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From GPS to GNSS: Enhanced Functionality of GPS-Integrated Systems in Agricultural Machines

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Introduction

Global Positioning Systems (GPS) are satellite-based navigation systems that utilize a network of earth orbiting satellites. GPS operates well under any weather condition and does not require a subscription fee. GPS is a crucial component of precision agriculture by providing precise location information with very high repeatability.

In recent years, GPS have improved in their level of performance and functionality in part because new GPS receivers can track satellites not only from the 32 NAVSTAR satellites of the United States but also from the Russian GLONASS (approximately 24 satellites) systems. These high-accuracy navigation and positioning technologies are categorized as a GNSS (Global Navigation Satellite System). We anticipate that even higher levels of performance will be achieved when the Galileo satellite constellation (European Union) becomes available in 2014 with an initial operating capacity of 18 satellites and expanding to 30 satellites by the year 2020. The changing technology motivates the need for precise definitions.

It is clear that GPS will continue to have a remarkable impact on production agriculture. Vehicle guidance or automatic steering control has been the most commonly adopted GPS technology among growers in the last five years. Every year new and improved navigation systems become available with a range of precision capacities to fit most mechanical operations and with new functional capabilities. This publication describes the latest trends in GPS technology and elaborates on topics of extra functionality such as variable rate application, land leveling, and yield monitoring; all are now available from the cab mounted display interface.

Key operational parameters of GPS receivers

Important operational parameters of GPS receivers include accuracy, correction service, and hardware selection. These technical aspects are explained in detail by our earlier publications (Andrade-Sanchez and Heun (2010 and 2011)) with particular emphasis in application in Arizona. The user must carefully select between multiple options in order to obtain satisfactory performance when implementing this technology in mechanized operations.

Accuracy. GPS receivers are built to achieve certain accuracy levels depending on their internal components, enabled communication protocols, and unlocked capabilities in firmware. Accuracy is perhaps the single most important factor; therefore it is worth checking the manufacturer's claims on pass-to-pass and year-to-year accuracy. Remember that GPS costs are related to their accuracy levels, so it pays to do a careful analysis of accuracy needs in your farm.

Differential Correction. This is an essential function of modern GPS receivers that is needed to obtain adequate levels of accuracy for machine applications. Most agricultural applications require sub-meter (less than 3 ft) pass-to-pass accuracy, but very often accuracy is needed as close as a few inches and even at sub-inch level. Correction services in the U.S. such as Wide Area Augmentation System (WAAS) are available free of charge. Private firms such as OMNI-Star and John Deere provide excellent services to subscribing clients by charging fees according to the accuracy levels. When selecting a particular GPS receiver, it is important to consider whether it comes loaded with WAAS or OMNI-Star capabilities, and to confirm that the receiver can be upgraded to perform at higher levels of accuracy (RTK).
Real-time kinematics (RTK) is the most accurate GPS correction system used in agricultural applications. Growers using RTK GPS need access to a ground base station through radio link. Users can choose to buy their own base station or subscribe to a local network of RTK signal correction stations. Subscribing to an existing station makes good economic sense if it is available in the area. Both options are very common in Arizona and in the near future we expect that more will become available. The Department of Transportation (DOT) is currently working in some states to provide wide-range coverage of RTK-level correction signals through their Continuously Operating Reference Stations

(CORS) system. There is much potential of widespread use of RTK correction under the CORS infrastructure. A model of application of CORS to agriculture has been tested in the state of Alabama (Winstead et al., 2009). Private providers are testing the delivery of correction signals through cell-phone modems.

Hardware Selection. One aspect often ignored is the selection of the external antenna that has to match the capabilities of the receiver. Newly released integrated GPS systems require dual-frequency antennas to track L1 and L2C satellite signals.

Enhanced GNSS systems

One way to present the improvement of these GNSS systems over GPS alone is to compare the level of dilution of precision (DOP) over the course of a day between the systems. DOP is a dynamic parameter that is affected by changes in satellite number and geometry with major implications for vehicle navigation. Higher DOP values translate to higher uncertainty of positioning and can result in agricultural operation down-time and lower productivity when auto-guidance is required for an operation. Figure 1 presents data generated with Trimble GPS planning software (available online at **http://trimble.com/planningsoftware.shtml**) with DOP values for Maricopa AZ on 8/10/2011 from 6:00am to 6:00pm. Note that a DOP of 2.0 is commonly accepted as a threshold above which performance problems arise. NAVSTAR plus GLONASS provides a solid platform for continuous work with better accuracy and a DOP consistently below 2.0.

Integrated Systems

The advances in computer hardware/software of the last two decades are evident in the design of new agricultural machines in which some mechanical controls have been replaced with computer-controlled systems of enhanced functionality. Electronic systems and computer displays are now a common scene in the cab of the tractor/sprayer or other power unit used in agriculture. Earlier versions of these displays were designed as to perform a single operation or series of operations of the same kind; this is the case for rate controllers for spraying systems, and early auto-steer displays. New versions of computer displays are capable of performing multiple functions from the same interface and reduces cab clutter. These integrated systems are the latest in off-the-shelf technology for precision agriculture. Figure 2 presents graphical examples of six integrated multi-function displays commercially available in Arizona through extensive networks of machinery dealers.

As of August 2011, the systems pictured in Figure 2 share the following features:

Screen. High-resolution color displays for real-time mapping. Touch-screen simplifies menu navigation. Multiple active windows enhance operation. Video cameras can be connected for better view and safe monitoring of equipment operation through live video. Active screens can be recorded and saved as screen-shots in electronic image formats such as PNG (portable network graphics).

Operating system. Upgradeable. Menu interface is available in multiple languages.

Multi-function. State-of-the-art computer processors allow these displays to handle all levels of navigation (steering control); application of multiple products and variable-rate of a single product; seeding rate control; yield monitoring; vertical position control for bucket blades performing land leveling, etc. Input/Output serial ports allow connection with the hardware required in each application. After the job is completed, these systems can generate job reports and export them in pdf format to maintain records of input utilization, field productivity, etc.

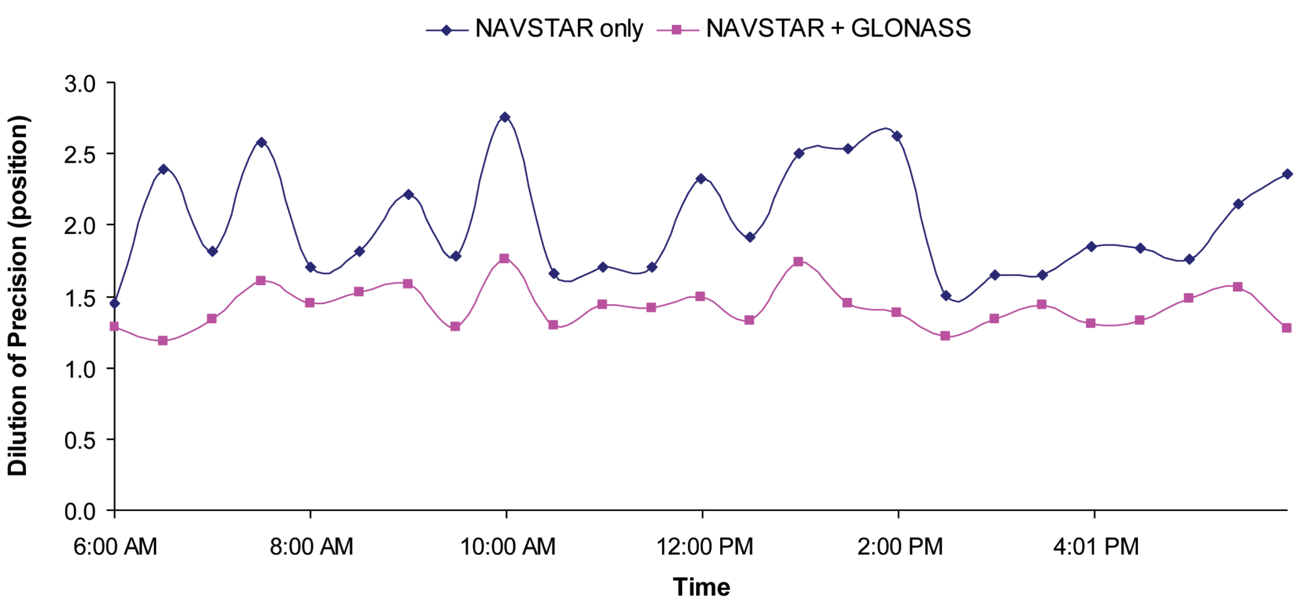

Figure 1. Diurnal changes in dilution of precision with two Global Navigation Satellite Systems in Maricopa AZ on August 10, 2011. Data generated with Trimble Planning Software v. 2.90.

Figure 2. Examples of multifunction displays currently available for tractors, sprayers and other agricultural machines. In clock-wise order beginning from the top-left: Ag Leader Integra, Hemisphere Outback S3, John Deere GS3 2630, Raven Envizio Pro II, Topcon X30, and Trimble AgGPS FmX.

Integrated GPS receivers. These GPS receivers use double frequency antennae to link LANDSAT and GLONASS satellites. Some of them have dual receivers to activate position monitoring of the implement.

USB. For uploading of operating system upgrades, and shape files (SHP) for navigation A-B lines and input prescription files. These ports allow downloading of yield, machine performance data, maps of as-applied inputs, error messages, screen-shots, etc.

External communications. Through radio and/or modem, this enables over-the-air data transmission and GPS signal correction. These systems can function as nodes in wireless networks. These displays are ISO-ready, which means that they can function in Virtual Terminal (VT) mode through ISO-11783 (ISO-bus) standard communication protocol to enable universal communication with implements, in particular, planter and sprayer controllers.

Functionality of these integrated systems

Steering control

The level of steering control applicable will depend on the level of work to be done and the machine itself. Light-bar type guidance systems use differential correction level GPS to track the vehicle position and then send signals to arrays of LED's to help the driver find the track to follow for the particular application. These devices are inexpensive and helpful in some applications where sub-meter accuracy is acceptable. However, they can require just as much of a driver's attention as traditional methods when a high level of precision positioning is required. If a higher level of accuracy (< 3ft) is needed, a hands-free steering system is in general a better way to go.

Hands-free auto-steering systems are guidance and control systems that take over a machine's steering system. They allow the driver to place more attention on vehicle/implement performance rather than to driving a straight line. Less expensive systems typically consist of an electric servomotor connected directly to the steering wheel. Although these steering wheel motor systems work well, they can take up a lot of space on smaller tractors but are often the only choice. If the tractor has a hydraulic steering system (no mechanical connection between the steering wheel and front axle), a solenoid valve can be installed in the hydraulic lines outside of the cab. This tends to be a much cleaner way of tapping into the steering system and works well with the more complex guidance systems. In addition to RTK level GPS, these auto-pilot systems need positioning sensors such as gyroscopes and accelerometers to achieve the highest level of navigation performance. Figure 3 shows examples of three levels of steering systems that range from the simple external light bar, the intermediate level of external control of steering, to the most advanced internal control of steering. These systems are connected to the computer display to perform their navigation functions.

Variable rate and section control for chemical applications and seed planting

Variable rate technology is at the heart of precision farming technologies because, in contrast to the uniform application, variable-rate functions set the stage for implementation of site-specific management of production inputs. All integrated displays shown in figure 2 have variable-rate functions based on prescriptions previously loaded. In order to perform variable-rate application functions, these systems need to interpret prescription maps that contain information on the field distribution of application rates. GPS information is used to find the tractor/sprayer location

Figure 3. Examples of GPS-based steering control. Left column shows three examples of dash-mounted light-bar systems, center column has two cases of steering assist, and drawing on the right depicts an auto-pilot system with fully-integrated steering control.

in the field and then a signal is sent to the rate controller, setting a particular rate. It is important to mention that at this level of hardware integration, these displays send GPS based speed information to the rate controller to adjust the flow of chemical according to travel speed. Another mode of operation available in some of these integrated displays is variable rate application based on real-time data acquisition of crop conditions. This mode of operation requires serial communication with spectral crop sensors and is particularly challenging because the system needs an algorithm to convert the sensor signal into an application rate. Significant advances have been achieved in this area but crop algorithms are still being developed and tested by the scientific community engaged in sensor-based management.

Along with variable rate solutions comes section control that is applied to planting and chemical application operations. Detailed information on the use of automatic section control for spinner-spreaders, sprayers, and planters has been described by researchers from Alabama A&M and Auburn Universities (see Fulton et. al., 2010, 2011-a, 2011-b). In the context of seed planting, section controllers are used to shutoff the delivery of seeds in areas of the field already planted. This section control can be implemented at the level of each individual planter unit or by whole sections by installing electrical or pneumatic clutches on the drive shaft of the planter. On the other hand, section control in applications of liquid chemicals, either sprayed or injected, refers to the ability of the system to shut-off sections of the spraying boom or injection-knife sections in order to avoid overlapping applications. Figure 4 presents a screen-shot of an integrated display when performing multiple operations. The red line in the map indicates the autopilot function; the input rates on the right indicate the ability of the system to handle this information. In terms of section control, the icon representing the tractor/sprayer shows with green color that only the right section has been enabled while the middle and left sections (in red) are disabled). These functions are simultaneously implemented in the field at the time of application.

Yield Monitoring

All of the multifunction displays shown in Figure 2 can handle yield monitoring functions. The benefits of system portability become evident since harvest is carried out at the end of the season. In Arizona, the crops with the highest potential for the implementation of yield monitoring technology are cotton and small grains. There are commercially available yield monitoring systems that can be used to retrofit harvest machines. In the case of cotton, yield is determined by measuring the mass flow rate of seed cotton as it travels from the headers to the rear basket. The sensors used for these measurements can be of two types: optical sensors that measure light attenuation caused by the flow of seed cotton, and microwave sensors that use the Doppler effect principle when the energy emitted by these sensors is reflected by the flow of cotton. In the case of small grains, yield monitors measure the impact force of the flow of grain in the grain elevator over a plate instrumented with a force transducer. There is a proportional relationship between the force of impact and the flow of grain.

To obtain yield data of absolute quality, careful calibration of flow sensors should be repeated at least three times during the harvest season. Yield information within the field allows growers to grasp the extent of variability and stimulates a process of determining the factors driving field variability. Based on the analysis of yield data, growers can develop their own improved management strategies to adjust practices that could potentially sustain or increase yield levels and product quality with reduced input. Figure 5 shows the extent of yield variability in a cotton field in Central Arizona (Buckeye, AZ). This map was generated with John Deere Apex software v. 2.7 after yield data was collected with a John Deere Green Star 2 integrated display and microwave sensors installed in a 6-row cotton picker.

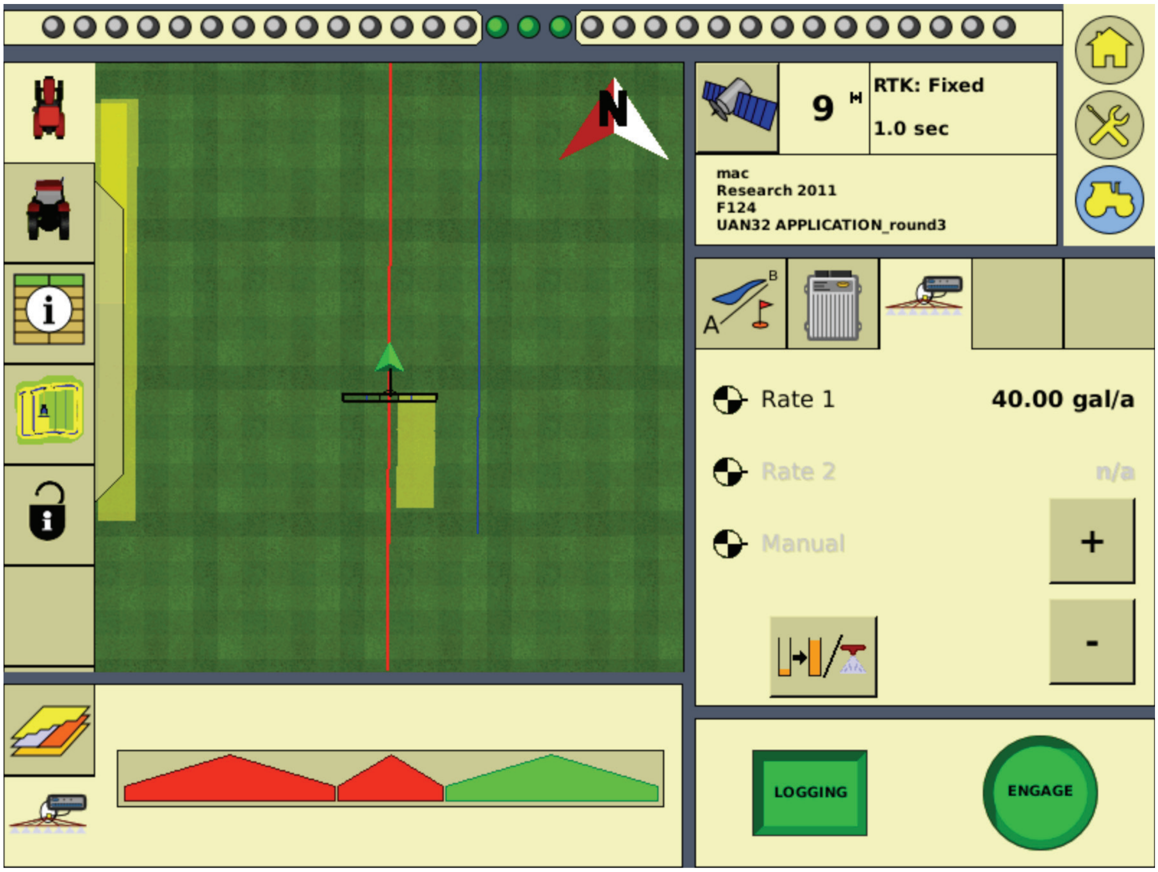

Figure 4. Screen-shot of Trimble FmX showing navigation, rate control, and section control functions carried out simultaneously.

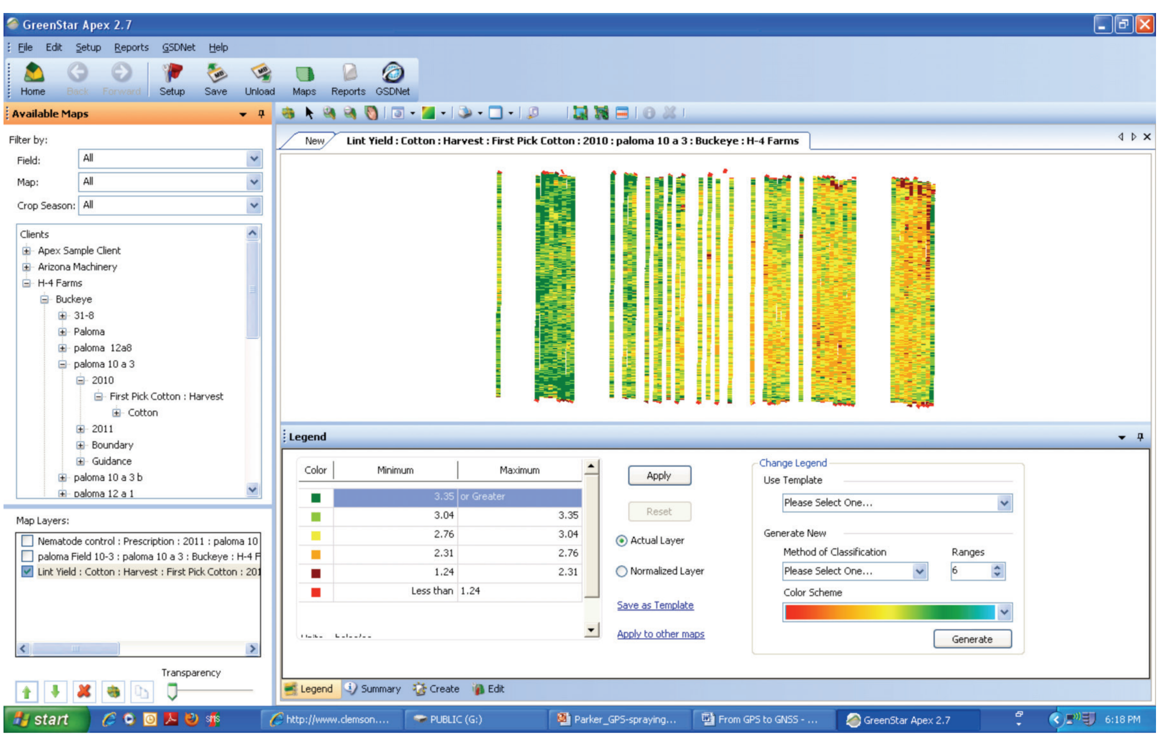

Figure 5. Screen-shot of John Deere Apex farm management software. The map shows the field distribution of cotton yield for a field in Buckeye, AZ, during the 2010 harvest season.

Figure 6. GPS-based land leveling solutions. On the left is John Deere i-Grade, and the right picture displays Trimble AgGPS FieldLevel II.

Land leveling

Now that we have sub-inch accuracy and control in the horizontal plane, what about the vertical plane? With the addition of the GLONASS constellation to the RTK system, elevation positioning is better than ever. Manufacturers such as Trimble, Topcon, and John Deere have integrated land leveling functions into their new tractor displays. Fields can be surveyed, mapped, designed, and leveled entirely from inside the tractor. RTK GPS equipment replaces the external laser leveling systems normally used. A dual antenna system is used to monitor the height of the scraper blade and hydraulic modules are added to control the flow of fluid that sets the blade's position. This added functionality can eliminate problems associated with gusting winds moving the laser tower. Recent releases of GPS solutions for land leveling are presented in figure 6. Both systems use RTK level of signal correction.

Summary

The integrated systems described in this publication represent the newest development in advanced systems for enhanced functionality of machines in production agriculture. As expected, these systems will keep evolving to improve their performance. Active competition between manufacturers will also result in affordable quality products that will benefit growers in their transition from conventional to more advanced systems. Two operational elements of these computer-display systems that are worth analyzing are their portability, which can be a money-saving attribute when many power units can share at least part of the new components. The other element is that the use of these new displays requires computer skills and therefore workforce training is an essential element of modern farm management systems to enable full utilization of this technology.

This extension bulletin is designed to be of an informative nature, and along with other publications in this series prepared by the Research and Extension Program in Precision Agriculture at the University of Arizona, we expect to help growers make informed decisions as they embark in the implementation of precision farming solutions. It is recommended that growers consult with equipment dealers to obtain specific information on system compatibility, upgrade options, and service.

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