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EMERGING TECHNOLOGIES FOR ESTIMATING FUEL HAZARD

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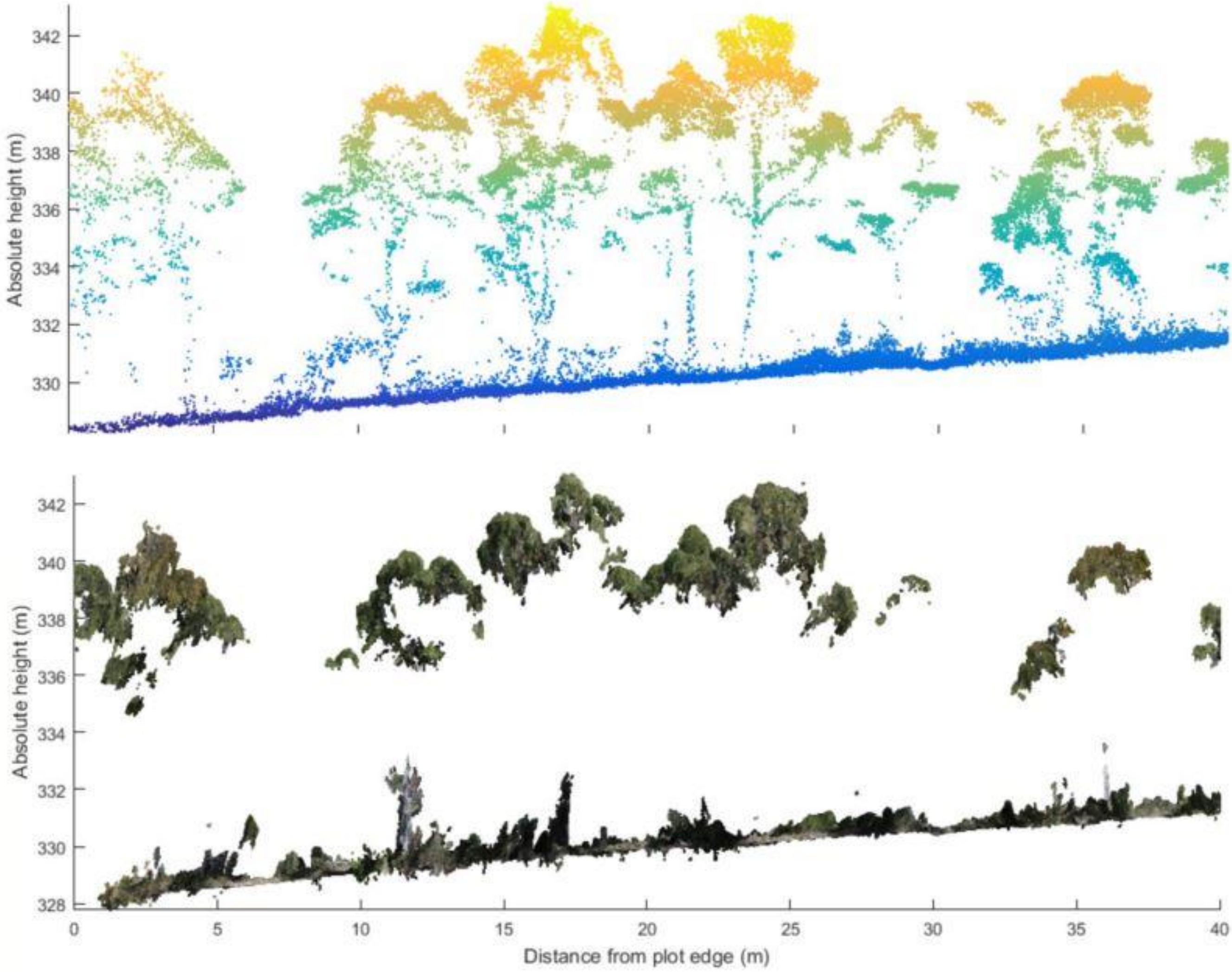

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BACKGROUND AND SCOPE

The increasing risk of wildfire resulting from climate change has demanded an increase in information to support mitigation, response and recovery activities by fire management agencies. Subsequently, there is a need for an ongoing review of currently available and on-the-horizon information and technology.

Fire has important national significance as Australia faces ongoing environmental issues including loss of biodiversity, increasing urbanisation into bushland environments and increasing risks of wildfire. Fire regimes are an integral part of the ecosystem processes of Australian forests and a prominent disturbance factor. It affects successional rates of ecosystems, species diversity, can increase habitat fragmentation and alter landscape functioning. At the same time, fire is an important tool in management for ecosystem health and is frequently used for fuel hazard reduction.

Remote sensing data can assist fire management at three stages relative to fire occurrence including (i) Before the fire (fuel hazard measures, time since last burn) to assist fire prevention or minimisation activities, (ii) During the fire (near real-time detection and location of active fire areas and (iii) After the fire (mapping and assessment of burned areas).

This report focuses on the use of sensing technology for generating a 3D representation of a feature or landscape. It examines the potential of emerging technology for measuring the structure and amount of vegetation within the landscape pre and post fire. Initial assessment of the sensing technology for mapping these environments is made based on the stage of maturity, sampling area, estimate accuracy and the expertise required to operate.

INTRODUCTION

The routine monitoring of fuel hazard across Australia's fire prone landscapes primarily involve the use of visual assessment through scoring systems. Guidelines and hazard scoring systems, such as provided in Gould et al. [1], have been developed to provide an easily interpretable and systematic method for assessing potential fire behavior. Nevertheless, it is well known that these methods are subjective with the resulting estimate of fuel hazard vary due to the experience of the observer and the rigor applied in making an assessment at the landscape level (i.e. number of plots). As such improved management of fire prone landscapes requires the development of objective, accurate and repeatable methods for measuring forest attributes. Developing such a method requires consideration of affordability, ease of deployment and the ability of the method to meet (or contribute to) current and future reporting requirements.

Terrestrial remote sensing techniques present a promising alternative to subjective field estimates. Capturing the 3D structure of an area using remote sensing technologies has the potential to provide quantifiable estimates of burn severity. The most advanced technology for this purpose is Terrestrial Laser Scanning (TLS). The data captured using TLS technology has been shown to contain information that can be extracted and used to characterise the 3D structure of forests and estimate biomass with a high level of detail [2], [3]. Furthermore, multi-temporal characterisation of forest structure using TLS has allowed change in forest structure due to growth [4], defoliation [5], biomass [6] and burn to be detected and quantified [7].

Accompanying TLS is a suite of emerging terrestrial remote sensing technologies that show potential in facilitating the characterisation of the 3D structure of forested environments. These technologies, however, remain largely untested for this purpose. This review seeks to document advances in these technologies. Section 1 provides an overview of the capabilities of TLS for measuring forest fuel hazard. Section 2 outlines the operating principles of the emerging technology and the potential benefits and limitations of these sensors for use in mapping burn severity. Section 3 summarises the previous sections and provides recommendations as to how best to make use of this technology for assessing fire prone landscapes.

LASER SCANNING AND THE TERRESTRIAL LASER SCANNER

Terrestrial laser scanning (TLS) has become a well-established method for the non-invasive assessment of the 3D forest structure. TLS refers to the collection of laser scanning data from a ground based static system often mounted on a tripod. Laser scanning systems operate by actively emitting light (commonly at infrared wavelengths) towards a target. The sensor detects the reflected component of that light and uses time or phase differences (in the detected reflection) to determine the distance to that target. In order to capture a 3D representation of the surrounding environment, TLS use a rotating mirror to vary the direction the light is emitted (effectively scanning the environment). Using this method TLS can capture the distribution of all objects within a scene that are within the maximum operating range of the scanner (varying between 10 - 1500 m) and are not occluded from view by objects closer to the scanner. The information describing these elements contained within the raw data produced by the point cloud varies depending on the sensor settings and the type of laser scanning technology. Raw data captured using phase-shift, time-of-flight, full-waveform and dual wavelength systems have all been used to describe various aspects of forested environments [8].

The operating principles of TLS enable the collection of highly detailed and accurate 3D point clouds, from which information describing the surrounding environment can be extracted (Figure 1). Laser scanning (including terrestrial, airborne and mobile (discussed below)) has the ability to penetrate through loosely arranged elements (i.e. of vegetation) and provide information on partly occluded objects. This penetration occurs due to the use of an active light source and the ability to acquire multiple reflections per emitted pulse. Collecting raw data representing the vegetation structure, as well as the underlying terrain, allows quantifiable estimates of vegetation height and biomass to be extracted from a single scan [2].

FIGURE 1 – AN EXAMPLE OF A TLS POINT CLOUD (SOURCE: HTTP://HYPERFOREST.VGT.VITO.BE/DRUPAL-7.0/CONTENT/VEGETATIONSTRUCTURE).

Collecting raw data representing the vegetation structure, as well as the underlying terrain, allows quantifiable estimates of vegetation height and biomass to be extracted from a single scan [2]To achieve this requires expert manipulation. This manipulation allows the 3D organisation or structure of forest elements forest biomass to model at varying levels of detail to be described [2], [9] and small variations within the environment to be detected [5]. As such, TLS systems offer an attractive data product for assessing burn severity with demonstrated capacity to accurately quantify fire-induced change in vegetation structure [7].

EMERGING SENSOR TECHNOLOGY

The data produced by TLS have been shown capable of providing accurate representations of static forest fuel loads as well as mapping fire induced change. Nevertheless, TLS hardware remains relatively expensive, and the collection of data and manipulation of the dense point clouds to extract biomass information requires significant expertise. TLS systems are also limited in the amount of area which can be captured due to the static nature. Although scanning times have reduced significantly in modern systems, rigorously capturing a small area (0.05 ha) in densely vegetated environments requires multiple setups and a carefully designed co-registration strategy.

This section provides an overview of emerging sensor technologies which have the potential to overcome some of these short comings, but remain relatively untested for measuring fuel hazard information.

MOBILE AND PERSONAL LASER SCANNING DEVICES

TLS is often refers to the collection of data usually with a static laser scanner placed in single or multiple locations. Mobile Laser Scanning (MLS) follow the same basic principles as TLS, however, make use of a dynamic platform to capture a wider area more rapidly. MLS data has been collected from personal (hand-held/backpack) devices [10], [11], light weight ground vehicles such as quad bikes [12] and Unmanned Aerial Vehicles [13]. As MLS systems are dynamic, measurement requires knowledge of the relative position and orientation of the scanner to locate objects within the scene. In comparison to TLS, this introduces further sources of uncertainty into the laser scanning system and decreases the registration accuracy of the produced point clouds.

FIGURE 2 – THE ZEB1 LASER SCANNER, THE BACK PACK SCANNER USED IN LIANG ET AL. (2014) AND THE UAV LASER SCANNER DESCRIBED IN WALLACE ET AL. (2012)

The potential of MLS systems for forest mapping is only just beginning to be explored within the literature [10], [11], [14]. As MLS systems have not been commercially available in a form factor suitable for deployment in forested landscapes, this research often makes use of ad-hoc systems developed using off-the-shelf components [10], [14]. These systems often rely on GPS position and inertial navigation to provide the instruments position and orientation and as such require open sky view.

The zeb1, a commercially available handheld laser scanner developed by the CSIRO, with the aim of developing a method of producing 3D maps of an environment without the need for GPS [11]. This operating principle allows the zeb1 to produce the accurate point clouds in GPS denied environments such as indoors or under dense canopy. Yebra et al. [15] briefly highlighted the applicability of the zeb1 system to mapping forest fuels in comparison to Airborne Laser Scanning. Initial testing of the Zeb1 scanner has shown positive results for mapping forest structure. Riding et al. [11], for example, provides a comparison of the Zeb1 scanner to a typical TLS setup, showing that the hand-held scanner provides a similar data product to the TLS scanner with drastically improved coverage (50 m^2/min in comparison to 0.43 m^2/min). It was also been highlighted, however, that the dynamic platform produces lower resolution data in comparison to TLS surveys which may preclude extraction of key information in some instances [11].

The primary focus of the majority of MLS forest measurement trials has been on the extraction of metrics such as stem diameter and solid wood volume for production purposes [10], [11]. As such further investigation is required to determine appropriate sampling strategies and system configurations for mapping fuel hazard and burn severity utilising MLS data.

3D PHOTOGRAMMETRY

Utilising overlapping optical imagery to derive 3D structure has re-emerged as a viable technique to map for forest mapping due to advances in technology (such as improved and digital stereo cameras), new photogrammetric algorithms (such as structure from motion (SfM)) that employ multi-image matching and that generate dense 3D point clouds, and by the increasing availability of powerful desktop computing. The potential of SfM in measuring vegetated structure has been demonstrated in various trial studies [16]–[18]. Dandois & Ellis [17] highlight low economic cost and the availability of spectral information within the point clouds as drivers for the use of this technology in forest management scenarios. Lucieer et al. [18] for instance, demonstrated how UAV based SfM techniques can be used to capture information describing fine scale vegetation (an example of an SfM point cloud is shown in Figure 3).

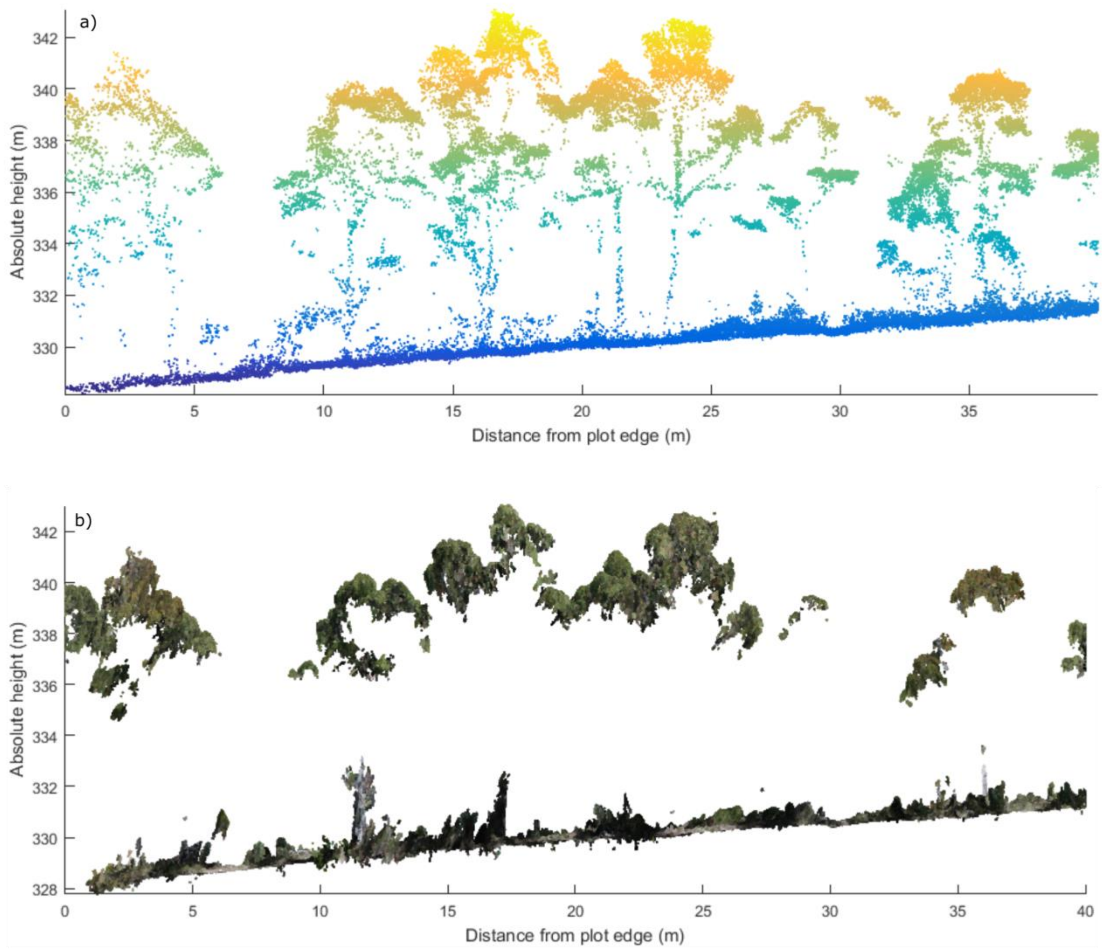

FIGURE 3 - POINT CLOUDS OF A FOREST LOCATED CAPTURED USING A) A LIDAR SENSOR AND B) SFM ALGORITHMS AND IMAGERY FROM A DIGITAL CAMERA FROM AN UAV PLATFORM.

Liang et al. [19] demonstrated that handheld photography can also be effective in mapping forest structure. Showing that in comparison to TLS, similar accuracy can be achieved in deriving metrics related to production forestry. Liang et al. [19] also suggests advantages of handheld SfM include the low cost of the equipment, the simple field measurements and the automated data processing software reducing expert interaction. Nevertheless, the use of 3D photogrammetry for quantifying burn severity is at a similar stage of technological development to MLS. Trial projects have demonstrated its applicability to mapping vegetation structure, however, the precession and sampling requirements for mapping change is yet to be investigated. Furthermore, it is expected that the use of 3D photogrammetry in a terrestrial scenario will require a trade-off between accuracy and data capture and processing time.

DEPTH CAMERAS

Depth cameras are cameras which utilise the principles of laser ranging or triangulation in order to provide a depth value at each pixel and allow the 3D structure of the scene to be estimated. Two main depth imaging technologies, Time-of-Flight (ToF) and Structured Light cameras have been identified as potentially suitable for monitoring burn severity. Each of these technologies work on slightly varying principles, however, produce similar raw data products allowing them to be grouped into a single emerging technology.

FIGURE 4 – EXAMPLES OF A) TOF (PMD CAMCUBE), B) STRUCTURED LIGHT (MICROSOFT KINECT) AND C) STEREO (POINTGREY BUMBLEBEE X3) CAMERA TECHNOLOGY.

ToF cameras are an active sensor and operate based on the same basic principles as a laser scanner. However, instead of scanning a scene using a rotating mirror, ToF cameras contain a matrix of detectors (up to 200 by 200) allowing the 3D properties of a scene to be captured based on a single burst of infrared light. Similarly, Structured Light (SL) cameras also emit infrared light, however, instead of using a detector the light is emitted in a structured pattern. The projection of this pattern on the target object is captured by an Infrared CMOS sensor and variations in the pattern are used to determine the range to an object based on the principles of triangulation [20].

TABLE 1 – EXAMPLES OF TOF, SL AND STEREO CAMERAS AND THERE SPECIFICATIONS.

Sensor	**Type**	**Approx. Price**	**Resolution**	**Minimum Range (m)**	**Maximum Range (m)**	**Field of View**
Kinect 360/windows	SL	$100 - 200	1280x1024	0.8	4	57 (h) 43 (v)
Asus Xtion	SL	$200 - 500	1280x1024	0.85	9.2	58 (h) 45 (v)
Structure Sensor	SL	$200 - 500	640x480	0.4	3.5	58 (h) 45 (v)
PMD Camboard nano	ToF	$1000	200x200	~0.5	7	40(h) 40(v)
Pmd CamCube	ToF	$12000	200x200	~0.5	7	40(h) 40(v)
Swiss Ranger SR4000	ToF	$4295	176x144	0.8	5	43(h) 34(v)
Point Grey Bumblebee® XB3	Multi-baseline Stereo	$3500	1280 x 960	0.5	60	variable

ToF and SL cameras have been used in similar application areas with focus being on the robotic and 3D modelling research. Early attempts at using this technology for capturing the properties of vegetation have focused either on single leaves [21] or small indoor plants [22]. The relatively untested nature of this technology for measuring vegetation properties can be attributed the properties of the sensors and their intended use. ToF and SL cameras have been developed for use indoors and Kizma et al. [21] has shown that sensor saturation of the detectors in ToF cameras can occur in direct sunlight, producing highly variable depth measurements. It can be assumed that similar saturation may occur in the low cost CMOS sensors and this has been reported for the Kinect sensor by [23]. Outdoor use has, however, been reported in [24] who suggest the collection of data in the shade or early morning and evenings.

Even with the outlined limitations the already low cost and high portability of SL cameras suggest that they have the potential to become an operation tool for quantifying burn severity at the local scale. Future technology developments (such as Google’s project tango, Mobil3d and Pelican) aim at embedding SL cameras in consumer grade smart phones and tablet meaning the use of this technology may not require an additional purchase on the behalf of the land manager.

Stereo cameras offer an alternative approach to depth cameras in capturing the 3D structure of a scene. Through the use of photogrammetric principles (primarily triangulation) and a known baseline between two or more lenses, stereo cameras are able to reproduce the 3D structure of an environment. The accuracy of the reproduced structure depends primarily on the processing algorithm, the complexity of the structure within the scene, the baseline between lenses and the resolution of the sensors. Similarly to depth cameras limited research has been conducted to determine the performance of these sensors in outdoor and vegetated environments.

SUMMARY AND RECOMMENDATIONS

This review has highlighted emerging sensor technologies which have scope to be used as a tool for quantifying burn severity. Each of these technologies has particular advantages in regards to stage of technological maturity and there demonstrate use in vegetation measurement applications, ease of deployment (expertise required and sampling area), accuracy and affordability (as summarised in Table 2).

Terrestrial and mobile laser scanners represent the most promising tools for quantifying burn severity. The technological trend is moving towards faster and more accurate TLS systems, however, the ability to capture a large area using these systems is limited by the requirement of multiple setups in order to limit occlusions. Mobile laser scanners, on the other hand offer rapid data capture, however, do not provide the same precession as TLS. As such the use of MLS and its ability to characterise change in forest structure in a similar manner to TLS systems requires further investigation.

Unlike laser scanning, other technologies such as depth cameras and 3D photogrammetry are unlikely to provide canopy penetration and therefore quantifying vegetation structure and amount from a single data capture may require auxiliary information (for instance an alternative description of the terrain). Measuring change at any scale with such sensors is likely to require a detailed analysis of potential sampling methodologies and investigation into the use of repeat visits to the same exact location. Nevertheless the low cost, likely high-availability in the future and ease of use of these systems warrant further investigation for monitoring burn severity.

The overall aim of Bushfire and Natural Hazards CRC project 'Disaster landscape attribution: fire surveillance and hazard mapping, data scaling and validation' work package 2+3 is to produce a landscape level estimate of burn severity. This review has focused on technology which show potential in measuring burn severity at the point (Depth cameras), plot (TLS) and transect and area (MLS) scales and to allow increases in temporal and spatial sampling. The applicability of these techniques relies not only on the ease of implementation, affordability and accuracy but also on scalability. Significant research is required to relate any measurements which may be extracted from the raw data provided by these sensors, to measures of burn severity which can be readily captured at landscape scale by sensors on board aircraft and satellites.

TABLE 2 – SUMMARY OF THE TECHNOLOGY REVIEWED IN THIS PAPER AND INDICATORS OF ITS POTENTIAL FOR USE IN QUANTIFYING BURN SEVERITY.

Technology	**Stage of Maturity (Measurement)**	**Stage of Maturity (Change Detection)**	**Sampling Area**	**Accuracy**	**Cost**	**Expertise Required**
TLS	Operational	Research	Plot	0.005 m	low	High
MLS	Research	Untested/Research	Transect / area	5 – 10 cm	Mod	Mod to high
Depth Camera	Untested	Untested	Point/object	2 – 30 cm	High	Mod
3D photogrammetry	Research	Untested	Plot	10 - 20 cm	High	High

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