WHITE PAPER

RTK base station networks driving adoption of GPS +/- 1 inch automated steering among crop growers

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Abstract

During the early 2000s, GPS guidance and automated steering systems gained the attention and interest of crop growers around the world. Such systems provide a wide range of potential benefits.

As growers have become more aware of the benefits of using GPS in agriculture, interest has rapidly increased in the most accurate level of GPS machine control—the +/- 1 inch performance made possible with Real Time Kinematic (RTK) signal correction. A major factor in this increased adoption rate is the advent of extensive RTK base station networks for GPS signal correction. These networks typically lower the cost of purchasing systems such as the Trimble AgGPS® Autopilot™ automated steering system by about 35 percent[1]. They also eliminate the need for growers to set up and maintain their own RTK base stations—a potentially stressful, time-consuming activity during critical fieldwork seasons.

As a result of this proliferation of RTK base station networks and related technology, +/- 1 inch farm vehicle operation has become affordable and easy to use for thousands of progressive growers worldwide.

Keywords: GPS, base station networks, guidance, automated steering, GPS accuracy, strip till, drip tape irrigation

Introduction

Certain row crop applications require precise machine operations with pass-to-pass and repeat accuracy of +/-1 inch (2.5 cm). Such applications include strip tillage and other types of precision fertilizer placement, as well as planting and harvest of high-value crops such as potatoes, peanuts and cotton. Another critical task for +/-1 inch accuracy is laying drip irrigation tape. Accuracy this fine requires GPS signal correction using Real Time Kinematic, or RTK, technology. Trimble pioneered the commercial use of RTK in 1992, and owns more than 30 U.S. patents pertaining to RTK systems and applications. Trimble RTK innovations are now used for a wide range of applications all over the world in the marine, survey, mining, construction, and agriculture industries.

While RTK technology includes similarities to popular GPS correction systems such as Differential GPS (DGPS) beacon, WAAS, and OmniSTAR correction, it is different in several distinct ways.

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Differences among DGPS, OmniSTAR XP/HP, and RTK corrections[2]

Characteristic	DGPS	OmniSTAR XP/HP	RTK
Satellites required for initializing	3 minimum; 4 required for sub-meter accuracy	XP: 5 HP: 5	5 minimum
Time required for initializing	Instantly	XP: 20-40 min. HP: 20-40 min.	About 1 minute
On-the-fly initialization (obtaining centimeter accuracy while moving)	No	XP: Yes HP: Yes	Yes
Receiver	Single frequency sufficient	XP: Dual frequency HP: Dual frequency	Dual frequency
Accuracy	Sub-meter (Horizontal axis only)	XP: ±3-5 inch (7.6-12.5cm) pass-to-pass; ± 8 inch (20cm) repeatable HP: ±2-4 inch (5-10cm) pass-to-pass; ± 4 inch (10cm) repeatable	About 1 inch (2.5 cm) or better in horizontal and vertical axes
Base station requirement	Operator-owned, fee-based correction service provider, or free radio beacon broadcasts (e.g., Coast Guard or WAAS)	XP: None HP: None	Operator-owned, or fee-based network, with station or repeater not more than about 6 miles (10 km) from field in which system is operating

Trimble RTK systems all use dual-frequency receivers. Such high-accuracy receivers are necessary for +/- 1 inch (2.5 cm) applications now being adopted by farm operators around the world. In addition to using the standard L1 GPS signals (i.e., Civilian C/A code and carrier phase) like all other GPS receivers, Trimble dual-frequency receivers also track the L2 carrier phase signal. Unique characteristics of carrier phase signals, when properly decoded, greatly add to the

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accuracy of the RTK correction signal. This use of the L2 signal enables Trimble RTK receivers to lock onto a higher accuracy level, and initialize more quickly, than systems using different types of GPS position and time data[3]. This ensures consistent accuracy and repeatability in demanding field operations. Repeatability is the ability to return to the same run-lines or area in the field within an inch at any later date.

Rapid adoption of RTK systems

From 2002 through 2006, grower interest in high-accuracy RTK systems has increased at a rate that surprised many industry experts. Reliable estimates indicate that as many as 80 to 100 million acres of U.S. cropland are now farmed with RTK-controlled equipment[4].

Such rapid, widespread increase in demand for the +/- 1 inch accuracy of RTK is the result of several converging economic, social, and technological factors. Some of these factors have stimulated growers to adopt machine operations requiring pass-to-pass accuracy of 6-8 inches available with OmniSTAR VBS, beacon, WAAS, and EGNOS correction. Other factors are prompting adoption of GPS systems delivering the 3-5 inch pass-to-pass accuracy of OmniSTAR XP correction or the 2-4 inch pass-to-pass accuracy of OmniSTAR HP systems.

However, many progressive growers are now "leapfrogging" to the superior +/- 1 inch accuracy and performance of RTK systems in areas where several of the following factors are converging:

Larger "large" farms

Over the past 50 years, U.S. farm size has undergone what agriculture statisticians refer to as a bimodal distribution shift: The mid-size farm, from about 500 to 1,000 acres (200 to 400 hectares) has become scarce and more farming operations now fall into two distinct size categories—relatively small or very large. Very large operations often range from 5,000 to 12,000 acres or more. Managers of such large operations tend to seek and recognize the boost in accuracy, efficiency, and productivity that RTK automated steering offers.

High input costs

As prices for fuel, fertilizer, and other crop inputs keep rising, growers must find ways to cut costs while improving yields. Several proven agronomic practices that require +/- 1 inch machine operations can indeed cut costs while increasing yields. These include strip-tillage, drip tape irrigation, twin-row peanuts, precision ridging (listing), tramlines that reduce soil compaction, and precision planting/spraying/ harvesting of high-value crops.

Narrow weather windows

In many growing regions, a combination of large operations, the trend to earlier planting dates, and erratic weather patterns has resulted in chronic planting-time crunches for growers. In a 2005 survey of 13,250 corn growers across more than 20 states, 77 percent of respondents associated timely planting with increased yields[5]. However, 75 percent of respondents said they were unable to finish planting by their preferred date. In light of facts such as these, it is logical that many farm operators have been seeking new technology to get more acres planted per day—including hours of darkness—during good weather.

Labor shortage solution

Many owner/operators of tractors, sprayers, and harvesters equipped with +/- 1 inch automated steering systems report that previously inexperienced operators can perform the most demanding machine operations—even in conditions of low visibility and darkness—after only a few minutes of in-field training.

Improved machinery efficiencies

A Mississippi Delta agribusiness executive says, "Everybody here wants to go to 12-row cotton, but

the cost of retooling hurts, and there are many 8-row planters and hippers around. As a result, many of my customers have gone to planting with Trimble RTK Autopilot automated steering systems for more even row spacing[6]." This means cotton growers can build ridges with 4-, 6-, or 8-row hippers, plant with 8-row planters, and harvest with 6-row pickers. In many cases this helps extend the life of older equipment and delay purchase of new machinery.

Also, many operators who equip a primary tractor with RTK automated steering find they run it for longer hours in more applications—and in more difficult conditions—than before. This process often results in selling or trading in a second high-horsepower tractor, potentially lowering machinery cost per acre.

Lower cost of guidance technology

As with most new technology, especially electronics, the cost of GPS systems continues to decrease. For example, a Trimble *Ag*GPS Autopilot automated steering system with an on-farm RTK base station typically cost about US$40,000 in 2004-2005. With the advent of new guidance-ready (factory installed hardware and hydraulics) tractors and combines, along with RTK base station networks, the incremental cost of a similar RTK system in mid 2006 typically ran as low as US$18,000.

Proliferation—and issues—of early RTK base stations

When Trimble first introduced the +/- 1 inch accuracy from RTK GPS technology to the agricultural industry in 1998, nearly all systems included a single mobile or static base station located on the grower's farm to provide accurate correction signals. Most sizable operations—especially those spread out several miles or more—used their base station as a mobile unit to avoid the cost of multiple base stations.

This strategy helped contain costs. However, it often required considerable time for moving mobile base stations from farm to farm, relocating the GPS receiver antenna, followed by correctly configuring the GPS for that site. As one industry veteran puts it, "Growers learned how to use the tractor with the RTK system on it and then they had to learn how to use the base station. At that point, there were a lot of opportunities for errors[7]." This process not only required a substantial learning curve with high stress potential—it reduced precious time available for growers to operate their planters, sprayers and harvesters.

To deal with these limitations, RTK system operators soon began devising fixed radio installations, typically on a grain elevator or existing FM radio tower close to the center of their farming operations. Many such base stations provided excellent line-of-sight RTK signal correction for a radius averaging six to eight miles from the antenna—commonly 150,000 acres (60,000 hectares) surrounding a given base station antenna. In areas such as West Texas with relatively little dense forestation and few hills, this approach provided good RTK correction signal strength with +/- 1 inch repeatability for many operations.

As RTK technology continued to spread throughout various U.S. and overseas farming regions, three related practices pioneered by Trimble gained widespread popularity across the U.S.:

Land-survey grade RTK: In 1993, Trimble released the world's first centimeter-accurate, Real-Time Kinematic (RTK) surveying system. Since its release, this technological innovation has been embraced by thousands of surveyors and engineers worldwide because of its accuracy and reliability. It soon changed the accuracy-conscious world of surveying forever[8], and is now changing the way farmers produce much of the world's food and fiber.

900 MHz spread-spectrum radios: This unique radio solution provides three distinct benefits to growers using Trimble RTK networks: noise-free operation, a high level of security, and license-free operation throughout the U.S. In many other parts of the world, licenses for radio transmission of the appropriate frequency are readily available.

RTK repeaters: Although RTK single-mount base station antennas atop grain elevators and FM antennas worked well in fairly flat areas with few obstructions, a better solution was clearly needed for rolling and forested terrain. The answer: RTK repeaters, to effectively fill in areas with restricted coverage or extend the range of base stations—an affordable solution for most growers.

While grower-owned and operated base stations made sense both technically and operationally, their cost was still a barrier for many growers interested in RTK technology. This quickly became evident to progressive growers and agribusinesses in several major growing regions, giving rise to yet another new concept: The RTK base station network. Such networks may charge a modest annual user fee—usually about 1/10th the cost of an on-farm RTK base station. This makes the purchase of RTK rover or vehicle-based systems much more attractive and affordable for thousands of growers.

Rapid expansion and acceptance of RTK base station networks

Since 2004, dozens of new RTK base station networks have sprung up around the U.S. For a typical grower, the availability of an RTK base station network cut the cost of adopting RTK technology by 35 percent or more. In addition to the benefits of reduced startup cost and "flip-the-switch-and-go" operation, early RTK base station networks also delivered increased, jam-free reliability and improved repeatability for most customers. What began as a handful of base stations owned and operated by innovative growers and agribusinesses quickly expanded to cover large areas of farmland, often spanning several counties.

During this period, growers in some areas might receive correction signals from more than one base station in the same network at different times of the year. In some situations, these base stations had been set up using different survey reference points—a potential source of conflicting signals. Clearly, a method was needed that enabled rovers to operate accurately and consistently from any base station in a given network.

Perfecting the RTK base station network

A two-part solution—common survey coordinates and individual base station identification numbers—paved the way for today's high-performance RTK base station network:

Common survey coordinates refers to using the same "view of how Earth is shaped" (referred to as common coordinates) when surveying the location of each base station within a given network. Use of the same survey coordinate system, such as NAD 83 (North American Datum 1983), ensures that a given square inch of a field is described as being at precisely the same latitude and longitude by every base station within the same network.

Network ID numbers perform two critical remaining tasks:

- They identify individual base stations within a network.
- They allow programming of rover radio receivers to communicate with only those base stations surveyed to the common survey coordinates of that particular network. This, of course, would be the RTK network with which the grower has contracted for RTK correction services.

Two critical technical points

It is important to remember that all RTK systems must provide the following two separate, distinct solutions in order to provide reliable, repeatable +/- 1 inch accuracy.

The GPS correction signal solution
As distances from base stations to rovers increase, major differences in RTK repeatable accuracy among various manufacturers' systems can, and do, occur. The variability in accuracy results from differences in manufacturers' proprietary GPS solution *algorithms*—predetermined instructions to GPS receivers for calculating and outputting RTK corrections using L1 and L2 (dual frequency) signals. Some algorithms are more accurate, and thereby more effective, than others.

The wireless communication solution between base station and rover
The presence of an RTK network does not automatically ensure +/- 1 inch accuracy within the planned coverage area of that network. To achieve true +/- 1 inch accuracy, a base station must relay its RTK correction signal by radio—reliably and accurately—to a rover operating several miles away. Despite optimistic claims, not all GPS manufacturers have developed effective and reliable radio solutions to carry out this critical aspect of RTK technology.

An Illinois agribusiness executive involved with the construction of major RTK base station networks summed up his grain-farmer customers' enthusiasm for true RTK base station networks with this observation:

> *"Some growers need the +/- 1 inch accuracy of RTK for fertilizer placement in strip-till systems. Others—especially the large operations—need the ability to get over large pieces of ground when the time is right, no matter if it's dusty, dark or foggy. When Mother Nature says it's time to plant, they want to keep going and get it done, and the Autopilot systems are great at getting the job done as quickly as possible. These farmers expect to pull out of the shed, turn on their Autopilot system and be locked into an RTK fixed network without doing anything else, period."*[9]

This sentiment is reflected in major U.S. and overseas growing regions by the following fact: During 2006, coverage of Trimble-affiliated RTK base stations in the continental United States has more than doubled. This trend is expected to continue, and perhaps accelerate, over the next several years[10].

Selecting an RTK base station network supplier

For those new to automated steering, it might seem that all RTK correction services fall into the category of a commodity, much like anhydrous ammonia and No. 2 diesel fuel. However, suppliers of RTK correction services are like suppliers of most other branded products and services purchased by crop growers—various suppliers offer vastly different levels of quality, service, and price. Therefore, when considering a supplier for RTK base station networks, one should weigh these factors:

Signal reliability and accuracy: When considering a potential service provider, request names and phone numbers of current customers in your service area. Obtain frank answers to these questions:

- **How reliable is the RTK correction signal?** Does the base station network operate 24 hours a day, 365 days a year, providing continuous, accurate RTK signal correction?

- **How accurate is the RTK correction signal when the rover is operating from two to six miles from the nearest base station?** Trimble *Ag*GPS Autopilot automated steering systems operating with Trimble RTK base station networks consistently deliver true +/- 1 inch accuracy and repeatability up to six miles from the nearest base station. This is not the case with all GPS systems claiming +/- 1 inch accuracy and repeatability.

Cost of service: When using automated steering systems for GPS machine control operations—as with other aspects of operating a business—there are seldom any "free lunches." No supplier can afford to provide RTK network correction signals as a public service. If a supplier offers "free" RTK network services, one can be sure that customers are paying for the cost of such services in one way or another—possibly in extra up-front charges for the automated steering system itself. Also, if the RTK correction signals provider cannot deliver reliable, accurate +/- 1 inch accuracy and repeatability, the cost of that provider's service—in whatever amount—may be prohibitive in terms of lost fieldwork opportunities and undelivered performance benefits.

System operating life: In times of such rapid technological change, one cannot afford to invest in a GPS automated steering system or base station network that could soon be rendered obsolete. For example, the Trimble Virtual Reference Stations (VRS™) are generating considerable interest, and possible concern, among those weighing new investments in RTK automated steering systems or base station networks. VRS is a topic unto itself, but the following points are worth noting:

- VRS implementations provide the same level of reliability and accuracy as current RTK base station networks in agriculture today.
- Current RTK base station networks are providing the highest level of accuracy for the lowest investment to agricultural users that is likely to be available from any type of correction service in the foreseeable future.

At present, more than 50 percent of all farming acreage using RTK operates on correction signals supplied by Trimble RTK networks. This makes Trimble the undisputed world leader in +/-1 inch RTK technology for agriculture. The "future proofing" policy of Trimble ensures customers that their investment in Trimble *Ag*GPS systems is protected by compatible new products, with no need to purchase all new equipment.

The future of high-accuracy agricultural GPS

Reliable +/- 1 inch control of heavy, fast-moving agricultural machines is now an every-day practice on many farms around the world. This rapid adoption raises two logical questions:

- What is the future likely to bring in the way of such "hands off" machine control technology?
- How much additional accuracy are progressive farmers likely to need—and be able to justify economically?

Some of the next advances in RTK— implement-mounted GPS steering systems—are already on the scene or waiting in the wings to help operators with rolling or hilly (even level) ground avoid side draft with drawn implements. This helps keep such tools precisely on the row, ensuring accurate placement of fertilizers and crop protection chemicals, preventing loss of valuable stand from so-called "cultivator blight," improving fuel efficiency, and extending machinery life.

Leading farm machinery and implement companies are already testing robotic tractors, harvesters, and machines, as well as various other GPS applications. With ongoing advances in the reliability and safety of such technology, one can surely expect to see such robotic machines in implement dealer showrooms in the not-too-

distant future. A certain number of new technology adopters will no doubt purchase such first-of-its-kind equipment. However, it will take time to determine how such technology will pay for itself and improve net income for a given farming operation.

Farming practices are changing dramatically because of the ability to control a vehicle within an inch. Strip till is just one example of a practice that is much more feasible and easy to achieve now with RTK and truly repeatable sub-inch GPS machine control systems. RTK and +/- 1 inch machine control will ultimately change the types of implements that will be manufactured.

At this writing, the U.S. Department of Defense is launching next-generation GPS satellites that will deliver improved services to civilian users, including agriculture. In late 2003, Trimble released three new future-ready dual-frequency GPS receivers containing Trimble R-Track™ technology, which will support the new L2C signal as soon as the launch of modernized satellites is complete and transmission begins. The Trimble R7 GPS system was the only L2C-ready land survey equipment available to test the new satellite signal by the Joint Program Office (JPO), which manages the Navstar GPS system. Trimble's proprietary R7 technology, compatible with today's GPS satellites as well as future L2C signals, successfully shows that Block IIR-M satellite data can be acquired, tracked and logged11.

Trimble invented and successfully developed the Real Time Kinematic (RTK) technology that made +/- 1 inch machine control for agriculture economically and functionally practical. Now, Trimble scientists and engineers are designing and testing the next generation *Ag*GPS systems, including next-generation RTK base station networks. This new technology will help further "future proof" GPS farming operations across the U.S. and around the world—this year, next year and as far into the future as exceptionally bright minds can imagine.

Conclusion: Trimble's strong commitment to GPS technology in agriculture.

Adoption of +/- 1 inch RTK is taking place at a rate faster than many industry experts had predicted. This is the result of several factors that include changing grower needs and the availability of Trimble RTK base station networks. These Trimble RTK base station networks now provide correction signals for more than 50 percent of U.S. acreage farmed with RTK technology. Agricultural GPS technology will continue to evolve, along with that of the land surveying, mining, construction, marine and other major industries. As Trimble continues its role as a world leader in GPS technology, its new "future proof" products and systems will continue to provide strong, proven products and services to farmers worldwide.

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