AUTOMATED DIGITAL TERRAIN MODELLING OF COASTAL ZONES

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ABSTRACT

Coastal geomorphology is the study of coastal landforms, their evolution, the processes at work on them and the changes now taking place. The coastal zone is a constantly changing environment. An awareness of the issues associated within the coastal zone and the need to deal with them in an integrated way, are becoming more prominent in coastal studies. The need for research into coastal processes is now widely recognised and photogrammetry can be used for the recording and interpreting of coastal change.

The process of gradual evolution from analogue to digital photogrammetry has brought about many changes in terms of the characteristics of photogrammetry, more notably the conversion to *softcopy* photogrammetry. This change brings about many potential benefits, such as improvements in accuracy, flexibility, more efficient processing and eventually a reduction in cost.

The Land-Ocean Interaction Study (LOIS) project has been implemented by the Natural Environment Research Council (NERC). The broad aim of LOIS is to gain an understanding of, and the ability to predict the nature of environmental changes in the coastal zone of the UK. The Coastal Geology Group at the British Geological Survey (BGS) are seeking ways of terrain modelling the coastal environment. One of the main objectives is to establish the history of coastal sedimentation.

The general aim of this research is to develop techniques using digital photogrammetry to survey and model the coastal zone in order to assess both cliff erosion and sediment movement along the beach. Repeated, detailed cliff profile surveys are time consuming and individual profile erosion rates have, in the past, been generalised to represent the erosion rate along entire coastlines. Digital terrain modelling of the coastal environment using new digital photogrammetric techniques, may offer an efficient method of quantifying sediment yield. This paper present results from some of the research presently being undertaken.

1. INTRODUCTION

The Land-Ocean Interaction Study (LOIS) is one of the largest and most ambitious projects implemented by the Natural Environment Research Council (NERC). The broad aim of LOIS is to gain an understanding of, and the ability to predict the nature of environmental changes in the coastal zone of the UK. The Coastal Geology Group at the BGS are involved with the NERC LOIS project and are seeking ways of modelling the coastal environment and its geology. One of the main objectives is to establish a history of coastal sedimentation. This data could then be integrated with the geological data for analysis of erosion rates and material movement along the beach. This is expected to be undertaken in a computer aided modelling system, so any models of the coastal area need to be in a form suitable for inclusion in such a system.

The Holderness coast lies on the eastern side of the UK between Bridlington and Spurn Head facing East across the North Sea towards Northern Europe. The area is well known for the very rapid rate of erosion of its cliffs (Pringle 1981). They are composed of boulder clay and silts, which upon cliff erosion are taken up into suspension by the waves, and along with sands and gravels provide the main source of beach material. An appreciation of the changes in cliff and beach morphology are fundamental in understanding the very rapid erosion of this coastline.

Many problems in coastal geomorphology require long term investigation continuing over several years, with repeated surveys of landforms to identify and measure changes and relate these to correlative studies of processes. Perhaps the most sensitive mechanism of the coastline are along the beaches. They react rapidly to changes in sediment type or its supply rate. Beach morphology is not an isolated system, a change in one area will be transmitted down the shore line to a whole succession of beaches.

The general aim of the research is to assess the suitability of using digital photogrammetry to survey and model the coastal zone in order to assess both cliff erosion and sediment movement (volume) along the beach, both quickly and accurately. The conventional method of surveying the beach by spirit levelling is accurate, but can be an expensive, laborious and time consuming exercise over large areas. Data capture by photogrammetric techniques and the quantification of sediment yield using digital terrain models, may offer an improved method on those currently in use.

2. DIGITAL PHOTOGRAMMETRY AND THE COASTAL ZONE

The coastal zone has a number of varied environments which image very differently on aerial photographs. The beach area, the cliff area and the zone inland from the cliff are the three main areas of interest. One of the greatest problems that is perceived by looking at the imagery is that there can be considerable differences in the appearance of features from frame to frame, particularly along the shoreline on the beach.

Initial research using both the Zeiss P3 analytical plotter and two digital photogrammetric workstations has shown that the manual placing of the measuring mark in a stereo model can be difficult due to the lack of texture and the tonal changes in the images. Whereas the cliff face offers a great deal of detail, some sandy areas of the beach offer very little detail e.g. pebbles, and the correct heighting of a point can prove to be difficult. This is compounded by the waves being positioned differently from one frame of photography to the next, making it difficult in places, to create the stereo image.

One of the most powerful capabilities offered by digital photogrammetry is automated digital elevation modelling Early general experiences showed that automated digital elevation modelling can produce a different quality of result dependent on the image of the terrain. With these very varied images of the coastal zone, mentioned above, it is important to test the suitability of automated elevation modelling before it is extensively used. Therefore, research into the effects of the different topography on the quality of results achievable is important.

Automated digital elevation model (DEM) generation can appear to be a simple operation but the underlying algorithms are complex and contain a number of variable parameters. These variable parameters have an impact on the operation of the algorithms and ultimately on the quality of the DEM. It is important to experiment to find the effects of these variable parameters with particular application to the coastal topography.

The study of the suitability of automated DEM generation will be broadly divided into three aspects:

a) To investigate the effect of varying the parameters used to control the automated DEM processes.

b) To compare the automated DEM with a DEM observed on an analytical plotter, to determine its quality against 'traditional' manual observations.

c) To undertake a comparison of the DEMs observed photogrammetrically with those created from traditional ground survey on site. The traditional survey is expected to provide a significantly more accurate result.

Research is presently underway in a) and b) defined above and the following sections show some of the results obtained. Initially work is being undertaken using selected single stereo pairs of photographs, later the study will be more extensive with the availability of a strip of photography.

3. TEST DATA

At present an investigation is taking place using 1:5000 scale (1993), full colour, vertical photography from along the coast at Easington. Individual DEMs are being created using the Intergraph ImageStation (ImageStation) at the British Geological Survey (BGS) and the ERDAS Imagine OrthoMAX system (ERDAS) at the National Remote Sensing Centre Ltd (NRSC).

Results from the 1:5000 colour photography have been compared with the DEM produced from an analytical photogrammetric plotter (Table 1). This 'datum' DEM has been produced by an experienced photogrammetrist on a Zeiss P3 analytical plotter. It is being planned to re-measure the datum to determine the precision of this particular model. All subsequent automatic DEMs created on both the ImageStation and the ERDAS OrthoMAX workstations, are being compared to this datum. Current research involves the extraction of the DEM (*X Y Z*) files from all three workstations to enable a comparison to be undertaken to determine height differences.

It can normally be expected that for a given photo scale of 1:5000, well defined ground control can be measured on the analytical plotter to give a heighting accuracy of ±0.15m and points of detail to ±0.2m. These are well known heighting qualities for manual observation and define what we might expect from automated DEM generation. However, the ImageStation quotes three different heighting accuracies for each of the three terrain settings i.e. *flat*, *hilly* or *mountainous*. The heighting accuracies quoted are, (h/10 000), (2h/10 0000) and (3h/10 000) for *flat*, *hilly* and *mountainous* settings, respectively, where 'h' is the flying height in metres. Thus, for 1:5000 photography, 'h' is approximately 750m. This gives heighting accuracies of ±0.075m, ±0.150m and ±0.225m for *flat*, *hilly* and *mountainous* settings, respectively.

4. DEM COMPARISONS

The height differences between the analytical and automatic DEMs are shown statistically in Tables 1 to 3. They show some of the variable parameter settings that have been investigated and the results which have been obtained.

All the DEMs used in Tables 1 to 3 have been produced on a 5m grid interval using the red colour band. Automatically generated DEMs can be produced on either the red, green or blue bands. Normally the red band is considered to produce the best results. Breaklines have also been digitised along the top and bottom of the cliff for the six DEMs produced on the ImageStation (is01-is06). At present, it is not possible to digitise breaklines using the ERDAS software.

Both systems contain a comprehensive list of DEM parameter settings which can be varied. The ERDAS software contains 16 settings, while the ImageStation has 28. Initial research into the production of automatic DEM generation has concentrated on what are thought to be the more influential parameter settings.

4.1 The DEM Parameter Settings

The ImageStation MATCH-T software generates the DEM points essentially from *feature mapping.* It identifies a large number of individual image feature points that are used for the subsequent derivation of the terrain surface points. The ERDAS automatic DEM algorithm is classified as an *area correlator* in which patches of pixels from one image are correlated during the matching process with conjugate patches on the other. The primary correlation measure takes into account overall differences in tonal contrast between the image patches.

The three ImageStation terrain setting options, *flat, hilly* or *mountainous* can be influenced by a smoothing filter which can be set at either *high, medium* or *low.* The ERDAS DEMs have been varied using just three parameters, namely the minimum and maximum template sizes and the maximum parallax value.

Thus, the template size refers to the dimensions, in pixels, of the correlation template. The software begins each correlation for an area using the minimum template size. If a successful correlation is not reached, then the next larger size template is used and another attempt is made. This is repeated until a match is made or until the maximum template size is reached, in which case the correlation attempts for the area are abandoned. The template sizes are normally considered as dependant on the image quality and content. In this coastal zone, the cliff top is mainly low, undulating relief of green furrowed fields. The beach area is essentially composed of fine sand and small pebbles. In both cases, one area looks almost identical to another i.e. low relief and low image content.

The maximum parallax parameter is a function of the elevation range in the model area. Each time a DEM correlation is performed, the algorithm allows the search area to be expanded above and below the predicted elevation of a point by this amount.

Larger values of maximum parallax will search over greater elevation ranges and smaller values often miss points due to not finding the elevation within the more restricted range. Separating the cliff top and the beach, at Easington, is a cliff line approximately 17m to 22m in height, which is high in image content, showing good variations in tone and texture. Thus, an optimum parallax value has to be obtained which allows for the best modelling of the steep cliff face and the flatter areas on the beach and cliff top.

4.2 Analysis of Results

The results in Tables 1 to 3 consider 9084 grid points covering the beach, cliff, and cliff top. The ImageStation settings used are shown in Table 1. A comparison between flat, hilly and mountainous settings using a low smoothing filter shows that the hilly setting is producing slightly better results than the flat setting which is producing better results than the mountainous setting. This is particularly shown by the percentage of points for the range ±0.2m and the higher percentage of points within the lower range, ±0.05m for the hilly setting. The hilly setting can also be compared with the flat setting for a medium filter and again the hilly setting would be considered better.

Looking at the effects of the smoothing filter, considering the flat terrain setting where there are high, medium and low filter results, shows the high filter producing results perhaps just slightly better than the medium filter and both are better than the low filter. Similarly for the hilly settings the medium filter is producing the best results. So the best settings for this model are the hilly, medium filter settings. Possibly the best results might have been achieved with a hilly, high filter setting.

If these results are compared with the theoretical values calculated in section 3, the theoretical flat and hilly values are probably somewhat optimistic. The theoretical value for the mountainous setting would perhaps be more appropriate for these two settings.

Terrain setting	Flat			Hilly		Mts
Smoothing filter	High	Med	Low	Med	Low	Low
Range (m)	is01	is02	is03	is04	is05	is06
Under -0.20	7.8	6.8	9.1	5.6	8.1	9.5
-0.20>-0.15	2.8	3.2	4.0	3.2	4.0	3.9
-0.15>-0.10	4.8	5.4	5.9	5.6	6.0	5.5
-0.10>-0.05	8.8	8.2	7.8	8.2	7.6	7.3
-0.05> 0.00	10.6	10.8	8.6	10.8	8.7	8.7
0.00<+0.05	11.1	10.7	9.9	11.5	10.3	9.9
0.05<+0.10	10.9	11.1	10.0	10.6	10.4	9.2
0.10<+0.15	10.0	10.0	9.3	10.4	9.4	8.9
0.15<+0.20	9.1	9.3	9.0	9.2	8.6	8.0
Over +0.20	24.1	24.5	26.3	24.9	26.8	29.0
±0.05	21.7	21.5	18.5	22.3	19.0	18.6
±0.10	41.4	40.8	36.3	41.4	37.0	35.1
±0.15	56.2	56.2	49.6	57.4	52.4	49.5
±0.20	68.1	68.7	64.6	69.5	65.1	61.5
Under -0.20	7.8	6.8	9.1	5.6	8.1	9.5
Over +0.20	24.1	24.5	26.3	24.9	26.8	29.0

Table 1 ImageStation DEM Comparison Statistics (% of points)

The ERDAS DEMs have been analysed by variation in the minimum and maximum template sizes and the maximum parallax value, as shown in Tables 2 and 3. Looking at the effect of the minimum template size, eo4 compared with eo5, and eo9 compared with eo10 reveals very little systematic change between each set of results. Comparing changes in maximum template size using eo1 with eo4, eo2 with eo5, and eo8 with eo10 there appears to be no consistency. Marginally better results with the smaller maximum template size with the smaller minimum template size. However, the larger minimum (and smaller maximum parallax) show the reverse. From these results there seems to be little correlation between the quality of result and the change in template size. From using eo7, eo1 and eo6 (maximum parallax 3, 5 and 7) the value of 5 gives very slightly better results than the value of 3 and both are better than those with the value of 7. From eo8 and eo3 there is perhaps a marginal improvement from using 5, however with eo5 and eo9 the maximum parallax value of 3 is slightly better than 5. Changing the ERDAS parameters have not brought about very consistent changes to height values.

A few general observations from Tables 1 to 3 show that there are a greater number of residuals which are positive rather than negative for both techniques. Also from an analysis of the number of points with small residuals, in general, the results from the ImageStation are slightly better than the ERDAS.

Min Template (p)	**7**	**9**	**11**	**7**	**9**
Max Template (p)	**9**	**11**	**13**	**15**	**15**
Max Parallax (p)	**5**	**5**	**5**	**5**	**5**
Range (m)	**eo1**	**eo2**	**eo3**	**eo4**	**eo5**
Under -0.20	7.9	7.0	6.4	7.4	6.6
-0.20>-0.15	3.1	3.1	2.8	3.3	3.0
-0.15>-0.10	4.1	4.5	4.6	4.6	4.4
-0.10>-0.05	5.9	5.6	5.5	5.4	5.4
-0.05> 0.00	7.4	7.6	7.6	7.2	7.1
0.00<+0.05	9.0	9.4	9.0	8.8	9.2
0.05<+0.10	9.9	10.1	10.7	10.1	10.6
0.10<+0.15	10.7	11.0	10.5	10.2	11.3
0.15<+0.20	9.5	10.0	10.3	10.3	9.9
Over +0.20	32.4	31.7	32.5	32.6	32.4
±0.05	16.4	17.0	16.6	16.0	16.3
±0.10	32.2	32.7	32.8	31.5	32.3
±0.15	47.0	48.2	47.9	46.3	48.0
±0.20	59.7	61.3	61.1	60.0	61.0
Under -0.20	7.9	7.0	6.4	7.4	6.6
Over +0.20	32.4	31.7	32.5	32.6	32.4

Table 2 OrthoMAX DEM Comparison Statistics (% of points, p = pixels)

Min Template (p)	**7**	**7**	**11**	**9**	**11**
Max Template (p)	**9**	**9**	**13**	**15**	**15**
Max Parallax (p)	**7**	**3**	**3**	**3**	**3**
Range (m)	**eo6**	**eo7**	**eo8**	**eo9**	**eo10**
Under -0.20	7.5	7.5	6.9	6.5	6.8
-0.20>-0.15	3.2	3.4	2.9	3.4	3.1
-0.15>-0.10	4.0	4.2	4.4	4.5	4.2
-0.10>-0.05	5.1	5.6	5.5	5.6	5.6
-0.05> 0.00	7.3	7.5	7.5	7.7	7.7
0.00<+0.05	8.9	8.8	9.2	9.5	9.4
0.05<+0.10	9.7	9.6	10.2	10.3	10.5
0.10<+0.15	10.2	11.1	10.6	10.9	10.9
0.15<+0.20	9.6	9.6	10.2	9.7	10.1
Over +0.20	34.5	32.6	32.6	32.1	31.9
±0.05	16.2	16.3	16.7	17.2	17.1
±0.10	31.0	31.5	32.4	33.1	33.2
±0.15	45.2	46.8	47.4	48.5	48.3
±0.20	58.0	59.9	60.5	61.4	61.3
Under -0.20	7.5	7.5	6.9	6.5	6.8
Over +0.20	34.5	32.6	32.6	32.1	31.9

Table 3 OrthoMAX DEM Comparison Statistics (% of points, p = pixels)

4.3 Analysis of Different Coastal Zones

The DEM comparisons can be studied further by analysing the individual coastal zones. Tables 4 to 9 give a summary of results, in percentages, from the DEM generation over the *beach surface only* and the *cliff face only*. i.e. the beach points (1734 in total) and the cliff face points (647 in total) have been extracted from the DEM which was created over the whole model (9084 points in total).

Range (m)	**is01**	**is02**	**is03**	**is04**	**is05**	**is06**
±0.05	21.1	20.6	18.2	20.8	18.9	17.8
±0.10	41.2	39.9	35.3	38.8	33.9	33.1
±0.15	57.8	55.0	50.2	54.1	49.1	45.7
±0.20	69.7	69.9	64.0	68.1	62.0	57.2
Under -0.20	9.3	9.3	11.1	9.6	11.4	13.6
Over +0.20	21.0	20.8	24.9	22.3	26.7	29.2

Table 4 ImageStation DEM Comparison Statistics, Beach Only (% of beach points)

Range (m)	**eo1**	**eo2**	**eo3**	**eo4**	**eo5**
±0.05	16.8	14.8	17.2	15.5	16.1
±0.10	32.1	31.4	32.5	31.0	31.6
±0.15	45.0	46.5	46.2	45.5	47.0
±0.20	56.7	59.3	59.8	57.4	58.7
Under -0.20	13.3	12.1	11.1	12.0	11.1
Over +0.20	30.0	28.6	29.1	30.7	29.9

Table 5 OrthoMAX DEM Comparison Statistics, Beach Only (% of beach points)

Range (m)	eo6	eo7	eo8	eo9	eo10
±0.05	16.9	16.4	16.7	15.8	17.1
±0.10	31.9	31.1	32.3	31.4	32.1
±0.15	45.5	43.7	46.2	47.0	46.6
±0.20	56.7	57.0	58.7	59.0	59.0
Under -0.20	11.6	11.5	11.7	11.0	11.2
Over +0.20	31.7	31.5	29.6	30.0	29.8

Table 6 ERDAS DEM Comparison Statistics, Beach Only (% of beach points)

Range (m)	is01	is02	is03	is04	is05	is06
±0.05	8.4	7.5	7.4	9.3	8.7	10.4
±0.10	15.5	16.3	16.8	19.3	18.4	19.9
±0.15	23.4	24.2	26.2	27.8	28.7	30.1
±0.20	31.6	32.0	32.6	37.6	38.0	38.3
Under -0.20	33.5	29.4	27.8	23.0	21.8	20.6
Over +0.20	34.9	38.6	39.6	39.4	40.2	41.0

Table 7 ImageStation DEM Comparison Statistics, Cliff Only (% of cliff points)

	eo1	eo2	eo3	eo4	eo5
±0.05	9.1	9.3	8.3	10.7	8.5
±0.10	17.8	17.0	14.9	20.4	17.8
±0.15	27.8	24.7	22.9	28.1	26.9
±0.20	35.9	34.9	29.6	37.1	35.7
Under -0.20	21.6	21.5	28.7	20.6	21.2
Over +0.20	42.5	43.6	41.7	42.3	43.1

Table 8 OrthoMAX DEM Comparison Statistics, Cliff Only (% of cliff points)

Range (m)	eo6	eo7	eo8	eo9	eo10
±0.05	9.3	9.7	7.7	8.5	8.0
±0.10	18.3	18.1	14.8	17.9	16.3
±0.15	26.9	26.6	20.6	26.4	22.4
±0.20	36.0	36.3	28.6	36.1	31.1
Under -0.20	21.8	20.6	31.5	22.3	28.6
Over +0.20	42.2	43.1	39.9	41.6	40.3

Table 9 ERDAS DEM Comparison Statistics, Cliff Only (% of cliff points)

The optimum DEMs for the beach surface are is01, is02, eo3 and eo10. Both is01 and is02 have been generated using a flat terrain setting with a high and medium smoothing factor, respectively. Not surprisingly, the poorest ImageStation DEMs have been generated from the Hilly and Mountainous settings. However, it can be seen that is04 has similar statistics to both is01 and is02, and has been generated from a Hilly setting, medium Smooth parameter. The optimum ERDAS DEMs have been generated using the larger template sizes and lower parallax values (see Table 2 and 3).

The optimum DEMs for the cliff face are is06, eo4 with slightly poorer results from is04, is05, eo6 and eo7. The particular ImageStation DEMs have been generated from both Hilly and Mountainous settings; the ERDAS DEMs from smaller minimum and maximum template sizes. However, it is interesting to note that an increase in the maximum template size, eo4, and not the maximum parallax, eo6, improved the overall correlation.

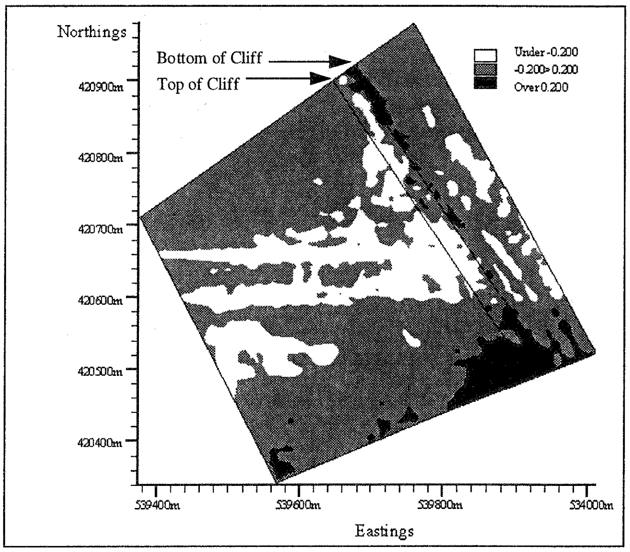

Figure 1 Height Difference Distribution Map (is01)

The Tables have shown the percentages of points within various ranges but it is also important to identify the distributions of the height differences. Figure 1 is a typical example of the distribution of height differences where the approximate top and bottom of the cliff line have been identified. A full analysis of these distribution plots is still in progress to identify the correlation between the magnitude of the height difference and the topography and image characteristics. It is interesting to note from just this single example that there are areas with greater than ±0.2m in all three coastal zones (beach, cliff and cliff top).

5. CONCLUSIONS

The results from these simple investigations have revealed some interesting general features of the automated digital elevation modelling process. The choice of parameter settings is important to achieve the optimum results. Choosing the appropriate simple terrain defining parameters in the ImageStation does consistently improve the quality of the results. The ERDAS system appears to be less predictable when changing the variable parameters. However, the analysis is still being undertaken.

The research project is to continue in greater detail to establish some criteria for using these DEM processes in the coastal zone. This analysis must be matched with the practical requirements of the environmental scientists and may result in a compromise in terms of a rapid data capture and processing technique, and the quality of result obtainable.

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