GEOLINK: PRECISION GPS NAVIGATION FOR IMPROVING AGRICULTURAL PRODUCTIVITY
**PRECISION GPS NAVIGATION FOR IMPROVING AGRICULTURAL PRODUCTIVITY**

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This article explains the unique positioning problems faced by agricultural commodity producers in applying seed, fertilizer, and chemicals, and discusses a system that uses GPS to achieve sufficiently precise positioning for farm equipment. Guidelines for software and automatic guidance system development are also discussed.

This inability to track where materials have been applied can easily cause the operator to skip some areas while overlapping others. Skips result in less than optimal use of the land and create areas in the field where weed infestations occur. Because skips are more obvious in the growing or harvested crop, most operators tend to overlap their passes. Overlaps, however, double the amounts of seed, fertilizer, and herbicides. Agricultural vehicles equipped with a precise positioning system such as GPS could reduce the production problems associated with skips and overlaps.

**FARMING THE SOIL**

Soil variability within a single field or crop area also affects production efficiency. The soil types present cannot be changed, but fertilizer and chemicals can be reallocated within a production area to better match the yield potential and chemistries of different soils.

Soil variability within a field has been researched by many different people and organizations. Since 1985 the Soil Conservation Service has actively pursued a program to classify and map the soils for all farmlands. A research program at Montana State University called "Farming Soils Not Fields" has shown that crop yield potential will vary with soil type within a field. Moreover, variations in fertility within a mapped soil type for a particular field may be even greater than the variations among soil types. Yet from an agricultural input standpoint, average rates are applied to the field without consideration of its inherent variability. The MSU project and other studies using aerial photographs, satellite imagery, test plots, and similar methods have documented the need for varying inputs to different locations in a field in response to the crop production potential.

The development of computerized geographic information systems and data collection techniques has progressed to the point that very small areas in a field, less than one square meter, can be uniquely identified. A GIS is composed of layers of data, particularly physical attributes, for a spatially well-defined area. Although the significance for productivity with soil differences among units as small as one meter has not been determined, variations in yields of up to 10 times have been measured in test plot-sized areas in the same field.

Optimum crop production requires a management map or database that is specific to a particular field. Ideally, this database would contain such information as soil attrib-
GPS assisted a fertilizer truck operator in spreading several compounds exactly where each was needed.

operator control machine position and speed. These devices can improve results in certain situations, but they have several drawbacks. For example, markers extending to the side of the machine greatly increase the width of the machine and make it more difficult for the operator to handle.

Machines have been developed to vary fertilizer application type and rates for different positions in the field. These machines use an onboard computer to control the inputs for different field positions. The database for the field is prepared ahead of time using soil maps, photographs, and soil tests and is subsequently stored on a microchip for transfer to the onboard computer. The computer then controls the machine’s fertilizer metering system as a function of field position, ground speed, and other data.

The accuracy of the relationship between a position in the database and the actual position in the field is a limiting factor in this type of system. An onboard radar speed sensor and a radio triangulation system have been developed by others to improve the correlation between these values. One system operating in Montana uses the radar speed sensor but relies on the driver’s judgment, essentially dead reckoning, to control machine position in the field.

In fact, operators can do this reasonably well if the soil variations in the field are large or if some small skips and overlaps are not critical. A more accurate approach to positioning is required when growers want to match application rates to variations within small areas and when skips and overlaps must be prevented. The combination of an automatic precise positioning system such as GPS with a field- and soils-specific GIS could fulfill the preconditions for highly targeted farming techniques.

PRELIMINARY GPS TESTING

Researchers at Montana State University have been developing a precise positioning system featuring GPS for agricultural producers since 1986. The ultimate goal of the project is to apply crop inputs such as seed and fertilizer exactly where they are needed by using GPS to guide agricultural equipment. Designing such a system has involved sampling soil to create a GIS database, modifying application vehicles to accommodate GPS equip-
A computer screen indicating the vehicle's position allows the driver to monitor field position as fertilizer application is taking place.

The concept of software for onboard navigation and guidance was developed in the Civil and Agricultural Engineering Department at Montana State University. It uses differential GPS to provide the high level of positioning needed for agricultural input placement. The position of the stationary reference receiver is determined before material application is started. Both receivers must "see" at least four satellites at the same time to determine position and time coordinates. The stationary receiver transmits correction data, which then transfers the vehicle's corrected position to the onboard computer.

These position data are shown as latitude positive north \( (x) \), longitude positive west \( (y) \), and elevation in meters from the center of the earth \( (z) \). The latitude and longitude are given in radians. These numbers are first converted to \( x, y, \) and \( z \) coordinates in meters for the field in Montana. The \( x, y, \) and \( z \) coordinates can be readily interfaced with a GIS database to develop a control signal for machine outputs. All \( x, y, \) and \( z \) coordinates are temporarily saved on disk so they can be used later if desired. External information on other crop and soil factors could also be collected automatically and added to the database.

A simulation displays the machine's position in three windows on the screen of the onboard computer. The upper right window shows the entire field each time a new position is received. This lets the operator know that the system is working. An area along the bottom of the screen displays messages for the operator to help in machine guidance.

The upper left window of the computer screen provides information for machine guidance (see photo). It helps the tractor operator to position the machine the appropriate distance from a previous line or path. This part of the screen is actually a zoom window that shows a magnified portion of the current position in the field. The zoom window shows the two previous GPS position updates connected by a line plus a projected point for the next position. Coordinates for the zoom window change continuously and are calculated so that the projected next point is always located at the center of the window. In this manner the vector for the travel path is always shown as a line with a direction that points toward the center of the window.

The previous path is also shown to help the operator gauge the distance from the current path. This arrangement has not worked particularly well, and the program will be changed to show a new travel path that is a given distance from the previous path. That will allow the operator to follow a line,
rather than try to draw a line parallel to a previous line.

The current software calculates the distance from the current point to the nearest adjacent path in the field. This feature has worked well where paths are parallel and of equal length. In many places in the field, however, the travel path extends beyond previous paths, resulting in confusing data messages. A change to show a proposed path of travel that extends to field boundaries should give good data over the entire travel range of the machine.

**AUTOMATIC GUIDANCE**

GPS-based precision farming systems offer a higher degree of accuracy than conventional positioning methods. To maximize the system’s benefits, however, operator driving errors must be minimized. An automatic guidance system appears to have the greatest potential for eliminating such errors.

The possibility of interfacing the GPS positioning system with an automatic vehicle guidance system has been discussed with a tractor manufacturer. Considering the human factors involved, the operator probably will not use a guidance system if it requires continuous reference to a computer screen, but will use the usual methods of navigation instead. The guidance system on the computer could be a valuable aid while turning and setting the initial width of cut, and it might occasionally be used during travel down the field. Most of the time, however, the guidance system probably would be ignored as too inconvenient.

An automatic vehicle steering system that performs something like an aircraft autopilot may be needed to effectively realize the precision farming potential of GPS. The autopilot should be under the operator’s control so that it could be activated whenever travel is in a nearly straight line or at a given distance from a previous path. With this equipment configuration the operator would be free to check other implement functions and relax. As the machine approaches the end of a field or a known obstruction in the field, the automatic control would signal the operator to take over. If the operator did not do so, the automatic control would shut down the machine. When the operator resumed control, the machine would remain under the driver’s control until the automatic control system was reengaged.

The GPS guidance system will always be looking backwards, telling the operators precisely where they have been. The system currently can predict where it will be, but the prediction is just an extension of the vehicle’s path from the last two points. An automatic guidance system must have data input that will indicate the directional changes that are needed and those that have occurred since the previous GPS position was determined. To achieve this, a steering angle detector could predict the position change that will occur between position determinations. With hardware to transmit this data to the com-

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**An antenna was mounted on the top of the fertilizer application vehicle.**
Four years of planning and research were put to the test last August, when the first GPS-guided agricultural fertilizer application system was used in a field trial on a winter wheat field in the northcentral Montana community of Power.

Using GPS position data integrated with a geographic information system (GIS) of the field and a truck equipped to dispense fertilizers at variable rates, Montana State University researchers and local farm cooperative personnel applied several types of fertilizer to different areas of the field. The types and rates of fertilizer applied were based on results of soil tests and historical crop yield records of different sections of the field.

A fertilizer application truck with six bins containing nitrogen, phosphorus, potassium, and sulfur materials mixed custom fertilizer blends “on the go” while equipment operators used GPS to navigate the 42-acre field. Based on soil fertilizer needs determined before entering the field, the truck delivered 40–80 pounds of nitrogen, 15–35 pounds of phosphorus, 0–20 pounds of sulfur, and 25 pounds of potassium to different parts of the field. Without a custom blend system and a way to identify specific field location, growers must apply a single mix of fertilizer to an entire field or cropping section.

In many situations, using GPS does not reduce the total amount of fertilizer used but instead reallocates it to potentially more productive areas of the field. Soils in the test field included clay loam and silt loam types with a wide fluctuation in fertilizer needs. Whether use of fertilizer and other chemicals can be reduced depends on each individual field.

YIELDS MAY INCREASE

The positioning capability of the system is estimated to be within a few meters, and could be considerably better, says Jeff Jacobsen, extension specialist with Montana State University’s Department of Plant and Soil Science. Researchers won’t know exactly how well the system performed until the wheat has grown and been harvested and crop growth data are analyzed in summer 1991.

Yields from the trial field will be compared to those of a similar field treated uniformly with 60 pounds of nitrogen, 25 pounds of phosphorus, 25 pounds of potassium, and 20 pounds of sulfur, the average rate for the trial field if the fertilizer had been applied uniformly. The economics of using a GPS-aided system to apply fertilizers will also be compared to the traditional method.

To take into account the varied application rates, yield determinations will be made by taking a grain sample from a four-foot pass every 25 feet. Researchers will sample the entire mile-long, 350-foot wide field.

Fields in the area generally average 40–45 bushels per acre. The GPS-aided system makes production more efficient by putting fertilizer inputs where they are needed in the correct amounts, so greater profits remain a possibility. The increasing sophistication of sensor technology and automatic guidance systems also offers opportunities for higher yields, increased efficiency, and ultimately increased profits.

ENVIRONMENTAL BENEFITS

Using GPS to place specific amounts of fertilizer and chemical exactly where they are needed is attractive not only economically but also environmentally. Researchers expect to find less residual nitrogen in the field after harvest. That, in turn, could re-
pected to do a better job than the operator does without the system. Improved accuracy also will make the GPS guidance system useful for automatic data collection.

An automatic guidance system needs to be developed and field tested. This system will include sensors to indicate the tractor response to steering inputs as well as software to compare the current position with the desired position. An added benefit of such a system would be the ability to perform field work at night, when lower winds result in reduced chemical drift. Human factors concerning operator-machine interface will have a major influence on the design of the software.

A software and control system will be needed to interface the GPS position location system with a GIS database and with machine controls. This will also require development of control devices that will attach to metering systems that automatically adjust crop inputs. Some systems have been used in tests with the GPS system, but new methods are needed.

Many different sensors will need to be developed to measure external factors that can produce the amount of nitrites present to leach through the soil and into groundwater after plants have ceased to absorb fertilizer and native nitrogen.

“It’s more efficient to minimize the amount of nitrogen left, and also much more environmentally benign if there is less to go through the soil profile when we get rain and snow,” says Jacobsen. “The same thing holds true for pesticides and other chemicals used to control fungi or diseases and weeds.”

With further equipment modifications, some of which are already underway, a producer may be able to apply all crop inputs on just one pass through the field. Such a system could decrease fuel and oil use as well as the air pollution released by combustion engines. In addition to these benefits, fewer passes across a field will reduce soil compaction and thus improve soil aeration and drainage as well as promoting nutrient uptake.

**FISCAL CONCERNS**

Although workshop attendees recognized the efficiency GPS could bring to agricultural production, most were skeptical that savings on fertilizer and chemical expenditures would cover the purchase and maintenance costs of such a system. Surveyors and navigators using GPS on a daily or weekly basis, for example, can recover the purchase cost of the equipment fairly quickly. Agricultural producers, however, typically use a piece of field equipment for a limited number of days each year. Unless a grower has a very large operation, it may take several seasons for the GPS outfit to pay for itself.

“GPS-based field navigation will be financially feasible in the future, possibly even in the next five to ten years,” says Jacobsen. “High-acreage corporate farms will find it cost-effective to purchase the equipment for themselves, and individual and family farms can benefit from it economically as well. GPS technology for crop input application offers a new business opportunity for cooperatives and individuals.”

In an informal survey conducted after the demonstration, workshop attendees were asked to define what they perceived to be the most important priority in continuing research on the GPS-guided farming system. Of the 64 responses, 20 (31.2 percent) noted economic returns and costs as the most important issue.

“Work on the cost models more. Profit is all there is!” commented a design engineer working in driver interface research and development.

Another engineer summed up the situation in a similar manner: “The challenge lies in merging all the pieces into a system which is cost-effective for agriculture. How do you manage and use the plethora of information that can be gathered to increase farmer profitability? Clearly, that’s the bottom line.”

Added a third participant: “Automation technologies may not yet be cost effective in agriculture, though they are imminently doable.”

Other issues receiving votes as the most important concern for GPS-aided farming included data collection techniques (10); applications of technology (7); delivery of technology (6); standardization of systems and equipment (6); “on the go” noncontact sensors (4); resolution, scale, and data exchange issues (4); three-dimensional navigation (3); effect on the environment (2); and extrapolation/validation of data (2).
Terrain modeling software allows agricultural producers to create a scale model of their property that can be used to test potential management practices.

Digital soil maps and terrain modeling would enhance the capabilities of the precision farming system. Digital maps are produced by entering into a computer soil characteristic information from U.S. Department of Agriculture soil survey maps and data from infrared photographs. The color tones of the photographs reflect different organic matter content, drainage, water holding capacity, degrees of erosion, and texture, all of which affect crop productivity. Soils with similar characteristics and production capacity are grouped together in categories to eliminate excess detail and simplify digitization.

Terrain modeling is a computerized method of representing three-dimensional topographic information attributes such as slope, aspect, and elevation. These features partly determine movement of water and pollutants, soil erosion, contamination of groundwater, rates of soil drying, crop yields, runoff volumes, peak flow rates, and insect and weed infestations. When combined with soils data, terrain maps can be used to predict areas requiring precise management. Because topography does not change rapidly, a terrain map would be generated only once every few years.

Another desirable development for the precision farming system would be the addition of squares on the computer screen window to represent GIS blocks or areas. Simulation has shown that field terrain information can be related to $10 \times 10$ meter squares. Other research has shown that this resolution is probably much finer than needed for most fields. Equipment operators have used on-screen soil fertility information for areas 20 or more times this size, or about two acres, without difficulty.

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The research described in this article was conducted as a team effort, with team members assuming responsibility for one or more specific aspects of the work. Bill Larsen provided the engineering interface between the position, the farm machine in the field, and its output. Jeff Jacobsen provided the soil fertility and field research project coordination. Jerry Nielsen developed the “Farming Soils Not Fields” concept with soil yield potential maps and management units. John Wilson developed GIS and terrain modeling procedures. Dave Tyler showed how real-time differential GPS would work for agricultural applications. Kirk McEachern compiled many of the on-farm GIS components. Dick Snellman acted as Power Farmers Elevator project leader for differential fertilizer application.

Several manufacturers assisted with the project. Cheryl Quirion of Trimble Navigation performed the GPS surveys and programmed the GPS receivers for real-time differential GPS. Thad Mauney of GeoResearch provided the GPS and GIS program linkage including the hardware and software development. Max Hammond from CENEX/Land O'Lakes provided the soil fertility spatial data analysis and mapping. Roger Knutson of SoilTeq, Inc. helped develop fertilizer application systems. Dave Ward of VERDE provided remote sensing for the mapping of agricultural fields.