OPTIMIZATION OF STRATEGY PARAMETERS USED IN AUTOMATED DIGITAL ELEVATION MODEL GENERATION.

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ABSTRACT

This paper describes research aimed at investigating the effect of strategy parameters on the accuracy of automatically generated Digital Elevation Models (DEMs). The parameters control the size of the template window, the movement of the search window and the acceptance and quality criterion of the conjugate points. The ERDAS Imagine OrthoMAX software has 14 such parameters and the incorrect specification can have a significant effect on the resulting DEM. Initial tests were carried out on two sets of imagery, one close range and the other one aerial, and results showed that identical parameter changes have a similar effect on the two sets of imagery; different areas of the same imagery and that some parameters have a greater effect on the derived DEM than others.

Accuracy assessments were also carried out on a set of 1:6000 aerial imagery for which check point data was available. A manual process of optimization was used to change the parameters and showed that a 35 per cent average improvement in the root mean square error could be achieved through manipulation of parameters. The process also made the algorithm more successful within twelve of the fourteen areas tested, where the level of interpolation was reduced. This is especially important in urban areas where the interpolation of points may result in points at street level being raised and roof tops being lowered.

This manual process of optimization is being carried out on other diverse sets of imagery to identify trends in the internal results derived from the DEM generation process. It is anticipated that these internal results can be used to classify the DEM. A system is being developed which will compare the results against a knowledge base containing areas for which improved strategy parameter values are known. The test DEM would then be regenerated using improved strategy parameters obtained from the comparison. This will reduce the emphasis placed on user experience in parameter specification and allow for DEMs with more than one land-cover type to be optimized.

INTRODUCTION

As digital photogrammetric systems develop and their use becomes more widespread, the skills required by the photogrammetrist are changing. The user now requires a knowledge of the matching algorithm used to automatically extract DEMs, the areas where it is likely to fail and the areas to which it is most suited. In order to optimize the accuracy of their system, users must also understand how to control how the algorithm searches and accepts conjugate points in the images.

With the Imagine Ortho*MAX* software from ERDAS, this control is facilitated through the use of a set of 14 strategy parameters. A full list of the parameters used in the Ortho*MAX* software can be found in table 1. The user has the option to alter the values for each parameter before the DEM is generated but this can be problematic and conversations with users suggest that many leave the parameters set at their default values. Smith *et al* (1996) states that the "parameters are written in a technical language and, even if the basic image matching technique is understood, it does not always help in determining the use of all the parameters as many are obviously software dependent."

Parameter	Default Value
Minimum Threshold	0.6
Noise Threshold	0.4
Maximum Parallax (x)	5
Minimum Template Size	7
Maximum Template Size	9
Minimum Precision	0.5
Rejection Factor	1.5
Skip Factor	2
Edge Factor	2.5
Start RRDS	4
End RRDS	0
y-Parallax Allowance	0
Resampling	Bilinear
Post-Processing	On

Table 1. Default OrthoMAX strategy parameters

The parameters control the size of the template window, the movement of the search window and the acceptance and quality criterion of the conjugate points.

Parameter selection allows the user a degree of control over the algorithm such that the nature of the resulting DEM can be changed (i.e. different levels of interpolation). Zhang and Miller (1997) state that the parameters are functions of terrain type, signal power, flying height, x and y parallax, and image noise level. In theory, a correct set of parameters will provide an accurate DEM with only successfully correlated points included and unsuccessful points rejected from further DEM processing. An incorrect set may result in filtering successful points and the inclusion of badly correlated points (known as false fixes) or simply failure in finding correlated points (Gooch *et al*, in press).

For example figure 2 shows a DEM of a section of farm-land in Germany generated from a set of 1:13000 imagery, whilst figure 3 shows the effect of changing one parameter, the minimum threshold from the default value of 0.6 to 0.5 (ERDAS suggest a range of 0.5 to 0.7 (ERDAS, 1994)). A large region denoted by the large black area on the right of the DEM can be identified where the algorithm has not estimated the elevation of the land correctly, a direct result of altering just one parameter. The histogram of difference between the two DEMs shows that 37 per cent of the points have been changed by at least 0.2m in the Z and 13 per cent of the points were changed by at least 1m.

This simple example illustrates the general problem of parameterization and its impact on accuracy. This is exacerbated and compounded by the availability of the additional 13 parameters.

This paper describes work currently being carried out in the Department of Civil and Building Engineering at Loughborough University. The research is aimed at defining a set of rules or heuristics which will help the user define an improved set of parameters for a DEM such that the accuracy is increased.

THE ORTHOMAX STRATEGY PARAMETERS

The following section (adopted from Gooch *et al*, in press) briefly describes each of the strategy parameters used in the ERDAS Imagine OrthoMAX DEM generation software. Further details can be found in ERDAS (1994) and Smith (1997):

The threshold values (Minimum and Noise) define the minimum acceptable correlation coefficients (0 to 1.0) between a window of pixels in the left and right images. A correlation coefficient below the threshold values forces the algorithm to reject the point and use an estimated value based on the elevations of the surrounding points instead. Setting a high threshold value means that the algorithm becomes more "selective" and only accepts points as valid matches if the correlation coefficient is high. Hence, the probability of obtaining a larger percentage of interpolated points increases, as more points are rejected. A smoothing effect may occur in such an event. If a relatively low value is specified, the algorithm will accept points with a lower correlation coefficient which may result in a higher number of potentially false fixes. Ideally, the correct value should accept the correlation's derived from corresponding points and reject all false fixes.

The Maximum Parallax and *y* Parallax Allowance parameters facilitate movement of the search window in the right image, in the *x* and *y* directions respectively (the units are in pixels). A Maximum Parallax specification of 5 pixels infers a maximum shift of 10 pixels (along the epipolar line) as the movement is not restricted to the positive direction (Stojic, 1997). The *y* Parallax Allowance is designed to enable successful DEM generation even when the bundle adjustment (triangulation) suggests that perfect collinearity has not been achieved. A *y* parallax setting is ideal for photogrammetric projects containing small residual *y* parallax. Both parallax allowances enable a greater area to be searched during DEM correlation. A consequence of the search relaxation is an increase in the processing time and, more significantly, an increased chance of finding false fixes (since more pixels are being included in the search).

The Minimum and Maximum Template Size parameters establish the dimensions (in pixels) of the square correlation template (a value of 5 indicates a 5 x 5 pixel template window). The image matching approach begins with the minimum template size and increments to a larger size if a successful correlation is not found. Larger window sizes are usually needed if the image content is low but has the effect of generalizing the terrain and potentially lowers the accuracy (peaks lowered and troughs raised). Again, raising the value increases the chances of finding success but increases both the processing time and the possibility of finding false fixes.

Once a pair of correlated points has passed the threshold tests, the corresponding precision in pixel space of the match is estimated. The precision is defined as the geometric mean of the error ellipse axes. The minimum allowable precision is defined by the user with the Minimum Precision parameter. Points failing the test are assigned a null status and the elevation of the point is subsequently interpolated using the surrounding known elevation values. Reducing this value makes the process more selective with respect to minimum allowable precision.

The Rejection Factor is considered a smoothing filter which removes local maxima and minima. The elevation of each point is predicted using the successfully correlated points within a local neighborhood of pixels. If the difference between the estimated and predicted value is greater than the Rejection Factor multiplied by the standard deviation of the surrounding elevations then the point is rejected and the predicted elevation used. A lower specification will force the algorithm to reject more points thereby creating a smoothing effect. A larger value will accommodate greater terrain variation, possibly created by false fixes, but may allow spurious results to be included in the final model.

In common with other systems, the DEM extraction algorithm employed by Ortho*MAX* uses a hierarchical Reduced Resolution Data Set (RRDS) approach which reduces the effects of false fixes associated with inaccurate estimations of the point elevations (ERDAS, 1994). Results from each RRDS are used as a "seed" for the next RRDS at a higher resolution.

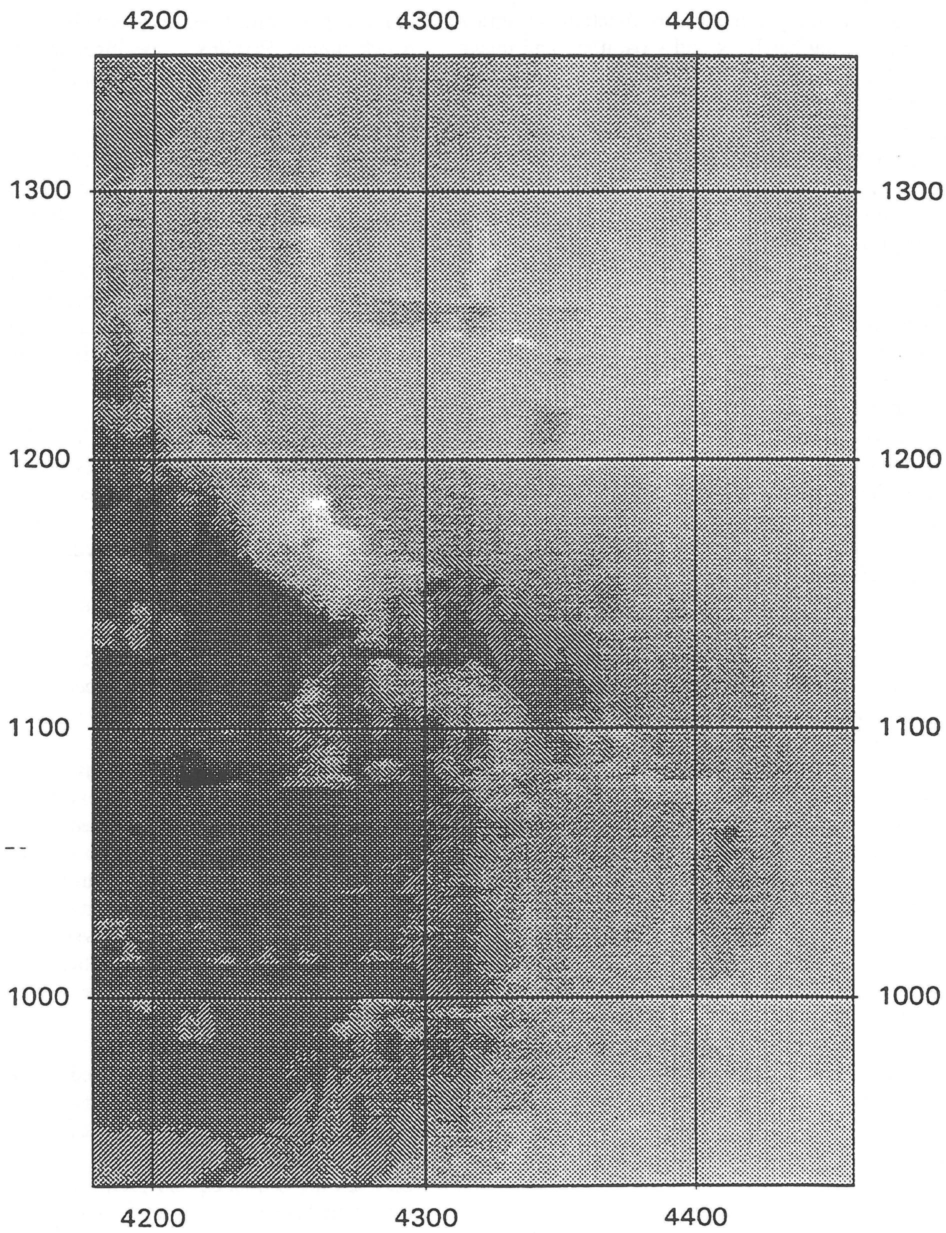

Figure 2. DEM generated using the default strategy parameters.

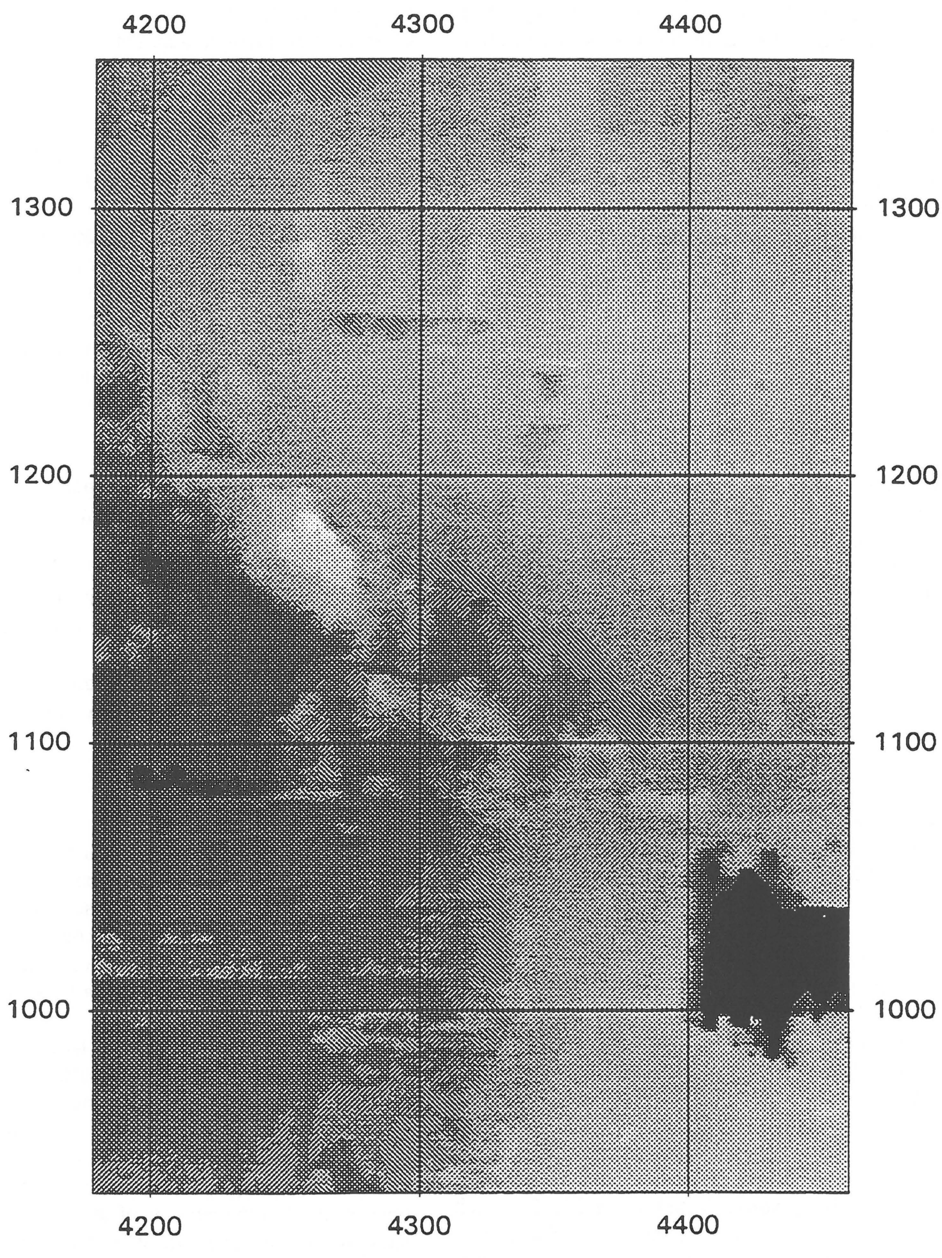

Figure 3. DEM generated with the Minimum Threshold parameter changed from 0.6 to 0.5

The reduced resolution data sets are derived by resampling the original imagery. The Skip Factor allows the collection rate to be increased by collecting grid points no closer than the specified value in all but the last RRDS. The last RRDS usually uses the original image unless otherwise specified.

The Edge Factor is used to minimize the number of false fixes in the final DEM caused by false correlation's along linear features. The error ellipsoid of each correlation is computed using the estimated precision of each correlated pair of image points. An elongated ellipsoid arising from what may be a linear feature suggests that the correlation may be unreliable. The Edge Factor describes the ratio between the major and minor axis of the error ellipsoid. If the ratio is higher than the factor then the point is rejected and an interpolated elevation used. Lowering the value will make the software more selective.

The Start and End RRDS values dictate the resolutions used in the hierarchical process. ERDAS do not recommend changing the End RRDS (ERDAS, 1994) but a larger Start RRDS value may be required for rugged terrain and is considered a more appropriate way of coping with rugged terrain than raising the Maximum Parallax parameter (Stojic, 1997). This raises the issue of the interaction between the parameters, a subject which can be complex to predict and model. For example, increasing the template size and lowering the minimum threshold are both ways of dealing with a low image content. However, changing both of these parameters is not necessarily correct and care should be taken in adopting this course of action without prior testing.

METHODOLOGY

An initial set of tests were carried out to identify if some of the parameters used in the Ortho*MAX* software have more effect on the resulting DEM than others. Two sets of imagery were used for this, one a set of close range imagery of a simulated riverbed with a photoscale of 1:70 (Stojic *et al.*, in press), the other, a set of aerial imagery containing a landslide on the coast of Dorset in England (Brunsden and Chandler, 1996) with a photoscale of 1:4000. The aerial imagery covers terrain with a wide elevation range (0 to 170m above Ordnance Datum) with a high textual content. In marked contrast to this, the close range imagery contains small elevation range and little texture.

To test the effect of individual parameters, six areas (three from each set of imagery) were selected and a DEM of each area created using the default strategy parameters. The default strategy parameter values are identical for all areas. These default DEMs provided a datum against which comparisons could be made. Each parameter was subsequently changed, both positively and negatively whilst keeping all the other parameters at their default values and the DEM regenerated.

Ortho*MAX* allows for DEMs to be compared with each other and creates a histogram of difference. Each DEM was differenced with its corresponding default DEM and the histogram created. If the histogram had a narrow, peaked distribution it was assumed that the parameter change had little effect on the DEM. If the histogram had a low and flat distribution however, it was assumed that the parameter change had modified the DEM significantly.

The results from these initial tests were very similar for all six areas and suggested that the following parameters had a particularly significant effect on the DEM generated:

- minimum threshold
- minimum and maximum template size
- minimum precision
- start and end RRDS

This was found to be the case for all six areas and so was a particularly important and significant result. It suggested that this could be applied to other data sets since the image content and scale of the two sets of imagery were so different. Unfortunately, accuracy assessments could not be undertaken because check point data (i.e. spot heights with a known and accepted elevation value against which the DEM can be compared) were not available for either set of imagery. It was therefore not possible to determine if the parameter changes were having a beneficial effect on the DEM with respect to accuracy.

ERDAS Imagine Ortho*MAX* generates a .log file for each DEM. This file contains a variety of results from the generation process including:

- percentage of correlated and interpolated points
- average and sigma (standard deviation) Signal to Noise Ratio
- average and sigma parallax changes
- failure analysis (reasons why points were rejected and subsequently interpolated)
- internal precision estimates
- time and speed of processing

These internal results were recorded for each DEM generated. One striking result from these initial tests was the similarity of the results when compared with each other. In particular, they showed that identical parameter changes had a similar effect on the results for the final RRDS of each DEM for both areas, the only difference being a small vertical shift of the lines.

Examples of this can be seen in figure 4 and figure 5. The graphs of estimated average precision in the image (pixel) space and the percentage of the interpolated points failing the peak threshold tests (one of the quality control tests) show an identical trend for the three photo scales (1:70 close range and 1:4000 aerial imagery used in the initial tests and the 1:6000 imagery used in the next set of tests). The tests (a to o) listed along the x-axis denote identical parameter changes applied to all three areas. For each parameter change, all other parameters were kept at their default values. For example, raising the minimum threshold parameter from the default value of 0.6 to 0.8 (test b) reduced the estimated average precision and increased the percentage of points failing the peak threshold test in all three areas by a similar magnitude. This phenomena was noted for all of the results in the .log file for all of the areas tested at all scales. This reinforces the conclusion from the initial tests that the parameter changes are having a similar effect on the different sets of imagery and different areas of each stereopair.

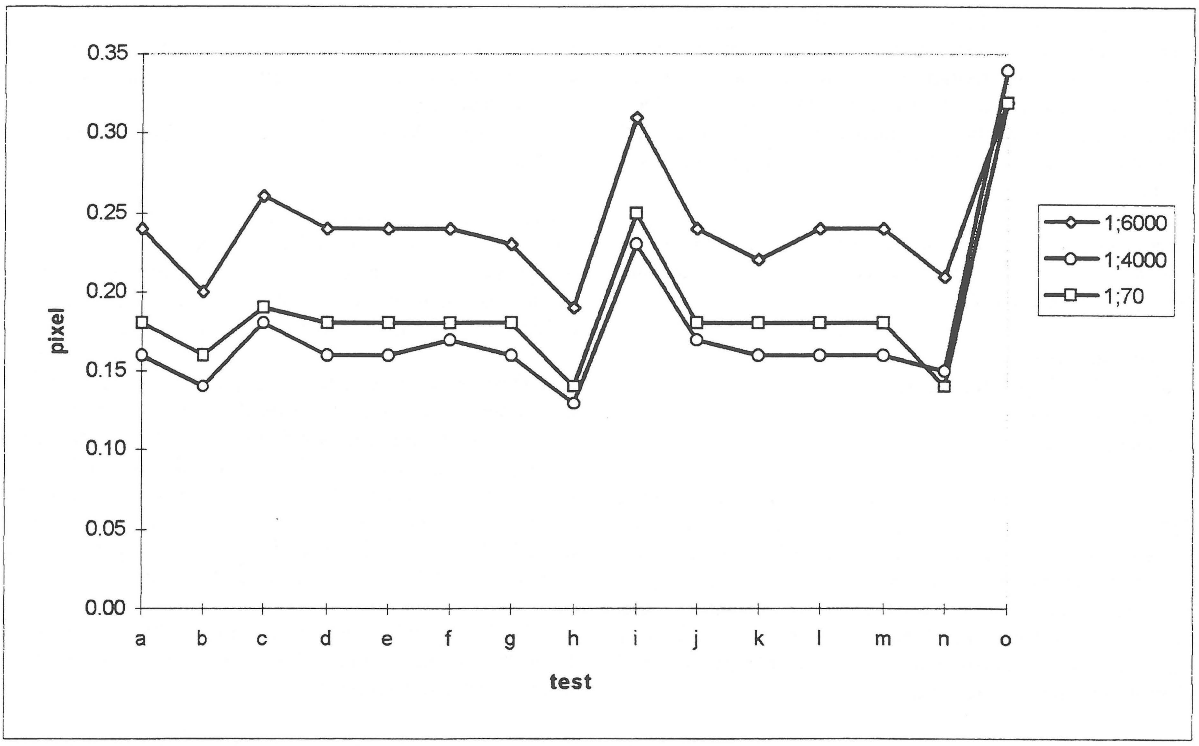

Figure 4. Estimated average precision in image (pixel) space.

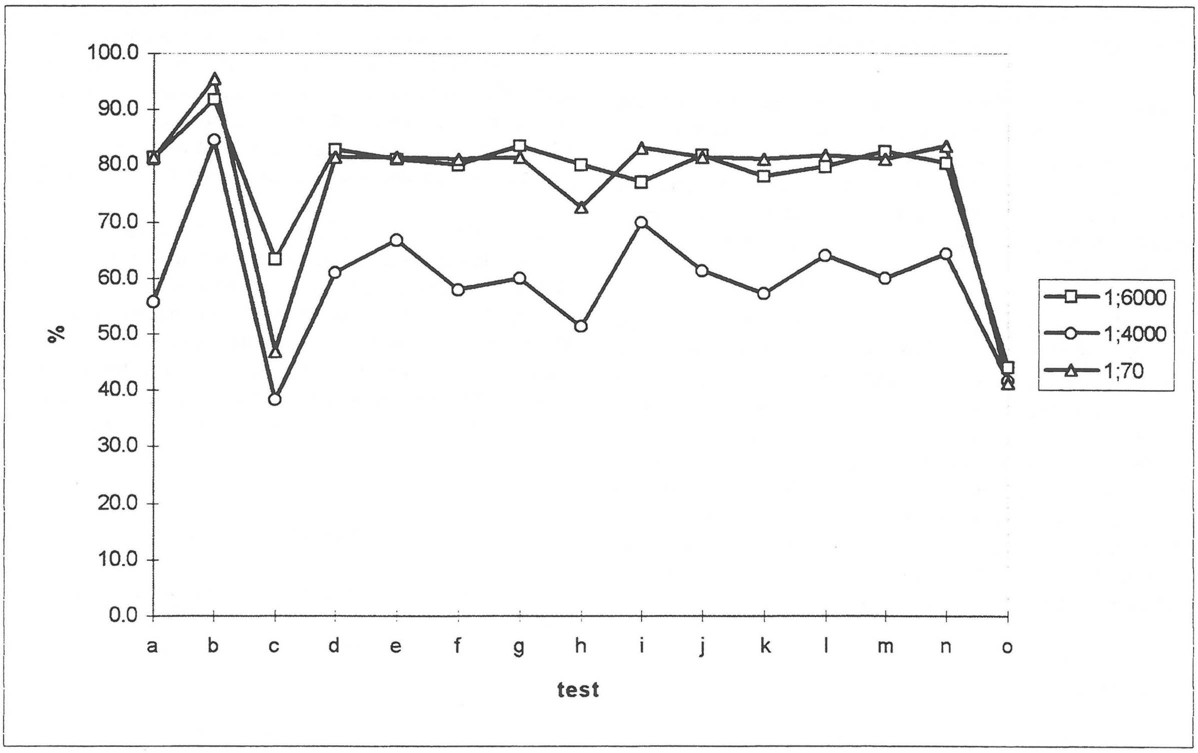

Figure 5. Percentage of interpolated points failing the peak threshold test.

A data set was obtained which contained a variety of land-cover types and check point data. This imagery covered a section of the City of London in Ontario, Canada and was captured using a Zeiss RMK A metric camera equipped with forward motion compensation at an average photoscale of 1:6000. The check point data was digitised from a set 1:2000 Ontario Ministry of Natural Resources topographic maps and represented clearly identifiable points such as road intersections.

Fourteen sub areas of the imagery were selected (Stojic *et al*, 1998) which generally were characterized by just one land cover type. These included:

- residential areas
- urban areas (larger buildings)
- open, rural areas
- forested areas

It was decided to record the majority of the log file for each DEM to try and identify (accuracy) trends in the data. Parameter changes which had a beneficial effect on the above results and primarily the root mean square error (r.m.s.e.)(Li, 1988) were combined in an attempt to optimise them. However, it was found that apparently beneficial parameter changes did not always combine in a positive manner, so a trial and error approach was adopted.

This method of optimization, whilst time consuming, produced a significant average improvement in the r.m.s.e of 35 per cent. This average does mask other trends. Considering the successful areas in isolation, this figure rises to 68 per cent. In four of the fourteen areas, no improvement on the default r.m.s.e could be made although a reduction in the level of interpolation was achieved for each of these areas.

The histograms of difference between the default DEMs and the optimized DEMs showed that between 58 per cent and 85 per cent of the points had their elevation estimates changed. Whilst these figures provide no guidance as to whether the change is beneficial to the accuracy of the DEM or not, it does indicate that the parameter changes are having a significant effect on the DEMs.

Examination of the optimized parameter sets for all fourteen areas showed that in 11 of the areas, at least one of the threshold parameters had to be reduced and that nine of the fourteen areas required an increase in either the x or y parallax allowance. These broad similarities support the conclusions from the initial tests from this study which found that the parameters had a similar effect on all of the areas examined and suggests that land cover type is not quite as important as was first thought. However, the slight differences between the optimized parameter lists for each area highlights the need for a method to assist in the definition of the parameters.

Current Work

The current work at Loughborough is based around extending the knowledge base of optimum parameter lists. As well as continuing to test the parameter combinations on the areas of the London, Ontario data set, other data sets are being introduced. These include:

- a OEEPE aerial data set with a photo scale of 1:13000
- a set of aerial imagery (1:7500) of rural farm land around Loughborough.
- two sets of close range imagery (1:160) of simulated river beds.

Check point data exists for all of the data sets so the parameters can be optimized with respect to accuracy. The use of such diverse imagery will facilitate the rigorous testing of the conclusions made from these early tests, the conclusions of Smith (1997) and the identification of any trends in the data.

One hypothesis that will be investigated is that the DEM can be classified according to the results from the .log file. It is anticipated that the user would create a DEM with the default strategy parameters and then enter the results into an interpolation program. This would automatically prescribe a recommended set of parameters based upon comparison with other DEMs for which the optimized strategy parameters are known. This will have several distinct advantages:

1. The DEM will be classified according to the internal results from the software, thus eliminating the need for human intervention and associated variability.

2. DEMs with more than one land cover type will be able to be classified and a suitable parameter set specified, reducing the need to split up the imagery into smaller sub areas and then mosaicing.

Some early tests on this system have shown encouraging results. Tests were carried out on nine DEMs generated from the 1:13000 OEEPE imagery. The results from the .log file of each DEM were entered into the interpolation program which compared them with the results from nine other DEMs for which improved strategy parameters were known. The revised parameters were then used in the regeneration of the DEMs.

The procedure was beneficial in five of the nine areas with an overall improvement in the r.m.s.e of 6 per cent. Considering just the 5 successful areas, the improvement was 15 per cent. It is hoped that the success rate can be increased as the knowledge base against which the results are compared is improved. This will be achieved by the addition of other test imagery, the manual process of optimization described earlier in the paper and further development of the system of interpolation.

CONCLUSIONS

This work shows that significant improvements in accuracy and success (as measured by the level of interpolation of the DEM) can be achieved through manipulation of the DEM strategy parameters.

The paper also describes a system which is being developed and tested at Loughborough University which will utilize the software's internal results derived from a test DEM to define an improved set of strategy parameters based upon knowledge of other DEMs. This has the benefits of reducing the level of user experience required and allows for the DEMs with more than one land-cover type to be generated and classified correctly.

REFERENCES

Brunsden, D., and Chandler, J. H., 1996. Development of an episodic landform change model based upon the Black Ven mudslide, 1946-1995. Advances in hillslope processes, (Ed: M. G. Anderson and S. M. Brookes), Wiley, Chichester. 2 Volumes.1306 pages:869-898.

ERDAS, 1994. Imagine OrthoMAX Users Guide. Vision International. 160 pages.

Gooch, M. J., Stojic, M. and Chandler, J. H., 1998 (accepted). Accuracy assessment of digital elevation models generated using the ERDAS Imagine OrthoMAX digital photogrammetric system. Photogrammetric Record.

Li, Z., 1988. On the measure of digital terrain model accuracy. Photogrammetric Record, 12(72):873-877.

Smith, M. J., Smith, D. G. and Waldram, D. A., 1996. Experiences with analytical and digital stereoplotters. Photogrammetric Record, 15(88): 519-526.

Smith, D. G. 1997. Digital photogrammetry for terrain modelling. Ph.D. Thesis, University of Nottingham.

Stojic, M., 1997. Accuracy assessment of automatically derived DEMs using OrthoMAX. Unpublished. ERDAS Inc.

Stojic, M., Chandler, J. H. Ashmore, P and Luce, J., 1998 (accepted). The assessment of sediment transport rates by automated digital photogrammetry. Photogrammetric Engineering and Remote Sensing.

Zhang, B. and Miller, S., 1997. Adaptive automatic terrain extraction. Integrating photogrammetric techniques with scene analysis and machine vision III. SPIE 3072:27-36.

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