Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 8 (1): 134-139, 2008
ISSN 1812-5654

Digital Elevation Model Accuracy Aspects

Mandla V. Ravibabu and Kamal Jain
Department of Civil Engineering, Geomatics Engineering Section,
Indian Institute of Technology Roorkee, Roorkee 247667, UA, India

Abstract: Within the context of Geographical Information Systems (GIS), several types of surface models are being used in a spatial modeling environment. DEM is a fundamental requirement for many GIS applications, both directly due to the influence of elevation on many environmental phenomena and indirectly due to the influence of variables derived from a DEM such as gradient and aspect on environmental phenomena and processes. DEM generated from Survey of India topomaps, ground survey and photogrammetric methods. It is Important to know the expected accuracy of DEM generated from different sources. This study summarizes different DEM methods and the expected accuracy.

Key words: Digital elevation model, accuracy, errors, quality, G1S

INTRODUCTION

DEMs represent elevation data and are the principal digital data source for slope and aspect map coverages used in Geographic Information System (GIS) analysis for resource management. Elevation data can be represented digitally in many ways including a gridded model (where elevation is estimated for each cell in a regular grid), a triangular irregular network, and contours. There are two main approaches for generating DEM: Interpolating the regular grid from an irregularly distributed elevation data set, or generating the grid directly using photogrammetric techniques.

Topographic maps are a widely available data source in which elevation is represented by contour lines and spot heights. Ground survey techniques using total stations (electronic tacheometers) or Global Positioning System (GPS) receivers are used to collect elevation data. Measurements may be made either at a randomly distributed set of point locations or in a more structured pattern such as at equal intervals along transects. The irregularly distributed contour lines, spot heights or profiles can be interpolated to create the DEM's regular matrix of elevation values. Burrough and McDonnell (1998) define interpolation as the procedure of predicting the value of attributes at unsampled sites from measurements made at point locations within the same area or region. In terms of generating DEM's, the measurements made at point locations are spot heights, points along a transect or the vertices of contour lines. There are many interpolation algorithms for generating surface models from point data, such as inverse distance weighting, spline fitting and Kriging (Burrough and McDonnell, 1998) and others that interpolate from contour lines (Carrara *et al*., 1997).

Photogrammetry provides the most frequently used data sources and techniques for generating DEM's (Stocks and Heywood, 1994), either by direct generation of DEM's or indirectly via its use in topographic mapping for production of contour lines. Photogrammetry either involves stereoscopic techniques for interpretation of aerial photography or digital image correlation applied to aerial photographs.

Use of photogrammetric sources has several advantages, particularly in mountain environments:

- Remote sensing avoids the need to gain overland access to the area being surveyed across potentially remote and hazardous terrain.
- Data with a wide aerial coverage can be acquired in a relatively short time.
- There is no need for accurate topographic maps to be available.

However, there are also a number of potential problems associated with obtaining aerial photography in mountainous areas, including:

- Frequent cloud cover and lengthy snow cover limiting the opportunities for good photography may reduce the aerial coverage, currency or clarity of aerial photographs;

Corresponding Author: Mandla V. Ravibabu, Department of Civil Engineering, Geomatics Engineering Section, Indian Institute of Technology Roorkee, Roorkee 247667, UA, India

- The military or political sensitivity of a number of mountain regions may restrict the availability of data, or reduce the opportunities for flying aerial photography;
- The high relief of mountain topography may cause detail to be unclear in shaded areas or totally obscured from view;
- Dense tree cover can obscure the ground surface.

These problems may mean that no elevation data can be derived, or measurements are of lower accuracy, or the elevation model actually records the height of another surface, such as a forest canopy. The problems can be mitigated by acquiring additional photography with less cloud, snow or shadowing, collecting extra data, such as undertaking a ground survey in forested areas, or further processing, such as subtracting average tree height from forested areas (Lillesand and Kiefer, 2000). In many situations directly generating a DEM from aerial photography is not a practical option due to the costs of purchasing suitable photography, software and hardware, non-existence of suitable photography or lack of suitably experienced personnel. The alternative is to interpolate the regular grid of a DEM from another elevation data set.

DEM APPLICATIONS

Elevation is just one of a number of properties of the terrain of an area which influence the distribution of environmental phenomena and the nature of environmental processes. The most important of these terrain properties can be grouped as attributes of surface form or surface topology and various environmental indices, which can be calculated by combining surface form and surface topology measures. DEM are widely used in many applications such as hydrology, geomorphology, ecology and Table 1 shows other applications.

ACCURACY ASSESSMENT OF DEM

Accuracy is one factor influencing the overall quality of a data set. According to Foote and Huebner (1997) describes how similar a data set is to the real world or true values. Error is a specific measurement of the different between a value in a data set and the corresponding true values. Goodchild *et al.* (1994) define accuracy as the difference between values recorded in a spatial data set and modelled or assumed values. They define error as the difference between the data set values and the true values. When dealing with continuous phenomena and their representation in GIS as surfaces, it is impossible to measure all true values and hence calculate all errors. So the true values must be modelled or estimated. So in the case of continuous phenomena one deals with accuracy indices derived from a limited number of error measurements.

Practically it will not be possible to measure true elevation from ground because of time and accessibility. Instead of determining the absolute accuracy of the DEM more commonly to measure the relative accuracy in comparison with sample point measurement known to be of a higher order of accuracy (Hirano *et al.*, 2003). There are two issues to consider when using sample points to check DEM accuracy. First, how should the sample points be selected? Second, how can measurements of a higher order of accuracy be obtained? These issues are examined below followed by a review of ways of measuring accuracy.

Selecting sample points: Comparing every grid point of the DEM with those of a more accurate DEM will provide a very reliable assessment of accuracy. This scenario is rare as the DEM concerned is usually generated by the most accurate means available. Exceptions are Day and Muller (1988), who subtracted the elevation values of a SPOT derived DEM from the elevation values in an aerial

Table 1: DEM derivatives and their application

Derivative	Description	Applications
Elevation		Potential energy determination; climatic variables; cut and fill calculations.
Gradient	Rate of change of elevation	Overland and sub-surface flow; land capability assessment; vegetation types;
Aspect	Compass direction of steepest downhill gradient	Solar irradiance; evapotranspiration; vegetation types.
Profile curvature	Rate of change of gradient	Flow acceleration; erosion/deposition zones; soil and land evaluation indices.
Plan curvature	Rate of change of aspect	Converging/diverging flow; soil water properties.
Flow direction	Direction of downhill flow	Computing surface topology; material transport.
Upstream area	Number of cells upstream of a given cell	Watershed delineation; volume of material passing through a cell.
Stream length	Length of longest uphill path upstream of a given cell	Flow acceleration; erosion rates; sediment yield.
Stream channel	Cells with upstream area greater than a specified threshold	Location of flow; flow intensity; erosion/sedimentation.
Ridge	Cells with no upstream area	Drainage divides; vegetation studies; soil, erosion and geological analysis.
Wetness index	ln(upstream area/tan(gradient))	Index of soil saturation potential.
Stream power index	Upstream area * tan (gradient)	Index of the erosive power of overland flow
Viewshed	Zones of intervisibility	Visual impact studies.
Irradiance	Amount of solar energy received	Vegetation and soil studies; glaciology.

(Source: Burrough and McDonnell, 1998)

photography derived DEM to create residual surfaces, and Sasowsky (1992) who compared a SPOT derived DEM with one derived from a topographic map. Usually more accurate measurements can only be acquired for a sample of the grid points. The fewer the number of samples, the more efficient, in terms of time and cost, the quality assessment exercise will be. however, fewer samples mean a less reliable quality assessment, especially in the highly variable terrain of mountain environments. So the choice of sample size is important. Li (1991) states that the optimal sample size depends partly on the heterogeneity of the terrain and partly on how reliable either the estimate of mean elevation error or the estimate of the standard deviation of the elevation error needs to be. Equation 1 and 2 are derived by Li using standard statistical theory to estimate sample size based on the required accuracy for the mean error estimate and for the estimate of the standard deviation of the error

$$n = \frac{Z_r^2 * \sigma^2}{R^2}$$

Where, n is the estimated required sample size, Z_r is the Z statistic for the required confidence level, σ is the estimated standard deviation of the elevation error and R is the required level of accuracy (or confidence).

$$n = \frac{1}{2R^2}$$

Where, n is the estimated required sample size and R is the accuracy of a standard deviation estimate.

As observed by Li (1992) and Gao (1997), sample density also had a significant influence on the accuracy of the grid DEM generation.

Accuracy measures: After obtaining a sample of control points from a more accurate data source and presuming that this sample is sufficiently large and representatively distributed, the difference between the DEM and control point's elevation values can be calculated. The next consideration is how to turn this set of individual elevation errors into an estimate of the DEM's accuracy. The sources of digital elevation data under the three main headings of ground survey sources, photogrammetric sources and cartographic sources. LIDAR data are of high quality and great uses in the future either to create DEMs and DSM or, more probably, to check the quality of DEM, other sources and their accuracy mentioned in Table 2.

Ground survey: Ground survey sources of elevation data involve actual measurement of elevation in the field. Electronic tacheometers, also known as total stations, can be used to create a network of surveyed points covering an area. The equipment allows highly accurate planimetric and altitudinal measurements. The data quality is also enhanced by the use of the surveyor's local knowledge to adapt the survey to incorporate key features and significant sample points, which provide a good representation of the terrain. The hazards and inaccessibility of mountain environments preclude the use of ground surveys for DEM generation (Stocks and Heywood, 1994).

GPS equipment has been considered as potentially more practical for ground survey in mountain environments. Equipment can be cheaper and more portable than traditional surveying hardware and data collection can be faster. However, a number of limitations do not currently make GPS a viable alternative for collecting a complete data set for creating a DEM. These limitations include inaccessibility, the trade off between portability and accuracy and between speed and accuracy, the high potential for poor satellite visibility and the difficulties of differential correction in mountainous regions. However, as described in introduction, GPS can play a role in assessing DEM accuracy.

Photogrammetric source: Aerial photography and satellite imagery can be used to derive digital elevation data. At present, the resolution of suitable imagery and the sophistication of processing mean that elevation data derived from satellite imagery is usually only suited to small scale applications covering large areas, such as national, continental or global studies (Lillesand and Kiefer, 2000). The properties of the imagery those

Table 2: A comparison of various DEM Acquisition methods

Acquisition methods	Accuracy of data	Speed	Cost	Applications domain
Traditional surveying	High (cm-m)	Very slow	Very high	Small areas
GPS survey	Relatively high (cm-m)	Slow	Relatively high	Small areas
Photogrammetry	Medium to high (cm-m)	Fast	Relatively slow	Medium to large areas
Space photogrammetry	Low to medium (m)	Very fast	Low	Large areas
InSAR	Low (m)	Very fast	Low	Large areas
Radargrmmetry	Very low (10 m)	Very fast	Low	Large areas
LIDAR	High (cm)	Fast	High	Medium to large areas
Map digitization	Relatively low (m)	Slow	High	Any area size
Map scanning	Relatively low (m)	Fast	Low	Any area size

(Source: Li *et al*., 2005)

influences the accuracy of data captures are: scale and resolution of the aerial photography; the flying height at which the photography was obtained and the base to height ratio, or geometry, of the overlapping photographs. These properties are inter-related and it is their combined nature, which determines the accuracy of the stereoscopic techniques. Both the minimum vertical interval of the contours that can be derived and the scale of the DEM that can be produced are also dependant on these image characteristics. A compromise must be made between the geometry and scale, or resolution, of the photography. A common choice is a wide-angle lens, for example f = 15 cm and a base: height ratio of 0.6. This allows a single spot height to be measured with an accuracy of between 1/5000th to 1/15000th of the flying height, dependent on the equipment used. This translates to an RMSE of 0.1-3.0 m on the ground. The accuracy is dependant on the contour interval, which in turn is determined by the flying height. The minimum possible contour interval that can be measured is approximately 1/1000th to 1/2000th of the flying height. At a low flying height of 1000 m, contour intervals of 1.0 m or less can be defined. In terms of RMSE, contour line sampling can provide measurements accurate to within 0.3 of the contour interval. If contours at a 1 m interval are measured, measurements with an RMSE of 0.3 m can be obtained (Gong *et al*., 2000). Point sampling involves static measurement techniques at each individual sample point. Therefore, more accurate data can be obtained than for the dynamic, or on-the-fly, contour line sampling method. The points from a contour line sample will have approximately three times the RMSE of single point samples.

Cartographic sources: Most DEMs with grid spacing of 50 m or less are produced from cartographic data sources. Contour lines and spot heights on most topographic maps have originally been derived using the stereoscopic techniques (Carrara *et al*., 1997; Kyriakidis *et al*., 1999). Accuracy is influenced by equipment, map distortion and operator or machine error. The accuracy of the equipment, in terms of the coordinates recorded, will be slightly less than the resolution, or precision, of the equipment. This precision will be in the range of 50-100 μm. At a map scale of 1:10,000 this equates to 0.5-1 m. Over a large format paper-based map sheet distortion, in the form of stretch or shrinkage, of several millimetres can occur. At the 1: 10,000 scale this equates to an on-the-ground error of 10 m or more. Regular scale changes can be removed to reduce the severity of distortions by recording the apparent location of control points on the map and then performing affine transformations on the digitised data. Operator and machine error is of more significance. On-line display of the digitised data and interactive editing reduce the likelihood and extent of such error. However, the potential for undetected errors remains important. Additionally, the extent of these errors is hard to quantify as it is determined by the skill and patience of the individual operator.

LiDAR is a remote sensing technique that involves emitting pulses of laser light from an aircraft or satellite towards the ground and measuring the return time. A LiDAR-equipped aircraft carries a pulsing laser, airborne GPS for determining sensor location, an Inertial Measuring Unit for measuring orientation of the sensor to the ground, a high accuracy clock, substantial computing power to process data in real time and data storage equipment (Lillesand and Kiefer, 2000). There are several advantages to LiDAR, which are encouraging its use for deriving DEM's. First, as with other remote sensing techniques, data can be captured in remote and otherwise inaccessible locations. Second, unlike aerial photography, data can be collected in steep, shadowed areas and at any time of day or night. Third, the laser pulses can penetrate vegetation. Therefore, one pulse can produce multiple returns reflected off different surfaces such as the vegetation layers in a forest. Fourth, a high density of high accuracy elevation measurements can be generated. Consequently, highly detailed and accurate DEM's and DSM's can be derived.

The two main drawbacks of LiDAR are, first that the large amount of sophisticated equipment required for data collection makes LiDAR data sets expensive and, at the time of writing, are only available for specific areas of developed countries. Second, the large data volumes can be cumbersome to handle, and separating multiple returns into different surface layers requires specialist software and expertise.

Taking into consideration all the above error sources, Li *et al.* (2005) states that the horizontal accuracy of digitised contours will lie in the range of 0.1-0.25 mm RMSE. This equates to 1-2.5 m on the ground at 1:10,000 scale. When obtaining digital elevation data from cartographic contour lines, a vertical error can only be caused by the operator tagging the wrong elevation value to a contour line. However, although displacement of a contour is horizontal, this will cause an apparent vertical error by the time a continuous DEM surface is.

More meaningful information on the overall spread of error values is provided by the root mean squared error (RMSE; Eq. 3), standard deviation of error and percentiles (Cuartero *et al*., 2005). The RMSE is easy to calculate, report and understand-it is just a single number. However, RMSE only gives a good description of error spread when the mean error is zero (Monckton, 1994; Wood, 1996). Many assessments of DEM error have found that this mean equal to zero criterion is not the case (Li, 1993a, b; Monckton, 1994).

$$\mathrm{RMSE}=\sqrt{\frac{\sum_{i}^{n}(Z_i-Z_j)^2}{n}}$$

Where, zi and zj are two corresponding elevation values (e.g., DEM cell value and corresponding sample point elevation) and n is the number of sample points.

Wood (1996) identifies a second problem with use of RMSE. Relative relief and scale of measurement influence the magnitude of the RMSE value, so comparison between areas is difficult. He proposes using an accuracy ratio (RMSE divided by a measure of relative relief; Eq. 4 to remove the effects of relative relief.

$$\mathrm{RMSE}=\sqrt{\frac{\sum_{i}^{n}(Z_i-Z_j)^2}{\sum(Z_i-\bar{Z}_j)^2}}$$

Where, zi, zj and n are as in Eq. 4 and $\bar{Z}_j$ is the average DEM elevation.

Standard deviation corrects for non-zero means and the use of this, along with a statement of the mean error, gives a more appropriate measure of DEM accuracy (Li, 1993a, b). However, both standard deviation and RMSE are open to influence by one or two atypical outliers. For this reason Kumler (1994) advocates use of the 90th percentiles to better characterise the spread of error values. The measure of reliability used by Day and Muller (1988) is essentially a companion to the use of percentiles as it indicates the percentage of sample points that can be assumed to be outliers.

FACTORS EFFECTING DEM ACCURACY

The accuracy of DEM is a function of a number of variables such as the roughness of the terrain surface, the interpolation function, interpolation methods and other three attributes (accuracy, density, and distribution) of the source data (Li, 1991, 1992).

Mathematically,

$$A_{DEM} = f\,(C_{DEM}, M_{modelling}, R_{Terrain}, A_{Data}, D_{Data}, DN_{Data}, 0)$$

Table 3: Comparison of the accuracy of DEM data obtained by different techniques

Methods of data acquisition	Accuracy of data
Ground measurement (including GPS)	1-10 cm
Digitized contour data	About 1/3 of contouring interval
Laser altimetry	0.5-2 m
Radargrmmetry	10-100 m
Aerial photogrammetry	0.1-1 m
SAR interfereometry	5-20 m

(Source: Li *et al.*, 2005)

Where, A_{DEM} is the accuracy of the DEM, C_{DEM} refers to the charactaristic of the DEM surfaces, $M_{modelling}$ is the method used for modeling DEM surface, $R_{Terrain}$ is the roughness of the terrain surface itself, A_{Data} is Accuracy, D_{Data} is distribution, DN_{Data} is density of the DEM source data and 0 is denotes other element (Li *et al.*, 2005).

The accuracy of contour can be written as:

$$m_c = m_h + m_p \times \tan\alpha$$

Where, m_h refers to the accuracy of height measurement, m_p is the planimetric accuracy of the contour line, α is the slope angle of the terrain surface and m_c is the overall height accuracy of the contour, including the effects of planimetric errors. The overall accuracy if digitised contour data will be within a 1/3 contouring interval. The accuracy of DEM source data from various sources is summarized in Table 3.

CONCLUSION

After reviewing on DEM accuracy following conclusion might be drawn as DEM accuracy depends on quality of input data source, The DEM accuracy depends on sampling size and density and Method of data acquisition generation should be selected on the basis of DEM accuracy requires in the project.

REFERENCES

Burrough, P.A. and R.A. McDonnell, 1998. Principles of Geographical Information System. Oxford University Press, Oxford.

Carrara, A., G. Bitelli and R. Carla, 1997. Compression of techniques for generating digital terrain models from contour lines. Int. J. GIS., 11: 451-473.

Cuartero, A., A.M. Felicisimo and F.J. Arisa, 2005. Accuracy, Reliability and Depuration of SPOT HRV and Terra STER DEMs. IEEE Transactions on Geoscience and Remote Sensing, 43: 404-407.

Day, T. and J.P. Muller, 1988. Quality assessment of digital elevation models produced by automatic stereo-matchers from SPOT image pairs. Photogrammetric Rec., 12: 797-808.

Foot, K.E. and D.J. Huebner, 1997. The Geographers craft, University of Texas, Austin. http://www.utexas.edu/depts/grg/gcraft/notes/error/error.html (Last Accessed 10.12.2004).

Gao, J., 1997. Resolution and Accuracy of terrain representation by Grid DEMs at a micro-scale. Int. J. GIS., 11: 199-212.

Gong, J. Z.L. Li, Q. Zhu, H.H. Sui and Y. Shou, 2000. Effects of various factors on the accuracy of DEMs: An intensive experimental investigation. PERS., 66: 1113-1117.

Goodchild, M., B. Buttenfield and J. Wood, 1994. Introduction to Visualizing Data Validity. In: Visualisation in Geographical Information Systems. Hearnshaw, H.M. and D.J. Unwin (Eds.), John Wiley and Sons, Chichester, pp: 141-149.

Hirano, A., R. Welch and H. Lang, 2003. Mapping from ASTER stereo image data: DEM validation and accuracy assessment. J. P RS., 57: 356-370.

Kumler, M.P., 1994. An intensive comparison of Triangulated Irregular Networks (TIN) and Digital Elevation Models (DEM). Cartographica, 31: 45.

Kyriakidis, P.C., A.M. Shortridge and M.F. Goodchild, 1999. Geostatistics for conflation and accuracy assessment of digital elevation models. Int. J. Geogra. Inform. Sci., 13: 677-707.

Li, Z., 1991. Effects of checkpoints on the reliability of DTM accuracy estimates obtained from experimental tests. Photogrammetric Engineering and Remote Sensing, 57: 1333-1340.

Li, Z., 1992. Variation of the accuracy of DTMs with sampling interval. Photogrammetry Rec., 14: 113-128.

Li, Z., 1993a. Theoretical models of the accuracy of digital terrain models: An evaluation and some observations. Photogrammetric Rec., 14: 651-659.

Li, Z., 1993b. Mathematical models of the accuracy of digital terrain model surfaces linearly constructed from square gridded data. Photogrammetric Rec., 14: 661-673.

Li, Z., Q. Zhu and C. Gold, 2005. Digital Terrain Modeling Principles and Methodology, CRC Press, New York, pp: 62.

Lillesand, T.M. and R.W. Kiefer, 2000. Remote Sensing and Image Interpretation. 4th Edn., John Wiley and Sons, New York.

Monckton, C., 1994. An Investigation into the Spatial Structure of Error in Digital Elevation Data. In: Worboys, M.F. (Ed.), Innovations in GIS 1. Taylor and Francis, pp: 201-211.

Sasowsky, K.C., G.W. Petersen and B.M. Evans, 1992. Accuracy of SPOT digital elevation model and derivatives: Utility for Alasks's North Slope. Photogra. Eng. Remote Sens., 58: 815-824.

Stocks, A.M. and D.I. Heywood, 1994. Terrain Modeling for mountains. In: Mountain Environments and GIS. Price, M.F. and D.I. Heywood (Eds.), Taylor and Francis, London, pp: 25-40.

Wood, J.D., 1996. The geomorphological characterisation of digital elevation models. Unpublished Ph.D Thesis, University of Leicester.