Fuels3D: barking up the wrong tree and beyond

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Emerging remote sensing technologies for data collection and methods for repeatable and quantitative measurements of fuel hazard.

Improvement of the understanding of how fuel characteristics correlate with fire behaviour and severity is critical to the ongoing handling of risk and recovery in fire-prone environments. Current standards and protocols for describing fuel hazard (for example, 'Overall Fuel Hazard Assessment Guide', Victorian Department of Sustainability and Environment) and post-burn severity (for example, 'Fire Severity Assessment Guide', Victorian Department of Sustainability and Environment) were written for collection of information in the field. The data collected are largely subjective descriptions of the landscape. The ability of information from these assessment techniques to be adapted to modern risk assessment tools such as fire behavior models, or for the calibration and validation of datasets, is limited. Quantitative data-rich methods of measuring and assessing fuel load and structure are the missing link between the knowledge of land management personnel in the field, and the model drivers and decision makers at organizational level.

Handheld devices with high quality sensors, in the form of off-the-shelf cameras, are increasingly ubiquitous, as is the availability of 3D point cloud data collected from active sensing instruments on terrestrial and aerial platforms. Rapid and comprehensive capture of information by these devices, coupled with the use of computer vision techniques, allows for the 3D description of the surrounding environment to be exploited to provide robust measurement of metrics that can be built into existing fuel hazard assessment frameworks. Providing key metrics as data products rather than a single product enables flexibility across jurisdictions and ecosystem types, and capacity to adapt as end-user requirements change.

The Fuels3D project has created a suite of tools and methods for image capture in the field during fuel hazard assessments. 3D point clouds are generated using computer vision and photogrammetry techniques. From these 3D point clouds, scale is added, and decision rules are programmed to calculate quantifiable surface / near-surface metrics that replicate those used in current fuel hazard visual assessment guides. Case studies are highlighted here.

Background

It is common practice for fuel hazard assessments to be conducted based on in-situ, visual field assessment. In Victoria, methods for fuel hazard assessment use the Overall Fuel Hazard Assessment Guide (OFHAG) in which visual estimates of vegetation or fuel variables within defined fuel layers are made, and which when combined provide a fuel hazard rating. These vegetation-based fuel variables characterise the structure (e.g. height) and cover (e.g. horizontal percentage cover) of fuels for each of the four fuel layers, surface litter, near-surface, elevated and canopy.

Fuels3D is a method to support in-field data collection for fuel hazard estimation. It has been designed to support and improve existing field observations and provide an easy, quick and repeatable method by which observations can be collected, providing improved reliability and accuracy of fuel hazard assessments. Fuels3D is a process and technology for applying photogrammetry and computer vision techniques to produce 3D point clouds of the environment from which fuel hazard metrics can be derived. Fuels3D supplements existing visual assessments with repeatable and quantitative estimates of surface and near surface fuel. Trials have been undertaken with end-user agencies across Victoria, South Australia and the Australian Capital Territory, and are planned in Queensland.

Fuels3D+ is an extension of the concept supporting the use of fuel hazard data and information from a wider range of sources than Fuels3D. Fuels3D+ is a process and technology for taking 3D point clouds, derived from Fuels3D or from a range of other sources such as aerial LIDAR, to generate spatial data layers of fuel layer height and cover and tables of fuel metric summaries. and provides quantitative data as input into fuel accumulation over time, burn severity, fire behaviour and spread models. Figure 1 below illustrates the Fuels3D+ concept as well as the original Fuels3D concept as two separate modules, delineated by the stages up to and including point cloud creation, and subsequent postprocessing to generate fuel related information.

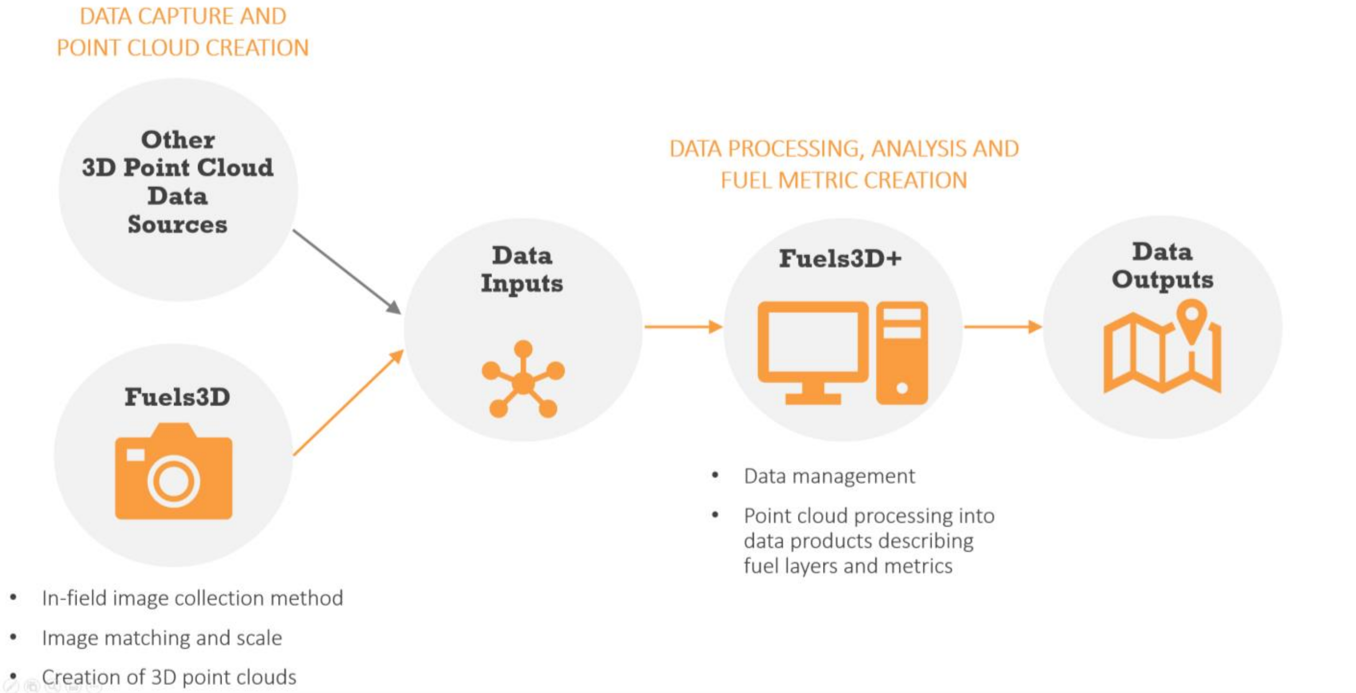

Figure 1: Overview of the key concepts and tasks in the Fuels3D and Fuels3D+ solution workflow.

However, it is important for users to understand that not all point clouds are created equal and different sources of point clouds (terrestrial systems versus aerial systems, image based versus laser-based sensors), landscapes types (closed tall forests versus open woodlands) and environmental conditions (illumination, wind and rain) can all affect the resultant outputs. Providing a solution that enables these different sources to be captured and processed is a step forward to improving current and future fuel hazard assessments.

Case study 1: repeatability and accuracy

Visual estimation is the standard practice for land management agencies across Australia for collecting fuel hazard assessments. Visual assessment provides a low-cost and efficient method to rapidly describe and estimate fuels and individual fuel layers. However, it is well known and documented in the literature, that visual assessments are subjective and can vary greatly between assessors. In response to understanding the performance of Fuels3D against visual assessments using the 'Overall Fuel Hazard Assessment Guide', an end-user field day was held with end-users from the South Australian Department of Environment and Water, ACT Parks and Conservation Service, Victorian Department of Land, Water and Planning (DELWP), the Victorian Country Fire Authority, Melbourne Water and Parks Victoria. The field day aimed to introduce end-users to the Fuels3D collection protocol and to assess its ease of use and repeatability between data collectors in comparison to traditional visual assessment techniques. Participants were asked to undertake a visual assessment and collect Fuels3D data across three plots in a lowland forest in a water catchment east of Melbourne.

The results, published in *Sensors* in 2017 (Spits et al. 2017), indicated that surface and near-surface metrics related to fuel hazard can be measured with greater repeatability between different observers. Even more critical was the propagation of this variation when the metrics were combined to calculate hazard ratings. The range of surface cover and height variation using the Fuels3D approach is in comparison to the visual assessment, significantly lower. This translates into fuel hazard classes spanning over two hazard class across all plots in the study in comparison to the visual assessment approach which resulted in an overall fuel hazard rating spanning across almost four classes.

Subsequently, studies were conducted to investigate the validity, accuracy and completeness of 3D point clouds. Quantitative measurements of above-ground vegetation biomass are vital to a range of ecological and natural resource management applications including fuel hazard mapping. In this study (Wallace et al. 2017), surface biomass of small area plots were imaged and scanned, and then destructively sampled. Volume is calculated, using the 3D point clouds and regressed against dry weight to provide an estimate of biomass. The results of this study demonstrate that image-based point cloud techniques are potentially viable for the measurement of surface biomass. However, while this study investigated the utility of point clouds to resolve end metrics such as biomass (and in other studies diameter at breast height, tree height etc.), there is still a fundamental requirement that assesses the accuracy of the point cloud itself. To date, there has been no standard method for validating the accuracy of a point cloud. A method for validating the structural completeness of understorey vegetation models captured with 3D remote sensing has been designed and implemented across a range of landscapes across Australia, South America and North America. This work is currently in review and expected to be published shortly.

Case study 2: inter-comparison of point cloud capture technologies

Examples of studies have demonstrated the potential of satellite and airborne remote sensing for assessing and measuring changes in vegetation or fuel structure, with recent examples of terrestrial remote sensing demonstrating the potential for precise measurements of change in understorey forest environments. Much of these technologies, such as those utilising Light Detection and Ranging (LiDAR) systems or Terrestrial Laser Scanners (TLS), offer a precise insight into the physical structure and arrangement of environments. However, at this point in time, these are cost-prohibitive and require expertise, in both data collection and data processing stages. As image capture devices or platforms, such as off-the-shelf point and shoot cameras, and unmanned aerial vehicles become increasingly powerful, cheap, portable and ubiquitous, there exists an opportunity for simple and rapid image acquisition. When coupled with computer vision and photogrammetric principles overlapping images can be reconstructed into scaled 3D point clouds from which geometric properties of vegetation or fuel structure can be calculated. The case study presented here investigates the performance and utility of non-destructive, remote imaging and laser scanning technologies, specifically Terrestrial Laser Scanning (TLS), Terrestrial Structure from Motion (TSfM) and Unmanned Aerial Systems Structure from Motion (UAS SfM), for quantifying vegetation and fuel characteristics.

The study area was located in the Mallee region of north-west Victoria. Three key Ecological Vegetation Divisions (EVDs) in the region were identified as Hummock Grass Mallee, Lowan Mallee and Heathland Sands. For each EVD three different age classes were identified as at disturbance, intermediate and mature. Suitable locations for plots within each of the EVDs and age class combinations were identified in consultation with DELWP, and finalised during field visits in July 2017 for Hummock Grass and Lowan Mallee, and in September 2017 for Heathland Sands. For each EVD plus age class combination a 50m x 30m plot was located, in which data was collected using TLS and UAV SfM to allow for wall-to-wall data to be created. Within the plot, up to six smaller 2m x 2m subplots were located to follow approximate transects across the larger plot. Each sub-plot was captured using TSfM. Ground control targets were distributed throughout the larger plot in locations that provided clear-sky views and maximised line of sight to TLS set up locations. The relative positioning of ground control targets varied between plots. Vertical targets consisting of 1m tall white PVC pipes were used to define the corners of each 2m x 2m plot. The survey was designed, and positioning established, in such a way as to support revisits to sites (e.g. post burn), and to allow for spatially and (near) temporally coincident inter-comparison of technologies. The Fuels3D+ workflow was used to extract fuel descriptors from the 3D point clouds produced from each of the technologies listed.

The biggest issue for the data capture using these technologies was the presence of wind, particularly for UASSfM. This presented significant logistical challenges for operation and impacted on the quality of data collected. While the UAV was able to be flown in winds up to 35km/h, all aerial and terrestrial technologies and resultant datasets were compromised in quality if captured during windy or gusty conditions; recognising certain vegetation types and elements being more susceptible to movement caused by wind than others. In terms of operator expertise, time and initial equipment costs, the TLS data capture was by far the most costly of the three approaches. Similar expertise overheads exist for UASSfM given the specific CASA and land management permit requirements necessary for flight approvals and operations, however, data capture per unit area can occur much more rapidly. In comparison, TSFM requires minimal expertise but performs as a sampling tool rather than as a wide-area data capture technology. Processing of the data for all three technologies required both CPU intensive automatic processing along with manual steps for digitisation of the ground control and vertical targets, and spatial co-registration of datasets collected by each of the three technologies.

Some key observations were made in respect to the overall quality of the data produced by each of the three technology approaches relative to the different fuel characteristics. TLS performs better at capturing elevated and canopy layers but becomes compromised in capturing the lower layers where obscuration and occlusion increases. In contrast, TSFM was found to be best suited to capturing information of the surface and near-surface layers, and to a degree the elevated layer. Being human operated it is limited in its ability to capture elements higher than the elevated fuel layer. The performance of the UASSfM using the current setup offered the least information value of all technologies assessed due to its decreased ability to offer a below canopy perspective and its sensitivity to wind. However, changing the camera and camera setup for UASSfM could offer substantial improvements and should be tested further.

Case study 3: pre- and post-burn change

Fuel reduction burns are commonly used in fire prone environments in Australia as a mechanism to reduce the risk of wildfire and increase ecosystem resilience. As such producing quantified assessments of fire-induced change is important to understanding the success of the intervention. Remote sensing has also been employed for assessing fuel hazard and fire severity and change (see Wallace et al. 2016). Satellite, airborne and UAV remote sensing, for example, have shown potential for assessing the effects of large wildfires and fuel hazard in areas of open canopy. Fuel reduction burns, however, often take place under dense canopy and result in little or no change to the canopy cover. Here, terrestrial techniques are needed to quantify the efficacy of these burns. This study presents a case study on the use of image-based point clouds, captured terrestrially for describing the change in fuel structure induced by a low intensity fuel reduction burn. The specific objectives of this study were to evaluate whether fuel structure maps produced from Fuels3D point clouds are sensitive to the changes that occur during a low intensity fuel reduction burn, and how these changes may be quantified.

The study was conducted in Cardinia Reservoir, Emerald, Victoria. An autumn prescribed burn was conducted by Melbourne Water on 28 April 2016. Pre-burn field data and imagery was collected on 11 March 2016 and post-burn data on 5 May 2016 for the same location across time points. The plots, 10m diameter in size, were selected based on being close to known ignition points in order to increase the likelihood of the vegetation undergoing fire induced change. From these image sets, point clouds were produced, from which metrics representing fuel volume, horizontal connectivity, and vertical stratification were derived. Fire-induced change in these metrics are assessed from which the efficacy of the burn in relation to fuel hazard are able to be quantified and mapped in terms of changes to fuel layer height, percent cover and amount burnt.

Future and conclusions

Remote sensing technology, when combined with computer visions methods allows for the 3D description of the surrounding environment. This project exploits this technology to provide robust measurement of vegetation structural metrics that can be built into existing fuel hazard assessment frameworks. Key metrics are provided as data products and can be combined into single assessments of fuel hazard. Use of 3D point clouds enables flexibility across jurisdictions and ecosystem types, and capacity for ongoing adaption to changes in the way fuel layers are defined and/or new fuel metrics arise. The project has completed numerous case studies for proof-of-concept and is continually extending the solution capacity into new elements of fuel hazard such as in-field mapping of bark hazard. Fuels3D uses point and shoot cameras to sample the environment and build in scale to create a 3D point cloud. Fuels3D+ is the part of the solution that takes a point cloud and derives measures of fuel hazard that form part of the case studies into point cloud capture technology and their comparisons indicate no single technology provides the whole solution for every landscape. As such, Fuels3D+ provides the processing solution for taking 3D point clouds (and this is being examined to extend to ingest 3D point clouds sourced from other commonly available and different technologies such as TLS and ALS) and transforming the data into measures of fuel hazard.

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