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Future Harvest: what might forest harvesting entail 25 years hence?

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Abstract

A review of current literature offers a basis for forecasting some future trends in forest harvesting. It is likely that major gains will be achieved through closer integration between informatics and harvesting technology. New sensing technology will allow harvesting machines to better optimise both vehicle movements and handling of harvested material, and to provide comprehensive inventory of the residual stand and of soil data to assist management of the residual forest. Such speculation about future harvest possibilities is important to foster planning and research. Industry-wide agreement about data protocols could facilitate development and adoption of new technologies.

Introduction

The jubilee issue of the *Scandinavian Journal of Forest Research* sought to review the past 25 years and to forecast the next 25 years of forest innovation in several subdisciplines (Hannerz 2010a,b). Amongst other reviews, Nordfjell *et al* (2010) offered a comprehensive review of the past 25 years of harvesting research and machine development in Scandinavia, but confined their forecasting to mechanical aspects of forest machinery. However, it is likely that the greatest strides will be made not through mechanical enhancements, but through development of new and better sensors (Murphy 2010) and better use of information to empower 'smart harvesting' (Vanclay 2009). Evidence in support of this contention is offered by sawmills, which have made great strides in efficiency and throughput largely through better use of information (scanners, optimizers, etc). Thus this paper seeks to review possibilities, suggest actions, and stimulate the better use of information in forest harvesting. Others have examined broader issues of forest production systems (Toppinen and Kuuluvainen 2010), so this paper is confined narrowly to potential gains that may be achieved through the integration of harvesting and information technology. Such speculation is important because (as the Cheshire Cat said in *Alice in Wonderland*) 'if you don't know where you're going, any road will take you there', and in that spirit this paper canvasses possible directions, desirable directions, and concrete steps that the industry may take.

The context

While it is difficult, if not impossible, to forecast the next 25 years in harvesting technology, it is possible to identify some trends that may shape future options. Foremost amongst these are global concerns about carbon, and the need to reduce fossil emissions and increase biosequestration. In addition, population increase will increase pressure on land, through competing land uses and increased demand for forest products, demanding greater production efficiency (Bennett and Balvanera 2007). Safety of forest workers and hence the management of fatigue and job satisfaction will remain paramount (Lilley et al 2002). Gustafsson et al (2010) questioned the future of clear-felling, and predicted an increase in continuous-cover-forestry (CCF; Pommerening and Murphy

2004), which may influence the design of harvesting machinery, much of which is designed for clear-felling rather than for CCF operations. CCF is likely to present a wider range of stem sizes, and to complicate the felling task through directional felling and the need to avoid damage in the residual stand. Nilsson et al (2010) predicted the greater use of "site-specific regeneration methods" supported by "ground-based or airborne sensing systems and knowledge of past regeneration success at the site". These are just some of the issues that will shape the future of forest harvesting.

The possibilities

Harvesting is a special time during the management cycle of forests because harvesters traverse most of the forest (thus offering opportunities to gather data) and generate revenues (thus offering an efficient point in the discounted revenue stream to make investments in forest management). Harvesters also incorporate many sensors, and have the potential to carry additional sensors with little impediment. In time, sensor and robotic developments will offer the possibility to assess forest stands faster, better, and cheaper. These sensors may be embedded within the harvesting machine, or may enable remote support services including robots that scout ahead, teleoperation that enables off-site guidance, and autonomous shuttles that deliver cut stems to roadside stockpiles.

Autonomous harvesting machines appeal because operator wages consume some 30-40% of the hourly cost of a forest machine (Hellstrom et al 2009), but the complexity of the tasks limit the prospects for a fully autonomous harvester (Billingsley et al 2008). However, there are opportunities for robotic support of harvesting. A lightweight autonomous scout (on wheels, or in the air) could precede a harvester to identify obstacles, map the optimal route, and suggest the optimal felling direction for each stem, thus leading to efficiencies for the expensive harvesting machine. Teleoperation may allow flexibility in vehicle design as well as safety and efficiency (Billingsley et al 2008, Hellstrom et al 2009). And autonomous shuttles appear both practical and efficient (Hallonborg 2003, Heinimann 2007). Such robotic teamwork has been demonstrated in other agricultural enterprises (e.g., Johnson et al 2009, Hansson and Servin 2010).

It is useful to consider three aspects of sensors that could support harvesting operations: the aerial components of the stand at the time of harvest, the potential harvest, and the ground (including subterranean biomass and soil properties). These are considered in turn.

Harvest attributes: Harvesting heads routinely gather data about the stems being cut and trimmed, and butt diameters and stem taper are used routinely to optimise bucking (Acuna and Murphy 2006; Marshall et al 2006). Other data that could be obtained from the harvesting head includes stem mass using load cells, acoustic velocity to gauge mechanical properties (Carter and Amishev 2010), and near infra-red or other spectral analysis of sawdust to gauge physical and chemical properties of stem wood (Acuna and Murphy 2006). Such data could better inform real-time decisions about optimal use, and thus influence bucking and handling decisions. Palmer and Vanclay (2009) established that relatively small amounts of data are needed to make useful inferences about tree attributes for simulation purposes.

Above ground forest attributes: Laser scanning has become fast and precise (Murphy 2008), and it may soon be feasible to incorporate a laser scanner in a lightweight autonomous scout or atop the harvester, allowing continuous scanning of the forest stand to reveal tree and stand properties (Pratihast 2010). An advantage of a scanner mounted on an autonomous scout is the ability to utilize multiple viewpoints and to process data before the harvester reaches the tree. Laser scanning could reveal detailed stand structure including the relative dominance, crown spacing, crown mass, branching and stem straightness of trees within the vicinity of the harvester (Murphy et al 2010), potentially informing harvesting decisions, such as whether or not to cut at this time, and suggesting the best direction in which to fell each tree.

Soil and below-ground attributes: Increasing land-use pressure will drive production forestry onto more difficult sites and demand greater efficiencies, so harvesting may become more site-specific. Under some conditions, demand for biomass may lead to uprooting rather than cutting of trees where soil conditions are suitable. In other cases, site conditions may warrant greater retention of roots and more careful monitoring of soil compaction. Sensors monitoring vehicle vibration and traction may be able to infer soil strength, and thus infer the risk of compaction (e.g., Han et al 2009), and provide data to guide future regeneration efforts. Ground-penetrating radar may allow assessment of soil depth, windfirmness, organic matter, and carbon content (Stover *et al* 2007).

Integrating information and operations: Gains from such machine-based data-gathering will be greatest when integrated and applied in real time, allowing optimal tree-by-tree decisions about whether to harvest (given potential products, prescribed silviculture and likely growth), how to handle (optimal bucking), and where next to direct the machine. At present, much forest management is directed on a block-by-block basis, but with better information forest management could be applied on a tree-by-tree basis with optimal decisions applied for each tree (Weintraub and Romero 2006, D'Amours et al 2008). This creates the possibility of negotiations between the harvesting machine and the central planning facility akin to the harvesting machine asking automatically "These trees are smaller than expected; should I relocate elsewhere in this stand?"; "These trees have very thin crowns; should we vary the harvesting prescription?" and "I may be causing unacceptable soil compaction; can I move uphill to drier soils?". It is even possible that the harvest and this negotiation will occur automatically by a semi-autonomous harvesting machine with minimal intervention by the driver.

Nordfjell et al (2010) reflected on the bundling of branchwood for use as bioenergy, but implied off-site use of this material. Advances in biomass-to-liquid technology may soon allow for on-site diesel manufacture, so that forest residues can be converted on-site to biodiesel, leaving biochar and nutrients in the forest and providing a heat source that may be used to partially dry logs to reduce green mass before transport (Lerou et al 2010, Knochen et al 2010). If this development comes to fruition, it will create additional options for on-board optimization in the harvester to secure the most profitable and environmentally-benign product allocation. It is likely that the harvester will sort material on-site into biofuel material (that may be processed on- or off-site) and sawlog and other material for export from the site. It is conceivable that biofuels will be made on-site, and that waste heat from this process may be used to dry logs to reduce the mass of wood transported. It may be that biomass sorting is optimised dynamically, taking into account the expected traffic congestion, product demand and fuel prices.

This section on possibilities is speculative, and except where referenced, should be considered science fiction. Such speculation, like brainstorming, is an important step in formulating visionary strategies (Hollins 1999, Saul 2002) – but it is equally important to take careful consideration of the likely reality.

The likely reality

All the options canvassed above are already feasible, but may not yet be possible in real-time or with the current financial situation. However, advances in sensor technology and processing power will make these possible and routine sooner than we may expect. Who anticipated, 25 years ago, the developments in portable computers, in mobile telephony, and in other consumer technology such as USB-memory, ipods, touch-screens, global positioning systems, and digital cameras with face-recognition? One lesson from the past 25 years is that sensors and software develop faster, better and cheaper than most of us anticipate. Nonetheless, most of the suggestions above will come to pass, and in time, will be cheap enough to be cost effective, probably sooner than we expect. It is likely that only 90% of these speculations will come to pass, but it is difficult to anticipate which of these predictions will not succeed. It is also likely that the timeframe will be much shorter than anticipated, and that most of these developments will appear within a decade rather than within 25 years.

These technologies all may assist in optimising forest management for the best environmental and production outcomes. The question then is whether they would be used, if they were available and affordable? It is likely that in time, the purchase cost will be no longer be a barrier, and the question of affordability will relate to the maintenance and reliability of the instruments rather than to the purchase price. Another possibility is that operators may employ this technology not to increase profitability, but to demonstrate adherence to environmental regulations and to company guidelines. In either case, it is likely that much of what appears to be science fiction today, will turn out to be routine tomorrow.

The way forward

If these technologies are going to become available and useful, what can we do to ease the transition and to help realize them more quickly and efficiently? One important difference between forest harvesters and fast-evolving consumer electronic appliances is the sales volumes involved, so collaboration rather than competition between vendors may be warranted, both within the forest sector and more broadly with other agricultural activities. One of the challenges will be the large volumes of data involved, and it is likely that agreement on a standardized open-source data structure may facilitate progress and foster input via decentralized efforts (such as PhD projects). Many resources will be developed outside the forest sector, and wide inter-sectoral collaboration will facilitate early uptake.

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