Construction of Regular Grid DEMs from Digitized Contour Lines: A Comparative Study of Three Interpolators

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Abstract

Regular grid DEMs were constructed from digitized contour lines using weighted averaging (WA), minimum curvature (MC), and kriging for three terrain units. The accuracy of the DEMs was assessed against 200 randomly selected checkpoints. Other factors related to the accuracy, such as grid size, number of elevations in the input sample, number of nearest neighbouring elevations, distance decay power, and the impact of missing observations, were also comparatively studied. It was found that DEMs constructed using WA are the least accurate, and those using the other two methods have a similar accuracy at 10 m. At a larger grid size all DEMs are comparable in their accuracy regardless of the interpolator used. The accuracy is not severely subject to change in the size of sampled elevation unless it is extremely small. If constructed using MC, the accuracy of the DEMs is the most sensitive to increment in the grid size. The accuracy is hardly affected by the number of nearest neighbouring elevations for kriging, but is adversely affected if the WA interpolator is used. Distance decay power improves the performance of WA only when it changes from 1 to 2. Of the three interpolators examined, MC handles topographic uncertainty caused by missing elevations in the input dataset better than WA and kriging.

I. INTRODUCTION

Digital elevation model (DEM) data form an indispensable component in a geographic information system (GIS) database designed for elevation-related applications such as watershed hydrology (Band, 1986; Martz and Garbrecht, 1992), geomorphology (Lee *et al*., 1992), hazard analysis (Gao, 1993), and intervisibility studies (Lee, 1991). Topographic surfaces may be stored digitally in a number of ways, such as digitized contours, profiles, triangulated irregular networks (TIN), and regular grids (Cater, 1988). Kumler (1994) comprehensively compared TINs with regular grid DEMs in terms of efficiency in representing a wide variety of terrain units. It was found that gridded DEMs yield more accurate estimates of surface elevation than any of the contour-based TINs. As a common format of terrain representation, regular grid DEMs allow such information as slope angle, aspect, shading, convexity, and concavity to be derived or achieved readily (Burrough, 1986). Regular grid DEMs may be constructed from stereoscopic aerial photographs using the photogrammetric method (Makarovic, 1984) or from topographic maps. The former method can generate DEMs more efficiently and accurately, but requires sophisticated and expensive stereoplotters and highly trained personnel. Not constrained by these limitations, the latter method is preferred if the accuracy requirement is not too strict. It involves sampling elevations along contours that are later converted to grid DEMs through TINs or spatial interpolation. Grid DEMs generated from TINs cannot accurately capture the topography where there is an abrupt change in slope gradient because Delaunay triangles are extremely acute in these locations (Davis, 1986). Similarly, Jaakkola and Oksanen (2000) found that triangulation of the captured contour data may cause serious morphological artefacts during TIN to DEM interpolation. This intermediate stage is unnecessary and can be avoided through direct spatial interpolation.

Spatial interpolation has received lots of attention in the literature (Crain 1970; Lam 1983). A number of authors have studied the accuracy of spatial interpolation. Van Kuilenburg *et al*. (1982) compared proximal, weighted averaging (WA), and kriging algorithms in interpolating soil moisture supply capacity. Dubrule (1984) evaluated spline and kriging in estimating petroleum reserves at undrilled locations. The main purpose of using interpolation in these studies is to obtain unbiased estimates. Because the true values at unsampled locations are unknown, it is impossible to evaluate the accuracy of the interpolated results. Furthermore, the findings from these studies, in which only limited number of samples are available, may not hold true in gridding DEMs from a huge number of elevation samples digitized from a topographic map.

In constructing DEMs from digitized contours, Braile (1978) compared four interpolation methods (surrounding triangle, WA, local surface fitting, and intersecting cubic polynomials fit to profiles) based on 200 randomly selected points. Evaluated in terms of Root-Mean-Square Error (RMSE) and computation time, local surface fitting was found to be superior to the other three methods. Polidori and Chorowicz (1993) compared bilinear and Brownian interpolators in constructing grid DEMs. Using various evaluation criteria, they found that these methods were not completely compatible with each other.

In addition to the accuracy of interpolation, several authors also studied errors in the gridded DEMs. For instance, Carter (1989) identified three types of errors in the United States

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Geological Survey gridded DEMs. Monckton (1993) further examined the spatial structure of errors in digital elevation data. When evaluating the accuracy of the interpolated DEMs, Li (1991) focused on how the characteristics of checkpoints, such as their accuracy, quantity and spatial distribution, affected the evaluation results. It was found that there was a close and complex relationship between evaluation results and the number of checkpoints and their reliability. Wood (1992), and Wood and Fisher (1993) investigated the effective methods by which the accuracy of interpolation for contours was visualised. These studies focused on the errors in the interpolated results and their display. How does one interpolation method performs in relation to another has not been comparatively examined. No one has attempted to study the impact of such factors as the size of sampled elevations and the ability to handle missing observations in the input data on the accuracy of the gridded DEMs.

The objective of this study is to comparatively evaluate the performance of grid DEMs interpolated from digitized contours using weighted averaging (WA), minimum curvature (MC), and kriging. These methods are selected because of their availability in SURFER (Golden Software, 1994), a grid-based contouring and three dimensional surface plotting graphics program. Besides the interpolation method itself, other factors that affect the DEM accuracy (e.g., grid size, sampling size, number of neighbouring elevations, and terrain features) are also studied.

II. INTERPOLATION ALGORITHMS EVALUATED

Weighted Averaging

In this method the attribute h to be interpolated is a weighted sum of n surrounding elevations, or

$$h = \frac{\sum_{i=1}^{n} h_i w_i}{\sum_{i=1}^{n} w_i} \qquad (1)$$

where w_i stands for the weight assigned to the ith neighbouring elevation. There are a number of ways to determine w. One common method is to use the inverse of distance d between the ith neighbouring point and the point under consideration, or

$$w_i = 1/d_i^m \qquad (2)$$

where m is known as distance decay power. It is assigned such integers as 1 or 2 in practice. Apparently, the larger the power, the less influence the neighbouring elevation exerts on the point in consideration. This algorithm is easy to comprehend, and its implementation does not require intensive computation.

Minimum Curvature

This interpolator is the extension of a one-dimensional spline into two dimensions. Splines are piecewise polynomials that are constrained to have continuous derivatives at joints between adjacent segments. Minimum curvature means that the sum of discrete squared curvature C at location (i,j) is minimum, or

$$\sum_{i=1}^{I} \sum_{j=1}^{J} (C_{i,j})^2 = Minimum \qquad (3)$$

where I and J are the row and column numbers (must be odd) of the DEM to be constructed; $C_{i,j}$ is determined using Equation (4).

$$C_{i,j} = (u_{i+1,j} + u_{i-1,j} + u_{i,j+1} + u_{i,j-1} - 4u_{i,j})/S^2 \qquad (4)$$

in which S represents grid size; and u stands for a polynomial function in two dimensions. At the second order it takes the following form:

$$u_{i,j} = a_0 + a_1x_i + a_2y_j + a_3x_i^2 + a_4x_iy_j + a_5y_j^2 \qquad (5)$$

where $x_i = (i-1)S$, $y_j = (j-1)S$ ($i = 1, 2, \ldots, I$; $j = 1, 2, \ldots, J$); a_i ($i=0, 1, 2, \ldots, 5$) are coefficients.

The border condition governs that

$$u_{i+2,j}+u_{i,j+2}+u_{i-2,j}+u_{i,j-2}+2(u_{i+1,j+1}+u_{i-1,j+1}+u_{i+1,j-1}+u_{i-1,j-1}) \\ -8(u_{i+1,j} + u_{i-1,j} + u_{i,j-1} + u_{i,j+1}) + 20u_{i,j} = 0 \qquad (6)$$

This equation is solved iteratively. Starting values are usually the nearest observation or a weighted sum of neighbouring observations. The iteration is terminated if the specified minimum curvature or the number of specified iterations is achieved, whichever is reached first. Both Equations (3) and (5) apply to non-border elevations only. For border and corner elevations, these equations have a slightly different version. Such information is contained in Briggs's (1973).

Kriging

Initially developed by Krige (1976), kriging is designed for interpolation of regionalized variables that exhibit some degree of predictability within a certain scale. There are two types of kriging, punctual and universal. Their difference lies in that universal kriging can handle any trend present in the dataset through a trend surface analysis first. The residual variation in the dataset is dealt with punctual kriging later. Since topography over a broad scale seldom exhibits a uniform trend, universal kriging is not suitable for terrain interpolation. Punctual kriging is implemented using a mathematical formula similar to Equation (1) except that the weight is determined from the semivariogram $\gamma(d)$ calculated from all the elevations surrounding the elevation $Z(x_i, y_i)$ in question, or

$$\gamma(d_i) = \frac{1}{2n} \sum_{j=1}^{n} [Z(x_j, y_j) - Z(x_j + d_i, y_j + d_i)]^2 \qquad (7)$$

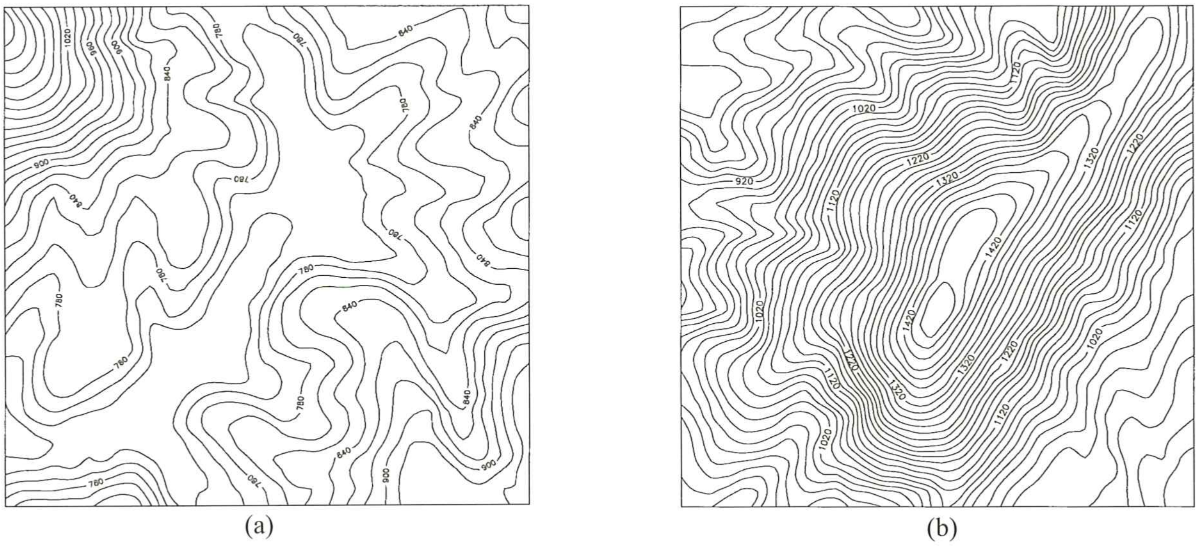
where n is the number of pairs of sample elevations separated by the distance d. In this interpolation method Equation (1) is applied twice. The first time h_i is replaced by the semivariogram $\gamma(d_i)$ to derive w_i through solving the multiple linear equations. The second time w_i is plugged into the equation to find the interpolated elevation, the same as in WA.

Kriging can be implemented either as point or block. Point kriging estimates the value of the points at the grid nodes. Block kriging estimates the average value of the rectangular blocks centered on the grid. Although it generates smoother contours, it is not a perfect interpolator. Oliver and Webster (1990) found that estimates from block kriging resemble closely those from punctual kriging, even though block estimates are more reliable. Thus, punctual kriging in the point mode is tested in this study.

III. RESEARCH DESIGN

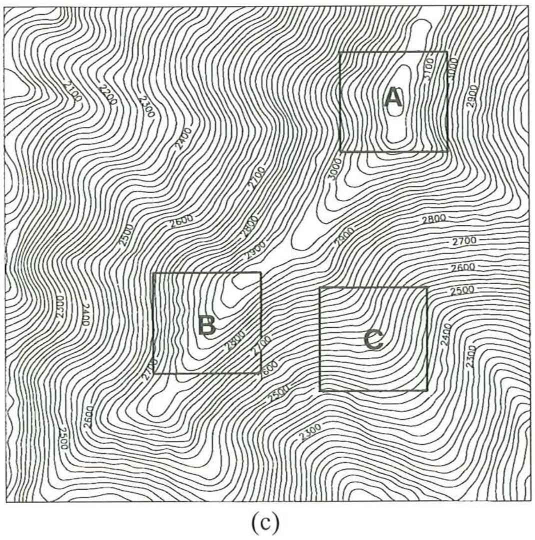
The topographic data used in this study were obtained from the U.S. Geological Survey 7.5-minute Horseshoe Mountain quadrangle of Virginia. This map sheet was initially mapped at 1:24,000 in 1967 and revised in 1981 with contours drawn at an interval of 6.1 m (20 ft). The map was enlarged over 200 percent to facilitate closer tracing of contours. Three 1 by 1 km² test sites were delineated from the topographic map. They represented three distinctive geomorphic features of ridge, peak, and valley, respectively (Figure 1). This selection was based on the continuity of the terrain, their uniqueness in geomorphological form, and the representativeness of terrain complexity that is defined as the vertical variation in elevation per unit area. Having the largest relief and standard deviation of elevations (σ), ridge is the most topographically complex (Table 1). Valley, on the other hand, is the gentlest. Both its σ and relief are the smallest among the three sites.

All the contours within the three sites were traced manually as closely as possible using PC ArcInfo. During digitization, elevations along contours were sampled as closely as possible to generate the most accurate DEMs. Thus, sampling density was dependent upon contour sinuosity and terrain complexity, but independent of inter-contour spacing. In total, 1,726, 2,659 and 3,958 elevations were sampled for valley, peak and ridge, respectively. Certain elevations within three sub-areas located at various sections of a slope were later deliberately removed from the initial samples for ridge (A, B and C in Figure 1(C)) in order to create topographic uncertainty artificially. The initial samples were then re-sampled to five other sizes by consistently dropping every other one, two, three, four and five elevations along a contour. The derived samples were then exported to SURFER® and gridded to DEMs of five cell sizes ranging



(a)

(b)



(c)

Figure 1. Topographic maps of the three test sites. They are plotted from grid DEMs of 30 m. Elevations are in feet (1 ft = 0.3048 m). (A) Valley; (B) Peak; (C) Ridge. A, B, and C in (C) are areas from which sampled elevations are deleted to create topographic uncertainties which are highest at A but lowest at C.

Table 1. Topographic characteristics of the test sites

Terrain type	Initial sample size	Elevation (m)		Density of contour lines (km/km)	Mean sampling spacing on map (mm)
		Standard deviation	Relief		
Valley	1,726	23.5	140.2	39.87	2.18
Peak	2,659	51.2	210	63.74	3.07
Ridge	3,958	89.9	403.6	97.16	3.16

from 10 to 50 m with WA, MC, and kriging. The selection of these grid sizes was primarily controlled by the limited size of the testing sites. Initially, all interpolation parameters were the default ones. For instance, the decay power was 2 and the number of nearest neighbouring elevations was 10 for WA. The search radius was 34.79 and the search method was normal (e.g., without regard to the distribution of the points in each quadrant). The number of nearest neighbouring points was later varied between 3 and 40 in order to examine its impact on the interpolated results. The distance decay power was set between 1 and 6. The two interpolation parameters for MC were curvature (0.005) and iteration (500). Since MC requires that the DEM dimension be an odd number, all DEM dimensions were thus increased by one row and by one column. The initial setting for kriging was a linear semivariogram model without drift. Anisotropy was not taken into account, as the topographic units under test did not exhibit any apparent directional patterns. Contours in all results were not smoothed.

The accuracy of the interpolated DEMs was evaluated against 200 checkpoints, randomly selected across the test sites, but made to fall on the nearest contour lines on the topographic map. Consequently, the value of these contours was used as the elevation for the checkpoints. Residuals or the disparities between the observed and interpolated elevations at the checkpoints were statistically analysed and used to evaluate the accuracy of the constructed DEMs.

IV. RESULTS

Accuracy of Interpolators

The discussion in this section is based on the terrain units of valley and ridge. The results in Figure 2(A) show that at 10 m the DEM constructed using WA has the largest RMSE (1.79 m) and that using kriging the smallest (1.18 m). Furthermore, the RMSE (1.21 m) of the DEM interpolated using MC closely resembles that using kriging. This order of RMSE values remains unchanged until the grid size reaches 50 m. From 10 to 40 m, all the RMSEs increase gradually. The rate of increase is the highest for MC, and nearly the same for the other two interpolators. There is a sharp increase in RMSE after 40 m probably because most of the topographic variations occur beyond a spatial range of around 40 m. At 50 m MC has the largest RMSE due to its higher increase rate. From 10 to 50 m the RMSE of WA increases by only 162 percent. The rate of increase is nearly doubled for MC (320 percent), and is also very high for kriging (290 percent). Consequently, the large range of the RMSEs at a smaller grid size is considerably reduced at a larger size.

If the test site is replaced by ridge, all the three RMSEs become larger, but the order of their values remains remarkably similar to that for valley (Figure 2(B)). The largest RMSE (2.80 m) is still associated with WA and the smallest with kriging at 10 m. All RMSEs are inversely correlated with grid size. As the cell size grows from 10 to 40 m the rate of RMSE increment is very slow. At a cell size larger than 40 m all the RMSEs

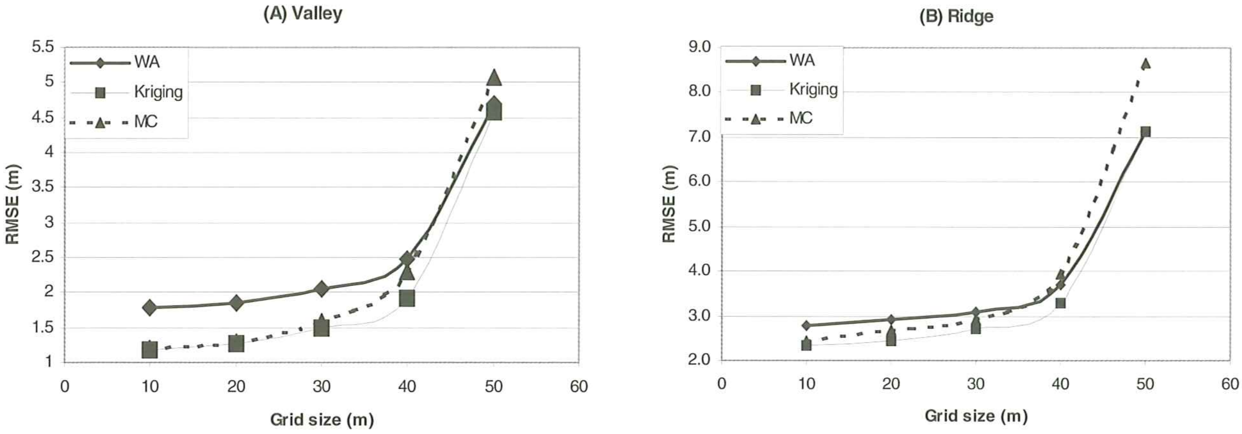


Figure 2. Relationship among DEM accuracy, DEM grid size, and interpolators (WA – weighted averaging; MC – minimum curvature, the same below).

increase substantially. The largest increase occurs for MC and the smallest for WA. From 10 to 50 m the RMSE increases by 154 percent and 254 percent for WA and MC, respectively. Because of the differential sensitivity of the algorithms to the expansion in cell size, the difference among their RMSEs becomes smaller at a larger size, at which the DEM from WA outperforms that from MC. In general, the DEM interpolated with kriging is the most accurate. From 10 to 50 m its accuracy is 9 percent higher than that from WA and 13 percent higher than that from MC.

Identical interpolations are carried out for valley and ridge. The only difference between them is that the complexity of valley is only 26 percent that of ridge if measured against the standard deviation of elevations or 41 percent against the density of contour lines (Table 1). A comparison of the two diagrams in Figure 2 reveals that all three interpolation methods are more accurate for a less complex terrain. However, terrain complexity does not affect their relative performance. Their accuracy is much more profoundly affected by the grid size of the DEM to be interpolated, especially if the terrain is more complex.

WA is less accurate than kriging because of two limitations. First, the number of elevations adjoining the point in question that should be used in an interpolation is arbitrarily determined by the analyst. Second, all neighbouring elevations used in an interpolation are assigned a uniform distance decay power m. In reality some of them, sampled along the same contour, have exactly the same elevation. In other words, the indiscriminate adoption of the same values for m and n is inappropriate and responsible for degrading the accuracy of the constructed DEMs. However, these problems are successfully overcome in kriging. Through the use of a semivariogram a unique weight is established for every adjoining observation based on its distance from the point in question. Those observations that are very distant from this point play virtually no role in the interpolation due to the tiny weights assigned to them.

MC is highly accurate at a fine resolution because the terrain surface at a local scale can be well fitted with a smooth mathematical function. As the grid size of a DEM decreases, however, more and more elevations are available to be fitted into the function. They make the precise modelling of the terrain surface difficult. A more complex terrain causes the fit to be even less accurate.

Ability to Handle Topographic Uncertainty

The reliability of the constructed DEMs is questionable at locations where no sampled elevations exist. The absence of observations in a locality creates topographic uncertainty that may be of different degrees. Because of the continuous nature of undisrupted terrains, topographic uncertainty exists in a relative sense and varies with the position of the missing observations. The level of uncertainty is the highest at topographic extremities such as peaks and pits, but is lower at the middle of a slope.

Topographic uncertainty was introduced to the input data sets after 136, 127, and 123 sampled elevations were deliberately deleted from three locations from ridge: at the summit (A), along a ridge (B), and in the middle of a slope (C) (Figure 1(C)). Thus, the degree of uncertainty is highest at A but lowest at C. In order to identify how the accuracy of the constructed DEMs is affected by missing observations, the three interpolators were used to grid DEMs from the modified samples. The results (Table 2) reveal that at a given level of uncertainty, the least accurate DEMs are always associated with WA and the most accurate with MC. As the uncertainty level rises, all RMSEs increase except for MC at the medium level of uncertainty. The increase rate is highest for MC (99 percent) and smallest for WA (50 percent). Associated with the largest RMSE of WA are its largest standard deviation of residuals, and the largest mean residual at any given level of uncertainty.

The superior capability of MC in handling missing observations lies in the fact that elevations at unsampled locations are estimated from a mathematical function that is derived from a number of known elevations nearby. The exclusion of certain sampled elevations from the derivation may change the specific form of the function, but only has a negligible impact on the estimated elevations. The use of a

Table 2. Capability of handling topographic uncertainties caused by missing observations as measured by the properties of interpolation residuals (6.1 m = contour interval).

Level of uncertainty	Interpolator	RMSE (m)	Standard Deviation (m)	Mean (m)	Number of residuals	
					< 3 m	< 6.1 m
Low	WA	16.76	14.57	8.39	103	91
	Kriging	10.72	8.87	6.07	76	52
	MC	5.19	3.63	3.72	62	34
Medium	WA	18.08	17.89	-46.37	114	97
	Kriging	11.82	11.58	-36.31	97	68
	MC	3.82	2.84	-7.97	63	14
High	WA	25.16	12.97	1.08	134	122
	Kriging	19.58	11.99	-0.34	119	101
	MC	10.32	7.44	-5.75	96	67

mathematical function also allows local maxima and minima to be estimated. These values may be higher or lower than the data points involved. On the other hand, both WA and kriging rely solely on the neighbouring elevations in their interpolation. The removal of certain elevations in the neighbourhood directly affects the accuracy of the DEM constructed. Since these methods are fundamentally an averaging technique, the estimated values can never exceed the range of elevational values in the input data. Therefore, neither of them is robust at predicting extreme values at pits and peaks.

Impact of Sample Size on Accuracy

The accuracy of the constructed DEMs is affected by the size of the input elevation as a larger sample enables the terrain to be modelled better. The results in Figure 3 illustrate that there is a reversed *J*-shaped relationship between the two variables irrespective of terrain complexity and the interpolation method. The accuracy of the DEMs constructed using kriging and MC is almost identically sensitive to reduction in sample size (Figure 3(A)). As sample size increases, the RMSE decreases almost linearly. However, the rate is noticeably reduced once the sample size exceeds 575 elevations. After it reaches about 1,000 elevations the RMSE becomes asymptote. If the test site is replaced by ridge, a slightly different pattern emerges (Figure 3(B)). The RMSE curve for MC is almost parallel to that for kriging. Their RMSEs do not drop as considerably as do valley's. A dramatic reduction in RMSE takes place when sample size is very small. The RMSE curve for WA is no longer parallel to those for MC and kriging because its RMSEs cease to decrease substantially until sample size reaches 1,879 elevations.

The DEM accuracy is sensitive to reduction in sample size only if it is very small because every elevation in the sample plays a critical role in accurately portraying the terrain. Any further reduction in the retained elevations will severely degrade the accuracy of the DEMs constructed. As more elevations are used, these sample elevations become closer to one another spatially, causing their elevations to increasingly resemble one another. The contribution made by each individual elevation to the estimate is gradually minimised. Once the sample size reaches a certain threshold, the similarity among some of the sampled elevations is so striking that their inclusion in the interpolation scarcely improves the DEM accuracy.

Impact of Number of Neighbouring Elevations

In addition to sample size, the accuracy of the constructed DEMs is also affected by the number of sampled elevations that immediately surround the point in question if the interpolation methods used are WA and kriging. The influence of this factor is studied through gridding DEMs of 50 rows by 50 columns from the same samples while only the number of nearest neighbouring elevations was allowed to vary from 3 (5 for kriging) to 40. It is found that as more and more neighbouring elevations are used, the gridded DEMs become less and less accurate for WA (Figure 4(A)). From 3 to 5 elevations the RMSE for peak hardly increases, but increases drastically for valley. After 10 elevations the RMSEs for all three terrains increase linearly at almost the same rate. Although no experiment was carried out with fewer than 3 elevations, the interpolation accuracy is probably maximised at about 3 elevations as indicated by the result obtained for peak. For kriging, the accuracy of interpolated DEMs is hardly affected by the number of neighbouring elevations used, especially if the number is over 15 (Figure 4(B)).

The above findings are explained as this. In constructing DEMs from topographic maps, all elevations are sampled along contours. In this study the average sampling spacing on the map is 2.18 mm, 3.07 mm, and 3.16 mm for valley, peak and ridge, respectively (Table 1). These intervals are smaller than inter-contour spacings. In other words, some of the neighbouring points actually come from the same contour line and thus have identical elevations. Their weighted averaging only makes the estimated elevation deviate more from its true value. Kriging is not so noticeably affected by the inclusion of more neighbouring elevations because the weight assigned to

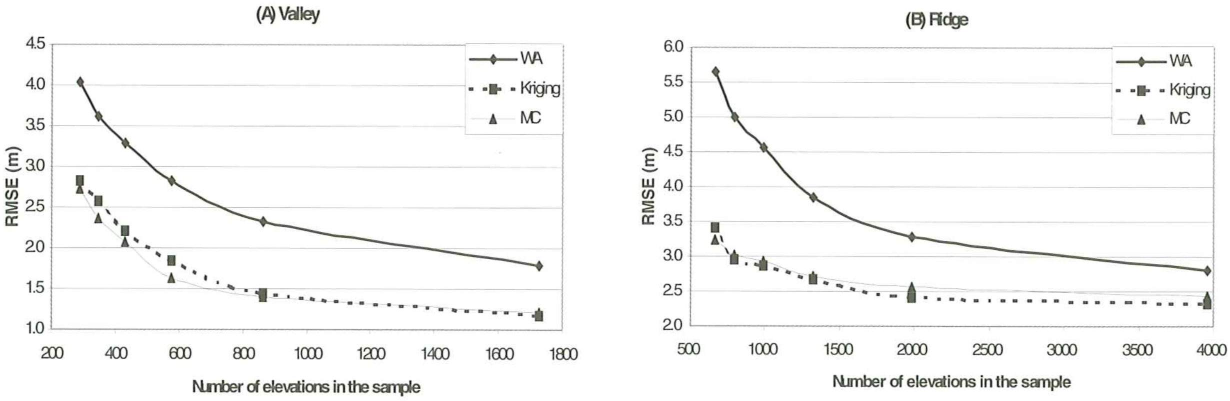


Figure 3. Relationship among DEM accuracy, interpolators, and size of sampled elevations used in the interpolation (DEM dimension: 50 by 50; grid size: 10 m).

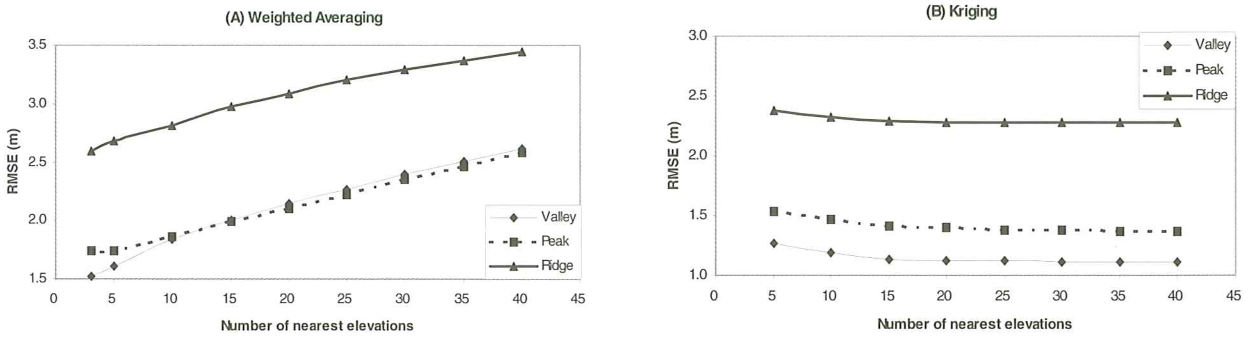


Figure 4. Relationship between DEM accuracy and the number of nearest neighbouring elevations used in an interpolation.

these elevations are determined from the semivariogram. The use of more neighbouring elevations inevitably results in some of them being farther away from the point in question. Diminutive weights determined from the semivariogram are allocated to them, causing minimal change to the estimated elevation. If too distant from the point in question, they are virtually excluded from the interpolation as the semivariogram becomes levelled off. Thus, the quality of the DEMs becomes stabilised.

Impact of Distance Decay Power

As shown in Equation (1), distance decay power affects the accuracy of the WA interpolator by governing the weight assigned to a neighbouring elevation used in the interpolation. In order to explore its impact, the three initial samples were interpolated into DEMs of 50×50 using WA in which distance decay power was set from 1 to 6. Figure 5 shows that this variable is inversely correlated with RMSE. As the power increases, the interpolated DEM becomes more accurate. The improvement rate, nevertheless, is not linear. There is a huge drop in RMSE from the first to the second order. After the second order there is hardly any improvement. Furthermore, the improvement rate is related to terrain complexity. The more complex the terrain, the less improvement it experiences. Such a finding is due to that most of the neighbouring points used in the interpolation have an elevation that is the same or closely resembles those of the point in question. This is more so for the more complex terrain because of the closer sampling spacing. The larger the distance decay power, the less significant the neighbouring elevation plays in the interpolation. After the third order, the weights change so slightly that the RMSEs show little reduction in their value.

V. CONCLUSIONS AND DISCUSSION

This study has demonstrated that in general the DEMs constructed with kriging are more accurate than those from the other two interpolators. If constructed using MC and kriging, the DEMs are much more accurate than those using WA, especially if the terrain is less complex and the DEMs are interpolated at a larger grid size. The accuracy of the DEMs built using all three methods is inversely related to the grid size of the DEM. The rate of accuracy decrease is very low from 10 to 40 m, but much higher after 40 m. The accuracy of the DEMs from MC is the most sensitive to the increment in grid size, followed by kriging. As a result, the DEMs are the least accurate at 50 m, at which the DEMs from kriging and WA are nearly the same accurate. Nevertheless, the DEMs from MC are much more accurate than those from WA and kriging if the input dataset contains topographic uncertainties caused by missing observations. The accuracy of all the DEMs interpolated with the three methods has a reversed *J*-shaped relationship with sample size. The accuracy is especially vulnerable to the change in sample size when it is very small. Initially, the DEM accuracy increases quickly with sample size. Once the sample size reaches a certain threshold, the improvement in the accuracy is drastically reduced. The number of nearest neighbouring elevations used in the interpolation does not exert a noticeable impact on the DEM accuracy if the kriging method is used, especially after 15 elevations. However, the more neighbouring elevations are used, the less accurate the DEMs interpolated using WA regardless of terrain complexity. Irrespective of the interpolation methods used, the accuracy of the gridded DEMs is barely enhanced by a larger number of neighbouring elevations. Distance decay power affects WA's performance discernibly if it is smaller than 2. The impact is more profound for a simple terrain than a complex one.

When the above findings are interpreted or applied elsewhere,

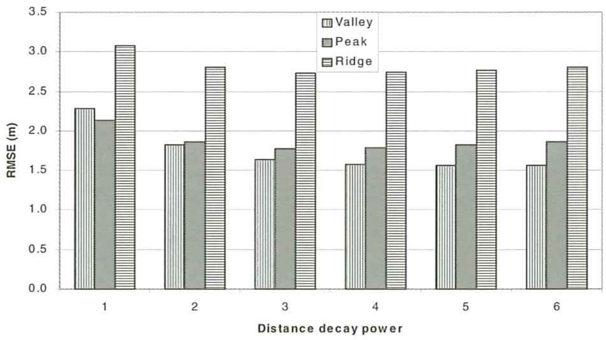


Figure 5. Relationship between interpolation accuracy and distance decay power for weighted averaging interpolator.

the following points need to be considered. (1) Complexity of terrain and its composition. All the three test sites encompass only one unique geomorphic unit. The results may vary if other study sites containing multiple geomorphic units are used. However, the results should remain similar if the test sites have a terrain complexity comparable to those presented in this study irrespective of its composition; (2) Sampling density. In this study elevations were sampled along contour lines as densely as possible. If they were sampled randomly or with a larger interval, the findings on the impact of nearest neighbouring elevations and distance decay power may vary slightly; and (3) DEM grid size. The conclusions drawn from this study apply to DEMs constructed at resolutions between 10 and 50 m. If extrapolated outside this grid size range, the results may vary.

ACKNOWLEDGMENTS

The author would like to thank one anonymous reviewer for the useful comments that helped to improve the quality of the manuscript.

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