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DIGITAL PHOTOGRAMMETRIC MONITORING OF RIVER BANK EROSION

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Abstract

Detailed understanding of the processes which control river bank erosion requires high resolution information concerning temporal changes in bank morphology. This paper describes the successful use of digital photogrammetry to extract high resolution digital elevation models (DEMs) from terrestrial oblique stereopairs of rapidly eroding river banks, using the commercial software package Erdas Imagine. This software was developed for use with aerial photography and satellite imagery; problems relating to the use of oblique terrestrial images are discussed and solutions presented. Photography was acquired using semi-metric cameras, mounted on tripods and positioned about 15 m from the eroding bank. Data for DEM point spacings of 20 mm were obtained, with accuracies of approximately ±12 mm in depth. Digital photogrammetry can permit faster analysis, provide better accuracies and involve less ground disturbance than conventional methods of monitoring river channel change. Most importantly, DEM generation is considered to be more useful than traditionally acquired points or profiles for landform monitoring strategies.

Introduction

River bank dynamics are of direct importance not only to landowners threatened by bank retreat, but also to engineers, ecologists and geomorphologists concerned with patterns of water quality, erosion and sedimentation, and channel migration. A number of diverse processes interact to control and alter bank morphology, from the mobilization of individual particles by water flow, to the mass failure of large sediment blocks in response to changing soil-water pressures. Various attempts have been made to describe and model the dominant processes of bank erosion in different environments (van Eerdt, 1985; Springer *et al*., 1985; Osman and Thorne, 1988; Budhu and Gobin, 1995; Darby and Thorne, 1994; Kovacs and Parker, 1994). However, such models have rarely been subjected to rigorous comparison with field observations which quantify the extent and spatial distribution of different bank erosion processes. Their parameterization and verification require detailed three dimensional description of morphological changes, information which has proved difficult to obtain.

Existing methods of monitoring bank erosion usually involve simple repeat surveying of the bank edge or channel cross-section (Ashworth and Ferguson, 1986; Odgaard, 1987), or the insertion of metal pins or light-sensitive cells into the bank face and monitoring of their gradual exposure by erosion, to give point information about bank retreat (Wolman, 1959; Lawler, 1993). These methods tend to require considerable field labour and may involve significant disturbance of the channel edge. More fundamentally, the changing three dimensional form of the bank face is unlikely to be satisfactorily described by measurements at a small number of points or profiles, especially since the accuracy of these measurements is generally not known.

Photogrammetry represents an alternative, non-intrusive technique for monitoring landform evolution (Chandler *et al*., 1987; Chandler and Cooper, 1989; Lawler, 1993; Lane *et al*., 1993). Geomorphologists have long used photography as a means of describing landforms, including river channels, but have only recently begun to appreciate the potential of the photograph to provide accurate three dimensional topographic information (Chandler and Moore, 1989; Lane *et al*., 1994).

A small number of studies have used analogue and analytical photogrammetric techniques to monitor rates and patterns of bank erosion (Collins and Moon, 1979; Welch and Jordan, 1983; Lane *et al*., 1994; Dixon *et al*., 1997). Conventional analogue and analytical methods are rigorous and produce detailed three dimensional representations of topography. However, they require hardware which is costly and specialized, and analogue methods impose mechanical limitations making analysis impossible in some geometrical situations. These conventional techniques are time consuming to use and may be subject to operator error.

Automated image correlation techniques allow much more rapid extraction of digital elevation models (DEMs) from scanned stereophotographs; hence digital photogrammetric workstations have replaced the analytical plotter as the main photogrammetric tool in a wide variety of applications (Dowman *et al*., 1992; Heipke, 1995; Brunsden and Chandler, 1996). One aim of the present project is to facilitate a photogrammetric "technology transfer" amongst geomorphologists, similar to that taking place in other industries (Fraser, 1993).

This paper describes the extraction of detailed DEMs of rapidly eroding gravel river banks from terrestrial oblique stereophotographs, using commercial digital photogrammetric software originally developed for use with normal aerial photography and satellite imagery.

Image Acquisition

Fieldwork was carried out in July 1995 on the proglacial stream of the Haut Glacier d'Arolla, Valais, Switzerland (Fig. 1). The steep slopes and unconsolidated gravels of the valley floor give rise to rates of bank erosion which are highly variable but may locally approach several metres per day at times of high discharge. Previous studies in the area have used conventional analytical photogrammetric methods to study channel dynamics (Lane *et al*., 1994); the present investigation applies digital methods to close range photographs of small sections of bank within the upper reaches of the river.

Hasselblad ELX 500 semi-metric cameras, with 55×55 mm format and fitted with a 25-cross réseau plate, were used to acquire imagery. The radial lens distortion of the cameras is described by a polynomial curve, on the basis of laboratory test field experiments.

Stereopairs of photographs of eroding banks were taken daily or more frequently; at times of rapid erosion photographs were taken at intervals of a few minutes. Tripods were mounted on the opposite bank of the river or on mid-channel bars, to achieve base: distance ratios of approximately 1:3 to 1:4. The camera/object distance was controlled by the width of the river, a distance of about 15 m having been used in the examples discussed below. The cameras have a cone of view of around 40°, so at this distance the entire height of the bank (1 m to 2 m) occupies only a small part of each photograph and, with approximately 100 per cent overlap, the visible width of bank is about 10 m. Control targets were glued onto stones on the bank face, where this was possible in safety and with minimal disturbance. Where the bank face was difficult to access or appeared sensitive to disturbance, L-shaped metal hangers were fixed to the bank top and used to suspend targets from the bank edge.

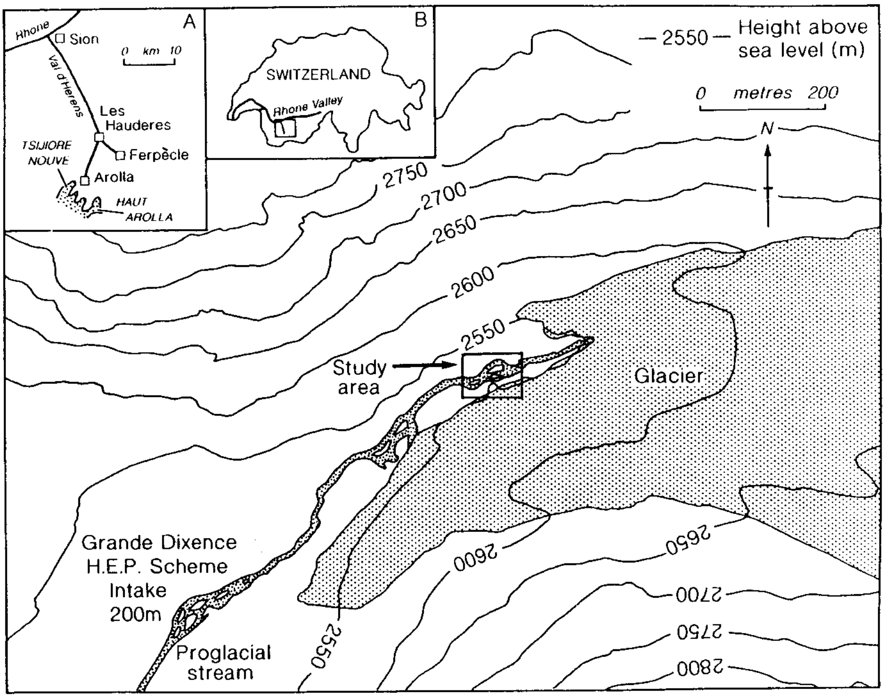

FIG. 1. Location of the study site: Haut Glacier d'Arolla, Valais, Switzerland.

In this way, the area of interest was surrounded by targets with little disturbance to the bank face itself. Sufficient targets were positioned to ensure that a minimum of five were visible on each pair of images. A Leica total station or digital tacheometer was used to establish the three dimensional co-ordinates of the targets and estimates of target positions were obtained by least squares adjustment (using the Generalised Adjustment Procedure, developed at City University).

Automatic image correlation requires ubiquitous small scale variations in light intensity in each image; the coarse gravels which dominate bank sediments at Arolla provide excellent texture of this nature. This advantage was somewhat offset by the difficulty of obtaining correct exposures for the area of the bank face, despite keeping apertures and shutter speeds around recommended values, because the harsh lighting at altitude gave rise to large contrasts between banks in shadow and brightly lit surrounding areas. A primary concern was that the image matching software might not be successful in areas of low or repetitive texture, particularly in areas which were slightly underexposed.

DATA ANALYSIS

The number of points recorded by a photograph is limited only by the grain size of the film; consequently, there is almost total flexibility in the amount of data which can be extracted (Chandler and Moore, 1989). In digital photogrammetry, the scanning resolution used to convert the images to digital form provides the effective control on the point density which is achievable in the image space. The camera/object distance and focal length determine the equivalent point density in the object space. The black and white Hasselblad negatives were scanned at a resolution of 20 μm with 256 levels of grey, using the Helava DSW100 scanning workstation at City University, each pixel representing in this case an area of approximately 4×4 mm of the bank face. The size of each image file is approximately 8 MB.

Analysis has been performed using the commercial remote sensing and GIS software package Erdas Imagine, mounted on an Ultra Sparc 140E workstation. Erdas Imagine includes the Orthomax module which performs automatic DEM extraction and digital orthorectification.

The operator enters the camera parameters (focal length, radial distortion model, position of fiducials) and the object space co-ordinates of the control targets, and uses a mouse to identify the fiducial marks, control targets, and an unlimited number of pass points on the screen. Orthomax computes the parameters of interior orientation and then absolute orientation, using a standard bundle adjustment.

Automatic stereomatching then allows the creation of DEMs and ortho-images. The image correlation algorithm used by Orthomax is an area correlator, which cross-correlates pixel intensity values between a "template" patch from the left image and a "search" patch from the right image. These values are normalized to take account of overall differences in contrast and brightness between the two source images. The algorithm is hierarchical, performing correlations at successively higher image resolutions before analysis of the raw imagery takes place, in order to constrain the template search area and minimize false fixes. Automatic post-processing at each resolution attempts to identify and exclude anomalous dips and spikes.

The image correlation algorithm is distinctive in its use of orthorectified images in the matching process; results from the previous, coarser, resolution are combined with those from the current resolution to orthorectify patches at a number of elevations both above and below that predicted for the point, using the calculated interior and exterior orientation parameters to model the imaging event. The cross-correlation coefficient is then calculated for each of these elevation "slices", and the most probable elevation is regarded as that which maximizes the correlation coefficient. This method avoids the need for image resampling either during correlation or in the creation of the gridded DEM, and is intended to improve the quality of image correlation by removing the effects of terrain variation, sensor geometry and camera position before stereomatching at the highest resolution is attempted (Vision International, 1994).

Orthomax is intended for employment with normal aerial photography and satellite imagery; its use with terrestrial oblique images required a modification to the co-ordinate system of the photographed area. A rotation was applied to the object space co-ordinates of the control targets, using a simple Visual Basic program, such that the bank face would appear flat in the normal vertical case. Since photographs were acquired with the camera axis almost normal to the near-vertical bank faces, this involved a rotation through approximately 90° of tilt. The images were then presented to Orthomax in the usual way, the co-ordinate system suggesting it to be a normal vertical projection.

This use of Orthomax therefore differs in several aspects from the aerial applications for which it is designed. There were four areas of particular concern:

(1) whether rotation of the co-ordinate system would be straightforward and produce results which enabled the image correlator to function;
(2) whether visual texture provided by the bank face would be sufficient for the stereomatching necessary for DEM acquisition;
(3) whether irregularities in the bank platform would give rise to values of relative relief (camera distance/object relief) outside the capabilities of Orthomax; and
(4) whether the package would allow analysis at the small scale required, for example permitting target object space positions to be specified with a sufficiently high precision for close range work.

Results

Digital extraction of DEMs from terrestrial oblique photographs of the Arolla river banks has proved both successful and straightforward; doubts that unusual features associated with this particular application (including the four points detailed above) would prevent analysis by Orthomax have not been realized. This paper

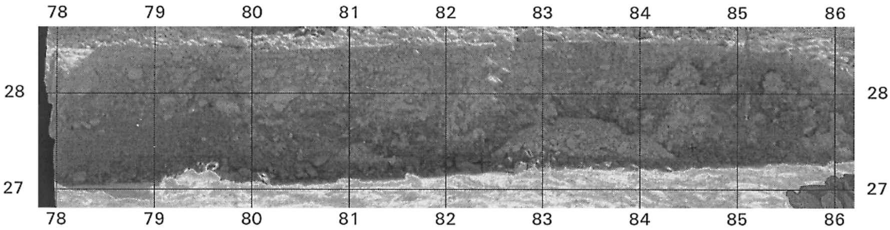

FIG. 2. Ortho-image of the bank face on 25th July, generated with optimum parameters. Grid in metres.

briefly discusses results derived from DEMs generated for an area of approximately 12 m^2 of river bank, using a 20 mm grid, for three epochs from July 1995.

Fig. 2 shows an ortho-image of the bank face from 25th July (the value of ortho-images is discussed further in the next section); individual coarse gravel and cobble clasts are visible in the steep bank face, and recent instability is evidenced by the small debris cone which has accumulated at the base of the bank between approximately $x = 82{\cdot}5$ m and $x = 84{\cdot}4$ m. The bank top is in strong sunlight and the chaotic foreground indicates failure of the stereomatching process in the imaged area of the river.

Qualitative inspection of a DEM of the same area of bank on the following day (26th July) suggested that there had been no change. However, it was possible to establish that localized but significant erosion had in fact occurred, by performing a simple comparison with the previous day's DEM. The topographic surface generated for 25th July was subtracted from that of 26th July to give a DEM of difference, shown as the upper image in Fig. 3: the pale grey pixels have values close to zero; white pixels have positive values, indicating deposition; and darker areas have negative values, indicating net erosion. The horizontal line at approximately $z = 28{\cdot}6$ m represents the top of the bank, and the line near to $z = 27{\cdot}2$ m is the water's edge. Most of the bank experienced little change, as initial inspection suggested. However, the dark area between $x = 80$ m and $x = 81$ m and above $z = 28$ m has pixel values of approximately $-0{\cdot}1$ m, suggesting that localized erosion has taken place. By itself, a DEM of the difference between two epochs is often difficult to interpret, but it is straightforward for the Imagine user to link the on-screen cursors between a DEM and an ortho-image of the same area, and thus unambiguously identify areas of apparent change. The two small ortho-images shown in Fig. 3 indicate that "real" change has indeed occurred in this area; it is clear that a cluster of stones immediately below the bank top disappeared in the 26th July image.

Non-photogrammetric monitoring methods would have be unable to identify such subtle and restricted changes, while the time required for conventional photogrammetric methods might have precluded DEM extraction for two epochs which appeared identical on initial inspection. However, digital photogrammetry allowed the identification and quantitative definition of quite subtle changes between the DEMs of 25th and 26th July.

Comparison of the 26th July results with those from a third epoch illustrates another aspect of the flexibility of the technique. Fig. 4 shows the DEM of difference produced by subtracting the 26th July surface from a DEM generated from photography on 29th July. In this case, the dark areas of the DEM of difference have pixel values of approximately $-0{\cdot}6$ m, and it is clear that substantial erosion has taken place across the majority of the bank face. This was also obvious in the field, because the L-shaped hanging targets at each end of the bank had disappeared during the erosion event. Target positions were established with reference to a wider control network, and so it was possible to position and survey a new set of photographic targets on the bank face, using the same datum, and to extract DEMs of the new bank face with only minimal inconvenience. This ability to measure erosion in areas which have suffered major disturbance is a particular advantage of the photogrammetric method. It is also significant that, while the loss of all targets and hangers suggested

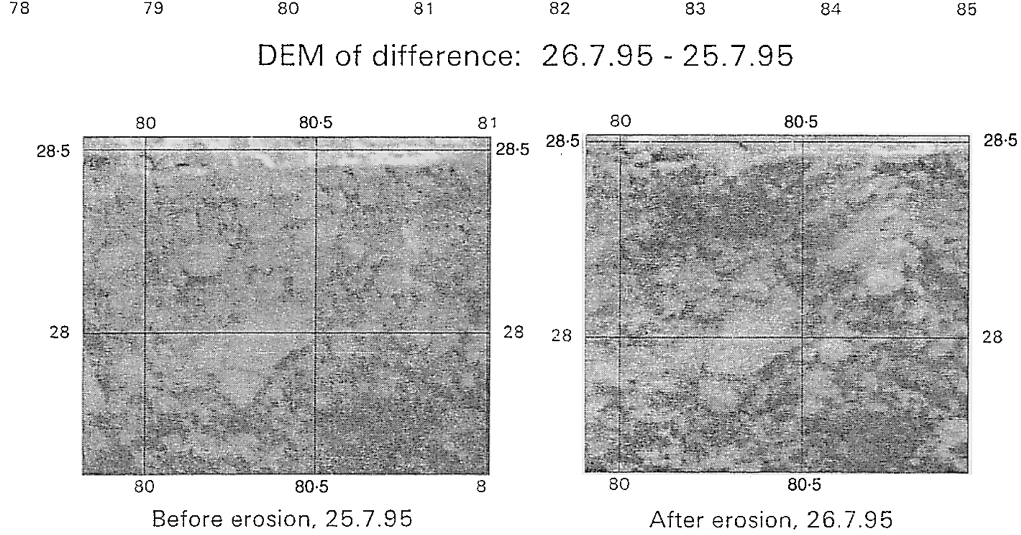

FIG. 3. Top: DEM of difference of the bank face between 25th and 26th July. Bottom: ortho-images identifying small area of change. Grid in metres.

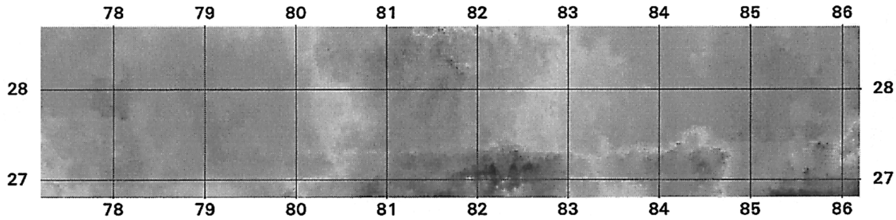

FIG. 4. DEM of difference of the bank face between 26th and 29th July, showing major change. Grid in metres.

that the entire bank face had been removed, Fig. 4 in fact shows that a central core (the pale area between $x = 81$ m and 82 m) of the bank suffered little and locally no erosion occurred. Landform monitoring strategies based on points or profiles which simply interpolate between widely spaced measured points would certainly have yielded misleading results in this example; even more seriously, *in situ* measuring devices would often have been destroyed by such severe erosion.

DEM Quality Assessment

The importance of assessing the quality of any measurement process is particularly significant where automated measurement methods have been used. The quality of the DEMs generated by Orthomax has been assessed in two ways: firstly by the visual inspection of ortho-images and secondly by the quantitative comparison of multiple DEMs obtained for a single area.

Visual Assessment of DEM Quality

Visual assessment of DEM quality is not straightforward. A typical initial stage in the analysis of a conventional large scale landscape DEM is a qualitative assessment of its geomorphic consistency, shown for example by the connectivity of ridges or stream channels, and its conformance to the operator's knowledge of the terrain (Bolstad and Stowe, 1994). However, the irregular topography and random sedimentary character of the bank face generally combined to make such an assessment of DEM quality impossible in the present case.

A satisfactory alternative method for the qualitative assessment of DEM quality has proved to be the visual inspection of ortho-images. An ortho-image is an image reprojected to remove the distorting effects of perspective geometry and relief; it is effectively the result of "draping" a DEM with one of the original images from which it has been derived. Areas of poor topographic representation give rise to errors in orthorectification, and appear as "wrinkles", "stretches" or blurred areas in the ortho-image. Distortions to the straight hangers to which control targets were attached also indicate errors in the image correlation and DEM extraction process. Such distortions act as a useful guide in identifying areas of poor performance and in rapidly differentiating between the results of DEMs collected with different user-specified parameters.

Considerable uncertainty surrounds the choice of parameters for use by the image correlation and DEM extraction software; a total of 16 parameters may be specified by the operator in the "DEM Tool" of Orthomax, with only limited guidance available as to the true significance of each. Qualitative experimentation to date suggests that DEM quality is improved by increasing the search range allowed for stereomatching, and particularly by the noise and minimum thresholds (the minimum correlation coefficients required respectively to consider or accept a point) which are specified (Table I). Contrary to expectations, best results have been achieved by applying very stringent controls on the acceptability of matches, even though this may increase the proportion of DEM points whose positions are estimated by interpolation.

TABLE I. Optimum and default parameters used for image matching and DEM creation by Orthomax.

Parameter	*Default value*	*Optimum value*
Minimum threshold	0·6	0·9
Noise threshold	0·4	0·7
x parallax search range (pixels)	5	10
y parallax search range (pixels)	0	1

The ortho-images in Figs. 2 and 5 illustrate the difference between results obtained with optimum and default image matching parameter values. The extensive wrinkled and blurred areas in Fig. 5 contrast with the clear results which were achieved with higher cut-off criteria and a larger search range in Fig. 2; in particular, the straightness of the control target hangers suspended vertically near to $x = 77{\cdot}9$ m and $85{\cdot}1$ m suggests that distortion is minimal.

Quantitative Assessment of DEM Quality

The quality of several parts of the DEM collection process may be evaluated quantitatively. For example, in close range applications, the precision of the control survey may provide the main limitation on the precision of the final DEM. In the present work, standard errors in the position of photocontrol targets were calculated as part of the least squares adjustment applied to the survey observations; these were generally better than 10 mm in *x* and *y*, and 1 mm in *z*. The bundle adjustment may improve these values further, however, and Orthomax provides a statistical estimate of the success of the triangulation process. The precision of the image matching process estimated by Orthomax is typically around 0·1 pixel (or 0·4 mm in the object space) and represents another partial measure of DEM quality.

However, the end user is primarily interested in the accuracy of the DEM itself, and this should also be assessed. Distortions to the DEM arise from the propagation of inaccuracies during interior and exterior orientation, resulting from errors such as inadequate modelling of the camera lens distortion, imprecise identification of targets or fiducial marks, as well as incorrect matching at the image correlation stage.

A standard test of DEM accuracy is the use of independent ground survey to provide independent check points, but problems of access and disturbance made this impossible in the present study. Provision of ground truth data is likely to offer only a partial assessment of DEM quality in small scale work such as this, because of the difficulty of measuring more than a very small number of points, ensuring survey accuracies better than a few millimetres, and unambiguously identifying each location with the corresponding point on the DEM.

The alternative method used to assess DEM accuracy in this study considered the reproducibility of DEM results for a single area. DEMs derived from different pairs of photographs have been compared for an area of bank which appears (from

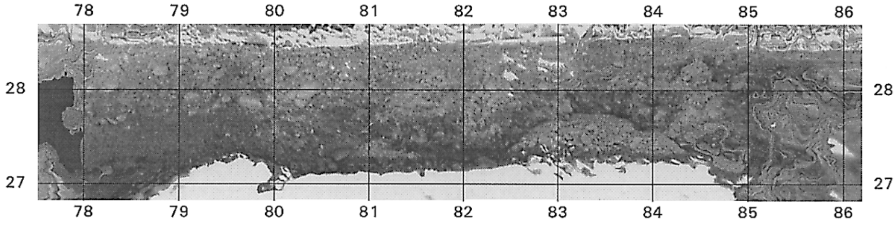

FIG. 5. Ortho-mage of the bank face on 25th July, generated with default collection parameters. Contrast the blurred and distorted areas with Fig. 2. Grid in metres.

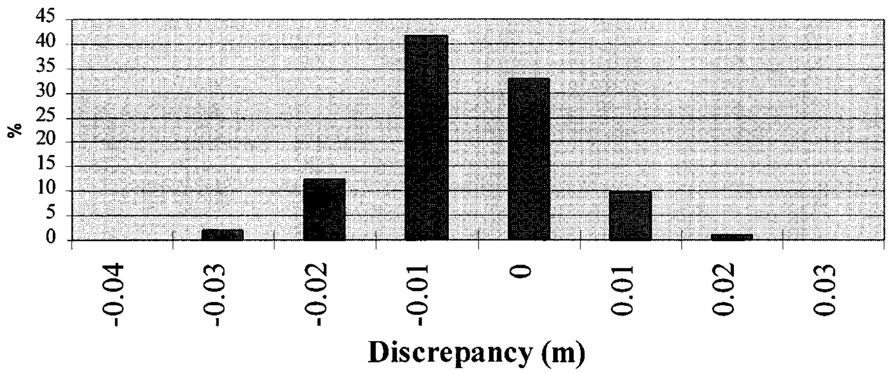

FIG. 6. Histogram showing pixel values of DEM of difference, for area of no change. Mean = -0·008 m, standard deviation = ± 0·012 m.

detailed inspection of clasts visible on the ortho-images) not to have experienced any change between two epochs.

Fig. 6 presents the results of a typical analysis, which is a histogram of the pixel values for 3800 points in the DEM of difference shown in Fig. 3 (away from the small area of change discussed above). If no erosion or deposition has taken place, the position of each point will be identical, and the value of each point on this DEM of difference should ideally be zero. Fig. 6 shows that pixel values are in fact normally distributed and centred around a mean of − 8 mm. The most useful indication of DEM accuracy is to state this mean value, and the standard deviation of the distribution of differences (Li, 1988), which in this case is ± 12 mm. On the basis of this sampled area, the accuracy of the DEM is therefore estimated to be − 8 mm ± 12 mm. This represents an accuracy of approximately 1/1000 of the camera/object distance, towards the lower end of accuracies achieved in aerial photography (Fryer *et al.*, 1994). This may be attributable to the close range nature of this study, because errors in the estimates of ground point positions are much larger relative to the camera/object distance than would be expected in large scale mapping. In terms of modelling the geomorphological processes, these accuracies are considered highly satisfactory.

DISCUSSION: GEOMORPHOLOGICAL SIGNIFICANCE

The coarse gravel banks analysed in this study are rich in fine scale visual texture, allowing successful image correlation and DEM production with Orthomax. The extent to which less favourable (fine grained) sedimentary environments can be monitored in a similar way is not yet known: current research on the River Severn aims to resolve this important question. Although grain scale texture will normally fall into the sub-pixel size range in such environments, river banks in fine grained sediments typically appear rich in texture at the ped or block scale, and initial results suggest that application to fine grained sediments should not prove problematic.

Digital photogrammetry is being used to support a geomorphological study addressing the relationship between soil moisture flow within river banks and the processes of bank collapse. Recent physically based numerical models have examined the effect on bank stability of soil moisture flow in response to changing river levels (Springer *et al.*, 1985; Budhu and Gobin, 1995). DEMs generated by the present work will be used to provide topographic boundary conditions for such simulations, and to provide detailed comparisons between model predictions and observed failure patterns as individual blocks of cohesive sediment slide down an internal failure plane.

An area of particular uncertainty has been the development of this failure plane, theoretical models of tension crack development being hampered by a lack of observational evidence (Darby and Thorne, 1994). The authors are also attempting to use automatically derived DEMs of collapsing river banks to define the position and shape of these failure planes for the first time.

A particular concern is the effect of DEM accuracy on model output. An increasing number of studies in the earth sciences are using DEMs to define the topographic boundary conditions for numerical models of geomorphic processes (Richards *et al*., 1995), allowing geomorphological theories to be tested against observed earth surface changes. However, errors in the representation of topography tend to be ignored unless their effects are so severe as to make analysis impossible (Garbrecht and Starks, 1995). For example, Burbank (1992, p. 484) states that current research demonstrates that "Earth scientists will have no trouble digesting whatever topographic data are sent their way"; where this trend involves the uncritical application of data whose accuracy is unknown, however, its benefits are questionable (Fryer *et al*., 1994). Rigorous evaluation is rarely performed even for probabilistic reliability analyses, which are increasingly important in hydraulic and geotechnical modelling and whose results depend on correct estimation of the uncertainties of input variables (Johnson, 1996). It is critical that DEM based modelling begins to incorporate a probabilistic approach, associating topographic positions with statistical error bounds (Hunter and Goodchild, 1995) in order to quantify the uncertainty in model predictions. A major advantage of digital photogrammetric methods is their potential for the straightforward generation of multiple DEMs for accuracy assessment in the manner which has been described above.

Conclusions

This study has used digital photogrammetry to map rates of retreat across approximately $12\,m^2$ of river bank, creating a series of DEMs with point spacings of 20 mm and accuracies of around $-8\,mm \pm 12\,mm$. A simple rotation to the object space co-ordinates of the photocontrol network was applied to simulate the normal case, and allowed the use of terrestrial oblique stereopairs in the digital photogrammetric workstation package Erdas Orthomax. Acquisition of distributed three dimensional terrain data involved minimal contact and allowed retrospective control over the temporal resolution of measurement, by the selection of significant epochs for analysis. The method has proved capable of measuring both subtle and major changes in bank form. Its most significant feature is its ability to reconstruct topographic surfaces at a very fine scale, avoiding the errors due to interpolation between widely spaced points which are implicit in traditional methods of monitoring landform change based on points or profiles. The DEMs created are considered greatly to increase the potential for detailed understanding and modelling of bank erosion processes.

Many areas of field and laboratory study in the earth sciences require high resolution topographic data, at a variety of scales and in situations which are no more geometrically complex than those described here. For such work, digital photogrammetry seems able to provide high resolution DEMs while involving less disturbance, providing better accuracies, and operating at greater speeds than methods currently in use.

A critical advantage of in-house DEM generation by digital photogrammetry is its potential for straightforward accuracy assessment. Statistical estimates of uncertainty can be made in the way which has been described, and the confidence limits associated with topographic parameters should be used to guide the sensitivity testing of subsequent process models.

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Résumé

Pour comprendre en détail la façon dont s'érode la rive d'un cours d'eau, il est nécessaire d'avoir des informations à haute résolution sur les variations temporelles de la morphologie de cette rive. On décrit dans cet article l'emploi réussi de la photogrammétrie numérique qui a permis d'obtenir des modèles numériques du terrain (MNT) à haute résolution à partir de couples stéréoscopiques de photographies terrestres obliques sur les rives d'un fleuve s'érodant rapidement, en utilisant l'ensemble des logiciels Erdas Imagine du commerce.

Ces derniers avaient été développés pour traiter des photographies aériennes et des images-satellites; on examine donc les problèmes que l'on a recontrés pour les appliquer à des images terrestres obliques et l'on décrit les solutions mises en œuvre. On a effectué la prise de vues photographiques avec des chambres semi-métriques, installées sur des trépieds et placés à environ 15 m du rivage érodé. On a réalisé les MNT avec des pas de 20 mm et obtenu des précisions d'environ ± 12 mm sur les éloignements. La photogrammétrie numérique permet de faire des analyses plus rapides, fournit des précisions meilleures et introduit moins de perturbations sur le terrain que les méthodes classiques de suivi des variations du cours des fleuves.

De plus dans les stratégies de suivi des formes du terrain, on considère que la production de MNT est plus utile que la saisie classique de profils ou de semis de points, ce qui constitue un élément très important.

Zusammenfassung

Ein detailliertes Verständnis des Prozesses, der die Erosion von Flußufern steuert, erfordert hochauflösende Informationen in bezug auf die zeitlichen Veränderungen der Ufer-Morphologie. Im Beitrag wird die erfolgreiche Nutzung der Digitalphotogrammetrie zur Gewinnung digitaler Höhenmodelle (DEM) hoher Auflösung aus terrestrischen Schrägbildpaaren von schnell erodierenden Flußufern unter Nutzung des kommerziellen Software-Pakets Erdas Imagine beschrieben. Diese Software wurde zur Anwendung auf Luft- und Satellitenbilder entwickelt. Probleme, die sich aus der Anwendung terrestrischer Schrägbilder ergaben, werden diskutiert, und es werden Lösungen dargestellt. Die photographische Aufnahme erfolgte mit Hilfe semimetrischer Kameras, die auf Stativen im Abstand von etwa 15 m von dem erodierenden Ufer aufgestellt waren. Für die DEM-Bestimmung wurden Daten mit 20 mm Abstand mit einer ungefähren Genauigkeit von ± 12 mm in der Tiefe erhalten. Die Digitalphotogrammetrie kann eine schnellere Analyse erlauben, liefert bessere Genauigkeiten und umfaßt geringere Geländestörungen als konventionelle Verfahren des Monitoring der Veränderung von Flußläufen. Am wichtigsten erscheint, daß die DEM-Erzeugung für die Erfassungsstrategien von Landformen brauchbarer ist, als traditionell gewonnene Punkte oder Profile.