

A subset of LiDAR scan over Barmah-Millewa forest, left to right: (1) forest height in grey shades, (2) individual tree health (green – healthy, orange – declining, red – dead) (3) individual trees indicated by different colours.

Forest for the trees: high tech tree accounting

New Australian research identifies how machine learning can account for one of the world's most valuable resources and perhaps transform climate change and resource policy development.

IURII SHENDRYK

The past sixty years have seen sizeable areas of forest in Australia experience dieback, driven mostly by drought and high temperatures. In order to develop initiatives to restore these valuable natural resources back to health, there is a need to quantify not only the distribution of trees, but also specific tree characteristics such as health, species and size.

Iurii Shendryk, a PhD student from the University of New South Wales (UNSW) has found that LiDAR technology offers an ideal method for quantifying such comprehensive characteristics of forests. As part of the Geospatial Analysis for Environmental Change (GAEC) lab at UNSW, Shendryk was tasked with developing such an accounting system of trees and set out for the Murray River to do just that.

There in the Barmah-Millewa forest near the border between Victoria and New South Wales is one of the largest colonies of River Red Gums, themselves one of the largest Eucalypt species. Shendryk and the GAEC lab developed algorithms to accurately classify the health of these individual trees and investigated the spatial relation of the forest's health to flooding events in the area.

Characterising forests from the air

One of the most prominent remote sensing tools used in forest studies at present is airborne LiDAR, which represents a perfect tool for individual tree extraction. The type and density of forest as well as the algorithm used, tends to dictate the success of individual tree extraction from LiDAR scans. The majority of existing algorithms use top-down algorithms and work best for trees with a distinct top. This is usually effective for coniferous, cone-shaped trees such as pines, however most broad-leaf trees including eucalypts are asymmetrically-shaped and often have complex structures, thus requiring a bottom-up algorithm for segmentation.

Therefore GAEC team proposed a bottom-up algorithm for extraction of individual eucalypt trees. It is a stepwise procedure, whereby first tree trunks are identified based on the spatial arrangement of points in the lowest part of the LiDAR point cloud. Secondly, the points representing individual tree trunks are labelled within the point cloud. Thirdly, a 3D model is built by connecting all points within a certain radius. Finally, based on the spatial connectivity of points to the labelled ones using a so-called 'random walks algorithm', the point



cloud is segmented into individual trees. The detailed description of Shendryk's use of the 'random walks algorithm' was recently published in *Remote Sensing of Environment* (2016).

The application of such an algorithm was possible thanks to high LiDAR point densities of 10-40 points per square metre, and was evaluated against an extensive field-measured dataset of tree positions. The LiDAR dataset used in this study was acquired in a full-waveform mode using a RIEGL LMS-Q560 system by Airborne Research Australia (ARA), and conducted along 17 flight lines covering 103 square kilometres, some 14% of the Barmah-Millewa forest.

The ground measurements consisted of more than 1,000 tree position readings using a Leica Viva GS08 Plus RTK GNSS rover, which were essential for optimisation and evaluation of the segmentation algorithm. The differential capabilities of GNSS were necessary to achieve sub-metre accuracies of tree positions in a forest with density of up to 700 trees per hectare. Overall, Shendryk's algorithm allowed correct segmentation of 68% of the trees in this complex forest site. The proposed algorithm is expected to produce even higher accuracies when applied to LiDAR scans collected over forest plantations or coniferous species. ►

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Tree health and other attributes

An accurate segmentation of individual trees using LiDAR suggests a wide variety of forest applications. From the exact height and width of individual trees it is trivial to quantify, for example, carbon storage or timber volumes.

The identification of individual tree species could also be obtained by incorporating such LiDAR attributes as intensity or returned pulse width into analysis. As an example, the GAEC team used accurately segmented trees to classify forest health using machine learning and field-measured tree crown dieback as indicators of eucalypt tree health. Although tree health is a subjective term, in the Barmah-Millewa forest it is best approximated by dieback levels (i.e. the proportion of dead branches to the total number of branches). This attribute was visually assessed in the field and grouped into three classes.

The LiDAR indices were then calculated for segmented tree crowns exploiting the full range of LiDAR attributes and tree geometry, and were used as predictor variables in objectoriented random forest classification. Random forest is a supervised nonparametric machine learning technique, and was particularly suitable for this study as it was able to achieve superior classification performance as compared to other ensemble learning algorithms with small training samples.

The results showed that tree health of individual eucalypt trees can be classified with an overall accuracy of 81%. The model was built from less than 100 fieldmeasured trees and allowed classifying millions of LiDAR-measured trees, and could easily be scaled up. Right: Individual tree segmentation procedure.

Imagine an airborne system that fires lasers out of the bottom of the plane, sweeping across the ecosystem and providing real-time information on forest attributes resolving individual trees in high resolution 3D. Yes, this type of 3D mapping is possible these days and could be used to transform climate change and resource policy developments.

However, in order to reduce the cost of larger scale studies, GAEC team suggests using very high resolution multispectral satellite imagery as a possible substrate for extrapolating LiDAR-derived individual tree health. This is the aim of Shendryk's follow up study, where he will use 800 square kilometres of DigitalGlobe Foundation granted very high resolution satellite imagery over the Barmah-Millewa forest to upscale his tree health maps.

Basically, individual tree crowns could be also identified in satellite imagery and their spectral signal related to the LiDAR or field measured tree health. Thus making the accounting system scalable and affordable.

Tree extraction represents one of the most difficult tasks when segmenting complex LiDAR scenes, due to their irregular and entangled shapes. Therefore, this newly developed algorithm could be

an ideal addition for modelling of urban areas to produce, for example, seamless 3D models of entire cities. Moreover, recent advances in the field of multispectral (e.g. Optech Titan) and space borne LiDAR systems (e.g. NASA's GEDI) could be a starting point for the potential development of a global accounting system of trees as well as large scale bio-banking schemes.

Informing environmental decisions

Recognising the signs of unhealthy forest and teasing out the causes are important both for sustaining the services that humans rely on and for the effective conservation of forest ecosystems. The decrease in flooding has been frequently identified as the main cause of tree health decline in Australia's floodplains.





To test this GAEC team overlaid the flooding frequency map derived from time series of Landsat imagery (1986-2011) with the LiDAR-derived tree health maps of the Barmah-Millewa forest. Their findings highlighted that trees located in infrequently flooded areas were most susceptible to dieback. This is crucial for management of, for example, environmental flows, as forest areas that require more water than others could be easily identified.

The GAEC team hopes that their methodology will act as a starting point

for the introduction of forest health monitoring framework in Australia, enabling to prioritise areas for forest health promotion and conservation of biodiversity. The potential users of such technology driven by smart algorithms span from governments to ecologists, as it promotes efficiency and large scale applicability.

References

Shendryk, I., M. Broich, M. G. Tulbure and S. V. Alexandrov (2016). "Bottomup delineation of individual trees from



full-waveform airborne laser scans in a structurally complex eucalypt forest." Remote Sensing of Environment 173: 69-83.

Iurii Shendryk is a PhD candidate at the University of New South Wales in Sydney, Australia. His research is focused on the integration of remote sensing, GIS and spatial statistics to explore interactions between species, environment and land use, with ongoing research and capacity building work focused on forest health monitoring.

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