USING GPS TO EVALUATE PRODUCTIVITY AND PERFORMANCE OF FOREST MACHINE SYSTEMS

by

Steven E. Taylor
Associate Professor
Biosystems Engineering Dept.
Auburn University
Auburn, AL 36849-5417
staylor@eng.auburn.edu
Voice: 334-844-3534
FAX: 334-844-3530

Timothy P. McDonald
Research Engineer
USDA Forest Service
520 DeVall Drive
Auburn, AL 36849-5418
tpmcdonald@fs.fed.us

Matthew W. Veal
Graduate Research Assistant
Biosystems Engineering Dept.
Auburn University
Auburn, AL 36849-5417
vealmat@eng.auburn.edu

Ton E. Grift
Assistant Professor
Biosystems Engineering Dept.
Auburn University
Auburn, AL 36849-5417
tegrift@eng.auburn.edu

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ABSTRACT

This paper reviews recent research and operational applications of using GPS as a tool to help monitor the locations, travel patterns, performance, and productivity of forest machines. The accuracy of dynamic GPS data collected on forest machines under different levels of forest canopy is reviewed first. Then, the paper focuses on the use of GPS for monitoring forest harvesting and site preparation equipment. Finally, the paper discusses future trends in precision forestry for intensive forest operations.

INTRODUCTION

The Global Positioning System (GPS) is being used in an ever-increasing array of applications for managing forests and our natural resources. When used on mobile forest harvesting machines, data collected from GPS and additional external sensors can improve forest engineering design and management decisions based on machine performance data as a function of terrain and timber stand variables. Applications employing GPS capabilities are being developed for use in site preparation, planting, and managing intensive culture plantations. Many of these applications stem from the successful integration of GPS into “precision agriculture”, which can be defined as managing crop inputs, such as fertilizer, herbicide, etc. on a site-specific basis to reduce waste, increase profits, and maintain the quality of the environment. Developments in GPS technology and precision agriculture are readily adapted to problems in forest operations, particularly in intensive forest production systems. This paper will review recent work at Auburn using GPS as a tool to help researchers and practitioners measure performance and productivity of forest machines. Also, future trends for precision forestry in intensive forest management will be discussed.

ACCURACY CONSIDERATIONS IN GPS MACHINE TRACKING

Before discussing applications for GPS machine tracking, it is important to understand the accuracy of dynamic GPS data collected in forest conditions. Most previous studies on GPS accuracy under a forest canopy were concerned with static positions. Spruce et al. (1993) used a typical mapping-grade GPS receiver and measured relative accuracy of travel patterns and velocities of a tractor operating in open sky and forest canopy conditions. They reported that GPS successfully tracked machines under open sky conditions; however, under forest canopies there was a major decrease in accuracy.

Veal et al. (2001) further quantified accuracy of GPS position data collected on wheeled skidders. Two different commercially available GPS receivers (12 channel Trimble ProXR and six-channel GeoExplorer II) were used to track wheeled skidders under different canopy conditions at two different vehicle speeds (5.4 kph and 9.1 kph). Three different courses were established in a loblolly pine plantation under different forest canopy density conditions: open canopy (0% crown cover in a recent clearcut), light canopy (57% crown cover in a heavily thinned area), and heavy canopy (85% crown cover in a lightly thinned area). While the skidders traversed each course, locations of the tires were marked. Traditional optical surveying techniques were used subsequently to determine the actual tire track locations. These actual vehicle locations were compared to the GPS machine paths to determine errors.

Maps from data collected by both receivers showed general travel patterns of the skidders; however, as canopy density increased, more discontinuities and irregularities were observed in GPS maps, especially for the GeoExplorer II. These discontinuities were attributed to multipath effects and to receivers switching satellite constellations. Figure 1 shows mean position errors in GPS data collected by both receivers under different canopy conditions. Position accuracy showed a decreasing trend as the canopy changed from open to heavy. For example, mean 3D position errors for the ProXR were 1.26 m, 1.77 m, and 3.76 m, for the open, light, and heavy canopy conditions, respectively. It is important to note that some of these errors are similar to the width of the machine. Tests conducted before and after deactivation of Selective Availability showed little differences in differentially-corrected GPS data. Finally, the machine speeds tested did not significantly affect accuracy of GPS positions for either receiver type.

These results indicate that researchers or practitioners need to be cautious when relying on GPS to track forest machines in heavy forest canopies. For general knowledge on where machines travel, many mapping-grade GPS receivers, when using differential correction, will probably be sufficient. However, for more detailed studies of travel patterns or environmental impacts at specific points (e.g. soil compaction studies), typical mapping grade receivers may not have the level of accuracy needed. For detailed studies that require sub-meter or sub-centimeter accuracy, more sophisticated hardware and firmware will be needed.

USING GPS TO MONITOR FOREST MACHINE SYSTEMS

Several recent research efforts have been aimed at learning more about performance, productivity, and site impacts from forest harvesting machines and from site preparation equipment by using GPS to monitor machine movements. Traditional methods of studying machine productivity and site impacts required researchers to work in close proximity to machines to observe and videotape activities and travel paths of the machines and people. These labor-intensive methods pose safety problems for personnel involved in the study. To alleviate these problems, GPS receivers can be mounted on each machine of interest to determine travel paths and velocities of machines during operations. Additional sensors and data acquisition equipment also can be installed on machines to record information on machine functions or performance. Using these types of data allows researchers to quantify and model productivity or potential site impacts of individual machines or the entire machine system.

Background

McMahon (1997) used a GPS-based system to evaluate site disturbance of tree-length harvesting systems by mapping paths of harvesting machines, then transforming the data to calculate area disturbed by machines. Thompson et al. (1998) used GPS to map the movements of tracked skidders in southeastern Australia. They produced maps of skid trail networks and measured traffic intensities (in terms of number of passes) over the network. Also, they estimated the time that the machine was performing each of six different machine cycle elements. Reutebuch et al. (1999) tried to determine time study data using GPS receivers on a feller buncher, a hydraulic shovel, and a tracked skidder. Machines were monitored so cycle distances and times could be calculated. Due to apparent large position errors (occasionally over 100 m), travel distances could not be calculated accurately. Stjernberg (1997) used the commercial Silvitracs system to map movements of site preparation equipment and develop coverage efficiency data for the equipment.

Estimating Harvesting Impacts from GPS Machine Tracking

In work at Auburn, McDonald et al. (1998a) developed a method to use GPS tracking data to determine the area impacted by a machine as it traveled over a site. The method, which was similar to one presented by McMahon (1997), used pairs of x,y position data to represent sampled locations of a machine, then assumed that machinery moved linearly between adjacent location samples. These x,y pairs were transformed into a map showing how many times the machine passed a given location. Final output of the transformation was a raster map, with cells in the raster having a value equal to the number of times the object, or machine, passed over a particular location in a rectangular region.

The model was tested initially by using data collected from a rubber-tired skidder working in part of a clearcut harvest. Several features of the harvesting operation were discernable from the mapped paths: the deck or landing, the delimbing area, the main skid trail, and the return skid trails. They noted that the receiver type made a significant difference in the apparent accuracy of the maps. Although they did not conduct any detailed position error determination, they concluded that overall the calculated travel patterns matched the true machine movements closely enough for stand-level assessments.

In a later study, McDonald et al. (1998b) and Carter et al. (2000a) used the same methods to map the travel paths of feller bunchers and skidders over an entire harvest tract. The output from this study was a traffic map of cumulative totals of traffic intensities and their distribution in the tract. Figure 2 shows the traffic intensity map resulting from this study. They found that 25 percent of the stand received no traffic, 25 percent received more than five tire passes, and 50 percent received one to five tire passes. When visual disturbance assessment methods were compared with GPS estimated traffic intensities, the visual methods overestimated the presence of heavily trafficked areas. They noted that the GPS-based method was superior to the traditional methods because it was less time consuming and presumably more accurate.

Carter et al. (1999, 2000a, 2000b) presented detailed results of the soil physical responses measured during the study introduced by McDonald et al. (1998b). They assessed the impact of traffic intensity on spatial variability of soil physical properties by measuring changes in the properties at select points that corresponded to estimated traffic intensities within the harvest tract. They found that bulk density and cone index responded to increased traffic intensities and achieved peak values after a limited number of passes. This ability to compare detailed data on traffic intensities with soil strength properties would not have been possible without integration of GPS into the impact assessment process.

Harvesting Machine Tracking – Automated Time Study

The machine tracking work begun by McMahon (1997) and McDonald et al. (1998a, 1998b, 1998c) was extended to facilitate time and productivity study of harvesting machines by McDonald (1999) and McDonald et al. (2000a, 2000b). The system to develop time study data solely from GPS position information was implemented using two components: 1) a feature extraction sub-system to identify characteristics of a machine path, given some site-level information, independent of the type of machine being tracked, and 2) an event processor that applied machine-specific knowledge to combine characteristic movements and sub-events into operational functions. The intention was to develop a system that incorporated no domain-specific knowledge and was therefore useful to analyze the functional performance of any type of machine where movement and position were important factors in its operation.

McDonald et al. (2000a) conducted further research using GPS for unattended time study of grapple skidders. During field operations, a time study was conducted by researchers using traditional methods. The GPS data were reduced to movement-defined events, then movement events were combined into machine functions, and elemental times (travel loaded/empty, delimbing, positioning and grappling) were determined. For gross time study measurements, the data acquisition system performed well, recognizing over 90 percent of the time elements. The average difference between total cycle time estimated from the GPS data and the manual time measurements was less than 3.5 percent. Skid distances determined by the GPS-based machine functions were significantly higher than those measured on the ground. Some of this distance discrepancy was attributed to additional movements recorded by GPS during grappling and delimbing that were not measured by typical manual techniques.

Elemental time study was also possible, but correspondence with manually-determined elemental times was not as precise. Travel empty and travel loaded times were close to observed clock times, but grappling times were subject to some large errors (in 25 percent of the cycles, grapple time was overestimated by nearly 100 percent).

These methods also have been applied to automating time study of wheeled feller bunchers (McDonald et al., 2000b). In addition to collecting GPS position data, a field computer in the machine monitored the states of two switches that indicated feller buncher activity: 1) cutting a tree as indicated by micro switches on the foot pedals that controlled the felling head grabbing arm, and 2) felling head tipping as indicated by a set of magnetic switches mounted on the felling head linkage. Figure 3 shows a map of feller buncher movements across a study plot as well as the locations of tree cut and head dump events as indicated by the data acquisition system.

The system performed well in a gross time study, and for individual felling cycles the automated system agreed well with traditional time study methods. With more accurate information on the location of cut trees and with an additional system to measure tree size, it will be possible to measure yield across the site. Current work at Auburn is developing a tree diameter sensor that can be mounted on wheeled feller bunchers. Also when the locations of the bunches are known, it may be possible to optimize skidder performance by routing skidders to the nearest bunch.

Site Preparation Machine Tracking – Time Study

Additional research has focused on defining the productivity of mechanized site preparation equipment, such as plowing and bedding and herbicide spraying operations. One example set of data is presented here for a broadcast site preparation sprayer. While the sprayer was operating, a GPS receiver recorded travel paths of the machine and times were recorded when the spray nozzles were turned on or off. The resulting map, in

Figure 4, shows areas missed or oversprayed. Productivity data from this type of activity can be used to plan operating procedures or to design machine features to make the operation more productive.

TRENDS IN MACHINE MONITORING AND CONTROL

The studies highlighted previously show just a few uses of GPS and data acquisition equipment as tools to help monitor the performance of forest machines. As data acquisition equipment manufacturers continue to offer more integrated GPS capabilities, engineers will be able to develop custom data acquisition systems to collect much more performance data as a function of machine location.

One of the most exciting areas of precision forestry, however, is in precision planning and implementation of forest operations. For example, today we are mapping tracts that need to be harvested and then planning optimal road layouts, deck locations, and harvest prescriptions. However, during future harvests, we should be able to map the locations and sizes of felled trees (i.e., yield maps) and then send these data to skidding or forwarding machines to help optimize performance and minimize site impacts. From these data, we have the potential to develop reforestation plans that minimize site impacts, soil erosion, machine costs, etc. While these operations take place, we can guide site preparation plows, sprayers, or tree planters. For sprayers or fertilizer spreaders, we have existing technology to control pumps and spray nozzles to prevent overspray and to apply appropriate amounts of inputs. For mechanical site preparation, GPS can help operators steer machines (or GPS systems can steer them) so that beds or subsoiled rows are placed on contours to minimize erosion. With new communications technology, we will soon be able to monitor forest operations remotely and be more responsive to changes in market or weather conditions. This can result in further integration of forest production, procurement, and product manufacturing, which in turn may facilitate more stable inventories and reduce external pressures on the wood supply.

SUMMARY

Using GPS as a tool to help monitor performance or productivity of forest machines is becoming more widespread. Several studies focused on using off-the-shelf GPS hardware to track forest machines and determine site impacts and machine productivity. This research successfully developed the methodology to determine number of machine passes over the terrain and to determine machine functions based on GPS travel patterns and additional sensors. At the same time, researchers quantified the position accuracy from using current GPS hardware to track machines moving through the forest canopy. In some cases where detailed soil samples or other site specific data are needed, more sophisticated GPS equipment may be required. However, for general machine tracking for productivity studies, typical mapping grade GPS receivers are sufficient.

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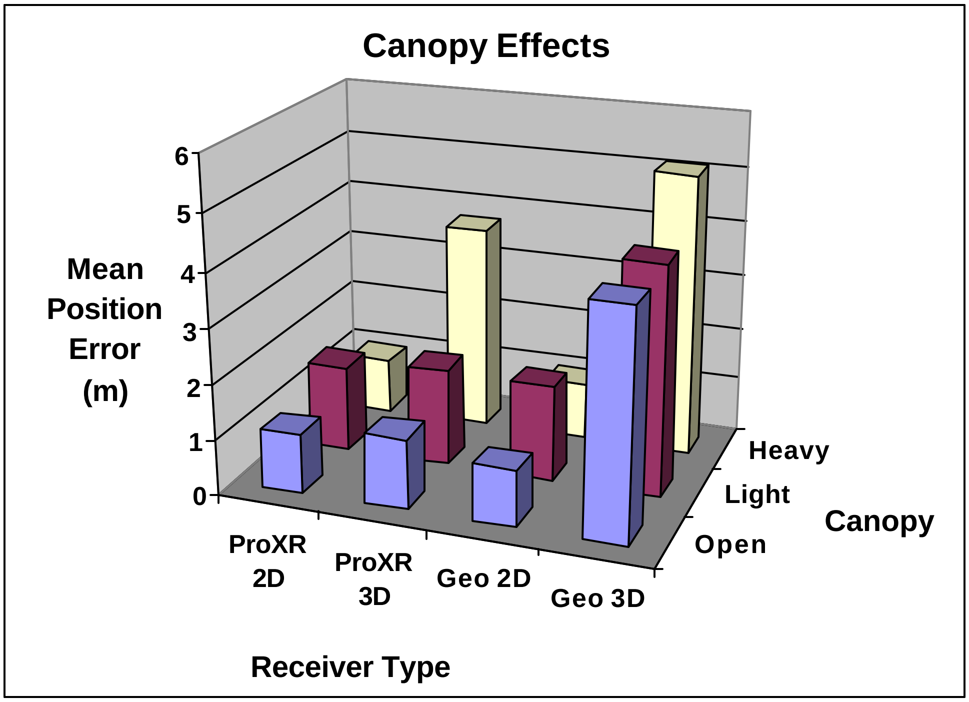

Figure 1. Mean dynamic GPS position errors for different canopy conditions. From Veal et al. (2001).

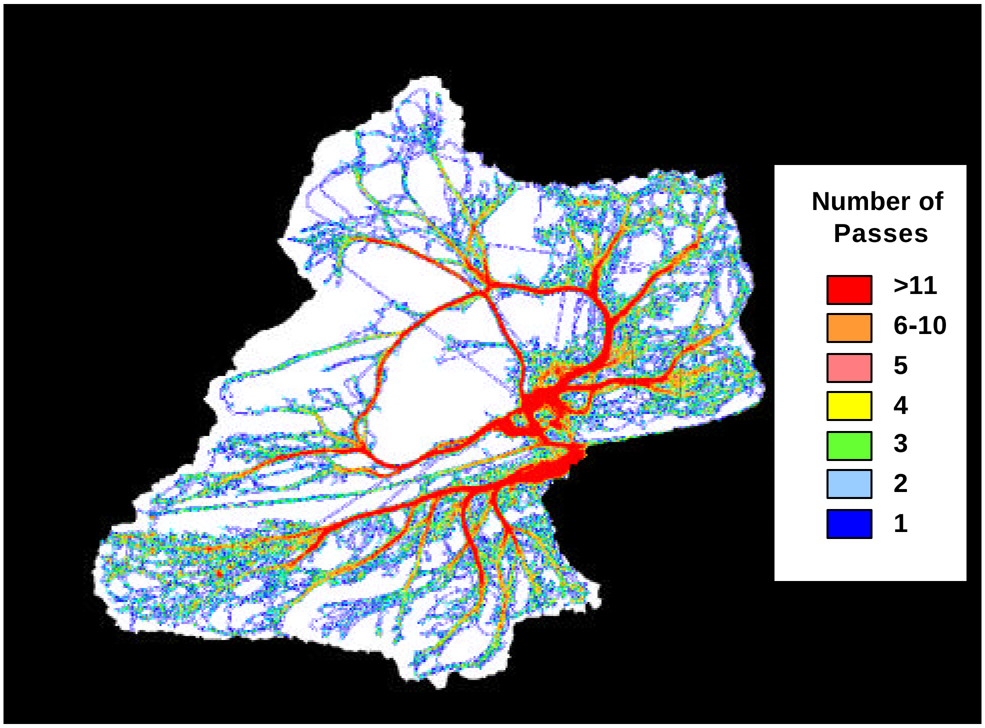

Figure 2. Harvest traffic intensities (number of vehicle passes indicated by colors) monitored by GPS during a clear-cut harvest of a loblolly pine plantation. From Carter et al. (2000a).

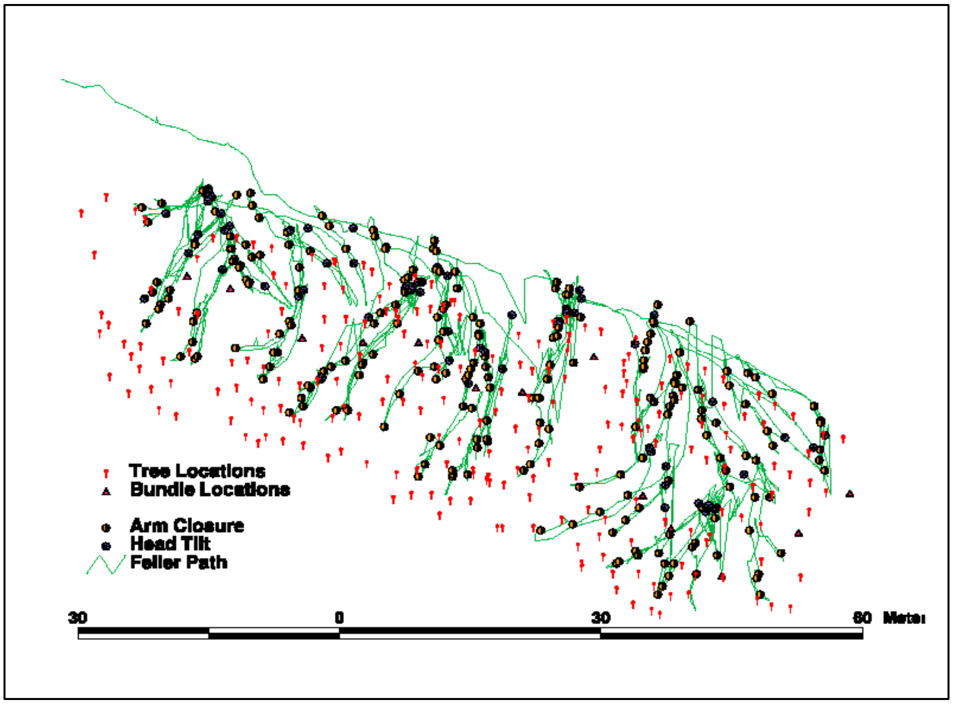

Figure 3. Map of feller buncher movements during harvest operations. From McDonald et al. (2000b).

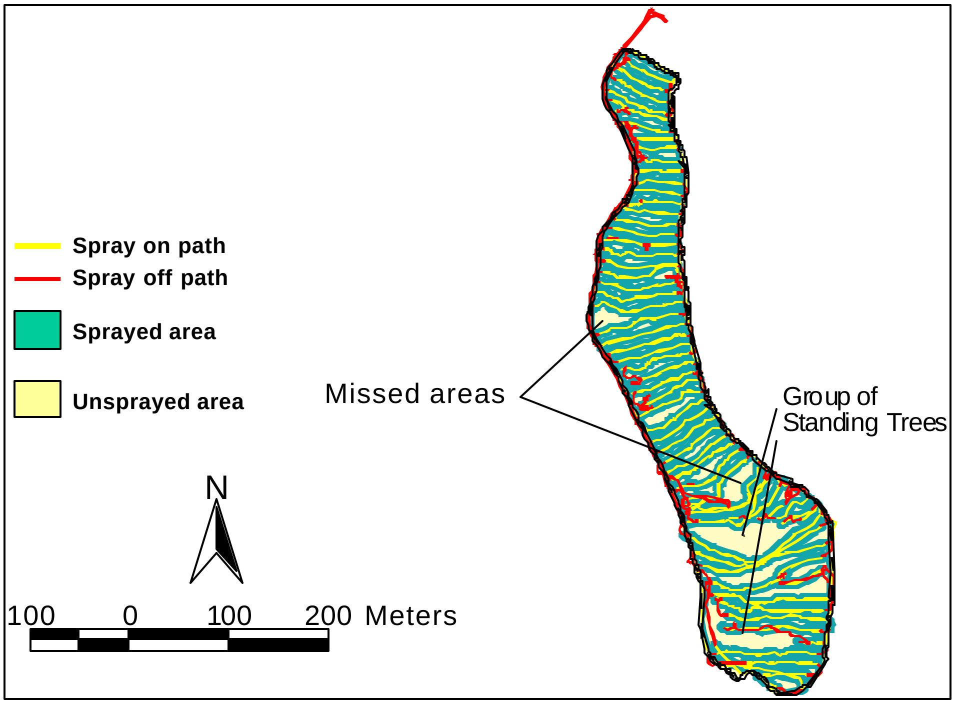

Figure 4. Results from tracking a site preparation sprayer while broadcast spraying herbicide.