

GUIDELINES ON BOTH SPATIAL STANDARDS FROM, AND THE MERGING OF DIGITAL TERRAIN DATA FOR EMERGENCY RISK MANAGEMENT PLANNING

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ABSTRACT:

This paper describes the development of a set of guidelines on the use and integration of digital terrain data for Emergency Risk Management (ERM) planning, specifically in relation to flood hazard. The guidelines were developed by a node of the Cooperative Research Centre for Spatial Information (CRC-SI) at the University of New South Wales (UNSW), Sydney, Australia, in conjunction with NSW Government Agencies. The guidelines focus on the applied use of data acquired by Airborne Laser Scanner (ALS) and Interferometric Synthetic Aperture Radar (InSAR) for digital elevation modelling and flood risk assessment at catchment to regional scales. Operational procedures for data capture and ground survey are outlined. Standardised techniques for generation of digital terrain and elevation data, accuracy assessment and feature extraction are demonstrated. The integration of geospatial data for flood risk and hazard assessment is discussed. The guidelines were designed to assist Local and State Government Agencies in undertaking future GIS based flood studies. The completed guidelines are available through the CRC-SI (<http://spatialinfocrc.org/>).

1. INTRODUCTION

Flood studies have increasingly relied on remote sensing data sources that provide rapid, cost-effective and spatially accurate terrain and elevation data. Data acquired by Airborne Laser Scanner (ALS) and Interferometric Synthetic Aperture Radar (InSAR) technologies have demonstrated ability in accurate terrain capture and extraction of urban and natural features (Crosetto, 2002; Elmqvist *et al.*, 2001). Spatially consistent terrain data provides a basis for simulating different flood and storm surge scenarios (Hollaus *et al.*, 2005). Translated into digital flood intelligence, this data is useful to land managers, local councils and state emergency services for urban and coastal planning, disaster mitigation and emergency response.

Flood studies are undertaken at a range of spatial and temporal scales and often rely on multiple data sources with variable accuracy. A consistent approach to Digital Elevation and Terrain Model (DEM/DTM) generation and pre- and post-flood analysis would reduce the uncertainty of these tasks, and contribute to more effective use of remote sensing data in future flood studies and for Emergency Risk Management (ERM) planning.

1.1 Components of the guidelines

The guidelines comprise an informative review of national and international standards of flood risk assessment and digital flood intelligence for ERM planning and technical documentation on ALS and InSAR data capture and processing techniques. Sample data for Wollongong Local Government Area (LGA) on the SE coast of Australia is presented as a case study in flood risk assessment at local (catchment) to regional

scales. This paper summarises some of the key topics presented in the guidelines.

2. DIGITAL FLOOD INTELLIGENCE

2.1 GIS based flood studies and ERM planning

ERM planning in the context of a flood disaster involves 5 keys steps (EMA, 2003): defining the scope of the flood event, identifying risk, analysing risk, evaluating risk and risk management. Digital flood intelligence is a key component of flood risk assessment, providing useful information on flood behaviour and the likely impact on communities and infrastructure. Remote sensing observations of terrain and land use, flood extents and simulated inundation maps are a useful complement to ground based flood intelligence. Geographic Information Systems (GIS) facilitate the integration of geospatial data on the urban-floodplain environment for the purpose of assessing flood risk and prioritising emergency response efforts (Brown and Johnson, 2005).

2.2 Remote sensing data sources for digital terrain mapping

Flood modelling requires consistent, high accuracy surface elevation data and the height and location of above ground features. Field survey provides high accuracy measurements of selected features but is often time consuming and limited by access. DEMs can be generated from stereo aerial photography at sub-metre accuracy; however ground control is difficult to obtain in extensive, bare areas and height estimation beneath the vegetation canopy is not possible. Light Detection and

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Ranging (LiDAR) data acquired by airborne scanners achieve vertical accuracies of 10 – 20 cm and provide useful information on the 3D structure of objects. Airborne data is expensive however, particularly if repeat coverage is necessary, and the extent of coverage is limited to local (catchment) areas. Airborne and satellite InSAR data can be acquired more frequently at lower cost over extensive areas. Moderate height accuracies of 1 – 4 m and 10 – 20 m are achieved by airborne and satellite SAR sensors respectively. Extracting a bare earth DTM from any data source is complicated due to the interference of vegetation.

3. DIGITAL ELEVATION MODELLING USING LIDAR DATA

3.1 Aerial and ground survey requirements

Airborne laser scanners can be flown at optimal times with respect to the seasons, prevailing weather conditions, stream flow and tide levels. Systematic ground survey at the time of image acquisition provides essential calibration and validation data. High accuracy height measurements can be undertaken over extensive areas by kinematic GPS survey, or at key locations with cross-sectional and point measurements. Sampling should also target any specific areas where errors in height retrieval are anticipated.

3.2 Pre-processing and point cloud visualisation

The raw point cloud requires initial sorting into ground, i.e., bare earth, and non-ground points, i.e., vegetation and buildings. The aerial survey company typically provides the sorted data to the client, but expert users may prefer access to the raw data to apply their own point classification algorithms. Depending on the application and accuracy requirements, several iterations of thinning and point classification may be applied to reduce high redundancy and sort the data. Mainstream software provide a variety of 2D and 3D visualisation tools, including image overlays, vertical profiles and point density surfaces.

3.3 Terrain modelling techniques

Depending on the user requirements, either a grid based or Triangular Irregular Network (TIN) approach to interpolation of the height surface will be selected. Grid based methods are capable of processing large point clouds but typically produce a smooth height surface (Figure 1a). Only one algorithm is applied to the dataset and surface irregularities are not taken into consideration (Kersting and Kersting, 2005). Unless sufficiently dense, grid based DTMs are less accurate in their representation of terrain than TINs.

The TIN method reconstructs the surface using a network of contiguous, non-overlapping triangles that satisfy the Delaunay triangulation criterion. Breaklines and other linear features can be inserted into the TIN to preserve the structural integrity of, for example, ridgelines and lake boundaries (Figure 1b). The process can be tedious however, without semi-automated approaches to the identification of breaklines. The improvement in DTM quality is significant for hydrological and hydraulic applications (Kraus, 2003). Advanced software is available that facilitates the generation of hybrid DTMs, which utilise the benefits of both methods of interpolation.

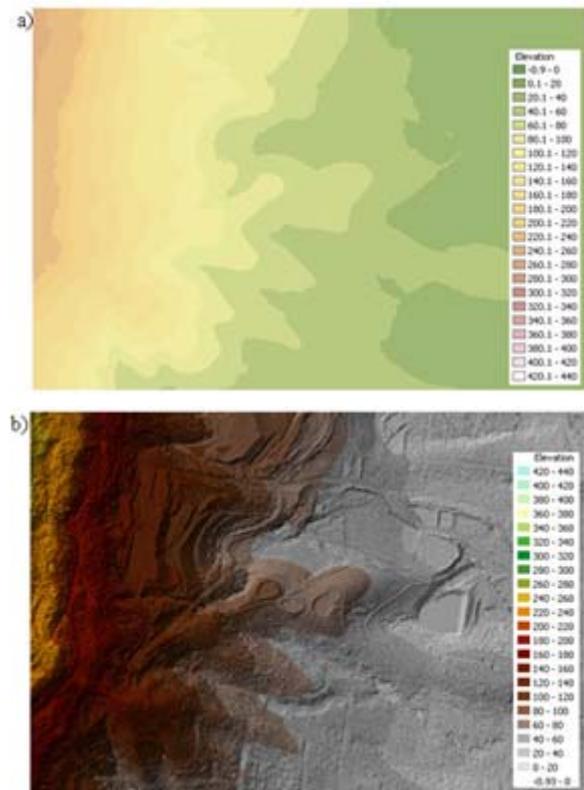


Figure 1. Comparison of approaches to interpolation of height surfaces using LiDAR data: a) Grid based Natural Neighbour (NN) interpolation; and b) Triangular Irregular Network (TIN).

3.4 A LiDAR processing toolkit

A stand-alone GUI was developed in the project to streamline the process of DTM/DEM generation and enable batch processing of large LiDAR datasets. The program facilitates the import of the point cloud in ASCII or LAS format, applies standard filter functions to generate raster grids of ground elevation or intensity, can threshold points by height, interpolate a ground or canopy elevation surface and export data in a variety of formats.

3.5 Accuracy assessment techniques

Both the positional and height accuracy of the interpolated surface can be evaluated by visual or statistical means. Consistency in height estimation over diverse terrain and using different methods of interpolation is assessed by comparing height profiles. Visual comparison of modelled features with high resolution optical data reveals the level of structural detail in the derived models. Point comparison between measured (field survey) and modelled (interpolated) heights and statistical measures such as root-mean-square error (RMSE) are used to evaluate overall DEM accuracy (Liu *et al.*, 2007) and height accuracy over different land cover types.

3.6 Surface characterisation and feature extraction

Knowledge of the terrain and land use characteristics will assist in identifying flood prone land and the potential impact zone of a flood event of certain magnitude. Both supervised and unsupervised classification techniques can be applied to LiDAR (height and intensity) data and optical (reflectance) data to classify the dominant land cover and surface types. Data

transform techniques may improve the visual discrimination of cover types. Spatial topographic data including slope and aspect, terrain contours and shaded relief models can be generated using the derived DTM as the baseline.

The extraction of above ground features such as buildings and vegetation is useful for hydraulic modelling. Typically these features increase surface roughness and impede the flow of water across the surface. Urban features can be identified and mapped using a variety of filtering, segmentation and classification routines applied to LiDAR and optical data. Individual trees and forests can be delineated using available segmentation and region-growing algorithms. By subtracting the DTM generated from last pulse LiDAR data and the DEM generated from first pulse LiDAR data, the height of the vegetation can be estimated (Figure 2). Tree crown maps are generated by displaying the corners (or nodes) of the TIN triangles sorted by height.

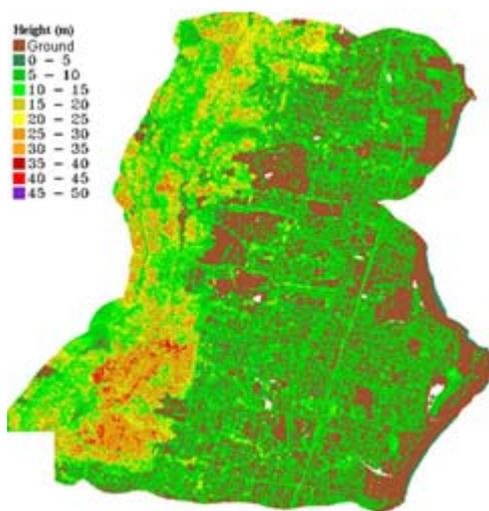


Figure 2. Canopy Height Model (CHM) showing the maximum height of the tree canopy in metres, generated by subtracting the DTM from the DEM.

3.7 Catchment hydrology analysis and hazard categorisation

Digital terrain data is fundamental to catchment hydrology analysis, providing useful spatial map data on catchment boundaries, stream networks and runoff characteristics. An ALS survey provides the optimal means of acquiring high accuracy digital topographic data for flood modelling. Flood events of varying magnitude can be simulated using a baseline DEM derived from LiDAR data. The more accurate the baseline, the better the calculation of gains or losses due to extraction, runoff or recharge. Hydraulic modelling also requires high accuracy terrain data for calculation of flood depths and velocities.

Local and catchment wide flood risk and hazard are assessed through the integration of digital terrain data and geospatial layers including critical infrastructure, drainage and population data. Additionally, on-ground floor survey data can be used to map the flood border and contours with elevations representing incremental flooding. Low, medium to high risk categories can be assigned to different parts of the floodplain based on the predicted impacts of flooding.

4. DIGITAL ELEVATION MODEL (DEM) GENERATION USING INSAR

4.1 SAR imaging geometry

Synthetic Aperture Radar (SAR) measures the amplitude and phase information of the backscattered signal from the earth's surface. SAR is an active system that illuminates the terrain with its own energy source and can operate both day and night and observe the surface through cloud and haze. SAR sensors exploit electromagnetic waves in the microwave region of the spectrum, with most spaceborne systems operating at wavelengths from X- (2.4 – 3.8 cm) to L-band (15 – 30 cm).

4.2 Methodology of radar interferometry

Interferometric SAR (InSAR) exploits the phase information recorded in two SAR images to derive the geodetic information of the terrain. At least two images are required for the process, and can be acquired at the same time using two separate antennas mounted on the aircraft or space shuttle (single-pass) or at different times by revisiting the site with a single antenna (repeat-pass; Rosen *et al.*, 2000). Satellite SARs are typically repeat-pass systems and airborne SARs are typically single-pass systems.

Airborne data is preferred for InSAR DEM generation as there is controlled spatial decorrelation and no topographic displacement or atmospheric disturbance. Decorrelation of the radar signal occurs as a result of the variable scattering properties within each imaging cell. Airborne SAR data is more costly to acquire however, particularly if sites are revisited, and aerial coverage is limited. Repeat-pass InSAR is strongly affected by temporal decorrelation; the amount of decorrelation being dependent on the temporal separation, local climate conditions, land cover, and height displacement between the two acquisitions.

The processing sequence for conventional repeat-pass interferometry involves data selection, co-registration, generation of the interferogram, flat earth fringes removal, phase filtering and unwrapping, geocoding and speckle reduction. At least two SAR images are needed to create the interferometric pair. High quality images with short temporal separation and long spatial baseline while maintaining low phase noise (decorrelation) are preferred. Rain-affected images should not be used. Precise co-registration of images is essential, and studies have demonstrated that an RMSE of <0.03 pixels can be achieved (Li and Goldstein, 1990).

Following co-registration, the phase difference, referred to as the interferogram, between the two SAR images is generated. The repeat-pass interferogram consists of information on the topography, any height displacement that occurred between the two image acquisitions, atmospheric delay and errors resulting in phase noise. Flat earth fringes resulting from the phase trend in the range direction in the interferogram are subtracted and the image filtered prior to phase unwrapping. Using established methods, the continuous phase of the topography is calculated, and then the height of the terrain can be computed. Geocoding of the result then converts the image from slant range projection (i.e., the imaging plane of radar) into a standard geographic coordinate system. After geocoding, the image can be further interpreted using other remote sensing data. Filtering and speckle reduction may be applied to minimise the noise associated with the radar images.

4.3 DEM generation using multi-frequency SAR data

Using in-house radar interferometric software developed by UNSW CRC-SI, repeat-pass InSAR DEMs were generated for a section of the south-east coast of Australia centred on Wollongong. InSAR DEMs were generated using multi-frequency SAR data, including that acquired by ALOS PALSAR (L-band), RADARSAT-1 (C-band) and TerraSAR-X (X-band). Tandem ERS-1/2 data have also been widely used for DEM generation due to the short temporal decorrelation and minimum ground surface displacement (Eldhuset *et al.*, 2003).

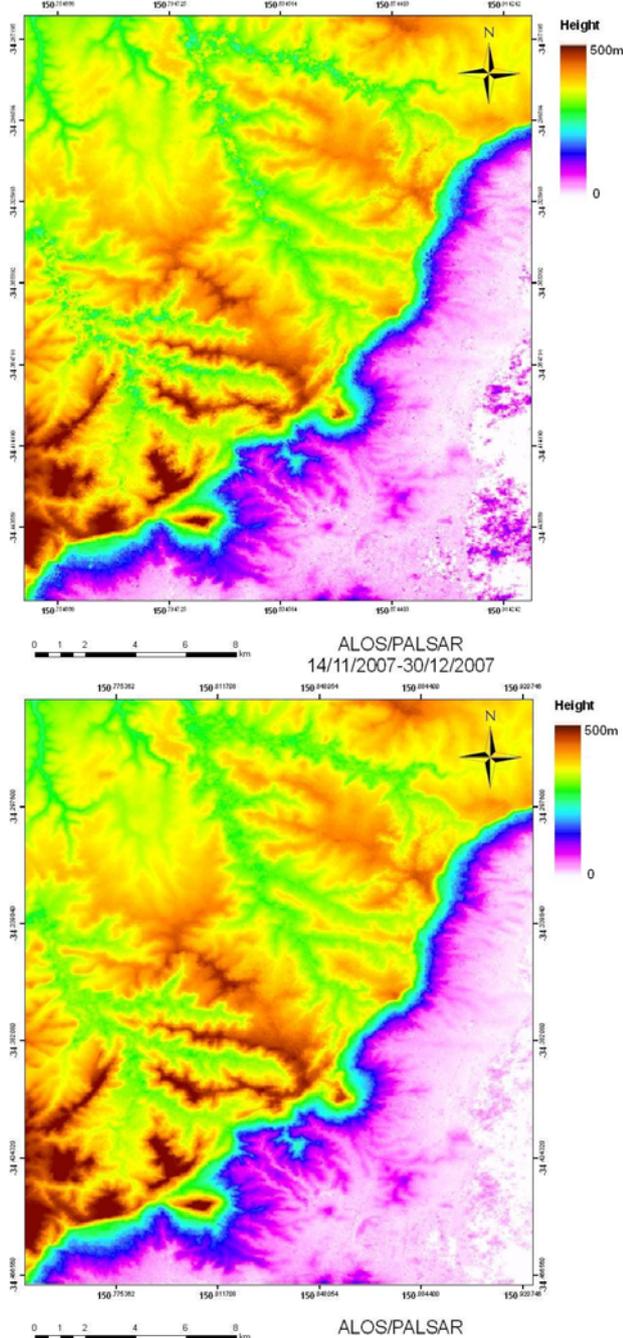


Figure 3. InSAR DEM generation using ALOS PALSAR data: (upper) single pair acquired on 14/11/2007 and 30/12/2007; and (lower) an average DEM of 5 interferometric pairs for Wollongong, NSW.

Figure 3 illustrates repeat-pass interferometry using ALOS PALSAR data. The upper image was generated using a single ALOS PALSAR interferometric pair, while the lower image was an average DEM of 5 ALOS PALSAR pairs with a common master image. The speckles in the DEM are reduced by averaging the DEMs.

4.4 Accuracy assessment techniques

The overall accuracy of the InSAR DEMs can be assessed through comparison with a higher accuracy DEM if available, or by extracting height profiles and calculating statistical measures (root-mean-square error). LiDAR derived heights and ground survey data are also used to evaluate the capacity for height estimation in different types of terrain.

If available, a photogrammetrically derived DEM can be used as the reference DEM for calculating height residuals between the two DEMs. Height measurements can be extracted every 100 m along a vertical and horizontal profile extended arbitrarily across the study site. The RMSE can be calculated and the height accuracy over urban and vegetated areas and undulating floodplain compared. The distribution of height differences in the InSAR and reference DEMs can be evaluated in a frequency histogram.

InSAR DEM heights can be compared against height profiles derived from LiDAR data or geotechnical survey and individual field survey points. The capacity for penetration of the vegetation canopy and height estimation over variable terrain and identification of surface features is assessed in the process. Longer wavelength SAR data tend to penetrate deeper through a surface or volume than shorter wavelength data. LiDAR may incur a return from any part of the canopy or underlying volume.

4.5 Land cover classification and feature extraction

The amount of SAR backscatter that is received by the antenna is dependent on imaging geometry, surface structure and dielectric (moisture) properties. Radar waves can penetrate dry materials with low conductivity (low dielectric constant) such as dry sand or sparse vegetation. Radar waves are reflected quite strongly from high dielectric surfaces such as flooded forests and soils with high soil moisture. The different frequencies and polarisations of SAR interact with different components of the surface and can be used to classify the dominant surfaces and cover types.

A segmentation and classification approach to cover type classification using SAR backscatter data is preferred. Established segmentation algorithms are applied to cluster pixels into groups based on radar spectral and textural response. The classifier is then trained by extracting samples from the clusters or segments and applying other distance or feature related rules. Spatial map data of the dominant land cover types, impervious surfaces and water storage or drainage features is generated in the process. Specific classes can be converted to vector polygons for inclusion in an urban database.

Contrast enhancement and data transform techniques including decorrelation stretching and Minimum Noise Fraction (MNF) transform of backscatter intensity data may also assist in the discrimination of cover types. Using the InSAR DEM as a base, spatial topographic data including slope and aspect, terrain contours and 3D perspective views can be generated.

Coastline detection algorithms are also being developed using a combination of satellite SAR and optical data. Research at the University of Siena (S. Martelli, Pers. Comm.) is investigating a multi-stage processing strategy comprising filtering and edge enhancement, local intensity calculation, thresholding and segmentation and opening/closing algorithms and masking to generate the coastline coverage. Initial results show good definition of the coastline, with occasional gaps in vegetated areas with low coherence adjacent to the coast.

4.6 Regional assessment of flood risk

The moderate height accuracies achieved in the InSAR DEM generation process limit their application in flood risk assessment. However, the integration of InSAR DEMs and derived topographic data and other geospatial layers is useful for broad-scale mapping and evaluation of potential flood risk over extensive areas. Airborne and satellite SAR data can be used to map floodplain topography and inundation area, and so provide an indirect measure of flood depth (Roberts *et al.*, 2000). For more detailed surface characterisation and improved accuracy of height estimation at the local (catchment) scale, an ALS survey is the optimal approach.

A coarse resolution DEM with a 20 – 30 m grid cell would suffice for regional flood modelling studies and can be derived using satellite SAR data and InSAR techniques. Multi-temporal SAR imagery can be used to determine flood extent, flood boundaries and seasonal flows within catchment areas.

5. CONCLUDING REMARKS

The key outcome from the project is a set of technical guidelines for the GIS component of flood studies. Operational procedures for data acquisition, ground survey, mapping scales, cost-benefit analysis, data processing and analysis, accuracy assessment and map production, are outlined in the guidelines. Wollongong LGA on the SE coast of Australia provided a case study on the applied use of digital terrain data for flood risk assessment. Terrain characterisation, feature extraction, catchment hydrology analysis and the integration of these data with other geospatial data for flood risk and hazard assessment in Wollongong was demonstrated. A GUI program that facilitates semi-automated grid based interpolation of height surfaces from LiDAR data was developed and included on CD-ROM with the guidelines. The guidelines are available to assist Local and State Government Agencies in undertaking future flood studies. A copy of the guidelines is available to all interested agencies through the CRC-SI.

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