Australia's National Science Agency

The identification and management of hazard trees to mitigate bushfire risk

Final Report

Thomas Lowe, Serge Lichman, Josh Pinskier, Changming Sun and Simon Dunstall

Report EP2022-2979
July 2022

Contents

PART ONE

1 Introduction

This is the final report pertaining to the research and development carried out by CSIRO for the project:

A comprehensive system for the identification and management of hazard trees to mitigate bushfire risk

Involving the Department of Environment, Land, Water and Planning (DELWP); Powercor Australia Ltd; and CSIRO. The project was intended to:

- Develop new models that enable a risk-based prioritisation of fall-tree inspections and hazard tree management through the fusion of network, landscape and remote sensing data and technologies.
- Design a system to better manage hazard trees incorporating network fault data, fire simulations, and the new models, so as to improve targeting, effectiveness and productivity of vegetation management.

The intended outcome of this project was to provide an evaluation of existing and potential technologies for the mitigation of bushfire risks due to hazardous trees situated close to the electricity network. The project developed a Hazard Tree Management System (HTMS) design that incorporates these approaches in conjunction with existing vegetation management practices and systems to deliver a risk-based prioritisation of hazard tree management. This was achieved through the delivery of a series of research and development work packages (WP) by Powercor and CSIRO as follows:

- WP1 - SYSTEM DESIGN A roadmap towards system(s) acting to signal to stakeholders what should be developed, what the technical challenges are, and what the developments need to integrate with.
- WP2 - TREE HEALTH: detecting tree health, structural problems, species, and maturity. The overall aim in this work package is to determine if and how symptoms/indicators of tree health/hazard, and species information, could be reliably detected at network scale.
- WP3 - TREE ENVELOPE: image segmentation and basic geometry. We seek the ability to segment vegetation imagery into individual trees. This ability enables sensed data such as colour indices and Normalized Vegetation Index (NVI) to be assigned/contextualized to individual trees and tree clumps.
- WP4: TREE DETAILS: structural geometry, branches and change over time. Given individually segmented trees, we seek to develop a detailed geometric model of each tree that identifies major structural elements of that tree. This will allow changes to the structure of each tree over time to be identified, analysed and tracked, providing a key input to the hazard tree risk assessment.
- WP5: PRIORITIZATION: data management and decision support systems. Information derived from historical data about hazard tree incidence, risk factors for hazard trees (species, maturities, soils, past fire activity, and so on), bushfire consequence (from fire spread simulations), tree geometries and detected health indicators (from WP2, WP3 and WP4) will be combined into a data management and decision support system that will support fire risk

managers to prioritize detailed aerial surveys, ground-based inspections, tree cutting and removal, powerline protection operational settings, and powerline asset hardening programs so as to actively minimise hazard tree risk and study trends and risk over time.

1.1 Motivation

Over the 2017/18, 2018/19 and 2019/20 fire seasons, there were 88 total bushfire ignitions (“fire starts”) related to Powercor electricity distribution system assets on Total Fire Ban (TFB) days. Of these, 20 of these were from vegetation (23%) which is the highest contributing cause of fire starts on TFB days for the Powercor network. 94% of all vegetation related fire starts on the network were due to fall-ins/blow-ins of vegetation originating from outside the required minimum clearance space around electrical assets. (The next highest cause is pole fires, with a much lower risk of ground fire starts.) If we consider fire starts from vegetation on High Voltage overhead lines (namely, 22kV and SWER lines), there were these 20 fire starts out of 55 in total (36%).

Thus, the problem of fall-in and blow-in trees and branches is real and sizable. It is Powercor’s biggest single fire start problem on TFB days, and a correspondingly significant problem for other electricity distribution businesses. Better identification and management of hazard trees, particularly from outside the clearance space, should directly reduce the number of fire starts across the network.

1.2 Theoretical versus empirical risk measures

Due to the scope and technical nature of this project, our focus has been on developing geometric and physically based risk indices. These are well-defined and repeatable metrics on the structure and location of the trees. In each case a higher value is associated with higher risk of a power line contact.

In order to go from risk indices to an absolute measure of risk (such as the expected loss due to vegetation strikes per kilometre of powerline span per year), it is necessary to fill in the “reality gap” around vegetation strike rates using empirical feedback. This feedback could be done through statistical or machine learning techniques applied to observed data, combined with knowledge about vegetation prior to an incident. The latter requires 3D scanning information (a point cloud) of the scene prior to a strike event, and an understanding of which tree or which branch caused the strike.

This “ground truthing” will be a slow process due to the rarity of branch strikes and a lack of historical data. There is not a land-based (vehicle-based) history of near-powerline vegetation scans, and the existing aerial (helicopter-based) data has a history of vegetation but provides insufficient detail on which branch or tree might have fallen in each vegetation-related incident in the past.

Consequently, the empirical risk measures fall beyond the scope of this project. They are best achieved as a follow-up and ongoing process in the form of:

1. at regular intervals: scan roadside trees and store all external plan-view indices (soil moisture, max wind speeds, rain etc.) that are considered relevant to tree falls.

2. on a reported strike, rescan the area and/or visually determine which tree fell, or which branch fell from which tree. Record the tree or branch loss, and whether it fell or blew into the line.
3. regularly perform linear regression (or machine learning) on the provided tree risk indices, together with the external plan-view indices, against the observed set of strikes.

This regression provides a mapping from indices to risk, and also a measure of how well-correlated each index is to real tree strikes. We consider such a design to be a necessary process for a fully integrated “absolute risk” assessment system.

1.3 Acknowledgements

This work, and the successful outcomes of the project, would not have been possible without the financial support of the Department of Environment, Land, Water and Planning and the in-kind contributions of Powercor and the CSIRO. We also knowledge Powercor key contributors Peter McTaggart and Mustafa Mustafa who provided the leadership, industry insights and expertise that greatly assisted in the development of Hazard Tree Management System.

2 Project review

In order to understand the risk posed by trees in the vicinity of power lines, it is necessary to have a three-dimensional description of these trees, in addition to the pre-existing 3D description of the power line locations.

For this reason, the primary input data is the lidar point cloud. While techniques exist to estimate 3D structure from video or stereo camera data, they do not currently have the accuracy or reliability of lidar data. The CSIRO research group at the centre of this work is also a leading group in the field of mobile lidar.

We made the decision to support two forms of lidar input:

1. Helicopter-based lidar- this uses the existing point cloud acquisition hardware and processes at Powercor, whereby a manned helicopter flies over the regions of interest at approximately 300 m altitude, with a fixed single-beam lidar. This provides an aerial viewpoint of the trees and terrain at a density of approximately 80 points per square metre. The advantages of this method are its large-scale acquisition, and the fact that it is a pre-existing process in Powercor, with no additional hardware costs.
2. Vehicle-based lidar- a new sensor is purchased or built, which is installed on the roof of a vehicle. The vehicle(s) regularly drive along the roads closest to the power lines in question. The advantages of this method are better observation of trunks and branches from the side-on viewpoint, and higher accuracy and density clouds. In the order of 1000 points per square metre.

Of these two inputs, we have assessed that the helicopter-based lidar is best suited to segmenting and reconstructing the environment at the tree level. The vehicle-based lidar is better suited to segmenting and reconstructing at the branch level. Consequently, each input is better suited to a different form of risk assessment:

- Aerial lidar is suited to assessing the risk of fall-ins (whole tree fall) due to exposure to wind.
- Vehicle lidar is suited to assessing the risk of blow-ins (branches blowing onto the line)

Figure 1 and Figure 2 illustrate examples of equipment that is suitable for vehicle-based lidar scanning.

Figure 1. The CatPack (Velodyne) lidar scanning device used for project work by the CSIRO team

Figure 2. The Stencil2-32 lidar scanning equipment that was purchased by Powercor for the purpose of this project

2.1 Tree health

There is a risk of branches or trees falling due to ill health. The assessment of tree health is very difficult from a distance. Arborists typically look for signs of rot, fungus, and examine the tree crotches and take core samples. None of these features is feasible to observe remotely.

We therefore considered the colour of leaves as an identifying feature of ill health. We examined the ability of RGB cameras to identify leaves by their colour. We used our proprietary technology (PaintCloud) to paint the video footage onto the 3D point clouds for our ground-based mobile lidar.

The high spatial frequency of tree foliage makes such pixel painting quite inaccurate, only half a degree of misalignment can result in a leaf being painted with the sky rather than leaf colour.

Additionally, the extreme brightness of parts of the ambient background causes significant bleeding into the observed colour of the leaves. Despite employing multiple methods to normalise for these lighting effects, our tests showed that there was not even enough consistency to even differentiate wood from leaves (Figure 3).

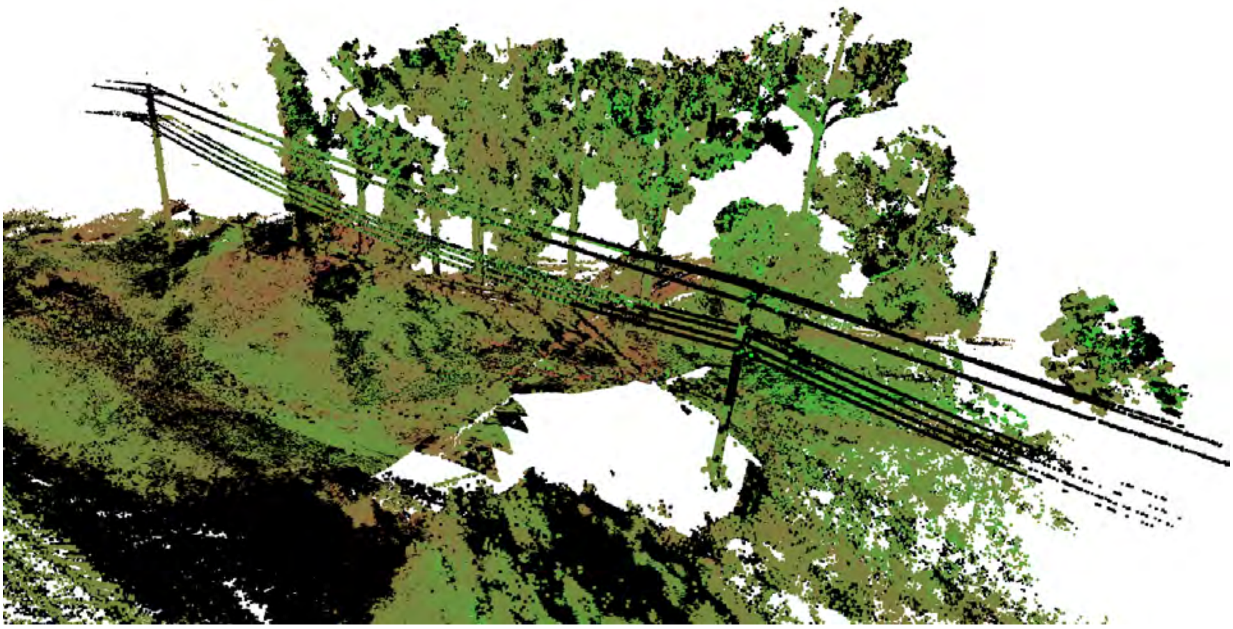

Figure 3. Using a colourised point cloud, comparing the ratio of red to green, with over/under-saturation set to black. This demonstrates the lack of a clear distinction between foliage, branches and terrain

Hyperspectral cameras may be a promising future avenue, but the extremely bright background light when observing from a vehicle was deemed to remain a significant barrier to assessing leaf colour.

As a result, we chose to focus instead on lidar-only techniques, which do not suffer from misalignment or bright sky artefacts. Rather than assess leaf colour, we focused on a more well-defined metric: foliage density. This is the one-sided leaf area per cubic metre within the canopy. The approximating assumption is that branches with fewer leaves are a potential indicator of ill health. This is particularly the case in Australia, which has fewer deciduous trees than other continents.

Foliage density can be estimated from lidar data with good accuracy, using the methods in the paper "Canopy density estimation in perennial horticulture crops using 3D spinning lidar SLAM" [1]. We employed this algorithm for the density estimation, but accurate values require the leaves to be distinguished from the branches.

For branch removal we employ two complementary techniques, which performs a more reliable separation than using either technique alone:

1. The return intensity from Velodyne lidars (used by CatPack and the Stencil2) is pre-calibrated for distance from lidar. So it is already a reasonable estimation of the reflectivity of the observed surface in the near infrared range. Since this is a reflectivity measurement from an emitted light, it is not particularly affected by whether the leaf is in the shade or not. From tests on the Velodyne lidar it is quite consistently the case that leaves give a lower return intensity than branches, and so this return intensity is the first index that we use.
2. The neighbouring points of each point in the point cloud can be described by a covariance matrix, which is an ellipsoidal representation of the point distribution. We use a new index to

represent the cylindricality of this neighbourhood, with the assumption that cylindrical distributions are more likely to be branches than foliage.

A linear combination of these two indices provides a robust measure of how likely each point is to be branch or leaf (Figure 4), and a threshold is used to remove all branch points from the cloud (Figure 5). This threshold can be reassessed for different forest types, or different lidars, in order to remain as optimal as possible.

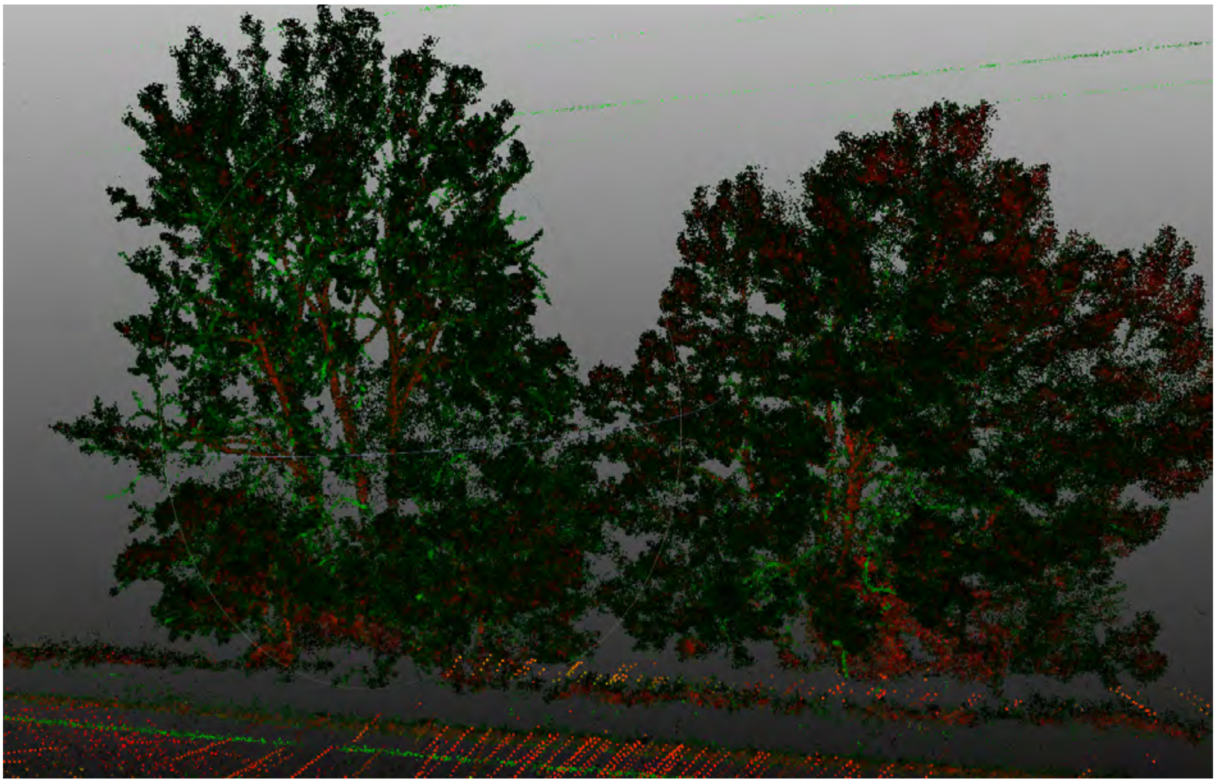

Figure 4. Trees coloured by IR reflectivity (red) and cylindricality (green)

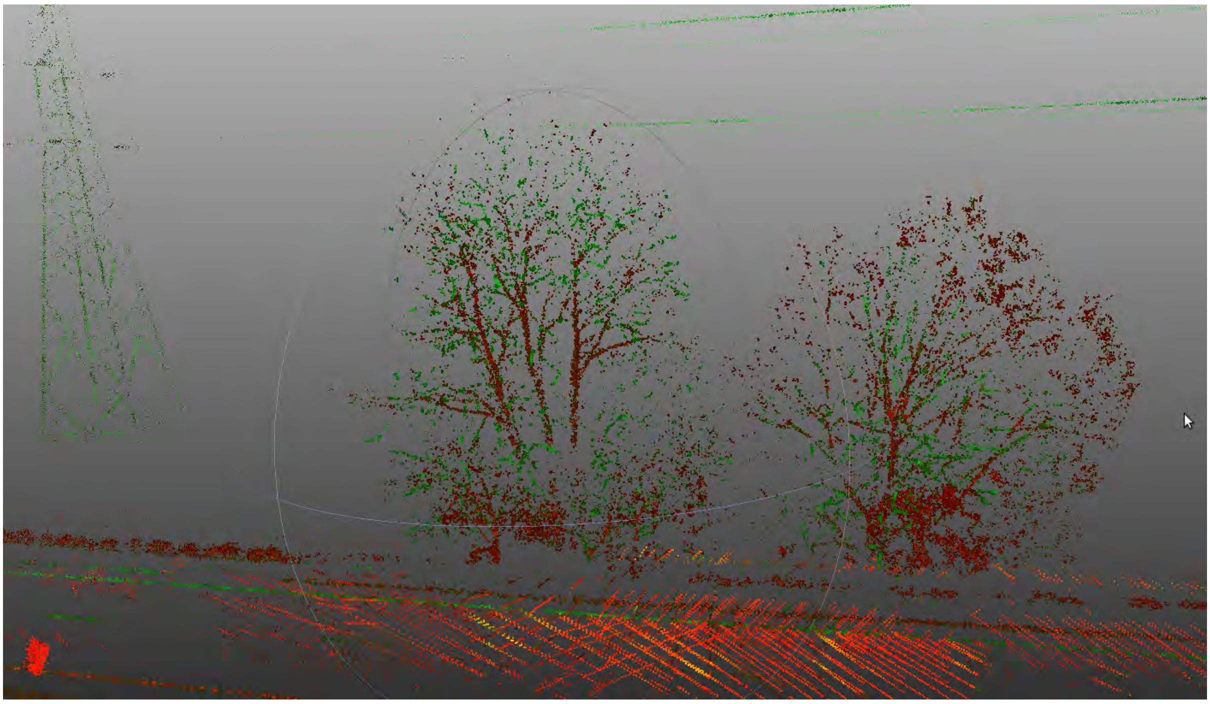

Figure 5. Thresholding reveals just the observed branches

The resulting cloud is then used in estimating foliage density, which can then be painted back onto the cloud on a per-tree or per-branch basis, in order to visualise this index that acts as a proxy for tree health. Since this technique does not require branch reconstruction, it can be used on both the aerial and the vehicle-based clouds.

There is no direct formula to go from foliage density to risk of a branch falling. The association is indirect. However, the effect of foliage density could be assessed empirically, in order to quantify its significance in branch falls.

2.2 Tree envelope

For aerial data in particular, there is not enough detail to reconstruct full tree structures, but it is still possible to estimate the location, size and height of the trees quite reliably. This is sufficient information to estimate fall-ins onto powerlines due to their exposure to wind. In fact, aerial data can be superior to vehicle-based data for this hazard as it provides a better observation of the tree canopies that are exposed to the wind, and of the more distant trees that shelter the proximate trees.

The enveloping algorithm inputs the aerial point cloud and outputs a segmentation of the trees (one colour per tree) and a trees file that specifies the location, height, width, and optional trunk radius of each tree.

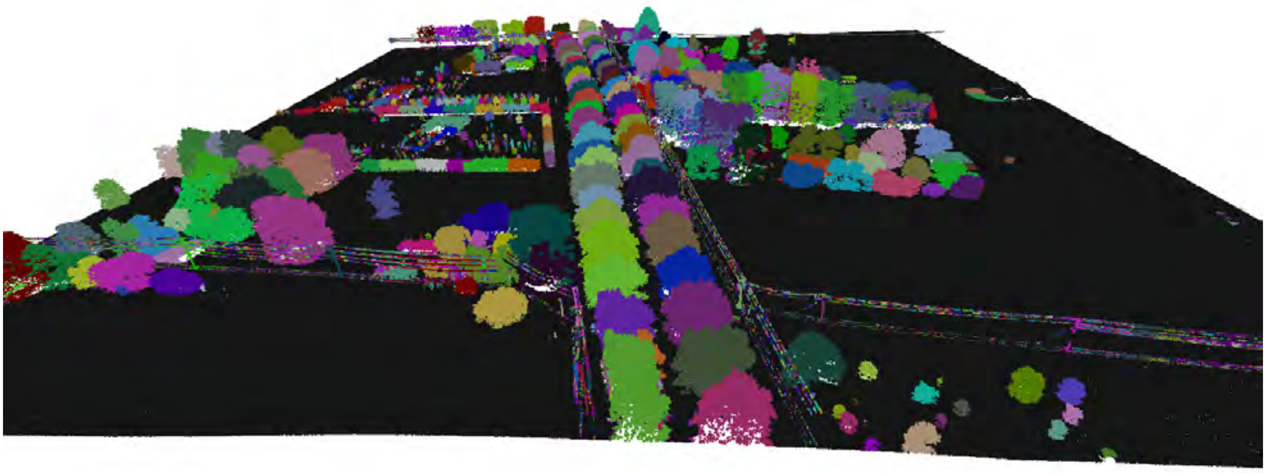

Figure 6. A tile from the Victorian helicopter-acquired lidar data containing roadside trees, segmented to a unique colour per tree

The method uses only the shape of the canopy top to estimate individual trees. It therefore will fail on trees with flat tops subjected to topiary, or densely clustered or very unevenly shaped trees. However, the algorithm is relatively fast (18 seconds on the quarter square km block of Figure 6) and so is effective for estimating the trees over large datasets, and where trunk information is not visible.

2.3 Tree details

The goal in this work package is to convert every point cloud into a Branch Structure Graph, which is a file that represents the set of trees as piecewise cylindrical approximations. This allows for non-straight branches but approximates the cross section as circular.

This higher-detail output requires a higher detail input in general. We have provided two algorithms depending on whether the input data is easy or hard:

- Easy: vehicle-based lidar, trunks and some branches visible. Higher density points.
- Hard: vehicle or helicopter data. Thick foliage or occluded branches. Lower density points.

Easy Case

The method we employ uses a minimal spanning forest algorithm to construct the clearest paths from the ground to the canopy, and clusters these paths into connected cylindrical branch segments. The output is a Branch Structure Graph and also a segmentation of the input cloud (a different colour per tree).

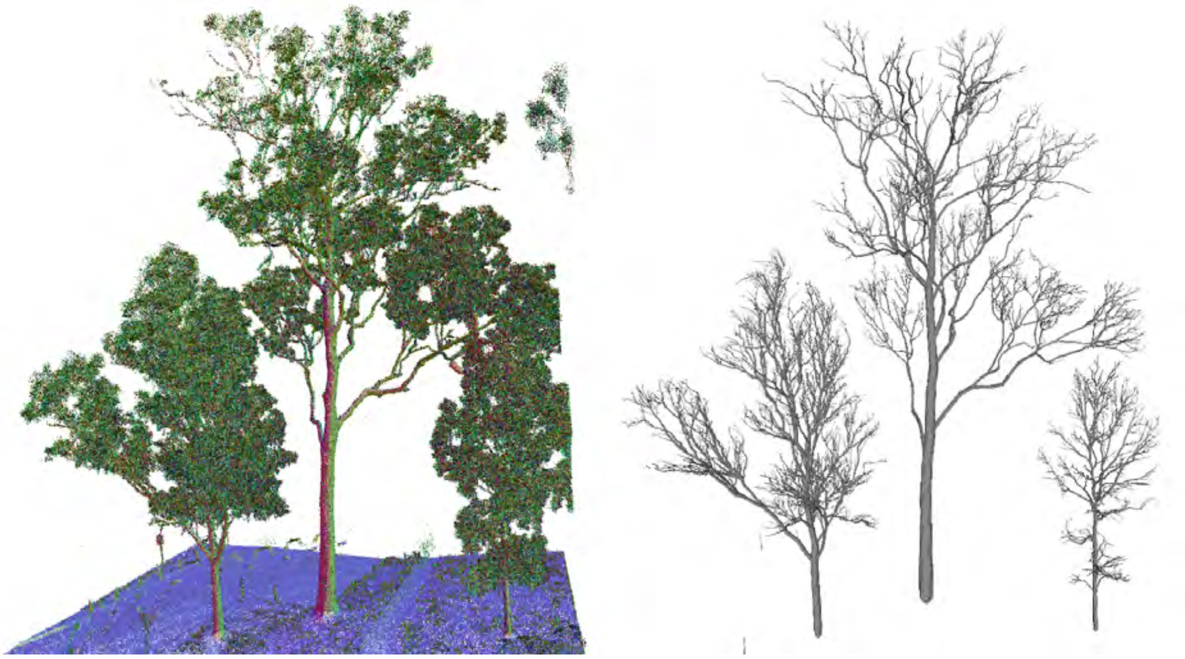

Figure 7. (Left) point cloud coloured by surface normal; (Right) reconstructed Branch Structure Graph.

The trees in the BSG have a well-defined correspondence to the segmented cloud colours, so a risk index calculated on each tree structure can be painted back onto the cloud (Figure 8).

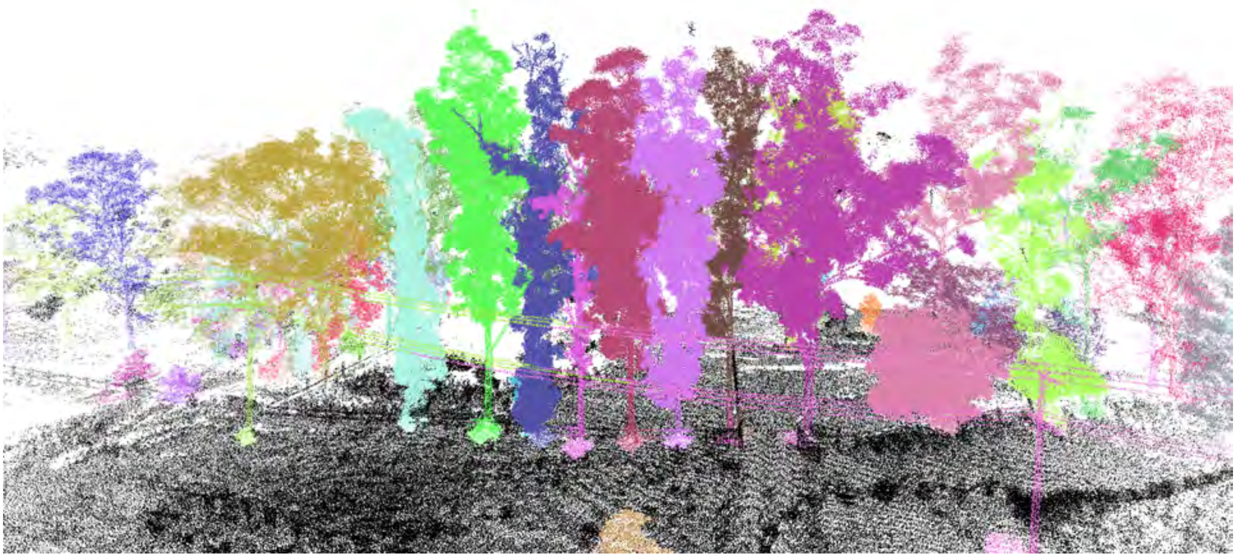

Figure 8. Crowded trees are segmented and separated from the ground in black.

The algorithm for segmentation and branch reconstruction is slower than the tree envelope algorithm, but still relatively fast, taking 40 seconds on the above 140 m span of trees, on a 3.1 GHz i7 laptop.

Tree extraction has been tested at the hectare scale, and (through our gridding method) can operate at any scale with fixed RAM requirements (Figure 9).

Figure 9. Large areas can be processed with constant memory using overlapping grids. This is a 0.25 square km map (25 hectares).

Hard Case

For this case we employ a topology optimisation method in order to find the strongest distribution of wood to resist applied wind loads at the observed lidar points. This voxel distribution of wood is then converted to a BSG. The method is capable of applying a well-justified distribution of branches to support the observations, even if these are just top canopy points, and even if they are just the surface points of a topiarised rectangular hedge. Whenever a branch or gap is observed these are also respected.

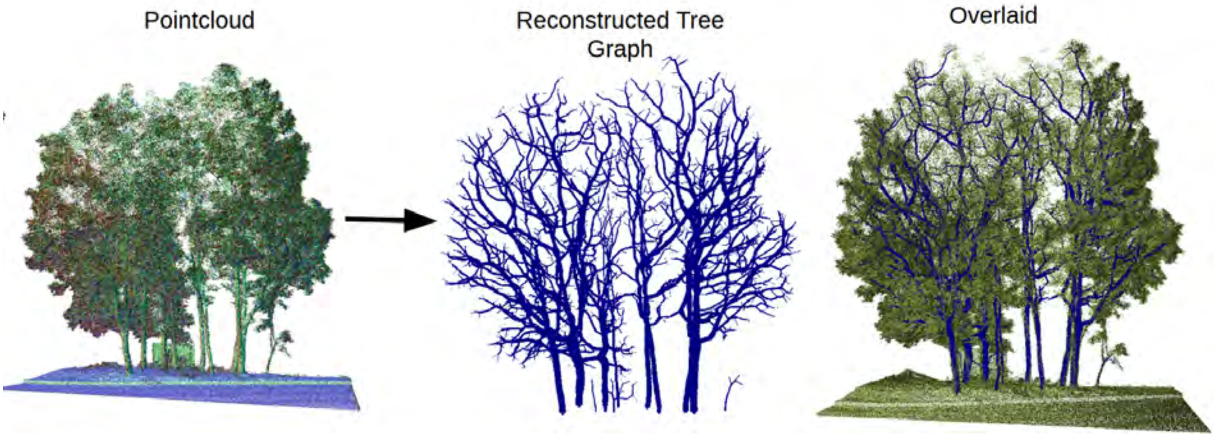

Figure 10. Branch locations are inferred from foliage shape wherever they are not observed.

Figure 11. This tree has no observed branches apart from the trunk stem. The reconstructed branches realistically support the foliage

The method has been submitted as a paper "Tree Reconstruction using Topology Optimisation" to ACM on Computer Graphics, and is currently on Arxiv [2]. The drawback of this method is its speed. There is room for some optimisation but even some scan segments three trees wide take several hours to process.

2.4 Prioritisation

Regardless of the method of generating the trees file, the goal of this work package is to convert the results into a risk index depending on the form of risk specified. As this is a domain specific question, we consulted with two Powercor arborists, and an expert in bushfires. These sessions helped to gain an understanding of what factors are important in power line strikes. Based on this and our acquired geometric information of the roadside vegetation, we provide four forms of hazard index (refer Figure 12).

Fall in

This is the simplest, it counts the number of branches that could break at their root and pivot onto any nearby power line. It operates on the assumption of equal chance of breakage, so a tree with more branches in the proximity of a power line has a higher probability of a branch striking the line. This method also includes a swing and shrink/expand range for the power line, to account for its potential different locations under wind or temperature changes.

Blow in

This models the path of each branch under sufficient wind speed to break it off. Since branch weight grows with volume and lateral drag force grows with exposed surface area, the larger branches follow a steeper downward trajectory than the small branches. Consequently more distant trees only contact the power lines with smaller branches. We quantify the hazard index by the maximum branch radius that can hit a power line.

Exposure

This method estimates the chance of a tree snapping at the base due to wind stress, and toppling onto a power line. Unlike fall ins which can happen due to old branches, heavy rain, and other factors, this method specifically looks at vulnarability due to wind stress. It estimates the exposed surface area to wind in the direction to the nearest power lines, taking into account shelter from other trees. It then uses the estimation of trunk thickness to determine the bending stress on the trunk. For a given wood material, equal stress represents equal probability of the stem breaking and the tree toppling.

Health

This method estimates the foliage density within the tree, as a proxy for the tree's health. In order to provide an index that increases with hazard level, we use the reciprocal of mean foliage density within the tree, which is the number of cubic metres per square metre of leaf area. If that number is high, then the tree has few of the leaves required to maintain life and moisture in the tree. The branches are more likely to be brittle, old, damaged or rotten.

Unlike the other indices, this one is independent of the location of power lines, so is an index that can be used to weight the fall-in index results, or to adjust the snap velocity in the blow-in and exposure indices. The absolute values of such weightings requires the empirical methodology described above.

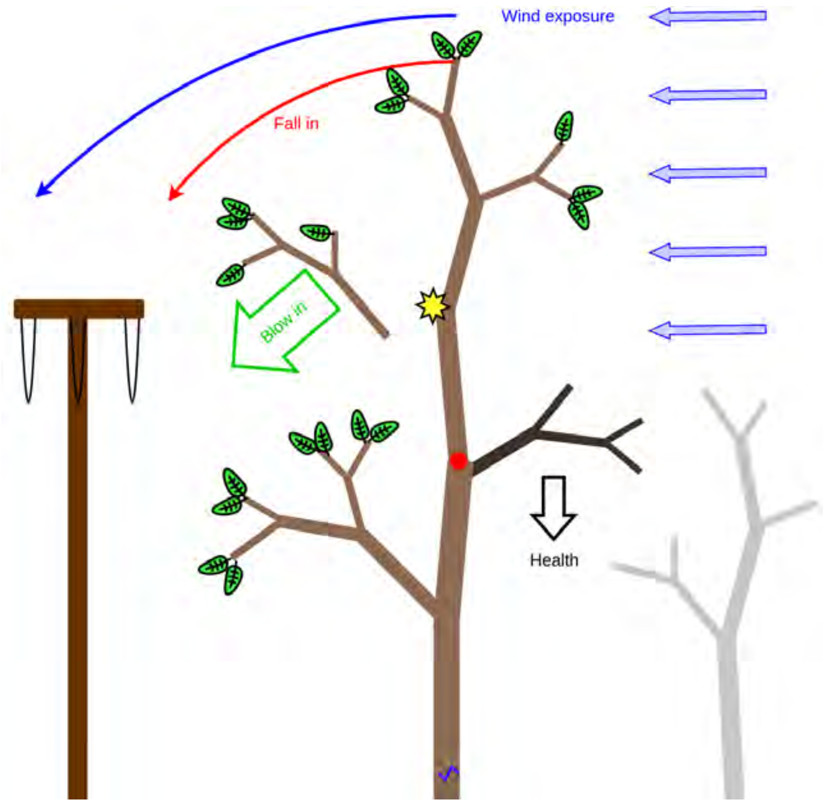

Figure 12. A graphic depicting the four hazard indices, in blue, red, green and black

In each case the hazard index is converted to a shade or colour, which can be visualised and compared in GIS and lidar cloud analysis software. Additional shading from external image-based indices is also supported, and all of these indices are ultimately available as inputs to regression modelling on real recorded power line strikes.

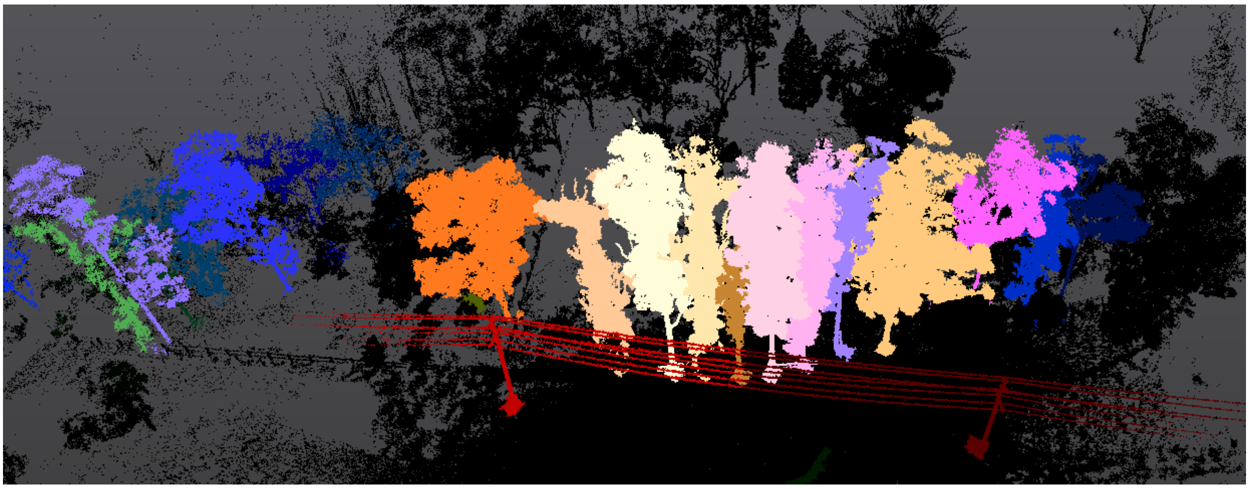

Figure 13. these trees are coloured by fall-in, blow-in and wind-exposure hazard indices in the red, green and blue colour channels respectively. The result visually indicates both the magnitude and the type of hazard.

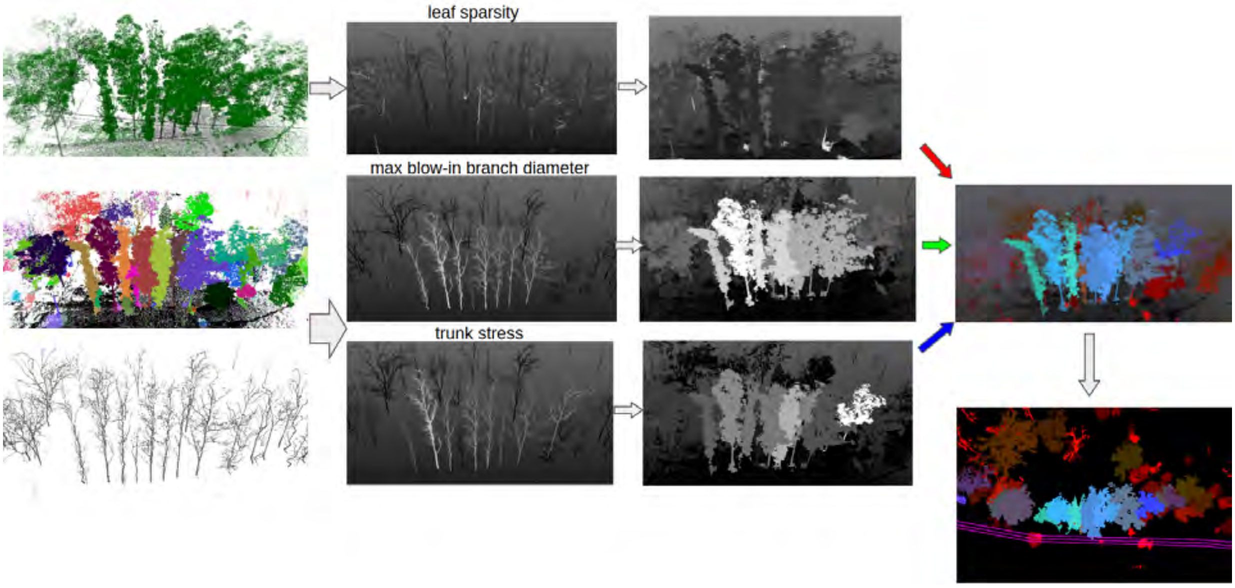

Figure 14. The data processing pipeline for calculating health, blow-in and wind-exposure hazards (top to bottom). Left: foliage segmentation, tree segmentation and Branch Structure Graph. Mid-left: risk-shaded BSGs. Mid-right: shade transferred to the cloud. Right: all three risks combined with r,g,b, and plan-view render.

2.5 System design

The system that we designed to achieve this analysis is based around sets of command line functions. There is one c++ library per set of commands, and each set is identified by a common prefix or suffix. The ray cloud processing suite is prefixed with **ray**, the tree files processing suite is prefixed with **tree** and the risk estimation suite is suffixed with **risk**.

The system is therefore a modular system of components, from which bigger tasks can be achieved by running multiple in sequence, and saving these as bash scripts if necessary. Command line functions provide a portable and reusable interface from which a GUI or plugin front end could be attached. If a closer degree of integration is required then the libraries can be linked to directly in C++.

Modular components require common file structures to work with. We use ray clouds to store lidar points and the location of the sensor within the same file, using the **.ply** format. We extend the pre-existing **raycloudtools** library [3] to perform the additional cloud processing operations. This takes care of common operations such as subsampling, denoising, gridding and colouring clouds. It also contains methods of reconstruction the ground mesh and aligning clouds together.

The Branch Structure Graph that stores the piecewise-cylindrical representation of the trees is kept as a text file, with one line per tree. The format is simple but extendible, allowing new per-segment attributes to be named in the header. This extensibility is what allows different hazard indices to be stored in the trees file. The TreeTools library is the library for processing these files.

The last common file format used is the power line file. Again it is a simple text file, with one line per cable. A start and end location and a scale value are sufficient to approximate each cable as a catenary curve.

As an output format, the risk-coloured ray clouds can be exported as point clouds, or rendered with per-pixel transparency to a geotif file. This image format allows the trees to be false-coloured and overlaid on street or satellite views of the region, using GIS software.

Figure 15. Example of a Stencil2-32 point cloud section with per-tree segmentation colouring, rendered to a geotif image and displayed in QGIS. Real usage would colour by hazard indices.

3 Benefits and outcomes of the project

The expected benefit of this project is that users have the necessary tools to estimate the most hazardous trees in the vicinity of power lines. This allows them to make informed decisions on which trees to inspect by an arborist, and possibly modify or remove. The expected outcome is that the arborists' time is more effectively utilised and the power line zones become less susceptible to damage from the nearby trees. The ultimate benefit would be a reduction in fire starts from branches and trees hitting power lines.

A secondary benefit from this project is that the Branch Structure Graphs (together with the extracted ground meshes and power line files) represent a canonical description of the power line zones; a digital twin. This opens up the prospect of a running database of all trees in the power line zones, with a full history of their growth over time. This would be an invaluable database in future for validating and calibrating fall hazards, for predicting tree growth, for predicting where fires might 'jump' the road gap, and other forms of digital analysis such as species identification.

References

[1] Lowe, Thomas, et al. "Canopy density estimation in perennial horticulture crops using 3D spinning lidar SLAM." Journal of Field Robotics 38.4 (2021): 598-618.

[2] Lowe, Thomas, and Joshua Pinskier. "Tree Reconstruction using Topology Optimisation." arXiv preprint arXiv:2205.13192 (2022).

[3] Lowe, Thomas D., and Kazys Stepanas. "RayCloudTools: A Concise Interface for Analysis and Manipulation of Ray Clouds." IEEE Access 9 (2021): 79712-79724.

PART TWO

4 Details of work packages

The details of each work package can be found in the delivered documents, with the following titles:

- Hazard Trees: Overview and Existing Work
- Hazard Trees: Work Package 1- System Design
- Hazard Trees: Work Package 2- Tree Health
- Hazard Trees: Work Package 3- Tree Envelope
- Hazard Trees: Work Package 4- Tree Details
- Hazard Trees: Work Package 5- Prioritisation
- Hazard Trees: User Guide

These provide details of the methods, choices made, and outcomes of each work package. The remaining text in this Part addresses the final report required responses.

4.1 The Objectives: The degree to which the Project has achieved its objectives as stated in Schedule 2 – Project Plan

We have developed new models that enable risk-based prioritisation of tree fall inspections, which was a primary objective. The key technology development was the conversion of lidar data into Branch Structure Graphs. This capability did not exist in existing software or existing academic papers, so this development is an enabling technology that opens up a wide range of possibilities for geometric analysis of trees and forests.

The other objective was to design a system to better manage hazard trees. This Hazard Tree Management System has been developed in the form of a modular architecture of command line tools that can be sequenced and ordered to suit the configuration of the system. We don't believe that this system is as fully integrated as was originally envisioned and we provide reasons for this:

1. We required a new vehicle-mounted sensor for tree structure extraction. This was only ready for testing within a month prior to project end.
2. A full integration of the system would require co-development with the development teams at Powercor over a number of months, which is only possible after the technology is complete at the project end.
3. An absolute risk measure requires statistical regression to be applied, through the feedback scheme described in part 1. This requires new processes and procedures within Powercor, and a significant period of time in order to record a statistically significant number of strikes.

These pieces of integration either require a tight co-development model, or they require these mechanisms to be developed by Powercor with consultation from CSIRO. These were found to be outside of the current project's scope.

However, the delivered system of tools is the key set of ingredients needed to support a full hazard management pipeline. It cleans and manages lidar data, generates the hazard indices, segments 3D maps per-tree, and provides multiple means of displaying and retrieving the hazard information, for use by the user.

We consider this tool suite to be a more effective means of integrating hazard management into Powercor's processes than any form of singular dedicated application.

4.2 The Deliverables: The degree to which the Project has delivered the agreed outputs as stated in Schedule 2– Project Plan

We consider the outputs to have been delivered in line with expectations. The outputs support a range of options for adopting organisations, from the existing helicopter data to high-detail vehicle mounted data.

The Tree Health work package deviated from our initial expectations due to the difficulty in acquiring accurate colour data from cameras taken against a bright sky. We chose to focus our time on the more reliable data available, which was geometry and infra-red reflectivity. This ended up being an effective means of identifying and ultimately quantifying foliage, by its density. While foliage density is a relatively crude proxy for branch health, it is also a reliable and repeatable (3% repeatability error [1]) measure.

The Intended Outcomes: The extent to which Recipient's performance of the Project has achieved the intended outcomes as stated in Schedule 2 – Project Plan

To the extent that the intended outcome was a suite of methods to allow users to prioritise hazardous trees, the project has been effective. It measures and reports real physical quantities, specifically: the number of branches that can hit power lines, the thickness of largest branch that can blow on a line, the maximum stem stress each tree could be exposed to, and the per-tree foliage sparsity.

The outcome of this is that large regions of Victoria's powerline corridors could be coloured by the multiple measures of risk. The next step is to integrate it and apply it.

4.3 Future Outlook: Details of the future outlook for the Project

The key features of this project have been the technology to extract reliable tree structures, forming a digital twin of the powerline regions; and the set of hazard indices that assess the digital twin at a per-tree and per-branch level.

The next step would be to start integrating and using this system by Powercor in an ongoing fashion. This would involve regular scans of powerline routes, assessment of powerline strikes to identify the offending tree or branch, and running the risk tools to obtain coloured output of the high risk trees.

Only then will it become clear which areas will need further development. However, certain areas are likely candidates:

1. Data management- how and where is data stored? Is a history required per tree, where each scan associates with the previous scan's trees. How is this managed? Is version control used, and will scans be merged together, or split into grids in order to make them manageable?
2. Powerline strike feedback- strikes need to be assessed to find the offending tree or branch in the digital twin, and the results need to be stored in a record that allows both calibration/validation of a learned mapping between hazard indices and this observed risk. Several models may be tried simultaneously, such as linear regression and machine learning.
3. Scale- this project has tested at the multi-hectare scale, but real use at larger scales may require development such as optimisation, parallelism, scripting and efficient use of data.

4.4 Appropriateness: The appropriateness of the approaches and methodology used in the development and implementation of the Project.

Our approach to the main algorithms was to investigate the existing work, incorporate any available state of the art, and extend where there are remaining scientific gaps.

This approach involved trying out multiple existing systems: raycloudtools, AdTree, 3D Forest, PANSFEM2 and LioSAM (as a more economical method of registering point clouds). Of these we found only raycloudtools and PANSFEM2 to be suitable for the tasks, and as such, we still required a significant effort to build the tree structure reconstruction algorithms. However, where we were not able to re-use existing software, we were able to extend existing ideas from the papers in the literature review.

If sufficiently robust methods already existed in software then the project would have been able to focus more time on integration and optimisation. But the positive aspect is that the end product of this project is a unique capability that the parties involved have full control of.

We consider the methodology to solving these difficult problems has been pragmatic, effective and appropriate for the project at hand.

As Australia's national science agency and innovation catalyst, CSIRO is solving the greatest challenges through innovative science and technology.

CSIRO. Unlocking a better future for everyone.

Contact us

1300 363 400
+61 3 9545 2176
csiro.au/contact
csiro.au

For further information

CSIRO Data61
Thomas Lowe
+61 7 3327 4027
Thomas.Lowe@csiro.au
csiro.au/Data61