Advantage

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Contents



# GPS-based navigation using ArcPad: implementation and sample applications

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**Abstract**

FERIC evaluated a GPS navigation system based on the ArcPad software in various forestry applications. This report provides guidance on the choice of components and how to integrate them to meet specific needs, and discusses operator training and data preparation. The trials described in the report include navigation of an excavator during a drainage operation, navigation of a single-grip harvester in multi-treatment harvesting, and navigation on foot (road location, etc.). ArcPad worked well, and shows considerable potential in forestry applications. Low-cost navigation systems based on this software offer (among other things) cost savings and the ability to perform tasks that would not be feasible without this technology.

**Keywords:**

GPS-based navigation, ArcPad, Forestry operations, Operational trial.

## Introduction

To help our members take advantage of the considerable potential of GPS-based navigation in forestry operations, FERIC conducted trials in the summer of 2001 to evaluate ESRI's ArcPad software in various navigational applications. This research was part of our ongoing efforts to identify affordable navigation systems. ArcPad is compatible with most GIS systems currently used in forestry, and has all the qualities required of a navigation software. This report provides guidance on the implementation of a GPS-based navigation system that uses ArcPad as its software, and describes the results of our trials.

## System components

This section of the report describes the recommended components and characteristics of a navigation system based on the ArcPad software, as well as the preparations necessary beforehand. A typical navigation system comprises three components: the software (ArcPad), a computer, and a GPS receiver (with optional use of DGPS corrections).

### ArcPad

The ArcPad software is designed for capturing field data, but also permits GPS-based navigation. In navigational mode, it receives positional data and various other attributes from a GPS receiver, filters this data based on predefined criteria, then displays only positions that meet these criteria. The software uses the "shapefile" (vector) format and can display georeferenced images (.jpg format). Thus, ArcPad lets users display a base map to assist navigation and lets them update data on the map or in the attached database.

File-manipulation utilities can also be added to ArcView. For example, data-entry forms can be created with the Dialog Designer extension (version 5.1). Version 6.0 of ArcPad also offers the ArcPad Studio module, which lets you customize the software environment (e.g., add or remove buttons). ArcPad costs around $750 and can be used with Windows 95, 98, 2000 (NT), or CE, but not yet with Windows XP.

ArcPad works in point, line, or polygon mode, and can record a "Tracklog" file that includes all the GPS data (e.g., position, PDOP, and time). While navigating a machine, operators should continuously record and display the machine's position so they can track the progress of their work and orient themselves with respect to the trails they have already created. This can be done by recording a line on the map or by activating the recording and display of the Tracklog data. The latter solution seems to work best, since all the GPS data are recorded and the operator has fewer keys to manipulate.

Currently, ArcPad does not automatically orient the displayed map to match the user's direction of travel, but this did not bother the operators during our trials. In addition, the software performs no data smoothing, but does use filters (e.g., for maximum PDOP) to eliminate certain errors and display only positions that meet the predefined criteria. Moreover, certain GPS receivers can themselves eliminate errors such as large multipath effects.

We recommend purchasing version 6 of ArcPad (or a more recent version), since version 5, which we used during certain trials, caused various problems. In addition, ArcPad 6.0 lets you set the radius of the pointer that represents the receiver's position on the screen, and this feature is useful in several applications. For example, the size of the pointer radius used on a single-grip harvester can be set to the minimum prescribed distance between trails to help the operator respect this spacing. Similarly, when flagging a 30-m buffer zone around a stream, displaying a 30-m-radius pointer lets the user align the end of the pointer with the stream's contour during flagging.

## Computer

### Onboard computers

An *onboard* computer should resist vibration, shocks, contaminants (e.g., grease, oil, dust), temperature extremes, and moisture, and should be sufficiently compact to fit within the limited space in the cab. The computer should be relatively fast so as to avoid delays in displaying data, which could decrease productivity, particularly during a change in map scale. The computer should be capable of running one or more of the various operating systems mentioned above. However, although Windows CE computers are often inexpensive, they generally have smaller screens, lower data-recording capacity, and slower performance. Look for the following additional characteristics:

- A screen integrated with the computer is preferable to an external screen because there are fewer cables to disconnect when you uninstall the computer; this lets you easily remove it from the machine to avoid theft or vandalism.
- We suggest installing a touch screen within reach of the operator and modifying ArcPad to arrange the buttons optimally, since it can be difficult for operators to accurately press buttons on a vibrating machine. If you don't use a touch screen, an easy-to-control joystick represents another option.
- A color screen is preferable when several "themes" (e.g., treatment types, exclusions) must be displayed. The screen should be legible both in sunlight and at night (depending on the application), and should have a range of brightness levels. An active-matrix screen lets the operator view the screen without having

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to sit directly in front of it. The screen should also work at temperatures below 0°C. Only certain screens meet these criteria, particularly for color screens. Screens that possess all these characteristics are generally expensive, but the additional cost is justified by the benefits they provide.

Select a rapid means of downloading the recorded data. "PC Card" storage capable of holding several megabytes of data represents one of the better solutions if your office computer can read these cards. Traditional 3.5-in. diskettes can also be used, but limit data storage to 1.44 megabytes; given that a Tracklog file for a single day can easily contain more than 2 megabytes of data, we recommend using PC Card storage instead.

Carefully secure the cables from the computer, the antenna, and the GPS receiver so they won't interfere with the operator. These cables must also be protected and equipped with quick-connectors. In addition, the computer should be solidly mounted in the cab. If it must occasionally be removed from the machine, plan for this during the installation. The computer should connect directly to the machine's master switch to reduce the number of times it must be rebooted as a result of stopping the machine. Thus, the computer should only stop running when the master switch is turned off or the operator decides to shut down the computer. A backup battery can help prevent unintended shutdowns of the computer. To protect the computer and the GPS receiver, we also recommend using a voltage regulator. If you use a high-intensity color screen, turn off the computer during long pauses in operation (several hours), since these screens consume considerable power.

FERIC's trials of onboard navigation used a Kontron computer with an external color screen. This high-quality screen could be read both in sunlight and at night. However, this computer cannot be used at temperatures below –20°C.

**Navigation on foot**

For *navigation on foot*, the computer needs to be rugged, water-resistant, and resistant to temperature extremes. Moreover, it should be compact and light, should have a battery life of at least one full day, and should come with a carrying case or harness to free up both of the user's hands. The screen should be integrated so as to reduce the number of cables, and should be legible in sunlight and at night. If an integrated physical keyboard is not available, the computer should provide a touch screen with an onscreen keyboard.

"Tablet" computers can also be used. These have a relatively large screen, but weigh more. Data-capture computers designed for field use (e.g., those manufactured by DAP, Itronix, and Symbol) are yet another option. Whichever computer you choose, pay attention to the operating system it uses and the processor type; ArcPad won't run on all processors capable of running Windows CE.

Our trials of navigation on foot used a Compaq iPaq handheld computer that wasn't really suitable for forestry use: it could not be used at low temperatures, was not waterproof or dust resistant, and was insufficiently rugged. In addition, the connection with the GPS receiver was too easy to disconnect, and the batteries only permitted 1 to 2 hours of continuous work.

## GPS receiver

Choose a GPS receiver that transfers its data in the standard NMEA exchange format. However, other formats specific to certain receiver manufacturers can also be used (e.g., TSIP for Trimble). The choice of GPS receiver depends primarily on the required accuracy. An accuracy of 5 to 15 m can be obtained in absolute mode, versus 1 to 3 m with real-time corrections. The quality of the receiver itself can also affect accuracy. For example, in absolute mode, a Garmin 12XL receiver provides an accuracy on the order of 5 to 15 m, versus 2 to 10 m with a Pro XR (Forgues 2000).

To take advantage of real-time DGPS corrections, confirm that these corrections are available in your area and can be captured. Currently available correction services include those provided by the Canadian Coast Guard (along navigable waterways) and satellite communication services such as Landstar. For the latter services, nearly any obstruction (e.g., dense cover) or topographical relief (e.g., cliffs or mountains) can block the signals. A new, free satellite correction service called CDGPS will become available in Canada in 2002, but will be subject to the same limitations as Landstar (obstructions and topography). Corrections can be captured directly, using a radio, or indirectly, using a signal repeater to retransmit the signal over short distances at difficult locations. A repeater can also be used with other sources of corrections, but working under more constraints. FERIC expects to test the use of repeaters once CDGPS becomes available.

The GPS receiver can include an integrated corrections demodulator and antenna (e.g., Leica's GS5 and GS5+, Trimble Navigation's Pathfinder Power), or can use a traditional receiver (e.g., the Pro XR or March II-E) with an external demodulator (e.g., the MBX-3 or ABX-3 from CSI Wireless, Trimble Navigation's Beacon-on-a-Belt).

When the GPS receiver will be *mounted on a machine*, carefully plan the locations of cables and how to protect them; the position, attachment, and protection of the antenna itself (which should be mounted near the machine's axis of rotation); and the connection between the receiver and the machine's battery.

For *on-foot navigation*:

- The batteries should last at least one full day, or should be easy to replace in the field.
- The receiver should be light, since a computer will also be integrated with the system.
- The connectors and the cables should be rugged.
- Transport should be via a backpack or harness if necessary.
- The antenna should attach to the user's hardhat or to a short mast. With an external DGPS corrections demodulator, a second antenna must often be attached.

## Training

Brief training is required before using ArcPad. The training should include instructions on how to turn the computer on and off, its operation (e.g., management of files and data), and any expected problems and potential solutions. Operators who perform data transfer must be familiar with the procedure so as to avoid data loss. In addition, with data entry from a keyboard, operators must learn how to use the physical or onscreen keyboard.

Ensure that the operator is comfortable launching and using ArcPad. Our trials demonstrated that for best results, users must learn the importance of map scale and its implications for accuracy. The larger the map's scale, the more accurate the position displayed on the screen. Thus, before beginning any work, you should define the minimum scale that the operator will use. ArcPad can also measure distances on the screen, and you should demonstrate this feature; it was one of the features that users appreciated most during our trials. Note that certain software, such as SRO's Event Manager, can automate some procedures (e.g., the activation of ArcPad from startup to the recording of data) to facilitate the work.

## Data

Preparation of the base files is also important. Typically, GIS files are enormous, thus you should extract the data required to do the work using ArcView. Any additions should be done at this time to facilitate the fieldwork. For example, if a stream must be flagged on foot, it would be wise to display a buffer zone along the stream so users need only follow the edge of this zone. It's also wise to reconnoiter the site before the operations to do a GPS survey of any exclusions and access roads, and to resurvey streams or other elements that will be critical for navigation. These data can subsequently be adapted (e.g., by the addition of buffer zones) and imported into the onboard system of the machine that will do the work, thereby eliminating the need for flagging or the need to rely on the operator's subjective judgment. For example, during one drainage trial, a stream had been poorly mapped, and the expected work failed to respect the regulations for the minimum buffer distance between the work and the stream. The operator himself had to determine where the work should stop, but if the stream had been accurately surveyed beforehand using GPS, this problem could have been avoided.

## Trials

Our studies tested ArcPad in three types of navigation applications that called for systems of different accuracy and operating characteristics. These applications were the *navigation of machinery in absolute mode*, the *navigation of machinery using Canadian Coast Guard DGPS corrections*, and *navigation on foot in absolute mode*. Although our results are specific to the conditions and configurations in our trials, we have presented them here as an indication of the potential results that can be obtained.

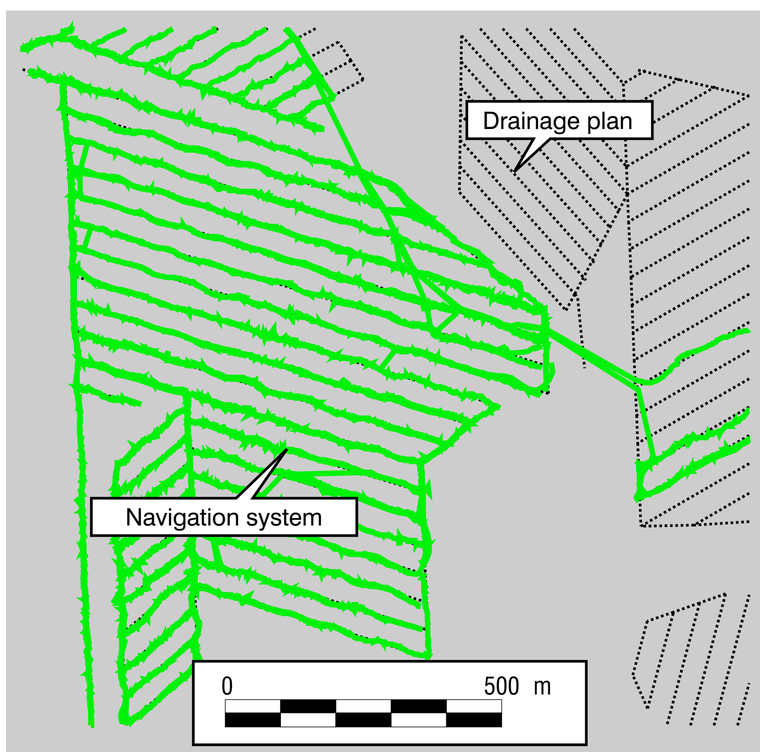
### Navigation of machinery in absolute mode

In our study of the *navigation of an excavator during drainage work*, the navigation system comprised the ArcPad software (version 6 beta), a Kontron computer with an external color screen, and a Trimble Navigation SveeEight GPS receiver (Figure 1), working in absolute mode without real-time corrections or post-processing. The operations took place in a spruce stand with tree heights ranging from 2 to 10 m, a high stem density, and flat terrain. To perform the work, a drainage plan was defined and displayed by ArcPad. No advance flagging of the ditches was done, except for a small area in which flagging was done using a compass and hip chain to permit a comparison of the results. The excavator operator dug the ditches following the predefined plan.

After the drainage work was complete, we performed a GPS survey of a sample of the ditches created using the navigation system and of the part performed using only flagging. A Leica GS50 receiver was chosen for this survey because of its accuracy under forest cover (Forgues 2001), and the data were post-processed. The predefined drainage plan was used as the basis for comparison in determining the navigation system's accuracy. Figure 2 presents

Figure 1. The navigation system using ArcPad.

Figure 2. (*bottom*) Extract from the map created using the navigation system.



part of the excavator's work assisted by the navigation system, along with the drainage plan.

Buffer zones of various sizes were added around the drainage plan so as to determine the percentage of the GPS positions surveyed by the navigation system that fell within these zones (Figure 3).

A visual comparison of the final ditch survey using the GS50 with the original drainage plan confirmed that the ditches had been accurately positioned using the navigation system, despite the lack of real-time correction or post-processing. This level of accuracy is better than what would normally be obtained over the long term during uncorrected GPS surveys, and in sustained use, lower accuracy should be expected. In addition, the drainage plan represented only straight lines, which are easier to follow than irregular routes, and the linear nature of the operator's work probably contributed to these good results. Note that because the distance between the ditches had to be at least 30 m, this value was set to a minimum of 35 m during the work planning to account for the expected GPS error in absolute mode.

The GS50 surveys demonstrated that the ditches dug following only the manual flagging averaged 15% longer than expected, and that their positions were offset from the planned positions (Figure 4). This probably resulted from the mode of flagging.

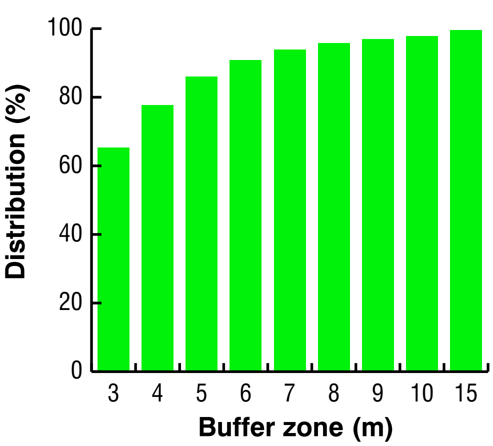
## Navigation of machinery using Canadian Coast Guard DGPS corrections

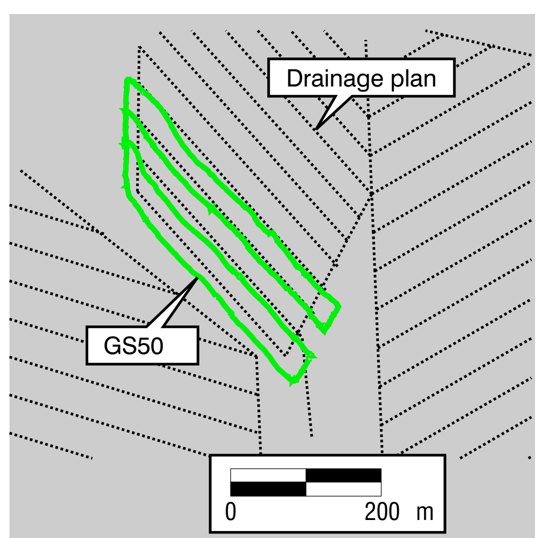
For *stand-level multi-treatment harvesting* using a single-grip harvester (Figure 5), the onboard navigation system comprised ArcPad (version 5), a Kontron computer with an external color screen, and a Leica Geosystems GS5 receiver (not the GS50) that captured Canadian Coast Guard DGPS corrections. Most of the operations took place in a fir stand, but some occurred in a spruce stand; both stands were on flat terrain. The height of the trees was around 15 m and stand density was average (classes B and C as defined by Quebec's Ministère des Ressources Naturelles). The study focused on harvesting with the protection of regeneration and soils (HPRS) and two levels of harvesting with the protection of small merchantable stems (HPSMS); these latter operations targeted the protection of stems 10 to 12 cm and 10 to 16 cm in DBH, respectively.

In this application, small areas normally had to be flagged to denote the specific treatment required. Different color flagging was used to distinguish these treatments, but the large number of colors complicated the machine operator's work. Often, operators had to climb down from the machine to identify the required treatment type, thereby decreasing productivity. The navigation system eliminated the

Figure 3. (*left*) Distribution of recorded positions within various buffer zones around the planned ditch locations.

Figure 4. (*right*) GPS survey with GS50 receiver of the ditches dug following the manual flagging.



need to flag the boundaries of each treatment area and helped operators to locate themselves. During changes of operators, the system also let the new operator see the progress that had been made and know exactly where to begin the new work.

For the 50 treatment changes noted during this trial, the positioning error averaged 4.9 m. In nine cases, the error was greater than 10 m. The sources of problems included the use of a display scale too small for the map because the operators didn't understand that a larger scale would have provided better accuracy. Despite this, the navigation system helped operators to respect the prescribed between-trail distances, particularly during night operations. With the system's help, occupancy of the site by trails was kept to around 20%.

During this trial, harvesting of the right-of-way for a future road was performed at night using the navigation system, with no prior flagging. Once again, the operator used a too-small display scale and part of the cut occurred a few metres offset from the planned road location.

## Navigation on foot in absolute mode

An on-foot navigation system was tested during *various flagging tasks* to determine its value. The system comprised ArcPad (version 5), a Compaq iPaq handheld computer, and a Garmin eMap GPS receiver. This low-end receiver was used in absolute mode, without real-time DGPS corrections or post-processing of the data.

After verifying that a permanent stream had been properly mapped, workers flagged its buffer zone using the navigation system. The GPS error was relatively low on this day, so the trial proved successful. However, because this error can vary greatly from day to day, it would be preferable to have access to real-time DGPS corrections during such work. In addition, some work had to be redone because the map scale used by the workers was too small, thereby decreasing the accuracy.

In another trial, the navigation system helped in surveying and flagging a future road during the road location crew's on-site verification of the ground before harvesting the right-of-way. Since the cut was to be performed by a single-grip harvester using a navigation system, flagging was done only at the start and end of the road. The navigation system let workers relocate part of the road in an area where the ground was too swampy. Such reconnaissance would normally have taken around 8 hours, but with the navigation system, it took only 2 hours. In addition, surveying the road by GPS during this reconnaissance allowed the new data to be transferred into the single-grip harvester's navigation system so the harvester could cut the right-of-way at night.

Our final trial compared the flagging of two polygons using GPS navigation and using the traditional approach (with a compass and hip chain). The latter method was considerably faster than the GPS-assisted flagging. With the GPS unit, the operator can only get oriented when the receiver is in motion; consequently, each halt requires operators to reorient themselves. Thus, whenever you stop to affix flagging, time is wasted because you have to start walking again before you can discover your new position and adjust your course based on the position displayed on the screen.

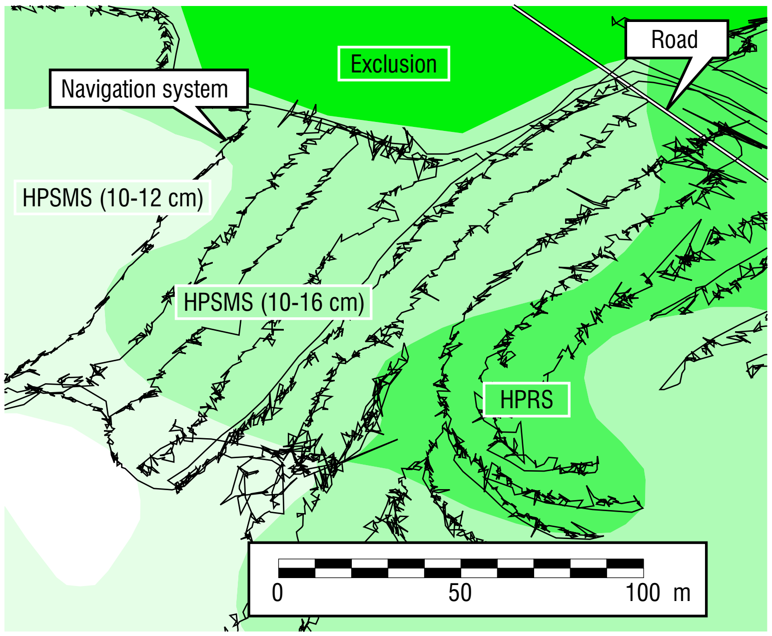



Figure 5. Excerpt of the navigation data from the multi-treatment harvesting operation.

## Implementation

Our study demonstrated that an on-board ArcPad-based system can effectively assist machine navigation in various contexts. However, the trials of navigation on foot demonstrated that using a navigation system won't necessarily be suitable for all flagging situations. For example, GPS navigation saved several hours of work during the reconnaissance of a road and during flagging of the buffer zone around a winding stream, but was less efficient than using a compass and hip chain during the flagging of a polygon with few sides.

Before obtaining such a system, carefully analyze your current and future needs. For example, if the current accuracy requirement is only 5 to 10 m, a low-end receiver can be purchased, but if you foresee using the system in applications that demand more accuracy, start out by purchasing a better-quality receiver that will provide the desired accuracy.

Our trials indicated certain advantages to using a navigation system, particularly on board a machine:

- *Saving time and money:* Certain flagging operations are no longer required, and time losses during field reconnaissance and finding areas are eliminated. Operators also have less ground-truthing to perform (Reynolds 1998).
- *Better performance and monitoring of work*: The multi-treatment harvesting operation could not have been achieved as efficiently without the navigation system. Various other techniques had been tried previously without success. In the drainage operation, the ditches were placed more accurately with the navigation system than with traditional flagging; in the latter case, the ditches were offset from the desired positions and longer than planned. In addition, thanks to the data files that are recorded, the status of the work is kept continuously updated.
- *Greater ease of meeting prescribed standards*: It was easier to respect the prescribed between-trail distances, particularly during night operations.
- *Safety*: Among other things, it's easier for operators to locate themselves, since their position is continuously displayed with respect to other terrain features. Dangerous areas such as cliffs can be displayed on the screen.
- *Improved monitoring of the work*: The work that has been completed can be seen at a glance; thus, it's easier to determine the amount of work remaining and plan accordingly.

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