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A Methodology for an Automated Three-Dimensional Heathland Assessment Workflow in Support of Bushfire Behaviour Modelling †

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Abstract: Bushfires are an intrinsic part of Australia, especially in the Blue Mountains (11,400 km^2), New South Wales (NSW). This region is dominated by fire-prone vegetation, such as heathland. Heathlands occupy a small portion of the Blue Mountains, less than 2%, but are highly combustible and can transition surface to crown fire. Three-dimensional vegetation models are essential for effective bushfire behaviour modelling and efficient bushfire combat. Therefore, this paper outlines the motivation for an automated three-dimensional heathland model and the workflow for implementing this model in support of bushfire behaviour modelling.

Keywords: voxel; point cloud; heathland; 3D modelling

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1. Introduction

Heathland is amongst the most fire-prone vegetation found in the Blue Mountains. Vegetation in this environment is structurally complex, vertically non-uniform, and discontinuous dominated by shrubs, ranging from 0.5 to 2 m in height, and sparsely scattered trees, rarely exceeding 10 m in height, or they may be present as mallee (multistemmed eucalyptus). The presence of flammable terpenes and waxes in the foliage of some shrubs and the mallee promotes the combustion of live fuel components. Moreover, the integration of heathland and woodland facilitates the transition of fire from a surface fire to a crown fire, making fire behaviour in this environment complicated [1].

To combat bushfires effectively, accurate prediction of fire behaviour is essential. In Australia, a number of models for predicting the rate of fire spread in various vegetation groups exits [2]. The model in [3] is the applied model for heathland fire spread modelling. The two primary input parameters for this model include weather parameters, such as wind, temperature, and relative humidity, and vegetation parameters, such as vegetation height or bulk density. However, current techniques for the classification of vegetation in NSW are unable to provide specific heath parameters, such as vegetation height and bulk density. The current techniques for the classification of heathland in NSW are two-dimensional. Two-dimensional techniques, such as image interpretation and satellite imagery with coarse resolution, are applied in some regions for the classification of heathland. While the classification of vegetation in these regions is leveraged off spectral reflectance, that depends on their geometric arrangement and their illumination conditions. The drawback of two-dimensional modelling is that, even with high spatial resolution, important vegetation attributes, such as height, continuity, canopy cover, and density, cannot be represented.

Compared to two-dimensional techniques, three-dimensional techniques have many merits. Three-dimensional techniques can provide both 3D geometric information, such as (x, y, z) spatial coordinates, and radiometric information, such as intensity and RGB. This information can be applied for the separation of objects at different heights above the Earth's surface [4]. Such techniques applied to vegetation modelling allow for the modelling of complex vegetation structures. Voxels, the 3D analogue to pixels, structure three-dimensional discrete points obtained from laser scanning. They combine qualitative geometric information with quantitative information, such as volume. Furthermore, high-resolution topographic maps, along with a highly accurate estimation of vegetation height, canopy structure, and vegetation density can be produced [5–9]. This is beneficial in the modelling of important heathland parameters, such as shrub continuity and height and tree and mallee height and volume.

Therefore, this research aims to design and implement a three-dimensional vegetation model that displays important heathland vegetation parameters and design, implement, and evaluate an automatic voxel-based method to derive such a model in support of bushfire behaviour modelling.

2. Methodology

The workflow is set up in four different phases.

2.1. Heathland Parameters

Through a literature review, important heathland parameters that are crucial for an automated three-dimensional heathland model, in support of bushfire behaviour modelling, as specified by [3], are identified. The important heathland parameters are heath shrub height (m) and their horizontal discontinuity (m), the height of sparsely scattered trees and mallee (m), together with their density (points/dm^3). These parameters are important as they can impact weather parameters.

2.2. Point Cloud Processing

Point clouds are generally produced by 3D scanners, such as Lidar scanners or by photogrammetry software. Lidar point clouds can be classified as airborne laser scanning (ALS), terrestrial laser scanning (TLS), and mobile laser scanning (MLS). The two different types of point clouds have advantages and disadvantages, and it is important to identify the most fitting method for heathland vegetation modelling. Photogrammetry point clouds are not suitable for predicting attributes related to the density of the canopy. This is because the image rays are unable to penetrate through the canopy foliage gaps even during optimal forward overlap conditions. Additionally, TLS requires multiple scan station setups, and this makes the processes of data acquisition time-consuming and uneconomical. Thus, ALS and MLS are preferred because they provide a synoptic view of the region. Point clouds derived from ALS or MLS can penetrate through canopy gaps to provide understory canopy details and record returns from the ground.

Point cloud density is an important attribute to consider when modelling heathland. High density, >100 points per square meter, ALS or MLS point clouds are required for the modelling of heathland. Low point density could affect the vegetation vertical complexity and impact the accuracy of heathland parameters. A high point density increases the overall ground return likelihood and the level of classification and estimation of vegetation structure.

2.3. Voxel-Based Vegetation Model

Point clouds are one of the most adequate sources of data for three-dimensional modelling. Their 3D coordinates, along with other attributes, make them appropriate for 3D reconstruction of the shape and size, along with other object properties. However, they have drawbacks: they can be very large (in the millions), noisy, sparse, and unorganised [10]. The sampling density of points acquired by lidar sensors is also typically uneven due to varying linear and angular rates of the scanner. Thus, attempting to manipulate such a large number of unstructured points is problematic. Meanwhile, segmentation of point clouds is based on points that fit the same plane, cylinder, or smooth surface. It is based on the recognition of a simple shape in a point cloud.

Voxels (VOlumetric piXELs) are the 3D analogue to pixels. They provide a unified geometric structure within which point clouds can be organised. They offer the means for straightforward and efficient processing algorithms [11]. Due to their structured nature, they can be applied in identifying the spatial connectivity of point clouds. An important voxel parameter is the voxel size, which affects the voxel density. A large voxel size can result in the loss of significant geographic data, while a small voxel resolution can enclose a small number of points in a single voxel. The voxel size and density are important parameters for heathland modelling. They are used to calculate the density of trees and mallee. Meanwhile, the voxel connectivity is utilised to identify heath shrub connectivity and discontinuity. Additionally, the voxel height is utilised to calculate the heath shrub, trees, and mallee height.

Following the voxelization, segmentation and classification algorithms are required. An object-based segmentation using voxel neighbourhood connectivity is required. Seeded region growing, based on neighbourhood connectivity, is recommended for the segmentation of the above-ground vegetation (heath shrubs, trees, and mallee). The results are further semantically segmented for the classification of the voxels based on different canopy height levels, such as (a) heath shrubs, (b) sparse trees and mallee, and (c) tall trees.

2.4. Validation

Validation of the derived model parameters is achieved through field inspection and aerial photography. Field inspection allows us to visually validate the results from the model to the real world. Additionally, aerial photography of the region can be utilised for vegetation delineation. This can be utilised for the validation of the classification results.

3. Conclusions

This paper outlined the importance of developing a specific workflow for heathland modelling. The current workflow includes several steps, such as identification of heathland parameters and selection of an appropriate scanning technology, specific to deriving needed parameters and validation. The parameters identified so far that are crucial for heathland fire behaviour modelling include heath shrub height and continuity and tree and mallee height and density. High-density ALS or MLS lidar point clouds are recommended for data acquisition, while a voxelized approach is a preferred method for the modelling of the point clouds. Through voxel-based segmentation and classification, the vegetation can be classified into canopy height levels; (a) heath shrubs, (b) sparse trees and mallee, and (c) tall trees. Finally, to validate the results aerial photography or a series of field inspections are required.

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References

1. Sullivan, A.L.; McCaw, W.L.; Cruz, M.G.; Matthews, S.; Ellis, P.F. *Flammable Australia: Fire Regimes, Biodiversity Ecosystems in a Changing World*; CSIRO: Canberra, Australia, 2012; pp. 51–77.
2. Cruz, M.G.; Gould, J.S.; Alexander, M.E.; Sullivan, A.L.; McCaw, W.L.; Matthews, S. *A Guide to Rate of Fire Spread Models for Australian Vegetation*; Australasian Fire and Emergency Service Authorities Council Limited and Commonwealth Scientific and Industrial Research Organisation: East Melbourne, Australia, 2015.
3. Anderson, W.R.; Cruz, M.G.; Fernandes, P.M.; McCaw, L.; Vega, J.A.; Bradstock, R.A.; Fogarty, L.; Gould, J.; McCarthy, G.; Marsden-Smedley, J.B. A generic, empirical-based model for predicting rate of fire spread in shrublands. *Int. J. Wildland Fire* **2015**, *24*, 443–460. [CrossRef]
4. Wagner, W.; Hollaus, M.; Briese, C.; Ducic, V. 3D Vegetation Mapping Using Small-Footprint Full-Waveform Airborne Laser Scanners. *Int. J. Remote Sens.* **2008**, *29*, 1433–1452. [CrossRef]
5. Barton, J.; Gorte, B.; Eusuf, M.S.R.S.; Zlatanova, S. A Voxel-Based Method to Estimate Near-Surface and Elevated Fuel From Dense Lidar Point Cloud for Hazard Reduction Burning. In Proceedings of the ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Gi4DM, Sydney, Australia, 30 November–4 December 2020; pp. 3–10.
6. Eusuf, M.S.R.S.; Barton, J.; Gorte, B.; Zlatanova, S. Volume estimation of fuel load for hazard reduction burning: First result to a voxel approach. *ISPRS* **2020**, *43*, 1199–1206. [CrossRef]
7. Kim, E.; Lee, W.-K.; Yoon, M.; Lee, J.-Y.; Son, Y.; Abu Salim, K. Estimation of voxel-based above-ground biomass using airborne LiDAR Data in an intact tropical rain forest, Brunei. *Forests* **2016**, *7*, 259. [CrossRef]
8. Vetter, M.; Höfle, B.; Hollaus, M.; Gschöpf, C.; Mandlburger, G.; Pfeifer, N.; Wagner, W. Vertical Vegetation Structure Analysis and Hydraulic Roughness Determination Using Dense ALS Point Cloud Data—A Voxel Based Approach. In Proceedings of the International Archives of Photogrammetry, Remote Sensing Spatial Information Sciences, Calgary 2011 Workshop, Calgary, AB, Canada, 29–31 August 2011.
9. Mücke, W. Full-Waveform Airborne Laser Scanning for Landscape Ecological Mapping: Methods and Applications. Ph.D. Thesis, Technische Universität Wien, Vienna, Austria, 2014.
10. Remondino, F. From point cloud to surface: The modeling and visualization problem. In Proceedings of the International Workshop on Visualization and Animation of Reality-based 3D Models, Tarasp-Vulpera, Switzerland, 24–28 February 2003.
11. Griffioen, S. *A Voxel-Based Methodology to Detect (Clustered) Outliers in Aerial Lidar Point Clouds*; Delft University of Technology: Delft, The Netherlands, 2018.