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Precision Farming Tools: GPS Navigation

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GPS: Its Uses and Potential Are Growing

Global positioning systems (GPS) are widely available in the agricultural community. Farm uses include:

- mapping yields (GPS + combine yield monitor),
- variable rate planting (GPS + variable rate planting system),
- variable rate lime and fertilizer application (GPS + variable rate controller),
- field mapping for records and insurance purposes (GPS + mapping software), and
- parallel swathing (GPS + navigation tool).

For a review of the principles of GPS to locate specific field points, refer to this GPS Tutorial (Trimble Navigation Limited, 2008). GPS and associated navigation systems are used in many types of agricultural operations. These systems are useful particularly in applying pesticides, lime, and fertilizers and in tracking wide planters/drills or large grain-harvesting platforms. GPS navigation tools can replace foam for sprayers and planter/drill-disk markers for making parallel swaths across a field. Navigation systems help operators reduce skips and overlaps, especially when using methods that rely on visual estimation of swath distance and/or counting rows. This technology reduces the chance of misapplication of agrochemicals and has the potential to safeguard water quality. Also, GPS navigation can be used to keep implements in the same traffic pattern year-to-year (controlled traffic), thus minimizing adverse effects of implement traffic.

Use of GPS navigation in agrochemical application with ground equipment has grown rapidly, and commercial applicators are quickly adopting the tool. According to a 2007 survey of those who offered custom application (Whipker and Akridge, 2007), 82 percent applied at least some of the fertilizer/chemicals using a GPS navigation system with a manual-control/lightbar guidance system. Twenty-nine percent said they used a GPS navigation system with an auto-control/auto-steer guidance system for at least some of their custom application. On average, for all custom applied materials, 57 percent was applied with GPS lightbar, and 12 percent was applied with auto-steer GPS. GPS navigation has become standard practice for U.S. aerial applicators. Crop producers are also starting to adopt these systems, because GPS navigation is an excellent way to improve accuracy, speed, and uniformity of application.

Why are navigation systems important to field operations?

Automated guidance of agricultural vehicles (tractors, combines, sprayers, spreaders) has been motivated by a number of factors—most important is to relieve the operator from continuously making steering adjustments while striving to maintain field equipment or implement performance at an acceptable level. This is not surprising, considering the many functions an operator must monitor, perform, and/or control while operating the vehicle.

The requirements placed on farm-equipment operators have changed drastically with increases in equipment size, power, multiple equipment functions, and speed—as well as monitors reporting on specific system performance. These increasing demands on the operator can result in increased errors in function, costs, environmental problems, and operator fatigue.

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Foam markers, a widely used technology

Foam markers are the most common form of navigation aid used during fertilizer and pesticide application. The foam is dropped and used to align the applicator during the return pass. Foam markers utilize an air pump to pressurize a tank containing the foaming agent. The pressurized fluid causes the foaming agent to flow into an accumulating chamber. The foam collects in this chamber until the accumulated mass overcomes surface tension, causing a foam blob to fall to the ground. Most often the foam accumulators are placed at the ends of the applicator boom or, alternately, at the center of the applicator when booms were not utilized, as in the case with spinner-disk granular applicators. Equipment operators use the foam blobs left on the field surface as a navigation aid to know where the applicator has passed.

GPS + Navigation Aids

Relatively inexpensive navigation aids known as parallel-tracking devices assist the operators to visualize their position with respect to previous passes and to recognize the need for steering adjustments. These aids are commercially available in several configurations. One system is a lightbar (Figure 1), which consists of a horizontal series of Light Emitting Diodes (LEDs) in a plastic case 12 inches to 18 inches long. This system is linked to a GPS receiver and a microprocessor. The lightbar is usually positioned in front of the operator, so he or she can see the accuracy indicator display without taking their eyes off the field. The lightbar can be mounted inside or outside of the cab, and the operator watches the "bar of light." If the light is on the centerline, the machine is on target. If a bar of light extends to the left, the machine is off the path to the left and needs to be corrected. In like manner, if a bar of light extends to the right, the machine is off to the right.

Software allows the operator to specify the sensitivity to and distance between the swaths. Similar GPS navigation systems have been used for aerial application since the early 1990s. Also, the GPS system gives the current location of the implement and, with past traffic patterns, the computer interface provides the operator directions to maintain proper swath width to match adjacent traffic paths. If an operator leaves the field to refill the applicator or is forced out of the field due to weather, upon return, the operator can resume and maintain accurate swath widths, and over-spraying on previous sprayed areas is eliminated.

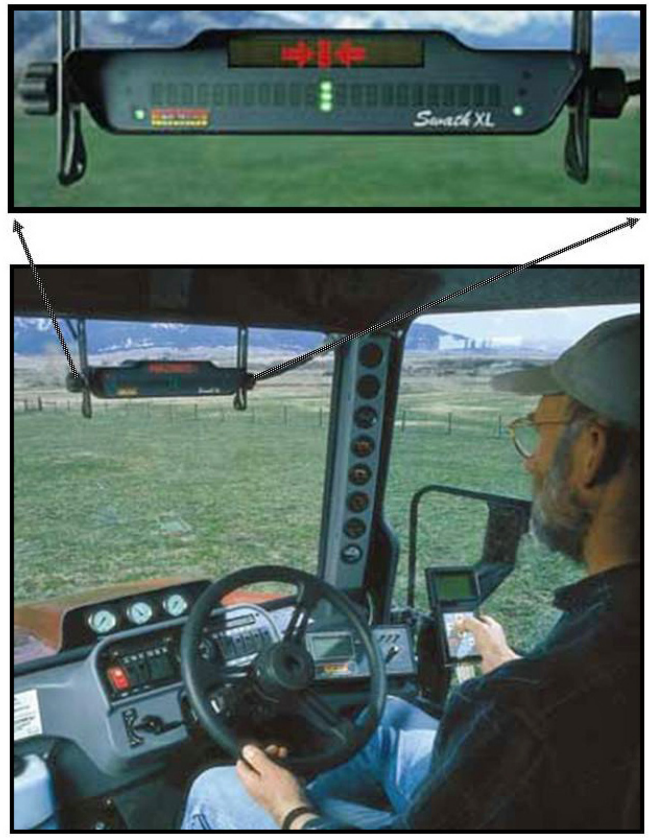

Figure 1. Lightbar navigation system mounted in cab and in view of forward travel.

More advanced systems have a screen showing the swath of the machine as it moves through the field (Figure 2). Early models only allowed straight-line parallel swaths, but current models are available for any contour traffic pattern. Areas covered with previous swaths are indicated on the screen. The advanced navigation system coupled with a variable rate spreader drive and software has the capacity to generate "as-applied" maps showing previous coverage and the application pattern. This provides an excellent record of the pattern and timing while operating in the field. Portions of the field that are not treated, such as wet areas, can be marked in the computer and stored for later operations when conditions permit application. All of this is done without having to physically mark the field area with flags.

GPS + Auto-Steer Navigation

More advanced navigation systems (auto-steer systems) possess similar capabilities as the navigation aids and also have the additional option to automatically steer the vehicle. Auto-steering is accomplished with a device mounted to the steering column or through the

Figure 2. Display screens for GPS navigation systems.

electro-hydraulic steering system. The accuracy level of these systems is based on the quality of differential correction and internal data processing: as the accuracy improves, the corresponding cost increases. These navigation systems are classified in three categories:

Submeter accuracy usually means approximately two feet to four feet year-to-year, and less than one foot pass-to-pass errors. The differential correction source could be from a Coast Guard beacon, WAAS (Wide Area Augmentation System), or satellite providers. These systems are relatively inexpensive (about $6,000 to $15,000) and can be used while performing tillage, some types of fertilizer and chemical applications, seeding, and harvesting. These devices can be easily transferred between vehicles, so the same steering system can be used on different vehicles. However, operations requiring highly accurate guidance are not feasible with submeter level equipment.

Decimeter accuracy provides approximately four inches to eight inches year-to-year and three inches to five inches pass-to-pass errors. This can be achieved using either a local base station or dual frequency receivers with private satellite differential correction subscription. With the increased performance, operators can use auto-steering during most of the conventional field practices. Prices range from $15,000 to $25,000 plus the satellite subscription (up to $1,500 annually).

Centimeter accuracy can be obtained by using a local base station with the real-time kinematic (RTK) differential correction. Both long-term and short-term errors (of approximately one inch) have been reported for these systems. Vehicles equipped with this high-level equipment can be used to conduct strip tilling, drip-tape placement, land leveling and other operations requiring superior performance—as well as virtually any other task. In addition to the ability to accurately determine geographic location, auto-guidance systems usually measure vehicle orientation in space and compensate for unusual attitude, including roll, pitch, and yaw (see "Additional Features" for definitions). The price ranges from $40,000 to $50,000 with no annual subscription fees.

GPS Navigation vs. Foam Markers

Potential advantages of GPS Navigation (GN) relative to foam markers for agricultural applications include:

- **GN is more reliable and more accurate than foam markers.** Using foam markers could cause about 10 percent of the field to be skipped or overlapped. With the GN, the skip and overlap rate drops to about 5 percent. Some tests have shown that with an experienced operator, the skip and overlap rate can be as low as 1.5 percent.

- **GN allows accuracy at higher speeds.** GPS navigation can attain a 13 percent to 20 percent higher speed than a foam marker (Buick and White, 1999). Naturally, an increase of speed is terrain dependent. If field conditions limit speed, then a GN benefit is unlikely.

- **GN is a possibility with spinner spreaders (Figure 3).** Foam markers are not generally used with spinner spreaders. The spreaders have no boom on which the foam equipment can be installed. Due to the spread width, a foam marker in the center of the machine path is difficult to see from the next swath, and the driver would still be using a visual estimate for the spreader swath.

- **GN is easy to use.** Anybody can learn to use GPS navigation systems, regardless of computer skills. The systems require only a little practice—typically about 30 minutes.

- **GN provides effective guidance over growing crops.** With solid-seeded crops, foam tends to fall through the canopy to the ground where it is almost invisible, contributing to skipping or overlapping. Crop height does not affect GPS.

Figure 3. GPS navigation system mounted in a spinner spreader.

- **GN allows operation when visibility is poor.** GN works at night, in dust, or in fog. This lengthens working time during critical planting and spraying periods. In many areas, nighttime is best for spraying because of low wind speed. Leaf orientation changes at night and herbicide may or may not be as effective as during daylight (check with local Extension specialists). Nighttime spraying of insecticides can protect sensitive bee colonies.

- **GN is less affected by weather.** In certain conditions such as low humidity, heat, and large fields, foam markers can be rendered ineffective. The foam can evaporate before the operator makes the return swath. GN works at any temperature, including low temperatures when foam systems freeze.

- **GN has lower recurring costs.** GN has no moving parts or tubes to clog. Depending on the manufacturer, software updates are usually free to system owners. Foam-marker systems require foam, dye, and tank cleaner.

The primary recurring cost for GPS navigation is satellite differential correction. Typically, the subscription costs $600 to $1,500 per year for each GPS unit. Many producers already have GPS for yield monitoring and may subscribe for differential correction. For them, GN has almost no recurring costs. In many areas of Virginia, it is possible to use the Coast Guard beacon or WAAS for GPS differential correction. These services are free and may be adequate for some applications, including dry fertilizer with a spinner spreader. Accuracy for spraying should be within six inches (10 centimeters); the GPS equipment supplier can provide information regarding the differential correction needs for a specific location. For more on GPS systems, review *Precision Farming Tools: Global Positioning System (GPS)*, Virginia Cooperative Extension (VCE) publication 442-503.

- **GN reduces operator fatigue and eye strain.** With the lightbar mounted directly in front, GN operators do not need to look backward or sideways. They can drive accurate swaths while looking straight ahead.

- **GN has lower setup time.** Foam markers require that tanks be filled and dyes be changed. GN begins working approximately 30 seconds after the machine is switched on.

- **GN is not affected by wind or boom bounce.** Blowing foam or a foam system bouncing over rough ground at the end of a long boom may introduce substantial error. GPS systems are not affected by rough terrain or wind.

- **GN reduces pesticide use by reducing overlaps.** If a 10 percent overlap is reduced to 5 percent, pesticide use also is reduced by 5 percent. The same is true for fertilizer and seed, so using GN is better for the environment and good for the bottom line.

- **GN reduces the need for people to enter already sprayed areas.** The operator can mark where spraying stopped without dismounting.

Additional Features

Decisions about adapting GPS navigation should be based on particular farm needs, farm operation procedures, and understanding of positioning errors. Such issues as vehicle dynamics, tracking of trailed implements, and field terrain also need to be considered. Proper alignment and installation of the GPS navigation system is required for effective field operation. Poor quality of the steering-control systems, a sloped terrain, or misaligned implements will cause the field performance of GPS navigation to suffer.

An important feature of GPS navigation systems is the ability to follow particular traffic patterns and provide effective feedback so that the operator or auto-steer system can appropriately respond. Most systems can effectively perform straight-line patterns (linear swathing), and many can follow contours and other field features (Figure 4).

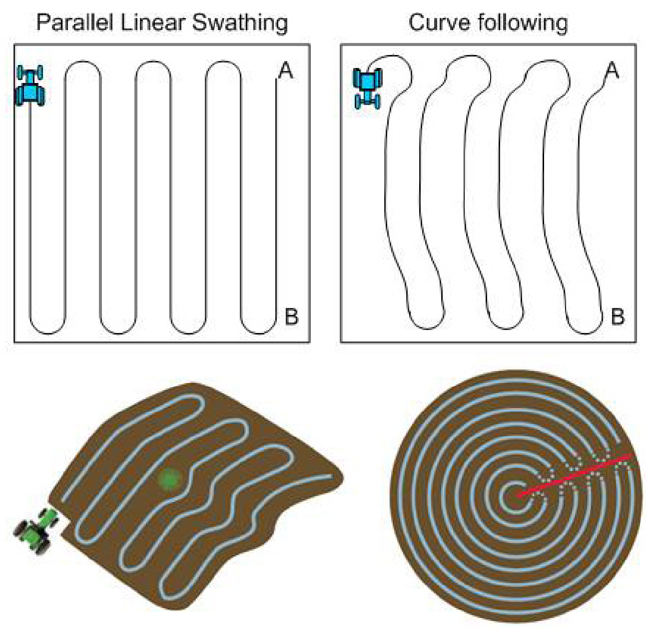

Figure 4. Examples of field traffic patterns that GPS navigation can follow.

Although most GPS navigation systems are designed specifically for the task of vehicle steering, some systems have features to collect spatial data (such as application maps and yield maps) or to operate variable-rate controllers. Additional features spread the cost of the system among several tasks while increasing efficiency in multiple areas of the crop production program.

The documentation provided by a GPS system could be used to show that the product or field work was applied in specific locations at a specific time. Setbacks specified by regulatory agencies and other sensitive areas (such as ornamental crops, nurseries, gardens, schools, and residential areas) may be defined as "no-apply zones." The "as-applied" map includes areas in which application occurred and rates can be recorded. It is possible to include not only position, but time and date information in an application record as well. Such documentation could be used for accurate recordkeeping for agrochemical application and machine operation and, potentially, for regulatory and legal defense purposes.

GPS navigation products are distinguished by the compactness of their components and user interfaces. Some systems cause technical challenges during installation and calibration, while others may be functional in less than an hour. User interfaces range from intuitive, colorful, graphic touch-screen displays to hard-key menus with limited graphics feedback.

A sloped terrain makes control of vehicle dynamics challenging. Roll (tilt from side-to-side), pitch (movement from front-to-rear), and yaw (rotation around the vertical axis) alter the GPS antenna location with the projected center of the vehicle (Figure 5). For example, when driving across a slope, the horizontal position of the GPS antenna is downhill with respect of the center of the vehicle, and the guidance will be in error down the slope (Figure 6). To compensate, some systems include gyroscopes, accelerometers, or additional GPS antennas. Less advanced terrain-compensation modules deal with only roll and pitch angles of the vehicle, while others can measure total dynamic attitude in six degrees of freedom and enable the system to compensate for variable terrain.

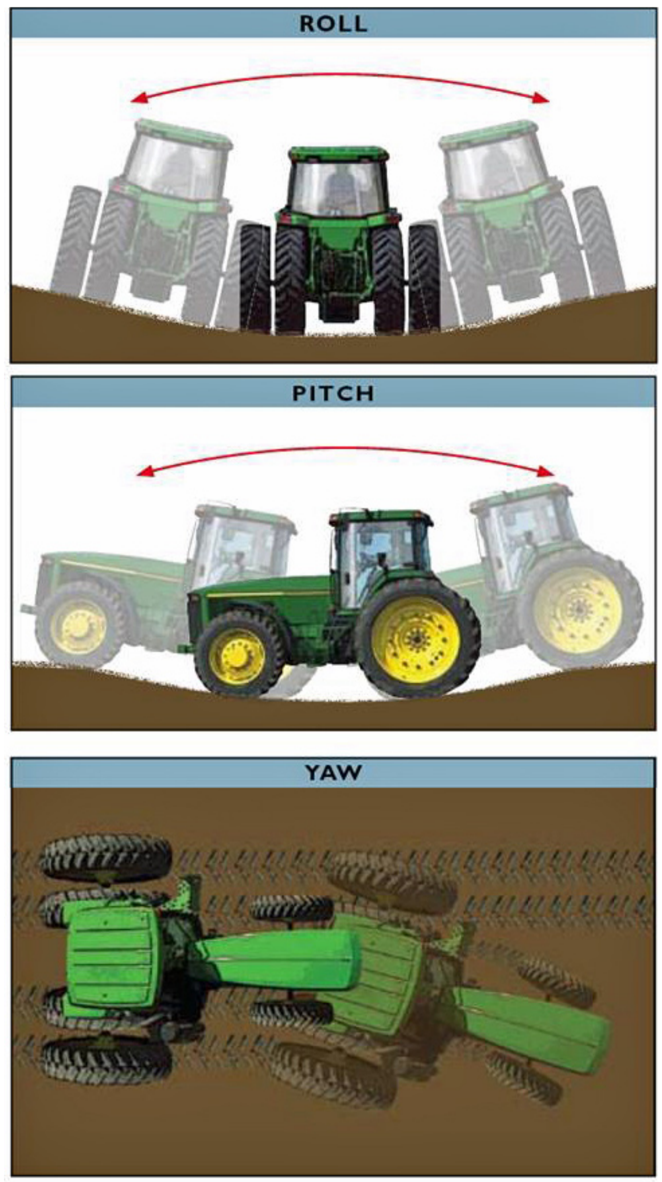

Figure 5. Compensation needed based on vehicle orientation and field operation.

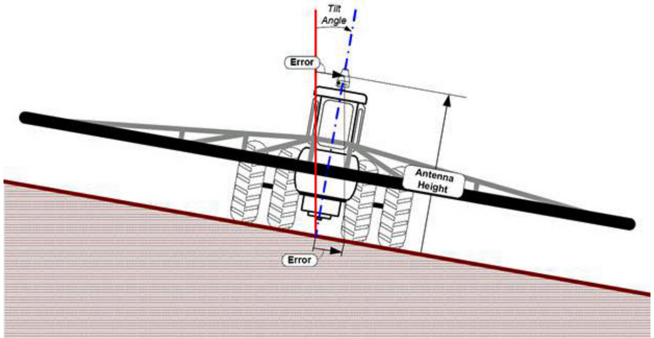

Figure 6. Antenna positioning error on sloping terrain.

Several manufacturers have add-on implement steering systems for proper implement tracking. Compensating for known geometry of the tracking from implements can be adjusted with the vehicle's trajectory to keep the implement aligned. Optical and crop-based tracking systems can be useful when positioning implements with respect to established rows.

GPS Navigation Cost

The most frequently mentioned disadvantage of GPS navigation is the up-front cost. Costs range from about $1,500 for a farmer who already owns a GPS to more than $14,500 for a commercial applicator who wants a system that keeps "as-applied" records as well as provides navigation. A fully automatic navigation system that steers a tractor, sprayer, or combine—with operator engagement only at field ends—could range from $6,000 to $50,000.

Current swathing aids such as foam-marker systems range from $500 to $3,000. Speed is also an issue in foam systems. The lower-cost foam systems are slower, but they work adequately when application is done with a tractor. Commercial applicators operating at 20 miles per hour need more foam output than some systems can provide.

Costs and benefits vary widely depending on the crop, acreage covered, swathing accuracy achieved, and other factors. To make cost comparisons, consult *Investing in GPS Guidance Systems?* VCE publication 448-076. *http://www.ext.vt.edu/pubs/agecon/448-076/448-076.html.* As a rule-of-thumb, a navigation system could cost six times more than a foam-marker system, which means that justification for GPS navigation over foam markers must be computed from the benefit side.

Estimates of the economic impact of sprayer skips are complicated because influence of weed control on crop yield varies by crop. For example, the weed population and long-term weed seed-bank effects have to be evaluated and assessed. For fertilizer and lime application, how much yield is lost if the area receives no application? A skip is much more costly in a higher-value crop, such as vegetables or seed crops, than it would be in a bulk commodity such as corn, soybeans, or wheat. If the skip occurs in a very clean field, the yield-loss effect due to reduced weed control may be minimal, but in a heavily infested field, the yield may drop to almost zero in the skipped area. Weed scientists suggest that the greatest economic effect of skips may be the creation of a seed bank that will lead to management problems and greatly increased weed control costs in future years. Similarly, for a field at pH 5.8, the yield loss due to skipping an area with lime application will probably be small during the first year, but will become greater in later years.

Bottom Line

GPS navigation has many advantages over conventional marking devices such as foam markers, and especially over the visual-estimation method for spinner spreaders. With an existing GPS being used for yield monitoring or field mapping and soil sampling, the GPS navigation system can increase the efficiency of the farm or agribusiness while minimizing adverse environmental impacts associated with overlapping applications. The system can also reduce operator fatigue and anxiety regarding fertilizer and pesticide application. Finally, use of this technology can demonstrate to the nonagricultural community that advanced technology is being used to farm efficiently and safely. The advantage of "as-applied" maps, provided by some systems, is documentation that applications were made at the appropriate location and rate.

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