Proceedings of the 8th International Symposium on
Spatial Accuracy Assessment in Natural Resources and Environmental Sciences
Shanghai, P. R. China, June 25-27, 2008, pp. 79-85

Large Area DEM Generation Using Airborne LiDAR Data and Quality Control

Xiaoye Liu [1, 2 +], Zhenyu Zhang [1, 2], Jim Peterson [2] and Shobhit Chandra [2]

[1] Australian Centre for Sustainable Catchments and Faculty of Engineering and Surveying
University of Southern Queensland, Toowoomba, QLD 4350, Australia
[2] Centre fro GIS, School of Geography and Environmental Science
Monash University, Clayton, Vic 3800, Melbourne, Australia

Abstract. Digital Elevation Model (DEM) is a crucial component in terrain-related applications. Researches on terrain data collection and DEM generation have received great attention. Traditional methods such as field surveying and photogrammetry can yield high accuracy terrain data, but they are time consuming and labour intensive, especially for large area. Airborne Light Detection and Ranging (LiDAR) - also referred to as Airborne Laser Scanning (ALS), provides an alternative for high density and high accuracy three dimensional terrain point data acquisition. LiDAR data have become a major source of digital terrain information and has been used in a wide of areas, with terrain modeling being the primary focus of most LiDAR collection missions. The use of LiDAR for terrain data collection and DEM generation is the most effective way and is becoming a standard practice in spatial science community. Although LiDAR data has become more affordable for users due to the gradually dropping of the costs of LiDAR data collection, how to effectively process the raw LiDAR data and extract useful information remains a big challenge. This paper presented ways to generate a high quality DEM in a large catchment area using LiDAR data. A number of research challenges such as terrain modeling methods, interpolation algorithms, DEM resolution, and data reduction were identified and discussed in detail for quality control of a LiDAR-derived DEM.

Keywords: LiDAR, DEM, interpolation, resolution, data reduction

1. Introduction

The Digital Elevation Model (DEM) is a crucial component in a wide range of terrain-related applications, including natural resource and environmental management. Researches on terrain data collection and DEM generation have received great attention. Traditional methods such as field surveying and photogrammetry can yield high accuracy terrain data, but they are time consuming and labour intensive, especially for large area. Moreover, in some situations, for example, in forested areas, it is very difficult to use these methods for collecting elevation data. Airborne Light Detection and Ranging (LiDAR) - also referred to as Airborne Laser Scanning (ALS), provides an alternative for high density and high accuracy three dimensional terrain point data acquisition (Liu *et al.*, 2007a). One of the appealing features in the LiDAR output is the direct availability of three dimensional coordinates of points in object space (Habib *et al.*, 2005). LiDAR data have become a major source of digital terrain information (Raber *et al.*, 2007) and has been used in a wide of areas, with terrain modeling being the primary focus of most LiDAR collection missions (Hodgson *et al.*, 2005). The use of LiDAR for terrain data collection and DEM generation is the most effective way and is becoming a standard practice in spatial science community (Hodgson and Bresnahan, 2004). Although LiDAR data has become more affordable for users due to the gradually dropping of the costs of LiDAR data collection, how to effectively process the raw LiDAR data and extract useful information remains a big challenge. Furthermore, because of the specific characteristics of LiDAR data, issues such as the choices of

+ Corresponding author. Tel.: +61-7-4631 5343; fax: +61-7-4631 2526.
E-mail address: liux@usq.edu.au.

ISBN: 1-84626-171-6, **ISBN13:** 978-1-84626-171-8

modeling methods, interpolation algorithm, grid size, and data reduction are challenging study topics for DEM generation and quality control(Liu, 2008).

In the past, a commonly used DEM in catchment management areas in Victoria, Australia, is *Vicmap Elevation*, a state wide 20 m resolution DEM. *Vicmap DEM* was produced using elevation data mainly derived from existing 1:25,000 contour maps and digital stereo capture. Estimated standard deviations are 5 and 10 m for vertical and horizontal accuracy respectively (DSE, 2002). For many applications related to DEM, more accurate terrain modelling in the catchment region is needed to meet the requirement for terrain description. LiDAR data accuracy and density are such that reliable and high accuracy, high resolution DEM generation can be confidently contemplated (Liu *et al.*, 2007a). Although DEM generation from airborne LiDAR data has been documented by several researchers (Lloyd and Atkinson, 2002; Wack and Wimmer, 2002; Lee, 2004; Gonçalves-Seco *et al.*, 2006; Lloyd and Atkinson, 2006), how to generating a high quality DEM using LiDAR data, especially in a large area is still an active research area. A number of factors that affect the accuracy of DEMs have been identified in the past researches (Li, 1992; Gong *et al.*, 2000; Li *et al.*, 2005). Due to the specific characteristics of LiDAR data, these factors must be paid special attention when using LiDAR data for DEM generation. High density LiDAR data also raise the efficient issue of generated DEM. This paper presents ways to generate a high quality DEM in a large catchment area using LiDAR data, a number of research challenge issues including terrain modelling methods, interpolation algorithms, DEM resolution, and data reduction are discussed in detail for quality control of a LiDAR-derived DEM.

2. Materials and Methods

2.1. Study Area

The study area is in the region of Corangamite Catchment Management Authority (CCMA) in south western Victoria, Australia. The landscape in the region can be depicted to north and south highlands and a large Victoria Volcanic Plain (VVP) in the middle. The VVP is dominated by Cainozoic volcanic deposits. It is characterized by vast open areas of grasslands, small patches of open woodland, stony rises denoting old lava flows, numerous volcanic cones and old eruption, and is dotted with shallow lakes both salt and freshwater. Terrain types vary between the comparatively treeless basins of internal drainage on Victoria Volcanic Plains (VVP) to dissected terrains north and south. The plains have high priority for a range of research projects pertaining to environment management issues addressed in the catchment management strategy plan. The study area, covered by LiDAR data with the area of 6900 km² is shown in Fig. 1.

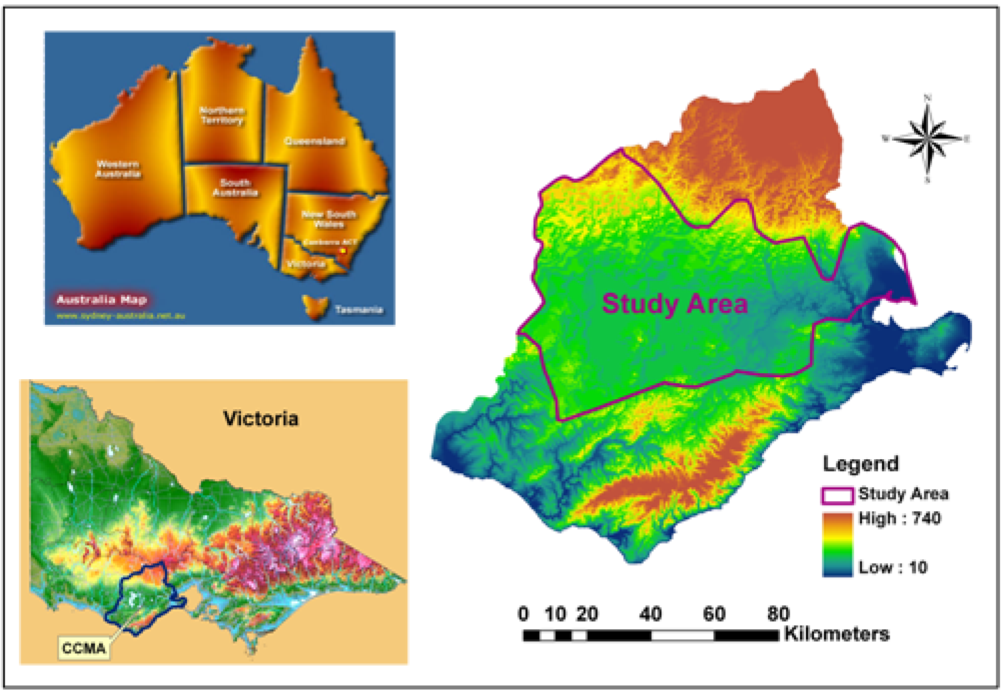

Fig. 1: Study Area.

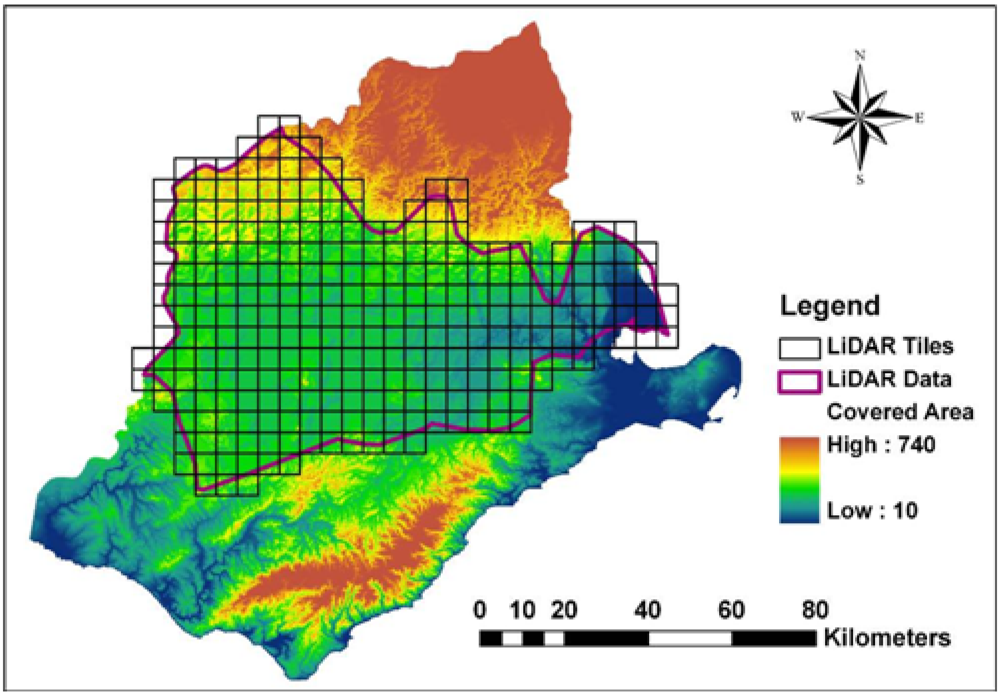

Fig. 2: LiDAR Data Tiles and Covered Area.

2.2. Data

LiDAR data, covering most part of VVP in the CCMA region, were collected over the period of 19 July 2003 to 10 August 2003 by AAMHatch Pty Ltd. The primary purpose of this LiDAR data collection was to facilitate more accurate terrain pattern representation for the implementation of a serious of environment related projects. The LiDAR data have been classified into terrain and non-terrain points by using data filter algorithms across the project area. Manual checking and editing of the data led to further improvement in the quality of the classification. The resulting data products used for DEM generation are irregularly distributed ground 3D points, with an average spacing of 2.2 m. The accuracy of LiDAR data was estimated as 0.5 m vertically and 1.5 m horizontally (AAMHatch, 2003). The LiDAR data were delivered as tiles (5 km by 5 km) in ASCII files containing x, y, z coordinates and intensity values. Total number of 277 LiDAR tiles and covered area are illustrated in Fig. 2.

2.3. Methods

Of the three commonly used digital elevation models, e.g. the grid DEM, the triangular irregular network (TIN), and the contour line model, the grid DEM is the simplest and the most efficient approach in terms of storage and manipulation (El-Sheimy *et al.*, 2005). Large volume of LiDAR data needs such a model for efficient storage and manipulation. Therefore, the grid DEM was selected for this large area terrain modeling. For DEM interpolation algorithms, it has been demonstrated that IDW (inverse distance weighted) method performs well if sampling data density is high (Ali, 2004; Blaschke *et al.*, 2004; Podobnikar, 2005). LiDAR data have high sampling density, and so the IDW approach is a suitable interpolator for DEM generation from LiDAR data (Liu *et al.*, 2007b). It is inappropriate to generate a high resolution DEM with very sparse terrain data: any surface so generated is more likely to represent the shape of the specific interpolator used than that of the target terrain because interpolation artefacts will abound (Florinsky, 2002; Albani *et al.*, 2004). The source data density constrains the resolution of DEM (Florinsky, 1998). On the other hand, generating a low resolution DEM from high density terrain data will devalue the accuracy of the original data. Clearly, the choice of the adequate resolution of a DEM is constrained by terrain input data density. McCullagh (1988) suggested that the number of grid cells should be roughly equivalent to the number of terrain data points in covered area. In this study, the DEM with 2 m resolution was generated.

3. Results and Discussion

With LiDAR data, a high resolution DEM, covering the area of 6900 km² in the CCMA region was generated, shown in Fig 3. LiDAR-derived DEM has advantages over DEMs generated with traditional methods in terms of resolution and accuracy. Compared with *Vicmap DEM*, LiDAR-derived DEM has a significant improvement in both resolution and accuracy compared with *Vicmap DEM*.

High density data make it possible to represent terrain in much detail. However, high density data lead to a significant increase in the data volume, imposing challenges with respect to data storage, processing and manipulation (Sangster, 2002). From DEM quality control perspective, issues such as the choices of modelling methods, interpolation algorithm, and grid size must be given special considerations. For large volume LiDAR data, it is no doubt that grid DEM is appropriate. Recently, hybrid models were used for terrain modelling, especially for high density terrain data. Hybrid model is a mixture of grid DEM and TIN. In flat area, the terrain surface is represented by regular grid in flat area while in a complicated terrain area, TIN is used to describe the surface in detail. The hybrid model has the advantages of both grid DEM and TIN (Kraus and Otepka, 2005). It is able to include breaklines to constrain the TIN structure to depict the complex terrain. The involvement of breaklines and other feature-specific points into the DEM generation is critical for data reduction (Briese *et al.*, 2007).

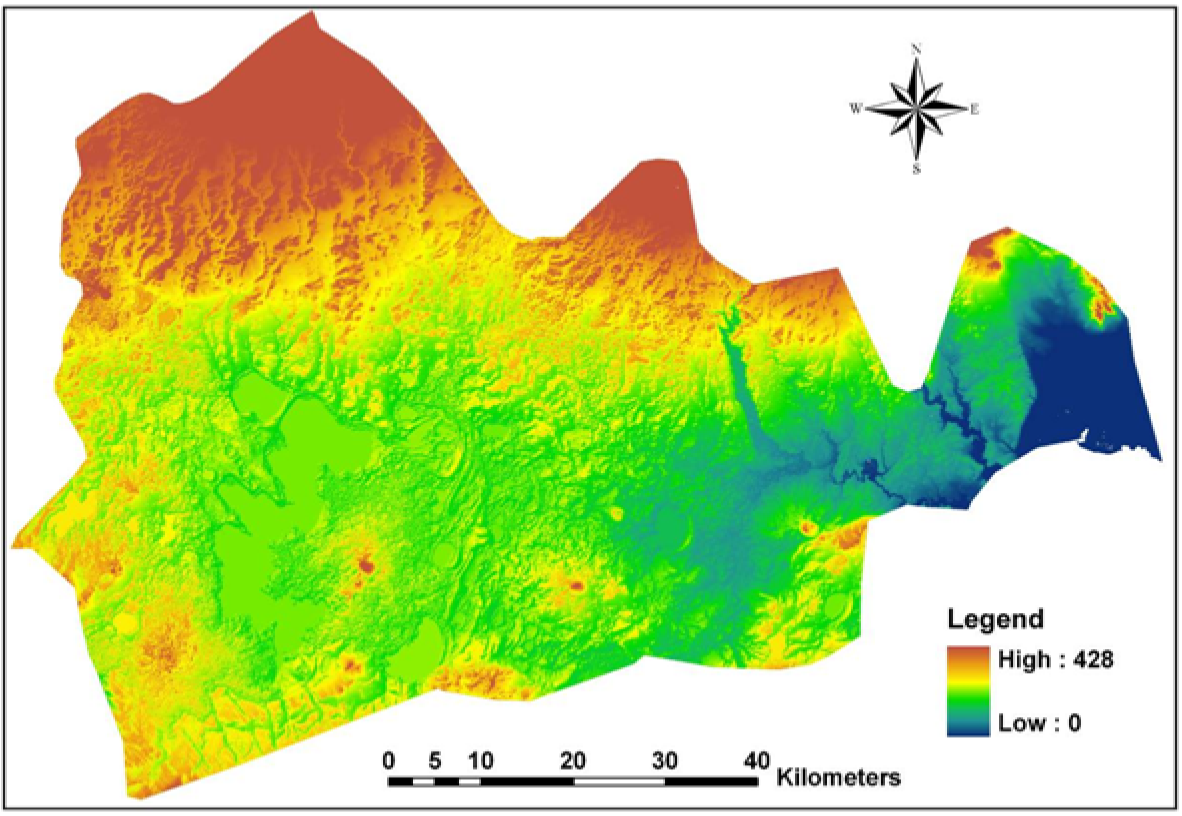

Fig. 3: LiDAR-derived DEM in CCMA.

The primary objective of data reduction is to achieve an optimum balance between density of sampling and volume of data, hence optimizing the cost of data collection (Robinson, 1994). LiDAR technology offers high accuracy and high density 3D terrain data capture for detailed representation of terrain surfaces. However, without sampling selection of high density data during input data preparation for DEM generation, the storage requirements and processing times can be inflated due to data redundancy (Liu et al., 2007a). Strategies for handling the large volumes of terrain data without sacrificing accuracy are required if efficiency is to be considered (Bjørke and Nilsen, 2003; Kidner and Smith, 2003; Pradhan *et al.*, 2005). Via data reduction (i.e. ratio of the information content to the volume of the dataset) (Chou *et al.*, 1999), a more manageably and operationally sized terrain dataset for DEM generation is possible (Anderson *et al.*, 2005a). It has been demonstrated that LiDAR datasets could withstand substantial data reduction yet maintain adequate accuracy for terrain modelling (Anderson *et al.*, 2005b). Our previous work showed that such data reduction can lead to significant decrease of both data file and processing time for DEM generation without compromising the DEM quality (Liu *et al.*, 2007a). LiDAR data reduction mitigates the data redundancy and improves data processing efficiency in terms of both storage and processing time. Given that different data terrain data elements contribute differently to the accuracy of produced DEM, data reduction should be conducted in such a way that critical elements are kept while less important elements are removed (Chou *et al.*, 1999). The inclusion of critical terrain elements such as breaklines into the construction of a DEM will decrease the number of data points while still maintaining high level of accuracy (Hsia and Newton, 1999). Breaklines (or called as structure lines or skeleton lines), such as ridge lines and valley lines, are important terrain features as they describe changes in terrain surface (Lichtenstein and Doytsher, 2004). Breaklines not only provide the elevation information, but also implicitly represent terrain information about their surroundings. They describe terrain surface with more significant information than other points (Li *et al.*, 2005). Their preservation and integration in the generation of DEM significantly contribute to obtaining a reliable, morphological correct and hydrologically enhanced DEM (Brügelmann, 2000; Lichtenstein and Doytsher, 2004).

4. Conclusion

LiDAR data have become one of the major sources for high density and high accuracy three dimensional terrain point data acquisition. Compared with traditional methods, LiDAR is the most effective way for terrain data collection, especially for large area. The use of LiDAR for terrain data collection and DEM generation is becoming a standard practice in spatial science community. LiDAR-derived high quality DEM in the CCMA resign offers much more detailed description than previously used *Vicmap DEM*. It provides a reliable spatial data infrastructure to benefit a wide range of resource and environmental management in the region. It also provides a successful example of using LiDAR for high quality DEM generation at a catchment scale in Australia.

Despite the wide range of application of LiDAR-derived DEM, issues raised due to the characteristics of LiDAR data, such as high density and without sampling density selection for different areas, must be taken into account carefully(Liu, 2008). Some challenge issues regarding LiDAR-derived DEM quality control, including terrain modelling methods, interpolation algorithms, DEM resolution, and data reduction are discussed in detail in this paper, with special focus on LiDAR data reduction. LiDAR data reduction reduces the data redundancy and improves data processing efficiency in terms of both storage and processing time. With LiDAR data reduction, a more manageable and operationally sized DEM is possible.

5. References

[1] AAMHatch, Corangamite CMA airborne laser survey data documentation, AAMHatch Pty Ltd, *Melbourne*, Australia, 2003.

[2] M. Albani, B. Klinkenberg, D. W. Andison and J. P. Kimmins, The choice of window size in approximating topographic surfaces from digital elevation models, *International Journal of Geographical Information Science*, 2004, **18**: 577-593.

[3] T. A. Ali, On the selection of an interpolation method for creating a terrain model (TM) from LIDAR data, Proc. of the American *Congress on Surveying and Mapping (ACSM)* Conference 2004, Nashville TN, U.S.A,2004

[4] E. S. Anderson, J. A. Thompson and R. E. Austin, LiDAR density and linear interpolator effects on elevation estimates, *International Journal of Remote Sensing*, 2005a, **26**: 3889-3900.

[5] E. S. Anderson, J. A. Thompson, D. A. Crouse and R. E. Austin, *Horizontal resolution and data density effects on remotely sensed LIDAR-based DEM*, Geoderma, 2005b, **132**: 406-415.

[6] J. T. Bjørke and S. Nilsen, Wavelets applied to simplification of digital terrain models, *International Journal of Geographical Information Science*, 2003, **17**: 601-621.

[7] T. Blaschke, D. Tiede and M. Heurich, 3D landscape metrics to modelling forest structure and diversity based on laser scanning data, International Archives of the Photogrammetry, *Remote Sensing and Spatial Information Sciences*, 2004, **36**: 129-132.

[8] C. Briese, G. Mandlburger and N. Pfeifer, Airborne laser scanning - high quality digital terrain modelling, Proc. of *Third International Scientific Conference "GEO-Sibirien-2007*", Novosibirsk, Russia, 2007: 79-92,

[9] R. Brügelmann, Automatic breakline detection from airborne laser range data, International Archives of Photogrammetry, *Remote Sensing and Spatial Information Sciences*, 2000, **33:** 109-116.

[10] Y. H. Chou, P. S. Liu and R. J. Dezzani, Terrain complexity and reduction of topographic data, *Geographical Systems*, 1999, **1** :179-197.

[11] DSE, Product Description - Vicmap Elevation, *Department of Sustainability and Environment*, Victoria, Australia, 2002.

[12] N. El-Sheimy, C. Valeo and A. Habib, Digital terrain modeling: acquisition, manipulation, and application, *Artech House*: Boston and London, 2005.

[13] I. V. Florinsky, Combined analysis of digital terrain models and remotely sensed data in landscape investigations, *Progress in Physical Geography*, 1998, **22**: 33-60.

[14] I. V. Florinsky, Errors of signal processing in digital terrain modeling, *International Journal of Geographical Information Science*, 2002, **16:** 475-501.

[15] L. Gonçalves-Seco, D. Miranda, F. Crecente and J. Farto, Digital terrain model generation using airborne LiDAR in a forested area Galicia, Spain, Proc. of 7th International symposium on spatial accuracy assessment in natural resources and environmental sciences, Lisbon, Portugal, 2006: 169-180.

[16] J. Gong, Z. Li, Q. Zhu, H. Shu and Y. Zhou, Effects of various factors on the accuracy of DEMs: an intensive experimental investigation, *Photogrammetric Engineering and Remote Sensing,* 2000, **66**: 1113-1117.

[17] A. Habib, M. Ghanma, M. Morgan and R. Al-Ruzouq, Photogrammetric and LiDAR data registration using linear features, *Photogrammetric Engineering and Remote Sensing*, 2005, **71**: 699-707.

[18] M. E. Hodgson and P. Bresnahan, Accuracy of airborne lidar-derived elevation: empirical assessment and error budget, *Photogrammetric Engineering and Remote Sensing*, 2004, **70:** 331-339.

[19] M. E. Hodgson, J. Jensen, G. Raber, J. Tullis, B. A. Davis, G. Thompson and K. Schuckman, An evaluation of LiDAR-derived elevation and terrain slope in leaf-off condition, *Photogrammetric Engineering and Remote Sensing,* 2005, **71**: 817-823.

[20] D. B. Kidner and D. H. Smith, Advances in the data compression of digital elevation models, *Computer and Geosciences*, 2003, **29**: 985-1002.

[21] K. Kraus and J. Otepka, DTM modelling and Visualization - the SCOP approach, *Proc. of Photogrammetric Week 05*, Heidelberg, Germany, 2005: 241-252.

[22] H. S. Lee, A hybrid model for DTM generation from LiDAR signatures, (PhD Thesis), *Department of Electrical and Computer Engineering*, Mississippi State University, Mississippi, 2004.

[23] Z. Li, Variation of the Accuracy of Digital Terrain Models with Sampling Interval, *Photogrammetric Record*, 1992, **14**: 113-128.

[24] Z. Li, Q. Zhu and C. Gold, Digital Terrain Modeling: Principles and Methodology, CRC Press: Boca Raton, London, New York, and Washington, D.C., 2005.

[25] A. Lichtenstein and Y. Doytsher, Geospatial aspects of merging DTM with breaklines, *Proc. of FIG Working Week,* Athens, Greece,2004.

[26] X. Liu, Airborne LiDAR for DEM generation: some critical issues, *Progress in Physical Geography*, 2008, **32**: 31-49.

[27] X. Liu, Z. Zhang, J. Peterson and S. Chandra, The effect of LiDAR data density on DEM accuracy, Proc. of *International congress on modelling and simulation (MODSIM07)*, Christchurch, New Zealand, 2007a: 1363-1369.

[28] X. Liu, Z. Zhang, J. Peterson and S. Chandra, LiDAR-derived high quality ground control information and DEM for image orthorectification, *GeoInformatica*, 2007b, **11**: 37-53.

[29] C. D. Lloyd and P. M. Atkinson, Deriving DSMs from LiDAR data with kriging, *International Journal of Remote Sensing,* 2002, **23**: 2519-2524.

[30] C. D. Lloyd and P. M. Atkinson, Deriving ground surface digital elevation models from LiDAR data with geostatistics, *International Journal of Geographical Information Science*, 2006, **20**: 535-563.

[31] M. J. McCullagh, Terrain and surface modelling systems: theory and practice, *Photogrammetric Record*, 1988, **12**: 747-779.

[32] T. Podobnikar, Suitable DEM for required application, Proc. of *the 4th International Symposium on Digital Earth,* Tokyo, Japan, 2005.

[33] B. Pradhan, S. Kumar, S. Mansor, A. R. Ramli and A. R. B. M. Sharif, Light Detection and Ranging (LiDAR) Data Compression, KMITL *Journal of Science and Technology*, 2005, **5:** 515-523.

[34] G. T. Raber, J. R. Jensen, M. E. Hodgson, J. A. Tullis, B. A. Davis and J. Berglend, Imact of LiDAR nominal post-spacing on DEM accuracy and flood zone delineation, *Photogrammetric Engineering and Remote Sensing,* 2007, **73**: 793-804.

[35] G. J. Robinson, The accuracy of digital elevation models derived from digitised contour data, *Photogrammetric Record*, 1994, **14:** 805-814.

[36] C. Sangster, Validating LiDAR - evaluating LiDAR accuracy using GPS, Applied Geomatics Research Group, *Centre of Geographic Science*, Lawrencetown, Nova Scotia, Canada, 2002.

[37] R. Wack and A. Wimmer, Digital terrain models from airborne laser scanner data - a grid based approach, International Archives of Photogrammetry, *Remote Sensing and Spatial Information Sciences*, 2002, **34**: 293-296.