Enhancing forestry supply chain through innovative integration of digital tools and techniques

Mohammad Sadegh Taskhiri
ARC Centre for Forest Value
School of Engineering and ICT
University of Tasmania
Hobart, Australia
Email: mohammadsadegh.taskhiri@utas.edu.au

Maciej Matuszak
School of Engineering and ICT
University of Tasmania
Hobart, Australia
Email: Maciej.Matuszak@utas.edu.au

Byeong Kang
School of Engineering and ICT
University of Tasmania
Hobart, Australia
Email: Byeong.Kang@utas.edu.au

Paul Turner
ARC Centre for Forest Value
School of Engineering and ICT
University of Tasmania
Hobart, Australia
Email: paul.turner@utas.edu.au

Abstract

Internationally forestry and wood products supply chains are being transformed. This traditionally resource intensive low technology sector is moving rapidly towards precision-manufacturing, advanced technology use and innovation in ways that increase the value and sustainability of wood within the emerging bio-economy. This research-in-progress reports on a major Australian Research Council funded applied industry based program integrating different digital tools and techniques along the forestry supply chain to improve product traceability, characterisation and knowledge management to stimulate and support market innovation. The paper provides insight into contemporary forest supply chains and illustrates the breadth of research being undertaken in this program. A specific example involving the innovative use of unmanned aerial vehicles (UAV) and digital telemetry to advance the speed and accuracy of forestry resource assessments is described. Preliminary results comparing manual and automated techniques for inventory estimation appear positive. Planned next steps for this project and the program are presented.

Keywords Unmanned aerial vehicle, digital innovation in forest inventory, sustainable value creation, eucalyptus nitens.

1 Introduction

Timber is a natural and renewable material drawn from trees grown throughout Australia. The Australian forestry and wood products industry is extensive and worth over $20 billion per year and employing over 60,000 people (ABARES 2014).

Inter-relationships along the value-chain from forests to buildings are complex and incorporate multiple forestry resources, manufacturing processes, product streams and applications. Project information that flows from the design and construction sector to the fabricator or supplier can be highly detailed and is regularly converted into digital formats for semi-automated cutting and assembly. However, information flow from the supply end is universally coarse, and usually only involves an identifying grade, volume data and some certification marks (Referenced deleted for review). Useful information can be generated at the supply end but currently no market benefit accrues from its transmission along the supply chain because of the way material is graded (i.e. the way potential material performance is assessed). (Referenced deleted for review).

This research in progress describes the work of one of the research questions of the ARC industrial transformation research hub, investigating the innovative integration and use of digital technologies for transforming forestry and wood product supply chains. The aim is to support industry to realise new opportunities in the growing bio-economy. This approach recognises that new markets are emerging that leverage consumer expectations tied to forest certification and concepts such as social license. It also recognises that current and future market opportunities may be different from those traditionally targeted by the Australian forest sector. For these opportunities to be realised, greater creativity and flexibility is needed in the specification of wood for engineering or architectural purposes and in the integration and management of what is a complex supply chain. The broader research program establishes innovative processes and training whereby information about the characteristics of a forest, a tree or a batch of wood can be assessed and passed along the supply chain from the forest to its final application, and vice versa. It is developing systems that allow required material performance to be matched to actual material characteristics. This aims to facilitate forestry, manufacturing and design precision, and establishes the potential for virtual vertical integration of enterprises. It will enable transformation in the ways for timber-users to define the required material properties, as well as how timber producers grow, mill, assess and market their resource. The supply of a certified raw material from a sustainably managed production landscape is essential and so the research program is also investigating innovation in the forest restoration and environmental planting activities that have now become a fundamental part of production forestry (Reference deleted for review).

The broader research program has three major research questions of which one of the questions deals with the innovative technology integration along forestry supply chains. The two other research questions deal with wood genetics and architecture and design. This paper primarily reports on the activities towards responding to the research question on application of digital tools and techniques along forestry supply chains.

This research question contributes directly to transforming business practices and performance through the innovative deployment and integration of new technologies along the forest products value chain. This will open up this traditionally fragmented sector by enhancing characterisation, tracking, grading and management of timber and wood products. By collating, analysing and disseminating these data, it will be possible to support strategic, tactical and operational decision-making. This will support improved resource utilisation and production efficiencies and enable value optimisation, product differentiation and future sustainability by enhancing integrated decision-making along the supply chain from tree growth to resource management and fabrication and design.

The result from this research question will demonstrate how intelligent information use can establish the value-adding role of logistics in forestry by more tightly integrating information and materials flows up and down the forest products value chain. By deploying smart information (mobile, cloud, web) and sensor technologies (LiDar, Acoustics, XRays, Digital Imaging Processing, Radio Frequency Identification [RFID] tags) to maximise useful information flow, it will be possible for the forest products industry to leverage innovations already occurring in the Australian building industry. This will deliver improved resource utilisation and value generation by enhancing the precision of information, the availability of information both in time and place along the supply chain, and to track products as they move along this supply chain. Working in collaboration with the other two themes, this theme will develop software for information transfer along the supply chain. There are several projects and sub questions across the main research question which are:

- Deployment of UAVs and 3D cameras for stem/volume estimations

This project examines manual automated techniques for inventory estimation in particular capability of aerial assessments carried out by drones. Improving the speed and accuracy of forest inventory is increasingly important in supporting forest managers ability to quantify their resource. Current inventory relies on manual processes, however, new techniques are being developed to automate the inventory process.

- Non-destructive timber assessment using NIR/Ultra-sound etc;

This project outlines potential technologies and methodologies for identifying the trees with clear wood from the one with internal damages, which cannot be observed visually. This work includes examining the capacity to differentiate the logs at the standing tree prior to the harvesting process into those that would be best utilise for the recovery of high quality sawn timber or veneer log. Results of this work should increase profitability by ensuring logs go into the right customer (wood processing company).

- Residue utilisation optimisation for bio-energy and EWPs;

This project investigates mechanisms within the forest industry supply chain that optimise value utilisation of eucalypt forest residues for bio energy & bio based product markets. This research aims to empirically investigate the availability, quality & feasibility of eucalypt residue utilisation to produce a multi objective optimisation of residue utilisation that includes consideration of socio economic environmental dimensions within an efficiency supply chain management model.

- Port scheduling and utilisation optimisation solutions integrated into forestry chains;

This project integrates the interface between the land maritime (ports) supply chains, with the aim of increasing operational efficiency. The project proposes the implementation & evaluation of an online scheduling tool for the woodchip export terminal at the port of Burnie to improve traffic flow. The tool is expected to reduce truck queueing time & therefore supply chain costs.

- Moisture management for transport cost reduction and value improvement

There is developing interest in the use of logging residues as biofuels. This project will examine the biomass supply chain with particular focus on predicting available quantities, investigating moisture content & determining the costs & scheduling impacts of infield drying of biomass. Results of this project will help develop a decision support tool for scheduling biomass collection that minimises moisture content & delivered costs.

The rest of this research-in-progress reports on a specific project example involving the innovative use of unmanned aerial vehicles (UAV) and digital telemetry to advance the speed and accuracy of forestry resource assessments is described. Preliminary results comparing manual and automated techniques for inventory estimation appear positive. Planned next steps for this project and the program are presented.

2 An investigation on the deployment of UAVs and 3D cameras for stem volume estimations in a Tasmanian plantation eucalyptus plot

In Tasmania, 58,000 ha of the state forest is dominated by Hardwood plantation of which 80% is E.nitens and 20% E-globulus (Stewardship report 2014). Currently, the plantation eucalyptus is utilised for the production of pulpwood only. The state forest is planning to supply high quality sawlog for local as well as the interstate and overseas markets (Stewardship report 2014). However, there is a challenge on obtaining information on the quality and quantity of forest resource, which is vital to improve the sustainable value creation. In Tasmania, the stem estimation has been doing manually for selected number of the trees in each plot using tape measurement in order to estimate the resource availability in the coupe. This leads to acquisition of limited data due the lack of accuracy and the speed of data collection as well as facing the forest crews the risks during the assessment process. Thus, an innovative digital technique is needed to estimate the stem with higher level of accuracy to reduce the disruption in forest business by supplying suitable logs (high quality sawlogs) from the plantation eucalyptus to the wood processing companies.

The aim of this study is to improve precision management and the cost effectiveness of forest inventory for plantation eucalyptus. A 3D stereo camera with an unmanned aerial vehicle (UAV) is used for digital aerial photography (DAP) to identify the location and diameter of stem throughout the trunk. The flight will be conducted over 40 circular sample plot of 400 m2 within two coupes of Tasmanian state forest composed by eucalyptus nitens. Dense point clouds from the entire set of images will be generated using Photoscan Professional Edition 1.1.0 (Agisoft LLC, Russia) software, which uses the structure-frommotion (SfM) technique to build the geometry of 3D scenes from 2D image using corresponding image points in multiple overlapping views (Koenderink and van Doorn 1991).

2.1 Cases of applications of UAVs in forestry

Improving the speed and accuracy of forest inventory is increasingly important in supporting forest managers ability to quantify their resource. Current inventory relies on manual processes, however new techniques are being developed to automate the inventory process. In the followings, several cases in the international and national level is presented.

Many researches discussed the application of remote sensing as an innovative digital technique on the various fields of forestry including forest monitoring, inventorying, and mapping applications. Some focus on the carbon storage and climate change (Hopkinson et al. 2016; Kaasalainen et al. 2014; Kumar et al. 2016; Srivastava et al. 2015). Many discussed the advantage of using remote sensing in deforestation degradation and the forest recovery after bush fire (Kamlun,et al. 2016; Chu and Guo 2013; Ghulam, 2014). Ulah et al (2016) investigate the extent of forest cover and its changes while Hall et al. 2016 assesses the forest health and the growth trend. Some researchers explore the level of biodiversity and structural type (Colomina and Molina 2014; Schäfer et al. 2016; Torresan et al. 2016; Steinaker et al. 2016). The selection of remote sensing technology for each field relies on specific process under investigation as well as the spatial and temporal scales of the analysis.

The data collection methods using remote sensing can be passive (e.g. optical method) or active (e.g. LIDAR) of which optical techniques are the most widely used method in the forestry (Toressan et al. 2016; Suarez et al, 2005). Satellite, aircraft and unmanned aerial vehicle (UAVs) are the most common tools as optical method to collect data for forestry purpose. In the last decade, UAVs (which also known drones) are being used widely as they have the advantages over satellite and aircraft. These benefits are low material and operational cost, high-intensity data collection acquisition with high spatial resolution (due to data capturing at lower height with lower speed), flexibility on mounting sensors, prompt and rapid data collection over target areas that are dangerous for manned observation (e.g. bush fire) or in case of pest outbreak (Tang and Shao 2015; Torres-Sánchez et al. 2013; Lehmann et al. 2015). Apart from the above benefits, however, the UAVs faced many disadvantages and cannot be used for many applications which large area and simultaneous data acquisition is required. In addition, it has the limitation on payload capacity and higher setting up time in comparison to other methods. Furthermore, a massive data processing capability due to the data acquisition in higher resolution is needed.

In the last 15 years UAVs have been used widely in civil, military industry and the market of services to end users. Totally, 4842 approved and authorised civil UAV operators have been counted worldwide by 2015 of which more than 50% operating in Europe (Foster 2015 and Gutierrez 2014). In Europe, the UAVs have been employed for many applications. Puliti et al (2015) compared the data captured from UAV imagery with ground based data for mean height, dominant height, stem number, stem estimation in a a boreal forest in the south-eastern Norway. They have used a fixed-wing UAV equipped with a near infrared (NIR) for UAV imaging over 38 circular sample plots of 400 m2 of softwood forest for spruce, scots pine and birch. Fritz et al (2013) employed UAV for 3D modelling and reconstruction of individual trees in a plot of 1 ha wide for old oak in Germany. An octocopter equipped with a VIS-RGB Lumix G3 camera has been used for image acquisition to generate a dense point cloud. The result compared with those obtained with terrestrial laser scanner (TLS) of the same area. Lisein et al. (2013) used UAV to create a regression model based on metrics extracted from a Canopy Height Model (CHM) generated from airborne laser scanner (ALS). A fixed-wing UAV equipped with a VIS-RGB GR Digital III camera considered for the collection of 441 NIR images within 36 plots of 1018m2 in an uneven-aged broadleaved forest dominated by old oak and sessile oak located in Belgium. Floris et al (2012) have discussed the application of UAV for stand volume estimation in the Italian forest. The authors have employed a hexacopter equipped with a VIS-RGB 550D camera to capture high resolution orthophotos in an approximately 8 ha wide forest compartment, composed by spruce fire, Scots pine, Austrian pine, larix, and sporadic broadleaf trees, located in the northeast of Italy. The same as the previous study, CHM derived from the photos used as base for creating a regression model in order to estimate the stand volume. In another case for UAV application, a multisensoral UAV has been developed for detailed mapping and modelling of trees in Finland (Jaakkola, 2015; Lin et al, 2011; Jaakkola et al. 2010). The UAV, which had a helicopter platform, was equipped with two German laser scanner, which were Lux and LMS151. The study was carried out on a Scots pine forest located in the southwest of Finland and the drone were flown manually without systematic altitude and route. The authors used the variable extracted from the laser returns to estimate the diameter of breast height (DBH, which is a standard method of expressing the diameter of the trunk of the tree at the height of 1.4m) and to generate the multitemporal point cloud for demonstration of the biomass change of a coniferous tree. In Australia, some researcher employed the UAVs for the inventory management and stand estimation (Wallace et al. 2012; Wallace et al. 2016). In the rest of the world, many researcher operated the UAVs for monitoring the tropical forest recovery (Zahawi et al. 2015), measuring in broadleaf canopies (McNeil et al. 2016) and bush fire identification (Ghamry et al. 2016; Yuan et al. 2015).

All above works have conducted the aerial photography by operating the UAVs over canopy and creating regression model to estimate the trunk volume. These studies are limited to identifying the resource availability. However, there is an information gap on the resource quality in terms of diameter. In addition, the diameter of the stem throughout the trunk from DBH to top is missing. This study will investigate the capability of flying drone under canopy within the coupe to provide the accurate information about the trunk and increase the value chain through improving the forest inventory for plantation eucalyptus. Currently, to do stem estimation, our industry partner selects few trees and cut them down to measure the diameters of the log throughout the trunk from stump to crown. This method is risky, time consuming and destructive. However, in this study we aim to measure the diameter of each tree via aerial imaging with UAV and 3D stereo camera.

2.2 Case study

In Figure 2, the general workflow is shown, the input parameters are in green, while the single workflow steps are in yellow and will discussed in the followings. Flight planning and Geo-referencing are the first steps in aerial image capturing with an UAV platform. The area under investigation is planned in the lab with google earth and the required ground sample distance is identified. The regulation to fly drone under 2 kg is checked with Civil Aviation Safety Authority (CASA) and the industry partner (forest grower). It is important to consider the limitation on flying drone in specific area. For example, the flight can be operated if the area of interest is at least 5.2 km from air-strips, helipads, controlled zones. In addition, an evaluation of the known Wedge tailed Eagle nests within proximity for the area under investigation should be undertaken. This is because to avoid potential bird strikes especially during the breeding season (July to January). As we are aware birds will view the use of a drone as a potential threat and regardless of the time in the season have been shown to attack this equipment. There is inherently more probability of this occurring during certain time of the year and within the breeding season. As a result to limit the probability of an incident and without formal management direction, the use of a dedicated spotter tasked with bird observation is a recommendation to limit both possible damage to the drone and disturbance of breeding eagles.

A quadcopter UAV with the payload of 500g is designed using a 3D printing technology. On-board stereo camera and GPU enabled computer are used for localisation and 3D mapping and collision avoidance.

With respect to the study area and the processing chain the following requirements of the UAV-platform will be investigated:

a. Capability of starting and landing within the forest through the coupe under canopy
b. Flying from the DBH height to the highest possible altitudes close to the canopy.
c. Ability of performing small meshed flight patterns.
d. Integration and of laser scanner, evaluation of laser based, image based or combined point cloud in forestry application.

A UTAS developed UAV will be used with a Stereo Camera to collect the 3D point cloud data. Data will be collected at full rate and evaluation will be done for required data rates.
Flight pattern will be designed to evaluate the optimal parameter of the flight:

- distance to the tree trunk (3D stereo camera optimal range depend on the camera baseline, for the camera we use 10cm baseline gets good depth up to 5m)
- vehicle speed / camera shutter (those has to be coupled with light condition to make sure sharp images are produced)
- flight pattern (based on required measurements and performance of the entire system, a flight pattern has to be evaluated)
- use of the laser scanner - if measurements only at certain heights will be sufficient then 2D laser scanner mounter in horizontal plane could be effective.

All the above will contribute to produce good quality 3D point cloud that can be used for measurements.

Typical 3D model acquisition is performed in 3 steps (Figure 1):

i. Mission Planning

During that phase, a forestry plot is selected with suitable for UAV flight, any required permissions are appropriated. General flight path is created with sufficient coverage to generate 3D model. A stereo camera depth perception is limited to certain range in front. Depending on the distance between cameras (camera baseline) the stereo matching algorithm can reconstruct depth between minimum and maximum distance. The camera we use is good for 1 to 6 meters. This range must be taken under consideration when planning flight path.

ii. Sparse 3D Model Acquisition

The Flight is performed in Collision Avoidance Assisted mode. The forest environment is visually complex and challenging for Collision Avoidance and Planning Algorithms. For that reason, a pilot controls the UAV in Position Stabilised mode or monitor the UAV in Autonomous Mode.

During the flight, a sparse 3D model is created onboard of UAV (Figure 2). This is streamed down to Ground Station for immediate feedback. The UAV is using Visual Inertial Position Estimation to provide precise position and orientation information for each image set collected. The Stereo Matching algorithm then recover depth for each pixel on the image creating a point cloud. The point clouds are then inserted into map using the position and orientation information.

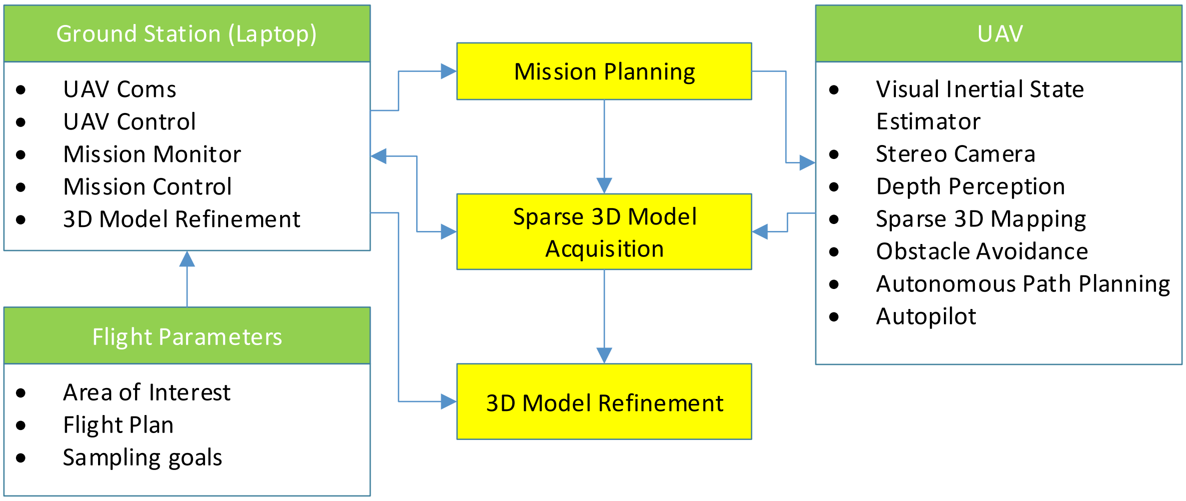

Figure 1 Typical acquisition and processing pipeline for UAV 3D Model

iii. 3D Model Refinement

During the flight, the position and flight path is constantly refined using Loop Closure algorithm. It analyses features in the image and can recognize previously viewed features. This information is used to re-localise the UAV within the onboard map correcting drift from State Estimator.

This cause the sparse 3D Model to be inaccurate. In the future flight, the updated path will be used to recreate the model with better precision.

iv. Model validity

Model validity, testing and sensitivity analysis are all carried out in regard to the UAV. Model validity has been used based on (Torresan et al. 2016). The field officer conducted testing over a period of 4 to 8 week in the lab and sensitivity analysis has been refined by series of trials.

3 Preliminary Conclusions and Next Steps

The study described the activities of one of the theme program of the ARC Industrial Transformation research hub as one of the three themes of the new ARC Centre for Forest Value that focus on the transformation of business practices and performances through the deployment of the innovative technologies. This work also presented in more detailed one of the ongoing projects of this theme as a case study for disrupting the forest inventory to increase the value chain using aerial photography with a quadcopter UAV. The UAV has been designed in the lab, tested and flown over a plot of 400 m^2 within a Tasmanian eculayptus nitens plot. The preliminary result shows that poor image network overlap could be obtained if the drone is flown in manually mode. This leads to the lack of accuracy of the image scale.

In the next step, we are implementing 3D sparse model generation onboard of UAV, this will allow for immediate feedback on the quality of the model. The generated 3D model must be evaluated for its accuracy and precision under different lighting and fly pattern conditions.

Forest is a challenging environment for UAV flight, there are many small obstacles and a challenging light conditions. We propose to supplement the vision based 3D model with laser scanner which is immune to lighting condition. Laser generated 3D point cloud is more accurate and can penetrate small gaps to reach the tree trunks.

Further, the level of autonomy can be increased by implementing algorithms to detect tree and autonomously plan efficient flight pattern for accurate model.

More broadly, the research program of this theme will continue to innovative and anticipates delivering even more tangible value to industry partners over the next 12-24 months.

Figure 2 the three image views of a eucalyptus niten taken by a 3D stereo camera mounted on a drone

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