High-Resolution DEM Generated from LiDAR Data for Water Resource Management

[1]Liu, X. **[1]J. Peterson, and [1]Z. Zhang**

Centre for GIS, School of Geography and Environment Science
Monash University, Wellington Road, Clayton, Vic 3800, Australia
E-Mail: Xiaoye.Liu@arts.monash.edu.au

Keywords: *Water resource; LiDAR; DEM; Drainage network; Catchment.*

EXTENDED ABSTRACT

Terrain patterns play an important role in determining the nature of water resources and related hydrological modelling. Digital Elevation Models (DEMs), offering an efficient way to represent ground surface, allow automated direct extraction of hydrological features (Garbrecht and Martz, 1999), thus bringing advantages in terms of processing efficiency, cost effectiveness, and accuracy assessment, compared with traditional methods based on topographic maps, field surveys, or photographic interpretations. However, researchers have found that DEM quality and resolution affect the accuracy of any extracted hydrological features (Kenward et al., 2000). Therefore, DEM quality and resolution must be specified according to the nature and application of the hydrological features.

The most commonly used DEM in Victoria, Australia is *Vicmap Elevation* delivered by the Land Victoria, Department of Sustainability and Environment. It was produced by using elevation data mainly derived from existing contour map at a scale of 1:25,000 and digital stereo capture, providing a state-wide terrain surface representation with a horizontal resolution of 20 metres. The claimed standard deviations, vertical and horizontal, are 5 metres and 10 metres respectively (Land-Victoria, 2002). In worst case, horizontal errors could be up to ±30m. Although high resolution stereo aerial photos provide a potential way to generate high resolution DEMs, under the limitations of currently used technologies by prevalent commercial photogrammetry software, only DSMs (Digital Surface Models) other than DEMs can be directly generated. Manual removal of the non-ground data so that the DSM is transformed into a DEM is time consuming. Therefore, using stereo aerial photos to produce DEM with currently available techniques is not an accurate and cost-effective method.

Light Detection and Ranging (LiDAR) data covering 6900 km² of the Corangamite Catchment area of Victoria were collected over the period 19 July 2003 to 10 August 2003. It will be used to support a series of salinity and water management projects for the Corangamite Catchment Management Authority (CCMA). The DEM derived from the LiDAR data has a vertical accuracy of 0.5m and a horizontal accuracy of 1.5m. The high quality DEM leads to derive much detailed terrain and hydrological attributes with high accuracy.

Available data sources of DEMs in a catchment management area were evaluated in this study, including the Vicmap DEM, a DEM generated from stereo aerial photos, and LiDAR-derived DEM. LiDAR technology and LiDAR derived DEM were described. In order to assess the capability of LiDAR-derived DEM for improving the quality of extracted hydrological features, sub-catchment boundaries and drainage networks were generated from the Vicmap DEM and the LiDAR-derived DEM. Results were compared and analysed in terms of accuracy and resolution of DEMs. Elevation differences between Vicmap and LiDAR-derived DEMs are significant, up to 65m in some areas. Sub-catchment boundaries derived from these two DEMs are also quite different. In spite of using same resolution for the Vicmap DEM and the LiDAR-derived DEM, high accuracy LiDAR-derived DEM gave a detailed delineation of sub-catchment. Compared with results derived from LiDAR DEM, the drainage networks derived from Vicmap DEM do not give a detailed description, and even lead to discrepancies in some areas. It is demonstrated that a LiDAR-derived DEM with high accuracy and high resolution offers the capability of improving the quality of hydrological features extracted from DEMs.

1. INTRODUCTION

Water resource management commonly requires investigation of landscape and hydrological features such as terrain slope, drainage networks, drainage divides, and catchment boundaries. Traditionally, these features are obtained from topographic maps, field surveys, or photographic interpretations (Garbrecht and Martz, 1999). Use of such source data is obviously tedious, time consuming and error-prone (Starks et al., 2003). Automatic extraction of these features directly from digital representations of topography has been an active research area over the last two decades (Jenson and Domingue, 1988, Garbrecht and Martz, 1999, Starks et al., 2003). The digital representation of the topography is referred to as a Digital Elevation Model (DEM). Automated extraction of hydrological features from DEMs is faster and less error-prone than the traditional manual techniques applied to topographic maps (Tribe, 1992). It should be noted, however, that DEM quality and resolution affect the accuracy of derived hydrological features (Kenward et al., 2000). Therefore, DEM quality and resolution must be matched to the application of the attributes as part of planning the hydrological attributes derivation process.

This paper evaluates the commonly used data sources for DEM generation for use by catchment managers. LiDAR (Light Detection and Ranging) technology and LiDAR-derived DEMs are described. In order to assess the capability of LiDAR derived DEM for improving the quality of extracted hydrological features, sub-catchment boundaries and drainage networks were generated from the Vicmap DEM and the LiDAR-derived DEM. Results were compared and analysed in terms of accuracy and resolution of DEMs.

2. DEM AVAILABILITY AND QUALITY

In Victoria, Australia, the most widely used DEM is distributed by the Land Victoria, Department of Sustainability and Environment. This DEM, known as *Vicmap Elevation*, was developed under the Victoria Geospatial Information Strategy 2000-2003 (VGIS), with a horizontal resolution of 20 metres. The *Vicmap Elevation* data represent the shape of Victoria's state-wide terrain surface. The source elevation datasets include contours, spot heights and breaking lines (Land-Victoria, 2002). It was produced by using elevation data mainly derived from existing contour map at a scale of 1:25,000 and digital stereo capture. In addition, elevation data from spot height, survey marks, the state wide gravimetric database and airborne geophysical surveys, and relevant hydrographical lines across the whole state were also incorporated into the DEM generation processes. *Vicmap Elevation* is delivered with raster data structure, consisting of a matrix of 20 by 20 metres square grid cells with the mean cell elevation stored in a two dimensional array to present 1690 tile-based DEM files covering Victoria. Each of these DEM files provides the same coverage as a standard 7.5-minute quadrangle Vicmap Topographic Map. To ensure a seamless state wide DEM mosaic and smooth transition of elevation at the tile boundary, each DEM file also has a 400m over-edge buffer (Land-Victoria, 2002). This representation of natural relief features across Victoria can be used in a variety of applications, particularly in emergency services, natural resource management, and planning and development (DSE, 2002).

The attainable horizontal accuracy of *Vicmap Elevation* can be attributed to the sum of errors from the source material, the conversion process and the manipulation process (DSE, 2002). The details of the quality for this DEM are expressed by Land-Victoria (2002): the standard deviations for vertical and horizontal data are 5 metres and 10 metres respectively (Land-Victoria, 2002). In worst case, its horizontal errors could be up to ±30m. It is recommended that this DEM should be used for applications at scales of not larger than 1:25,000 (Land-Victoria, 2002).

Other sources for DEM generation include high resolution stereo aerial photos. In the study area of Corangamite, colour air photos at scale of 1:25,000 were taken in January 2001. There seems to be a potential of using these aerial photos to produce a high resolution DEM. However, using currently available commercial software such as Leica Photogrammetry Suite (LPS) can only directly generate DSMs (Digital Surface Models). The DSM depicts a surface across both natural and man-made surfaces (Toutin, 2004) and so can not be used for hydrological modelling. For this, DEMs, generated using only the bare-earth data must be used. Manual removal of the non-ground data from the DSM yields a DEM but this process is time consuming and tedious. Furthermore, as the first step for DEM generating using stereo aerial photos, ortho-rectification must be conducted. Ground Control Points (GCPs) are needed in this process. One of the approaches to acquiring GCPs is to directly use Vicmap Transport and Fence data for horizontal control and *Vicmap Elevation* data for vertical control. The errors from these Vicmap data will propagate into the resulting DEM, which cannot be expected to have a good accuracy. In order to improve DEM accuracy, field survey such as differential GPS (Global Positioning System) survey must be carried out. Obviously, using stereo aerial photos for DEM production with currently available techniques may not be an accurate and cost-effective method.

LiDAR, a relatively new technology, offers advantages over traditional methods for representing a terrain surface. The advantages refer to accuracy, resolution, and cost. One of the most attractive characteristics of LiDAR is its very high vertical accuracy which enables it to represent the Earth surface with high accuracy (Ma, 2005). Water resource management and hydrological modelling require high quality DEMs (Garbrecht and Martz, 1999) because the accuracy of DEMs does affect the accuracy of hydrological predictions (Kenward et al., 2000). Therefore, LiDAR data are applicable to water resource management and hydrological modelling.

For the purpose of accurate analysis of terrain and water flow path in the Corangamite Catchment area, LiDAR data for the total area of 6900 km² were collected over the period 19 July 2003 to 10 August 2003. A LiDAR-derived high accuracy and high resolution DEM will be used to support a series of salinity and water management projects addressed by the Corangamite Catchment Management Authority (CCMA). The DEM derived from the LiDAR data has a vertical accuracy of 0.5m and a horizontal accuracy of 1.5m. Compared with the DEM (*Vicmap Election*) delivered by Land Victoria, significant improvement of DEM quality has been achieved. This will lead to derivation of much detailed terrain and hydrological attributes with high accuracy.

3. LIDAR AND LIDAR DERIVED DEM

3.1 LiDAR System

LiDAR is the use of lasers to determine distance from the instrument to specific targets (Barber and Shortrudge, 2004). For the terrain mapping purpose, an airborne LiDAR system is typically composed of sensor, Inertial Navigation System (INS) monitoring the pitch, roll, and altitude of the aircraft and thereby the directional orientation of the laser scanner, and differential GPS receiving unit determining the location of the laser scanning system in three dimensional space (Hodgson et al., 2005, Barber and Shortrudge, 2004). Incorporating the technologies of INS and GPS into the LiDAR system results in the capability of determining the three dimensional location of the sensor, the direction of the ranging laser, and the distance to a target (Barber and Shortrudge, 2004). With this information, target location in three dimensional spaces can be determined at high accuracy. A typical LiDAR system is illustrated in Figure 1.

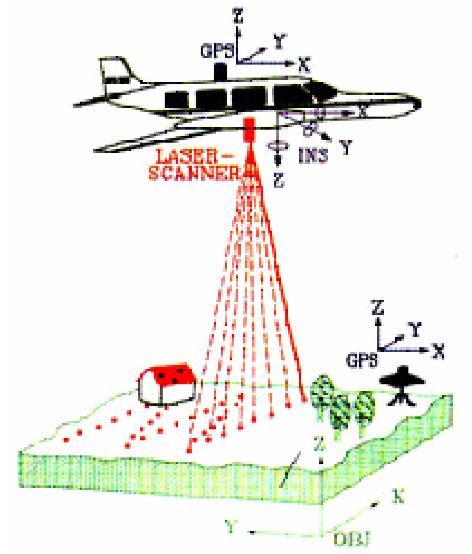

Figure 1. A Typical LiDAR System (Gross, 2003)

A laser scanner emitting pulses at 10,000 times per second can record 600,000 points every minute (MMSI, 2001). A LiDAR system can also detect multiple returns from an individual pulse and measure an intensity of each return (Barber and Shortrudge, 2004). The accuracy of LiDAR data depends on flying height, speed and scan angle. The scan angle of the airborne laser system is less than ±20º (Ackemann, 1999). Most LiDAR systems fly at an altitude of 1000m above the terrain surface (Ackemann, 1999, Hodgson et al., 2003). The density of the data is related to the flying speed and the size of the signal on the ground. Generally, raw laser point spacing on the ground varies from 2 to 4 metres (MMSI, 2001). The horizontal accuracy could be calculated as the flying height multiplied by 1/2000. The vertical accuracy of cloud points can be within 0.1 metres and the horizontal accuracy within

0.5 metres if the density of cloud points is 1-5 per square metre (Lohr, 1998).

3.2 LiDAR Derived DEM

The raw data from LiDAR system are three dimension cloud points with intensity values. Laser returns are recorded from no matter what target the laser happens to strike (Barber and Shortrudge, 2004). The desired target for the generation of digital elevation model is the bare-earth. However, the LiDAR raw data include everything on the ground such as buildings, telephone poles, power lines (Means et al., 1999), and even birds (Hodgson et al., 2003). The post-processing of LiDAR data involves the removal of undesirable points by using filter algorithms (Zhang et al., 2003, Axelsson, 1999, Lin, 1997, Lee and Younan, 2003). The final cloud points for DEM generation are those points which strike to the bare-earth ground.

LiDAR data used for this project were classified into bare-earth and non-ground points by AAMHatch (2003) using different algorithms across the project area. Manual checking and editing of the data were also conducted to further improve the quality of the classification (AAMHatch, 2003). Using ArcGIS software, a regular 5 by 5 meters grid DEM was created with the bare-earth points by means of the inverse distance weighted (IDW) interpolation method. In order to compare the accuracy of hydrological features generated from the 20 metres resolution the Vicmap DEM and from the LiDAR-derived DEM, the 5 meters resolution LiDAR DEM was resampled by the nearest neighbor assignment resampling technique to a 20 metres. The two DEMs that was comparable with the Vicmap DEM in terms of horizontal resolution. All these DEMs were georeferenced to GDA94 geodetic datum and projected to MGA Zone54 coordinate system.

4. HYDROLOGICAL FEATURE GENERATION AND COMPARISON

Increase accuracy in determination of hydrological features such as drainage networks and catchment boundaries is very welcome to water resource managers. Some researchers have demonstrated the feasibility of automated extraction of hydrological features from DEMs. However, the accuracy of these hydrological derivatives is affected by the DEM quality and resolution (Zhang and Montgomery, 1994, Wolock and McCabe, 2000). The LiDAR-derived DEM is of higher accuracy and higher resolution than the traditional type of DEM such as the Vicmap DEM. Here, the improvement of quality of some of the hydrological features extracted from the LiDAR derived DEM will be investigated. This investigation will take into account the effects of both accuracy and resolution of DEMs on extracted hydrological features.

4.1 Study Area

Corangamite Catchment Management Authority (CCMA) is in the south western Victoria. It covers an area of over 1.3 million hectares with a population of over 400, 000. The landscape in the region can be depicted to north and south highlands and a large Victoria Volcanic Plain (VVP) in the middle. Over 21,000 hectares of land in CCMA, mostly in the VVP, has been estimated as being in the salinity risk area (Dahlhaus et al., 2003). LiDAR data coverage for the Corangamite Catchment are shown in Figure 2.

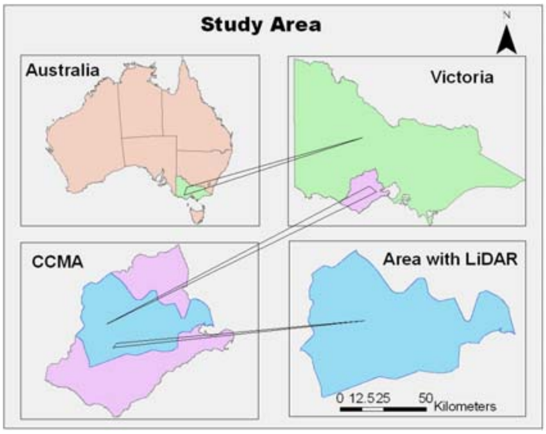

Figure 2. Study area

4.2 Elevation Differences

As mentioned, a LiDAR derived DEM has higher accuracy than Vicmap DEM, but in what scale do differences in elevation exist between these two DEMs? It needs to be analysed. The 20m resolution LiDAR DEM that was resampled from 5m LiDAR-derived DEM was used to compare with the Vicmap DEM of same resolution in terms of elevation. One of the most direct methods to obtain the elevation differences between the two DEMs is to generate an elevation difference image, here, created by raster calculation from the ArcGIS spatial analyst. The statistical analysis from the generated difference image shows that the maximum elevation difference between the Vicmap DEM and the LiDAR DEM is up to 65m. The elevation differences between these DEMs are significant, especially in some specific areas, where the approximation for elevation in the Vicmap DEM is insufficient for detailed modelling.

4.3 Sub-Catchment Boundaries

Sub-catchment, also called basin or watershed, is one of the most important elements in hydrological analysis. In order to investigate the performance of automated extraction of sub-catchment from different DEMs with respect to both accuracy and resolution of DEMs, sub-catchments derived from the Vicmap DEM and the LiDAR-derived DEM both with 20m resolution are shown in Figure 3. Sub-catchments generated from LiDAR DEMs with 5m and 20m resolution respectively are shown in Figure 4.

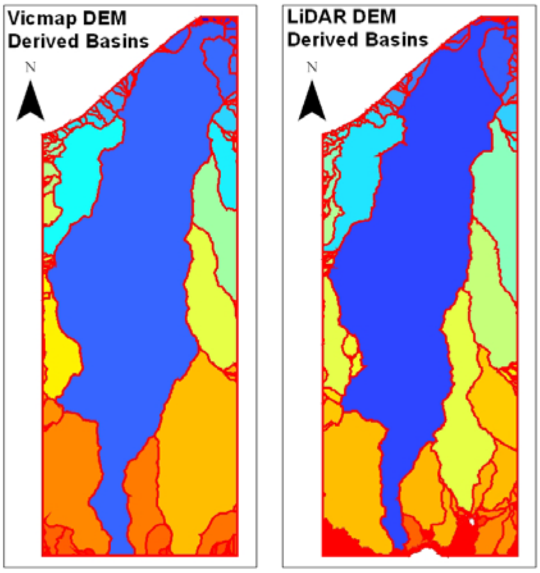

Figure 3. Sub-catchment boundaries derived from Vicmap DEM and LiDAR DEM

Figure 3 shows that there is considerable difference in the sub-catchment boundary pattern derived from the different DEMs. This is especially true in the southeast corner. LiDAR DEM produced many more sub-catchments than the Vicmap DEM. For this typical region, a total 190 numbers of sub-catchments were derived using the 20m Vicmap DEM while 348 sub-catchments were created from the 20m LiDAR DEM. Although the Vicmap DEM and the LiDAR DEM have the same 20m resolution, the higher accuracy in the LiDAR-derived DEM provides the capability of generating sub-catchments with more detail.

There is an even greater difference in the pattern of sub-catchment boundaries between outcomes of using the 5m and 20m resolution LiDAR DEMs (Figure 4). The higher resolution LiDAR DEM corresponds with a detailed delineation of sub-catchments, with a total number of 2979 sub-catchments. Clearly, many details for representation of sub-catchment boundaries were lost when the coarser resolution DEM was used. The coarser resolution DEM cannot represent important topographical objects that are below the DEM resolution (Garbrecht and Martz, 1999). Without doubt, the generation of sub-catchments is sensitive to the DEM resolution used even though the same vertical accuracy may apply in many cases.

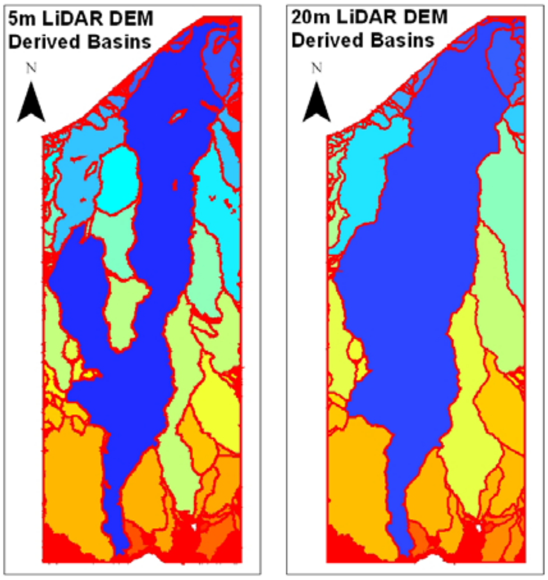

Figure 4. Sub-catchment boundaries derived from 5m and 20m resolution LiDAR DEM

4.4 Drainage Networks

Drainage networks are delineated from the digital catchment area cell. All cells within a catchment area greater than a user defined threshold are classified as part of the drainage network (Martz and Garbrecht, 2003). In order to assess the impacts of DEM accuracy and resolution on the delineation of derived drainage networks, three groups of drainage networks (shown in Figure 5), were generated. One was from the 20m resolution Vicmap DEM, and the others refer to 20m and 5m resolution LiDAR

DEMs. A same threshold value, 500 (which means all cells that have more than 500 cells flowing into them are identified as part of stream lines) was used for the calculation of all three groups of drainage networks. Here, the selection of the threshold value is mainly dependent on the easy visual comparison of the results.

Visual overview of the three groups of drainage networks in Figure 5 illustrates that the high resolution LiDAR DEM gave a much more detailed description of drainage networks, which can be used as reference networks for comparison with networks derived from other types of DEMs. Lack of congruence is evident between the stream networks derived from the three DEMs tested in our study (Figure 5). Much of the difference is due to the lower vertical accuracy of the Vicmap DEM which leads to the incapability of representing some important topographical features such as ridge or break line. Compared with the results from LiDAR DEM, drainage lines from 20m Vicmap DEM are much shorter.

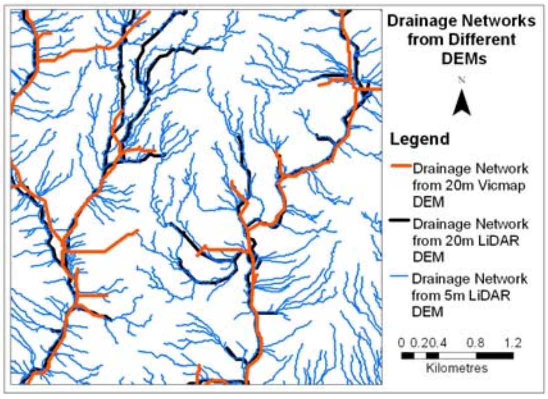

Figure 5. Drainage networks from Vicmap DEM and LiDAR DEMs

5. CONCLUSIONS

The quality of DEM-derived hydrological features is sensitive to both DEM accuracy and resolution. Elevation differences between Vicmap and LiDAR-derived DEMs are significant: they are up to 65 metres in some areas. Sub-catchment boundaries derived from these two DEM types are also quite different. In spite of the same resolution for the Vivmap DEM and the LiDAR-derived DEM, higher accuracy LiDAR DEM gave a more detailed delineation of sub-catchment. Again, the Vicmap DEM derived drainage network offers less detail than the LiDAR DEM derived network. Indeed the drainage networks derived from the Vicmap DEM exhibit some anomalies when the two are compared. The experiments demonstrated that the LiDAR-derived DEM with high accuracy and high resolution offers the capability of improving the quality of hydrological features extracted from DEMs. Further work will involve ground truth fieldwork designed to compare and verify the experimental results.

6. ACKNOWLEDGEMENTS

The authors are grateful to the Corangamite Catchment Management Authority for providing LiDAR data to support this project. We would also like to acknowledge the helpful comments of the two reviewers.

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