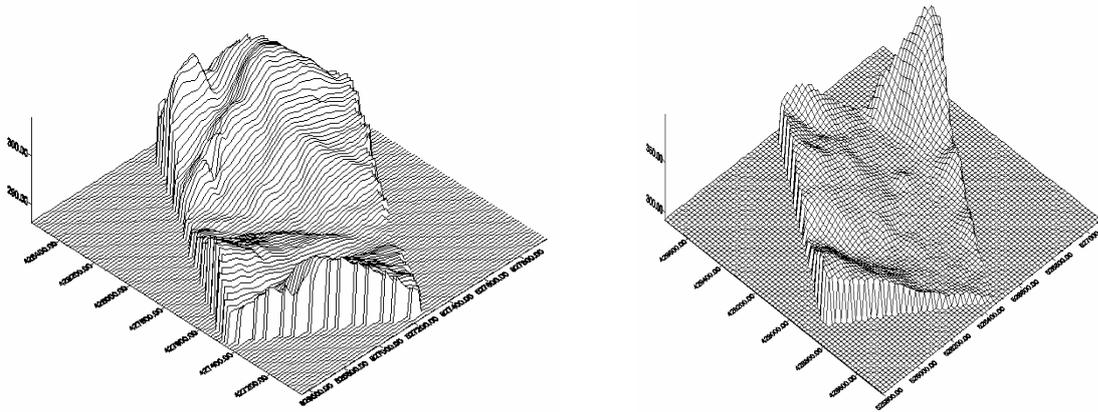


Figure 2. Perspective DEMs for models A, B.

Table 2. Analytical plotter DEM statistics for both models

Model	No. points	Min. ht. m	Max. ht. m	Avg.	μm
(A)	10992	285.472	308.257	293.958	5.269
(B)	8223	292.952	399.575	312.506	14.75

Table 3. Times required for DEM extraction on analytical plotter for model (B)

	Time	% of total time
Photo preparation and setting of computer and plotter	10 min.	3.4 %
Interior orientation	10 min.	3.4 %
Relative orientation	15 min.	5.1 %
Absolute orientation	15 min.	5.1 %
DEM collection	4 hr.	82 %
(For Model B. 8223 points at 10m X 10m grid. Total time \approx 5 hr)		

Digital Photogrammetric Approach and Discussions:

For automatic DEM extraction, the softcopy program first re-samples the stereopair into epipolar geometry. Then, performs image matching according to the selected patch window size. The values of x-parallaxes obtained are used to calculate heights of points. In order to study selected aspects in the automation process, various sets of DEMs have been created from the two test models. The DP program doesn't produce DEMs in a regular grid. For that, all output files were exported to SURFER program to create grids that are suitable for graphical representation and comparisons whenever required (grid spacing was chosen to match those used in the analytical part). This conversion itself is a source of small errors, according to the interpolation method used [8].

The next subsections discuss two types of tests on the produced DEMs. Discussions first care to the interactively edited DEMs, followed by analysing the fully automatic approach with no manual intervention.

Interactively-edited DEMs.:

Editing tools provided by the DP software were used together with the special screen and stereo visualization crystal glasses to remove errors that are detected through out the matching area in model (B) for the three resolution cases. Functional tools such as “point edit, polygon edit, interpolate between two profiles”, and others were used according to the nature of error and shape of the ground. The reliability indicator provided by the software was of limited help. Most errors were noticed in large areas of poor textures such as bare uncultivated soils, dense forest, isolated trees and urban areas. Editing and height corrections were made by modifying the floating cursor location to fall on the ground surface, except at dense forests where the reference surface was maintained at treetops. It was impossible in these locations to locate points on ground surface. Similar logic was followed in DEM collection using the analytical plotter for the sake of comparison.

A specific observation in DEM editing is the considerable time required and the difficulty even with the help of powerful software tools. Reported editing times are 2, 5 and 10 hours for the resolutions of 112, 56 and 21 μm respectively. This time varies according to terrain type and specific setting of the running parameters and operator experience. Editing problem is more serious at the edges of the displayed model. At these regions, the interpolation functions may not work properly and the user has to edit numerous points. Also, it is very difficult to edit quickly in dense forest areas since stereovision at treetops requires great skill and patience due to the difficult texture of these surfaces. In the model, large areas representing cultivated open lands have quite good results. Automatic DEM produces acceptable results in these regions even without manual editing. After manual editing, the RMSE of differences in heights at grid nodes with respect to analytical results was found to be around the threshold of 0.1 % of flying height [9]. See Table 4

Table 4 Height accuracy of edited DEM in meters

Image resolution \ μm	RMSE m.
B112	1.06
B56	1.0
B21	0.82

Un-edited DEMs.:

A bottleneck problem in digital photogrammetric work is the need to test reliability of output results and perform manual editing for thousands of error points. As noticed in the previous section, the DEM editing process is the most time consuming and has to be performed manually by the operator. Any attempt to improve existing software performance should be directed towards minimizing or eliminating this task.

Few software parameters that are controlled by the user during execution have their effects on the final product. In this session of work, It is required to test the reduction in DEM error level that is attainable while varying selected program parameters. This test analyzes DEM output that is achieved without interactive editing. The aim is to give an insight into the

degree in approaching an accurate output in the process without human intervention. The major parameters used by the system are:

- Type of terrain: The user has to specify the type of terrain since internal calculations use default values for specific terrain type. Wrong setting will either prolong automatic processing time, or it may give erroneous results. For the case of this study, the type set is “undulating terrain”.
- DEM spacing in both directions: The default setting value is 10 m, which was used initially for this work.
- Image matching window size in both directions: In this case, the program default size is 15 X 15 pixels. Tests were also made on other values in later stages.

Numerical tests are made to assess outputs and provide quantitative comparisons. Comparisons are made between the analytical plotter DEMs and those of the three resolutions obtained in this phase of DEM extraction.

At grid nodes, the difference in height values are calculated between analytical plotter and digital products. Table 5 lists related data out of this comparison. It shows that the average values of height differences are all small, indicating that no bias is found in these results. In the meantime, the table shows that the ranges of height differences between the two systems cover a range of high values in the negative and positive ends. These are shown in the first three columns of the table. These extreme values are created at blunder points due to failure in automatic matching. In the table, it is seen that model (A) has the lowest negative values of height differences. This probably explains the obvious raise of vertical axis in the perspective shown in Figure 3. The RMSE values in height differences show that model (B) is slightly worse than (A). This is due to existence of more areas of bare soil and forests.

Table 5 Selected statistics for DEM height differences calculated from both systems

Model Res. μm	Range in height. Difference m			Avg. Difference m ht.			RMSE in ht. Difference m		
	21	56	112	21	56	112	21	56	112
(A)	-45,19	-23,31	-73,13	0.9	0.4	0.6	3.45	3.53	3.78
(B)	-14,42	-11,36	-4,33	0.75	0.9	0.9	4.81	4.67	4.32

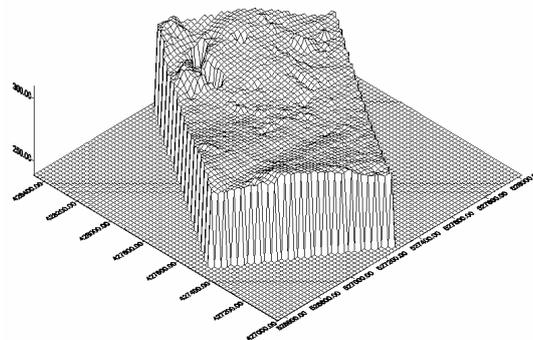


Figure 3. Perspective DEM for model A, using digital photogrammetric approach.

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In calculating height differences at grid nodes of the DEM outputs from both systems, all points having large residual values of more than (3σ) were treated as blunders. Discarding these points slightly improves the overall accuracies of outputs. Table 6 presents statistics before and after this process on both models with varying patch window size. Careful study of this table shows that, deleting of points having height differences of more than 3σ will drop the error level (σ) by a range of 12.2 % to 57.8 %. This is shown in the last column of the table. The number of affected (deleted) points ranges from 1 to 3.5 % of the total DEM points. The strategy of deleting here is effective against blunders (spikes) in the output data. In the mean time, this method should be used with caution for highly undulating and mountainous terrain since deletion may affect even ground surface irregularities. Comparing Tables 4 and 6 reveals that fully automatic DEM outputs have in the average 4 times the amount of error values that are obtained from manually-edited results.

Table 6 Statistics before and after deleting points of higher error values

Model	window Size, pix.	DEM points	σ of differences	DEM after deletion	New σ of differences	% change in number	% change in σ
A21	15 X 15	260315	3.45	256775	3.03	1.3	12.2
A56		36428	3.53	35889	1.49	1.4	57.8
A112		9102	3.78	9005	1.97	1.0	47.9
B21	15 X 15	214404	4.81	207138	2.55	1.4	46.9
B56		30141	4.67	29079	2.32	3.5	50.3
B112		7570	4.32	7309	2.18	3.4	49.7
B21	39 X 39	31726	4.66	30630	2.12	3.4	54.5
B56		-	-	-	-	-	-
B112		1112	4.098	1073	2.13	3.5	48.0
B21	5 X 5	-	-	-	-	-	-
B56		-	-	-	-	-	-
B112		68190	4.93	65881	2.88	3.4	41.6

To proceed the tests on effect of changing program parameters on DEM outputs, new runs are performed by changing the DEM interval to 1, 20 and 30 m respectively. Surprisingly, all results were identical to the default cases of 10 m interval. No clear explanation for this result. In this regard, many researchers using other DP systems reported similar conclusions and conclude the Black box term that many software parameters are not well documented and their uses and effects are not clear. [10].

Measurements of times required throughout different steps during automatic DEM extraction for model (B) are summarized in Table 7. The most time critical step is that of editing of matching results to obtain DEM output of acceptable accuracy. This time is calculated for an average experienced operator. It depends on many factors including terrain variability and number of extracted DEM data points and image quality and resolution.

Unlike the analytical plotter timing which was listed in Table 3. Here, digital photogrammetric DEM activities have negligible processing times. This is due to the higher degrees of success in automation in most of these steps. However, manual editing consumes most of the time, and at higher resolutions, it may not be competitive to the analytical plotter method.

Table 7. Time (sec.) required for various activities in automatic DEM extraction*

Resolution.	µm	112	56	21		
Window Patch size in pixels		15 X 15	15 X 15	15 X 15	39 X 39	5 X 5
I.O.(manual, on-screen pointing).		180-300	180	180	180	180
R.O. & A.O.		< 30	< 30	< 60	< 60	< 60
Epipolar Resampling		3	3	< 60	< 60	< 60
Image Matching		3	< 30	120	120	420
<i>Edit Matching. (manual)</i>		<i>2 (hrs)</i>	<i>5 (hrs)</i>	<i>10 (hrs)</i>	<i>10 (hrs)</i>	<i>10 (hrs)</i>
Create DEM		2	5-15	< 30	< 5	< 90
Orthorectify		5	5	< 80	< 80	< 80
Create Contours		2	5	5	< 5	< 7
Export Products				< 60		

*: Preparatory works and GCPs collection and image inputs < 40 min.
Time required for many steps depends on the terrain variability and operator skill. Manual editing times in italic.

Conclusions:

Editing time is still a problem and it may seriously degrade the benefits of the digital method if it approaches the collection time using the conventional method. We think that more work should be focused towards reducing editing time rather than improving other processing activities. The use of geometrically and radiometrically good quality film is a must for reducing the chances of error. Visual interpretation is not sufficient to draw more understanding out of this work. In studying the error that is emanating from DEM and automatic matching process, the following notes are briefed.

- Matching errors that arise from featureless areas cannot be edited unless there is some kind of supporting data as an additional input source of information, e.g. additional spot heights in these portions.
- Matching errors that result from dense forest need supporting data. This may be multivariate imagery or laser radar imagery that penetrates foliage.
- Matching errors in urban areas that result from shadows and occlusions. This case also needs supporting data preferably of multiple images.
- Sparse trees produce matching-errors that can be reduced by filtering the DEM files using suitable sizes of windows.

The reduction in automatic processing time is not of so much importance per se. However, interactive editing time is the critical issue. In this case, the total time may not even be shorter than conventional methods if large areas of errors are produced. Interactive editing

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is easier at smooth regions. It may be tedious in rugged locations. The shapes and trends of contour lines generated automatically agree in general with manual methods. However lines created are harsher especially in higher resolution images due to modeling finer details of ground cover. This result is not favorable in areas containing scattered trees or urban structures. It is worth noting that in cases of forest, sparse trees and urban imageries, an erroneous DEM output might be accepted as a digital surface model (DSM). The interpretation depends on the specified needs of the user.

Statistical corrections for errors show that only marginal improvement is possible, that cannot be easily detected by visual inspection alone. Digital photogrammetric method can to a large extent replace the human operator in automating DEM creation with greater speed, lower cost and less training skills. This is true only for almost ideal cases of terrain and photography. Here, the term "ideal" cannot be clearly quantified. The operator always has to check the results. As a guideline, "ideal cases" include, open ground with neither dense forest nor urban structures, no large shadows or occlusions exist. The camera and film also should be of high quality. It is expected that smaller scale images will be of fewer problems due to the vanishing effects of urban structures, trees and minor ground irregularities. Accuracy of DEM obtained from automatic matching is higher in bare soil if the texture is suitable compared to that in other land covers. The result that DEM accuracy is in the range of 0.1 to 0.15 % of flying height using digital photogrammetric methods is found conforming to other related findings though this test was not exhaustive. It is noted that, what is called "automatic" in digital photogrammetry has not been put into the right perspective. Different systems at different stages of work have reached variable degrees of automation.

Digital systems are relatively lower in price than conventional plotters. They offer more functionalities such as different sensor models, 3-D views, image processing and many other processes depending on the particular system type. The speed and non-biased automated solution of large projects are the most benefits of using these systems. However, the reliability aspects are still imperfect.

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