○ SPATIAL DATA INTEGRATION FOR CLASSIFICATION OF 3D POINT CLOUDS FROM DIGITAL PHOTOGRAMMETRY

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Under increased urban settlement density, access to a high resolution (land-parcel scale) bare-earth Digital Elevation Model (DEM) is a pre-requisite for much decision support for planning: stormwater assessment, flood control, 3D visualisation, automatic delineation of flow paths, sub watersheds and flow networks for hydrological modelling. In these terms, a range of options face the DEM-building team. Apart from using necessarily expensive field survey, or use of out-of-date terrain information (usually in the form of digital contours of less-than-satisfactory interval) the model will be built from point-clouds. These will have been assembled via digital photogrammetry or acquisition of LiDAR data. In the first instance, both these data types soon yield a model that is known as a digital surface model (DSM). It includes any buildings, vehicles, vegetation (canopy and understory), as well as the "bare ground". To generate the required 'bare-earth' DEM, ground and non-ground features/data points must be distinguished from each other so that the latter can be eliminated before DEM building. Existing methods for doing this are based on data filtering routines, and are known to produce errors of omission and commission. Moreover, their implementation is complex and time consuming.

I report here, the results of deploying spatial data integration instead of the previously favoured filtering routines. The challenge was to identify a process flow for separating the ground and non-ground points. It is shown that this alternative approach can be implemented if the client can supply a range of ancillary height data, this being most economically forthcoming if archivally available. The relative significance of these archival datasets emerges from exploring the various process flow paths and devising relevant quality tests designed to distinguish input suitable to support modelling at a land-parcel scale of analysis. Then the ArcGIS topological overlay technique was used to collect zonal statistics for each 3D point. Thus each output 3D point acquires z (elevation) values derived from the digital photogrammetry and "z-statistics" (minimum, maximum, mean) of its assigned zone. Clearly there is value in spatial data integration for a city with spatial data archives of adequately supportive scope and quality.

INTRODUCTION

Planners at Victorias' fastest-growing LGA, the City of Casey (2005) (~ 400 square kilometres on the south-eastern edge of Melbourne) are formulating the Cranbourne West and Lyndhurst Residential Development Plan in the spirit of Melbourne 2030 (Department of Sustainability and Environment 2002). Under increased urban settlement density, access to a high resolution bare-earth Digital Elevation Model (DEM) is a pre-requisite for much decision support: stormwater assessment, flood control, 3D visualisation (Hodgson and Bresnahan 2004), automatic delineation of flow paths, sub watersheds and flow networks for hydrological modelling (Wilson and Gallant 2000). The DEM choice, quality and resolution is known to be of very critical importance for realistic definition of the watershed and sub-watershed boundaries and topographic

input, and subsequent simulated outputs (Luzio et al. 2005). In these terms, a range of options face the decision-support team.

Traditionally, DEMs have been produced by survey methods or by stereo photogrammetry (Sties et al. 2000). The airborne light detection and ranging (LiDAR) technology is revolutionising a high-resolution DEM generation by producing the means for rapid measurements of topography over a large area (Zhang et al. 2003; Hodgson and Bresnahan 2004). Since the introduction of LiDAR in the mapping industry, its applications in GIS and other areas has increased exponentially and diversified innovatively. Airborne LiDAR systems usually obtain measurements for the horizontal coordinates (x , y) and elevation (z) of the reflective objects scanned by the laser beneath the flight path. These measurements generate a three-dimensional cloud of points with irregular spacing. Digital photogrammetry is evolving as the art, science and technology of obtaining reliable measurements, maps, digital elevation models and other GIS data about the earth and its environment from aerial and satellite imagery. Photogrammetrists are responsible for all phases of mapping projects and provide spatially accurate base maps that form the foundation for many GIS applications. Digital mapping cameras (DMC) like Ultracam-D, allow true integration of digital photogrammetry and remote sensing mapping (Perko et al. 2004; Leberl and Gruber 2005).

LiDAR provides very accurate position and height information, but less direct information on the geometrical shape of objects within the field of view. High-resolution imagery on the other hand offers very detailed information on object attributes, such as spectral signature, texture and shape. Davis et al., (2002) found that for monitoring volume changes in riparian resources, photogrammetry provides more accurate monitoring data than LiDAR, although more careful photogrammetric processing is necessary to attain monitoring accuracy requirements within vegetated zones with any kind of canopy. It is found that photogrammetry and LiDAR have their unique advantages and drawbacks for building extraction during 3D city modelling (Tao and Yasuoka 2002). This illustrates the general point that some of the shortcomings of one method can be compensated by taking advantage of unique capabilities offered to users of the other method (Schenk and Csatho 2002).

Urbanisation brings terrain change, which in turn makes even the costliest elevation models obsolete. This is most evident in the fast-developing suburbs such as found in the Melbourne metropolitan City of Casey. Procurement of high resolution imagery (e.g. Aerial photos) is a prerequisite for monitoring land-cover changes. Often it is not economical to opt for both Aerial photos (for image map) and LiDAR data (for elevation). As always, the principle of economy (Dale and McLaughlin 1988) dictates deployment of data integration. In the absence of access to LiDAR data, or a contour map of very close contour intervals, the key data set will be from photogrammetric analysis of stereo-pairs of air photos of suitable (nominal) scale. In that, Casey City procures high resolution aerial photos as part of the image map acquisition, there is potential for widening the data and information flows for terrain modelling if the coverage is in stereo. However, first there is a need to assess the scope for delivering a bare-earth DEM of high-enough quality via this path.

Both the LiDAR and the digital photogrammetry most readily generate a model that is known as a digital surface model (DSM), which include buildings, vehicles, vegetation (canopy and understory), as well as the “bare ground”. To generate a ‘bare-earth’ DEM, measurements from ground and non-ground features have to be identified and classified (Sties et al. 2000; Zhang et

al. 2003) from the 3D point clouds of DSM. Removing non-ground points from 3D point clouds either from digital photogrammetry or LiDAR has proven to be a challenging task (Zhang, et al. 2003).

Kraus and Pfeifer (1997; 1998) utilised linear least squares interpolation iteratively to remove tree measurements to generate bare-earth DEM in forest areas. This method was extended later to filter buildings and trees in urban areas by (Pfeifer et al. 2001). The iterative linear interpolation method removes a low-degree polynomial trend surface from the original elevation data to produce a set of reduced elevation values. This method requires that the reduced elevation follows a random process of ergodic property. However, this criterion is hard to satisfy in urban areas where significant anthropogenic modification of natural terrain occurs. Vosselman (2000) proposed a slope-based filter that identifies ground data by comparing slopes between a 3D point and its neighbours.

There are two basic error types in classifying 3D point clouds by virtually any filtering method: they refer to errors of commission and errors of omission. In the first of these, non-ground points are classified as ground measurements (Congalton 1991). The errors of omission occur when ground points are mistakenly removed. Vosselman (2000) demonstrated that good filtering results could be obtained by using threshold slopes from training datasets. However, to achieve such good results, the training datasets have to include all types of ground measurements in a study area. This is not always practical. Other attempts to improve the slope-based filter have been published by Roggero (2001) and Sithole (2001). The implicit premise of applying the slope-based filter is that there is a distinct difference between the slope of terrain and that of non-ground objects such as trees and buildings.

Haugerud and Harding (2001) developed an algorithm to filter tree points in forest areas by comparing local curvatures of point measurements. Ground measurements were selected by removing tree vertices iteratively from a triangulated irregular network (TIN) constructed from 3D points. Alternatively, ground points can be classified by iteratively selecting ground measurements from an original dataset. Axelsson (2000) suggested adaptive TIN models to find ground points in urban areas. First, seed ground points within a user-defined grid of a size greater than the largest non-ground features are selected to compose an initial ground dataset. Then, one point above each TIN facet is added to the ground dataset with every iteration if its parameters are below selected threshold values. The iteration continues until no points can be added to the ground dataset. The problem with the adaptive TIN method is that different thresholds have to be given for various land cover types.

Another commonly used algorithm to remove non-ground objects is a mathematical morphology filter which is applied to a grayscale image (Kilian et al. 1996; Lohmann et al. 2000; Vosselman 2000). The elevation of trees, cars, and buildings is usually higher than those of surrounding ground points. If 3D points are converted into a regular, grayscale grid image in terms of elevation, then the shapes of buildings, cars, and trees can be identified by the change of gray tone. It is well known that compositions of algebraic set operations based on mathematical morphology can be used to identify objects in a grayscale image. Mathematical morphology composes operations based on set theory to extract features from an image. Two fundamental operations, dilation (focal maximum) and erosion (focal minimum), are commonly employed to enlarge (dilate) or reduce (erode) the size of features in binary images. Dilation and erosion operations may be combined to produce opening and closing operations (Zhang et al. 2003). This process has been

tested in the current study. It was found that like other filtering methods, the progressive morphological filter is also subject to omission and commission errors. Moreover, its implementation is complex and time consuming. Also, the raster-based approach is not found to be suitable for classifying the input points, because too many non-ground points tend to be removed.

Accordingly, given the complexity involved, the following are the objectives of the papers: a) to explore spatial dataset archives for range of ancillary height data wishing to make most out of the data, b) to identify GIS methods to help performing a quick quality check on ancillary height data, c) to identify a process flow for the classification of 3D point clouds into ground and non-ground points with the help of spatial data integration.

TEST SITE

The test site (between 38.088 to 38.108 S and longitudes 145.245 to 145.270 E, see Figure 1) covers a part of City of Casey, Victoria, Australia and is supported by all the data required for the study.

Figure 1 Location map of the test site.

SOFTWARE AND DATA USED

Leica Photogrammetry Suite (LPS©) (<http://www.gis.leica-geosystems.com>) photogrammetric tools and ESRI © (<http://www.esri.com>) ArcGIS Spatial Analyst tools were used in this study.

High resolution aerial stereo photos from Qasco (<http://www.qasco.com.au>) with camera calibration information were assembled in digital form. Access to the Victorian Spatial Database Infrastructure (VSDI) datasets, along with ancillary data from the City of Casey and South East Water Corporation (eg Manhole covers) completed the list of primary input data.

SPATIAL HEIGHT DATA INTEGRATION

The VSDI offers elevation spatial datasets including 10-20 m contours and spot heights (Figure 2) fit for TIN modelling. VicMap is also planning to develop 1 to 5 m elevation datasets (Ratcliff 2005). The elevation at any of one of these contour intervals may not offer an elevation model that reflects the changes in the land scape caused by land parcel sub-division and on-going intensification of the engineered drainage network.

Figure 2 Map showing VSDI elevation contours of 10 m and spot heights.
Note the elevation datasets will not offer credible elevation model that reflects the landscape change caused by land parcel sub-division.

The urbanisation in progress in City of Casey involves drainage network and related asset installations. For instance *Manholes* are installed for maintenance access to trunk sewer pipes. City of Casey archive shows that the *Manholes* data are available in spatial format and tagged with elevation information. The point-data density pattern is depicted in Figure 3. It clearly shows that the *Manholes* could form a very valuable elevation data source to create a base DEM to reflect the current landscape, before a high resolution digital elevation models can be built.

Figure 3 Test site showing the coverage of the *Manholes*. They could form a very potential elevation data source.

DEVELOPMENT OF THE BASE DEM

Before attempting densification of the elevation data using the *Manholes* data the quality of the data needs to be checked. As shown in the flow diagram (Figure 4) GIS visualisation tools are used to understand the nature of the elevation data represented by the *Manholes* data.

Figure 4 Densification of elevation data for the development of a base DEM that reflects the current landscape

Using the Jenks (1977) algorithm of natural breaks, the *Manhole* elevation values are classified as shown in Figure 5. This classification facilitated clear visualisation of errors in the data values (Figure 5).

The *Manholes* with bad values are identified and ignored. Then the base DEM (Figure 6) was built using the TOPOGRID command in ArcGIS (ESRI 2004b). This DEM is used for the rest of the study as described in the next section.

Figure 5 Map showing *Manholes* displayed based on their elevation values.
GIS tools to display data values with natural break algorithm found to be a way to visualise the errors in the data.

Figure 6 Base DEM generated with the help of VicMap elevation contours, spot heights and the selected *Manholes*.

3D POINT CLOUDS (DSM) EXTRACTION FROM DIGITAL PHOTOGRAMMETRY

The first step in the process of 3D point clouds extraction from digital photogrammetry is collection of ground control points (GCPs) necessary for ortho-rectification and aerial triangulation. Figure 7 depicts a process flow diagram for the generation of these 3D point clouds.

Figure 7 Process flow diagram for the generation of high resolution 3D point clouds.

GCP assembly refers to horizontal (x, y) and vertical (z) measurements of locations which can be seen on the aerial photos. Ideally, GCPs should be collected on ground via traditional surveying techniques, but, for most tightly-scheduled land-parcel sub-division projects, ground survey for large areas is prohibitively expensive and time consuming. Typical GCP collection involves use of the VSDI Road network to identify x, y positions. If the digital roads network does not offer suitable GCPs, other means must be used. In some cases suitable GCPs can be found in other datasets (eg *Manholes*). Otherwise, the extra time needed for field work with differential Global Positioning Systems (dGPS) must be found.

For DEM building, collection of the most credible vertical measurement (z) for a ground control points is crucial (Kunapo et al. 2005), but typically, is not readily available in the same information flows used to assemble the x, y information. Ground control z-value (ground elevation) collection is always more difficult than assembly of the concomitant 2D (x, y) information.

During the study reported here, it was found that most of the *Manholes* locations can be clearly seen on the aerial photos (Figure 8). Immediately they became preferred objects for defining the control points. In the areas where manholes are not found or can not be seen, road intersections were used to collect x, y information. In such cases, the base DEM is used for establishing the z value of such points.

Once GCPs are defined and the aerial triangulation performed, the 3D point clouds could be easily generated using the DTM extraction tools in LPS®. These 3D point clouds included all non-ground objects which need to be separated one from the other.

Figure 8 Manholes can be seen as rounded objects in the back yard of the parcel.

CLASSIFICATION OF 3D POINT CLOUDS

A process flow (Figure 9) is identified to achieve the separation of ground and non-ground 3D points.

Based on the topography reflected by the base DEM, the study area has been divided into zones of 100 sq. m. Using ArcGIS Spatial Analyst tools (ESRI 2004c), zonal statistics are generated with reference to the base DEM to collect uni-variate statistics for each zone (Figure 10).

The ArcGIS topological overlay technique (ESRI 2004a), point on polygon, was used to collect zonal statistics for each 3D point. The output 3D point clouds then have the z (elevation) values derived from the digital photogrammetry and statistics like minimum, maximum, mean etc of the concomitant zone. The following VBA script was used to update the class_id column of the 3D point clouds attribute table.

```

Dim intClassID as Integer
If [Z] < [MAX] + 0.25 and [Z] > [MIN] - 1 then
    intClassID = 1
else
    intClassID = 0
end if
class_id = intClassID

```

where Z is elevation values derived from the digital photogrammetry and MAX and MIN are the maximum and minimum elevation values from the concomitant zone. ClassID 1 indicates ground points whereas 0 indicates non-ground points. A threshold value is used to accommodate more ground points. The classified output (Figure 11) points are then used for various applications.

Figure 9 Process flow diagram for the classification of ground and non-ground points.

Figure 10 Map showing zones defined for the study along with their zonal statistics.

Figure 11 Map showing part of the study area with classified ground and non-ground points.

RESULTS AND DISCUSSIONS

The process flow (Figure 9) tested here applied to an institutional context that will support spatial data integration. In such cases the principle of economy is well served. Ancillary height data from *Manholes* was found to be very useful to densify the elevation data for possible development of a base DEM for preliminary planning purposes. Deployment of the natural breaks algorithm (Jenks 1977) was found to be very helpful for representing elevation data of continuous nature. Bad values can be easily identified using this method. In this study, it has been identified that the GCPs from *Manholes* are more reliable than the GCPs from road intersections. GCPs from *Manholes* can even replace expensive ground survey. Should there be any minor errors in the selected *Manholes*, the aerial triangulation RMSE report will indicate them to facilitate a second round of bad data points elimination. With the help of the final set of GCPs, a very accurate DSM can be generated.

Most of previous studies which use filter techniques focussed on removing non-ground points. In contrast, the current study aims at just separating them. When successful, there is no loss of useful data. The non-ground points can be further used in the feature extraction process and in building the 3D city. The high definition of ground data can be seen in Figure 11 is possible where roads and drive ways are defined very clearly. This is possible because data loss has been avoided.

Reward for terrain classification emerges in higher quality orthophoto mosaicing (Figure 12), 3D visualisation and flood inundation modelling (Figure 13), stream network modelling and detailed sub-catchment delineation (Figure 14).

Figure 12 Ortho-photo mosaic generated with the help of high resolution half-meter bare-earth DEM shows the accuracy of the image registration.

Figure 13 The half-metre DEM supports credible and detailed 3D visualisation of flood inundation modelling.

Legend

- Catchment
- DrainageLine
- DrainagePoint

0 162.5 325 650 Meters

Figure 14 Sub-catchment delineation at parcel level is possible with the help of half-meter bare-earth DEM.

CONCLUSIONS

It is shown that the City spatial datasets offer a range of ancillary height data, the relative significance of which emerges from exploring the various process flow paths (Figure 4, 7, 9) and devising relevant quality tests (Figure 3, 4). The best results were obtained when the ground control points are augmented by addition of asset inventory data, (especially manholes) with high quality z values.

The study shows that the DEM generated with digital photogrammetry and ancillary data from the City digital spatial data archives supports a range of mapping and modelling tasks of relevance to planning of new land-parcel sub-division for sub-urbanisation. The method identified in this study is found to be easily implementable, repeatable, and to preserve useful data during data quality refinement and to be less time consuming. This method can also be applied to LiDAR point clouds. Clearly there is value in spatial data integration for a city with spatial data archives of adequately supportive scope and quality.

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