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Integration of GNSS in harvesters as a tool for site-specific management in plantation forests

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TABLE OF CONTENTS

1 EXECUTIVE SUMMARY

The primary goal of the Future Forests Research (FFR) harvesting research programme is to realise substantial gains in productivity and reduce the cost of harvesting on steep country by introducing improved harvesting technologies that are more productive and cost effective than existing equipment. The secondary goal is to remove workers from the hazardous tasks of manual tree felling, breaking out and unhooking.

The specific aim of project Task 3.2 in the FFR programme is to investigate innovative technologies through a programme of international technology watch projects, and to inform future harvesting research projects such as integration of multiple functions.

Innovation is not only finding and developing new technologies, but also taking full advantage of what we already have available. One example is the integration of harvester head software and Global Navigation Satellite Systems (GNSS). While both of these tools/technologies have been used to manage harvesting operations, study environmental impacts of these operations, assess harvesting machine performance, and estimate total biomass from forests, there are still many opportunities to take advantage of integrating these technologies.

A possible application of such technology is the generation of forest productivity maps that can help us to recreate with a high level of detail the characteristics of the forest across the terrain. Having a detailed productivity map could serve as a means of understanding variations across sites, and exploring the possibility of site-specific management. This is a concept widely applied in agriculture that begins with understanding the variations across the area. Integrating harvester head software and GNSS provides a method that, compared with using LiDAR and manual ground methods, is a reliable and low cost source of information for forest productivity mapping. This method does however require validation to establish the level of accuracy, a clear procedure for the method, and determine the costs involved. Another clear opportunity is to use the information for managing harvesting systems, including automatically capturing productivity data as it relates to stand and terrain factors such as piece size, extraction distance, and terrain slope.

The aim of one project in the FFR programme was to investigate the applications of geospatial information for mechanised harvesting. The project commenced with a comprehensive literature review on the benefits of capturing GNSS information and integrating the data with data from tree harvesters. Analysis of the potential benefits of these precision forestry concepts was conducted, and a work plan for further FFR research work was developed.

2 LITERATURE REVIEW

Modern harvesters are equipped with computers capable of collecting and storing a great deal of data of stem measures, harvesting production, and machine parameters. This data is automatically collected by the measurement system in the harvesting head, GNSS receiver (when available), harvesting directives and records of operator's decision (Möller *et al.* 2011). This is potentially an invaluable source of information for management, control and improvement of forest operations. However, it is not a fully utilised resource for harvesting operations, forest management, and research. This information is all recorded under a de-facto standard called StanForD (Standard for Forest Data and communication) used by all major manufacturers of cut-to-length (CTL) machines across the world (Arlinger & Möller, 2007). Furthermore, Strandgard (2011) described other developments to assess machines' performance (productivity, geographical position, and utilization) based on tracking their location by using GNSS and data loggers recording additional information entered by the operator and data gathered by the machine's system.

Based on this capacity to generate information (in the machine or an external attached system), research has been conducted in order to evaluate machines' productivity (Folegatti, 2010; Gerasimov *et al.,* 2012; Strandgard, 2011; Strandgard *et al.,* 2013; Taylor *et al*., 2006) and the accuracy, and therefore reliability, of that information (Andersson & Dyson, 2001; Eggers *et al*., 2010; Moller & Arlinger, 2007; Walsh, 2012). In addition, some research has been conducted on site productivity or yield mapping using two different methods – one, using an optical sensor installed in a feller buncher to measure the butt diameter of the trees and Light Detection and Ranging (LiDAR) technology to determine tree height in a Full Tree (FT) harvesting system, and the other by measuring manually all the trees in a trial stand (Taylor *et al.,* 2006).

2.1 Accuracy and errors in harvesting measurement system under StanForD

Some studies showed variable accuracy in the measuring system (for length and diameter) in harvesters under StanForD among different machines, due to a lack of proper use of the measurement system, infrequent calibration and incorrect programmed targets (Andersson & Dyson, 2001; Plamondon, 1999). It has been suggested that these errors, among other factors, are causing loss in value recovery when compared with optimal bucking solutions (Boston & Murphy, 2003). Marshall *et al*. (2006) found a significant value loss, ranging from 3% to 23%, attributed to measurement errors comparing harvesting bucking simulation with an optimal bucking solution.

Over time, research has proved the system to be acceptably accurate, precise (within a low margin of error), and therefore reliable (Moller & Arlinger, 2007; Ulrich *et al.*, 2010). Eggers *et al*. (2010) found no difference between the harvester and manual method to optimise value recovery for pine sawn timber production in South Africa; they also found no effect from stem branchiness, forked trees, stem diameter and tree breakage on the system measuring accuracy. In addition, the capabilities of the machine's software (system) when compared with tree length systems was found to be a better option for value recovery in logging operations (Hamsley *et al.,* 2009). Nieuwenhuis and Dooley (2006) found acceptable accuracy in length and volume estimation of saw logs (within 5% of manual measurements in eight out of nine check runs) from harvester measurement.

Another factor affecting the accuracy, or the perception of the accuracy, of the harvester measurement system is the assumption that manual measurements are the true value and logs are regular in shape. Strandgard (2009) questioned this assumption, quantified the manual measurements errors, and suggested simple techniques to minimize their influence. Therefore, to keep the system reliable and useful, good operating practices were found to be key factors. These practices included: daily accuracy check, quality control, good maintenance, and most importantly regular calibration (Makkonen, 2001; Conradie, 2003; Nieuwenhuis & Dooley, 2006; Strandgard, 2008; Strandgard & Walsh, 2012). In Sweden and Finland, procedures for regularly monitoring accuracy and certification have been created to ensure accuracy of the system (Arlinger & Möller, 2007; Möller *et al.* 2007). Moreover, to the authors' knowledge there is no research comparing harvesting measurements against more accurate ways such as scanning or gravimetric methods.

2.2 The use of GNSS to monitor machine performance

GNSS during the last three decades has proved to be a useful technology for tracking machines in forestry operations. Cordero *et al.* (2006) assessed machine productivity and utilisation in two different harvesting systems, namely CTL (cut-to-length using the harvester – forwarder system) and FT (Full-Tree using feller buncher – grapple skidder system). This was done by tracking machines with GNSS and using a Geographical Information System (GIS) that combined the machine's progress GIS layers with inventory grid based on plot samples. Berkett (2012) combined GNSS machine tracks with digital accelerometer registers for 22 different machines to evaluate the slopes on which machines were operating, and compared machine slopes with slopes from digital terrain maps. Folegatti (2010) used positional data from GNSS (integrated with a data logger) installed in a feller buncher to map harvest units, determine date and time of harvesting operations, and by fitting GNSS in a skidder, calculated travel distance. Once processed, this data was used to develop harvesting productivity models (Folegatti, 2010).

Many studies have been successfully carried out using GNSS to undertake time study of forestry machines (to measure utilisation and productivity), resulting in a cheaper option than traditional ground methods (Folegatti, 2010; Kopka & Reinhardt, 2006; Westlund & Jönsson, 2011). GNSS machine tracks have served also as a source of data to study environmental impacts of forest operations such as soil compaction (Cordero *et al*., 2006; McDonald *et al.*, 2002; Seixas *et al.*, 2003), and the delivery of sediment to streams from forest harvest operations on steep terrain (Bowker *et al.* 2010). New developments such as autonomous forest vehicles are being developed using GNSS technology with Real Time Kinematic (RTK) correction system for estimating position and path direction (Hellstrom *et al.* 2009).

2.3 Precision Forestry

The use of geospatial technologies in forestry machinery for research or management purposes is included under the term "Precision Forestry". This is a concept which originated in the United States in 2001 (Heinimann, 2007; IUFRO, 2006) and is now used by forest management and engineering professionals. Precision, according to these sources, refers to the use of computers, sensing technologies and other state of the art electronics to coordinate and control processes at spatial scale, and to manage temporal variability. This relatively new approach was first applied in agriculture and was known as Precision Agriculture.

Even though there is not a unique definition for Precision Forestry as a discipline, all those who have provided definitions agree that Precision Forestry is the use of modern technology such as computing, sensing, GNSS, GIS and data processing capability for sustainable site-specific management throughout all forestry activities (planning, control and operations), including processing and merchandising, whether for forest products, forest and environmental services and/or ecological values (Bare, 2001; Dyck, 2003; Heinimann, 2007; Kovacsova & Antalova, 2010; Sarre, 2001; Taylor *et al*., 2011). However, this term can also have a different meaning for people according to their expertise, vision and background (Dyck, 2003; Kovacsova & Antalova, 2010). Furthermore, Taylor *et al*. (2011), who have done several research projects in the field, mostly in forestry plantations, distinguished three main focus areas:

- The use of geospatial-information to support management and planning in forest activities
- "Site-Specific Silvicultural operations"
- "Advanced Technologies-coordinated harvesting, product evaluation, and transportation systems".

In this context, some authors have pointed out that precision does not necessarily mean accuracy (Farnum, 2001; Heinimann, 2007). While accuracy refers to a measure of what is believed to be reality (the true value of something), precision addresses the repeatability of results (the result should be the same each time it is measured or calculated), which can have error associated. Yield mapping based on a crop harvesting machine's measurement system (for example, grain flow sensors) and GNSS information is a current practice in agriculture. Moreover, it is frequently used as a tool for site-specific management practices in the subsequent cycles (crop rotations) such as fertilisation, density of seed, herbicide applications (weed control), and genetic material (i.e. variety) to be planted (Bongiovanni & Lowenberg-DeBoer, 2006; Zhang *et al.* 2002).

In New Zealand forestry the management unit in harvesting is traditionally the "harvest area", an area that can vary from a few hectares up to 70 hectares (Visser, 2014). There has been little emphasis on a site-specific management in forestry plantations, even though it is possible to obtain the site productivity information by harvesting trees with forest harvesters, since the information of each stem and each log (diameters, height/length, products assortment, volume) can be recorded automatically. In addition, the technology for site-specific management in silviculture of planted forests has been developed and used in some countries such as Brazil, Uruguay and the United States based on technologies and equipment used in agriculture and adapted to forestry machines for silviculture. These technologies include the use of GNSS guidance and quality control in soil tillage, GNSS-controlled equipment for application of herbicides in band or total area, fertilization in bands, total area or localized application, application of insecticides, and manual and machine planting. The use of these technologies also includes the management of the information generated, for example application maps, initial assortment and plant localization, and quality control (McDonald *et al.*, 2006; Taylor *et al*. 2002; Vieira *et al.*, 2012). However, there is no evidence of site-specific silvicultural operations based on geospatial data collected by harvesters.

2.4 The potential use of data from harvesters for site specific management

The majority of today's cut-to-length (CTL) harvesting machines and harvester head software (manufacturer computer) have the option to integrate a GNSS receiver. Research has shown that when equipped with a GNSS receiver, a harvesting machine can also record the stem position in the forest (Arlinger & Möller, 2007; Taylor *et al*., 2006). When machines are calibrated properly and frequently it is likely that this data will be more accurate than traditional inventories, which are based on plot samples (Gordon, 2005; CRC for Forestry, 2010; Murphy, 2010). This is because this data is a full enumeration (a census) of all trees and their correspondent measures, and their assortment, rather than a sampling in a given forest. In comparison, sampled areas vary from around 1 to 10% of the total area, depending on the heterogeneity of the forest and the desired accuracy (Goulding & Lawrence, 1992). Additionally, the direct costs of collecting data is reduced, since harvesters and processors can record all this information during the operation whether it is used or not.

A forest yield map with information of volumes and assortment at detailed level would therefore be a useful tool for research and decision making for the next rotations. Based on this information the variation in volume across the terrain (the site) can be evaluated and the more productive areas determined according to final stocking, geographical position, and seed origin. These spatial variations can also serve as a basis for site stratification according to productivity. Having this sort of stratification site evaluations such as soil sampling to further better understand forest productivity correlated to soil attributes can be determined. This knowledge can allow site-specific management in the forest activity. Ortiz *et al*. (2006) and Gonçalves (2012) working with *Eucalyptus* sp. plantations in Brazil and Vergara (2004) in an analysis of forest plantations in Chile (*Pinus radiata* (D.Don) and *Eucalyptus* sp.) have described the importance of variations in terrain (soil and relief) and their effect on plantation growth at the detailed level for sustainable and profitable forest management.

Tracking machine travel across the terrain with GNSS and linking this data to forest productivity maps and topographic maps allows the establishment of machine productivity patterns related to both terrain characteristics (relief, soil attributes) and forest characteristics (stocking, individual volume). Several studies based on ground methods have established significant differences in harvester productivity (expressed in m^3/hour) and hence cost related to slopes (Fernandes *et al*. 2013; Simões & Fenner, 2010), soil type (Malinovski *et al*. 2006), and individual tree volume

(Bramucci & Seixas, 2002; Burla, 2008; Heinimann, 2001). Assessing the micro level forest productivity variations can help forest managers and forestry researchers make the best decisions and define the most sustainable and profitable practices for the next rotation (such as fertilization, plantation density and most suitable progeny to be planted). Additionally, with that information it is possible to define, update or even improve site index analysis, productivity models and volume functions.

3 FURTHER RESEARCH WORK

3.1 Validation

The next step in this project is to validate precision forestry concepts in forest plantations using the integration of GNSS technology with harvester head software. These concepts include micro-level stand management and automated machine costing and benchmarking, as well as improved forest management and research processes. The potential results of this project will provide information for planning the next rotation based on the data collected at time of harvesting. Figure 1 shows graphically the opportunity (timing) of taking advantage of this technology over a 60-year period (which roughly corresponds to two forest rotations in New Zealand). The figure presents detail for the one year period at Year 30, when the first rotation is harvested and the following one is to be planted.

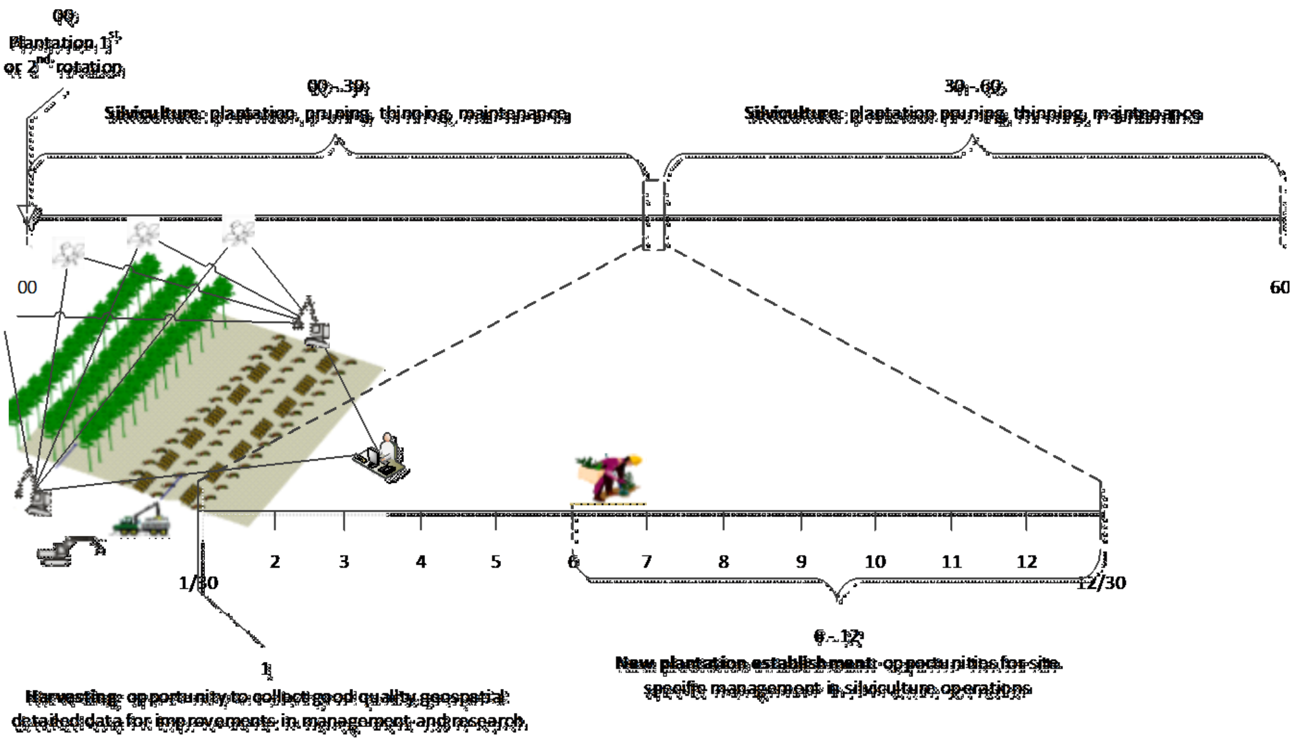

Figure 1: Sketch diagram of the project concept showing the opportunities at harvesting time for forest management improvement.

Therefore the aim in this project is to evaluate the usefulness of integrating GNSS in forest harvesters (harvesters head software) in forest plantations as a technology platform to collect forestry plantation information and its geospatial location at the harvesting time to allow site-specific management and research, and automated machine costing and benchmarking.

It is planned to achieve this goal by completing the following specific tasks:

1. Generate yield maps (volume, assortment and value) to assess site productivity patterns and establish their interrelations with site characteristics such as slope aspect, position in the terrain, and stocking at a detailed level.
2. Assess machine productivity patterns at a detailed level and establish interrelations between:
    a. productivity and site characteristics such as slope (aspect and inclination);
    b. productivity and stand factors (stocking in stems per hectare and individual tree volume).
3. Evaluate the cost and potential benefit of collecting and processing this information for forest management and research purposes.

3.2 Development

For developing yield maps, assessing site productivity and machine productivity patterns the following stages are proposed:

1. Gathering information at harvesting time by using harvester on-board computer and on-board GNSS. At this stage, equipment required is:
   - Harvester equipped with on-board computer (software) under StanForD.
   - On board GNSS receiver with external antenna.

2. Obtaining digital cartographic information of the areas where the field work will be carried out:
   - Digital elevation model (DEM) or topographic (contour) maps. Desirable 1-2m resolution, because previous research concluded that less detailed resolution is not adequate to determine the real machine slope (Berkett, 2012).
   - Soil classification maps.

3. Obtaining digital forest information of the plantations to be harvested within the project framework. This includes at least:
   - Pre-harvest inventory data (species, sampling methodology, plot locations, stocking, predicted assortment, etc.);
   - historical stand records (year of planting, thinning and pruning history); and
   - stand maps.

4. Processing this data using both GIS and statistical package.

Figure 2 presents a conceptual diagram of the project's inputs, intermediate stages and outputs.

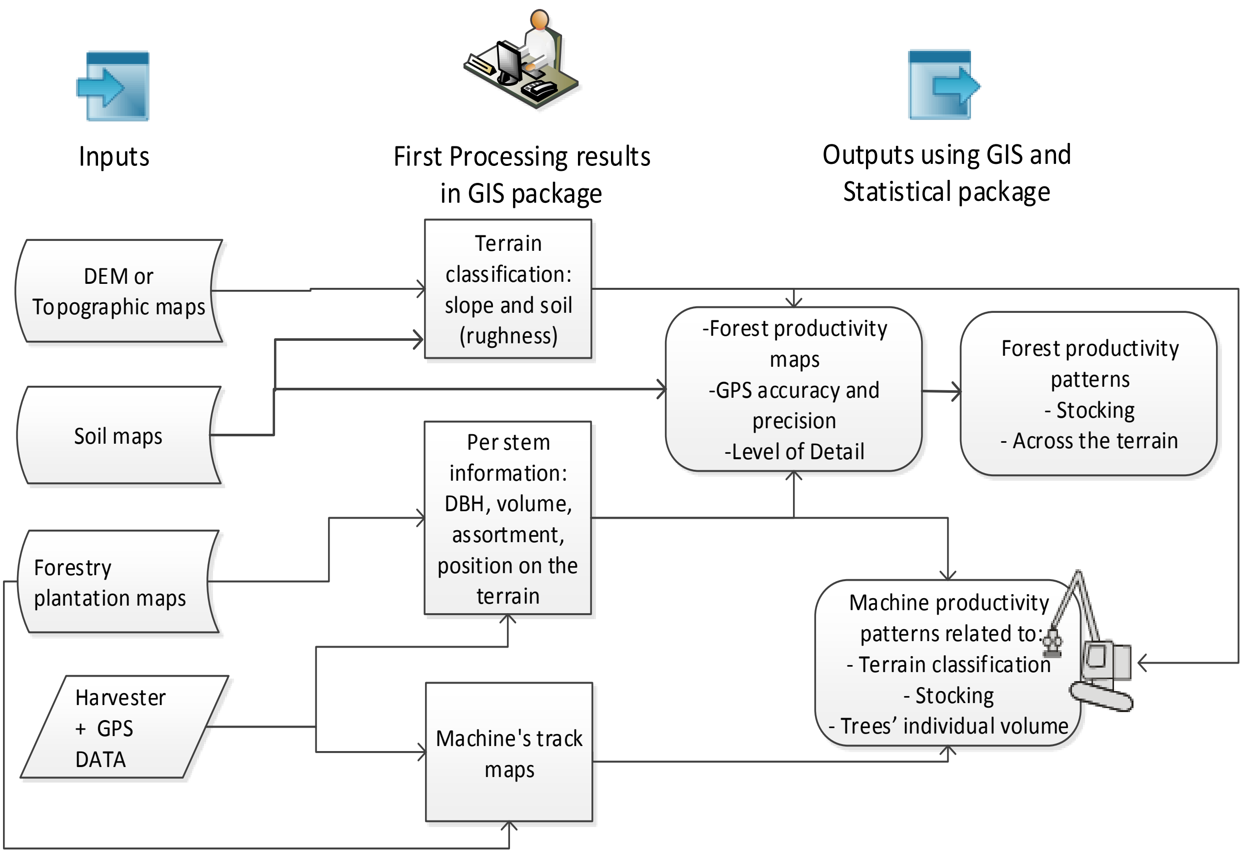

Figure 2: Conceptual diagram of the project

The fieldwork itself requires a series of initial tasks:

- Setting up equipment and machines: installing and programming GNSS.
- Training: machine operators and other staff members involved in the project.
- Pre-testing and validation: checking computer information with manual ground-based data, analysing a set of data from a small trial area in order to check the procedure and manage incidentals.

The fact that the GNSS device is installed in the machine's cabin will affect the accuracy of tree location data because the distance between the harvester head and the cabin varies constantly during the activity. This determines an associated error for tree location, and will limit the resolution of the information. The extent of this error will be addressed in the study.

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