GPS System Integration And Field Approaches In Precision Farming

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BIOGRAPHIES

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ABSTRACT

Two phases of a precision farming project jointly undertaken by Alberta Agriculture, The University of Calgary. and the University of Alberta, are described. Phase I consists in the collection of data from four test fields across Alberta using DGPS combined with crop yield monitors and electromagnetic (EM) ground conductivity meters for measuring salinity. A Geographic Information System (GIS) is used to analyze and combine various layers of information obtained from each field in order to analyze yield variation. Positions better than 50 cm horizontally and 1 m vertically are obtained in DGPS mode using a robust carrier phase smoothing of the code approach. The accuracy of the DGPS positions is verified independently through a crossover point analysis and a comparison with an ambiguity resolution on-the-fly (OTF) solution. DGPS positions are used to generate maps which indicates that fields are not homogeneous in crop yields when they have been treated without considerations for variability of soil, salinity, topography or field history. Phase II, which will consist in the application of variable rate fertilizer based on the information gathered in Phase I, is summarized.

INTRODUCTION

It has long been accepted by agricultural producers that homogeneous treatment of a field gives sub-optimal crop production due to the variability of many factors within the field. To realize optimal crop potential (within the controls of science), these variabilities must be understood and treated accordingly. The major hurdle to achieving this has been the positioning problems that occur when trying to gather the information. If data is too sparse, errors in interpolation may draw researchers to incorrect conclusions. Denser data is very often too time consuming and not cost effective to collect. DGPS has effectively provided accurate positioning capabilities and through integration with other sensors, has allowed much of the necessary data to be collected during normal farming duties.

This paper deals mainly with solutions to the positioning problems, accuracies obtained and integrated systems used for data collection. Several field tests were conducted in which DGPS data was collected on various test fields on different days. Several strategies were implemented to process the data, such as carrier smoothing of the code and OTF carrier phase ambiguity resolution. Position consistencies at the cross-over points during any one session and also between sessions was used to verify the level of accuracy achieved.

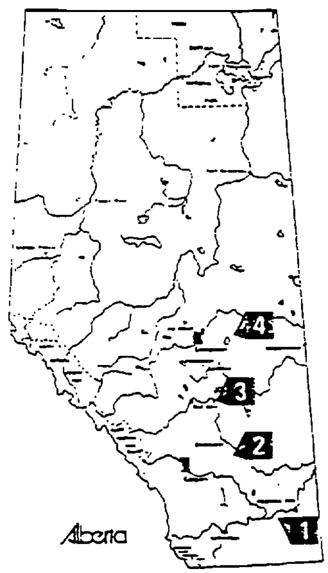
Handling of the data and preliminary maps of the results from some of the four test sites within Alberta, are presented. Figure 1 shows the four test areas. The approach for Phase II, namely variable rate fertilizer application, is described as well as the proposed integrated system for navigation and mapping of this task.

1 - Bow Island

2 - Hussar

3 - Stettler

4 - Mundare

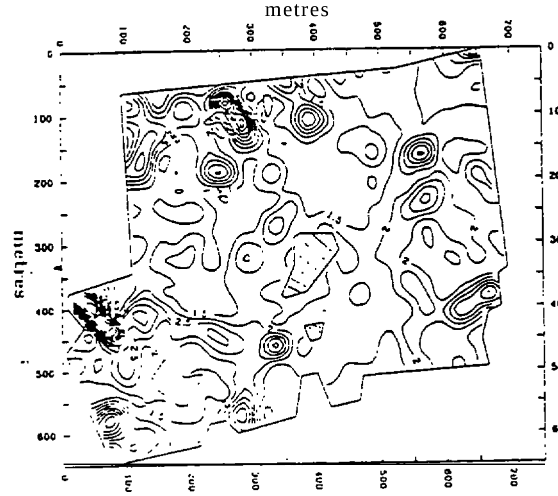


Precision Farming Project Sites
Figure 1

SYSTEM DESCRIPTION

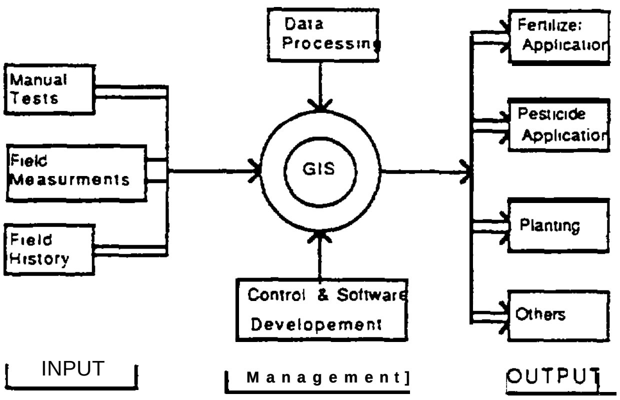
The svstem consists of several components which-include GPS receivers for positioning, a yield monitoring system which outputs the instantaneous Bu per acre, an EM conductivity meter for salinity measurements, and soil samples for determination of soil types and nutrients The DGPS/yield monitoring data can be collected under normal combining operations and is the focus of this paper. Two lo-channel C/A code narrow correlator spacing NovAtel GPSCard™ sensors and antennas Model 501 were used (Fenton et al 1991, Van Dierendonck et al 1992). They have shown to provide sub-meter accuracy in previous field tests using a robust carrier phase smoothing of the code approach (e.g. Cannon and Lachapelle, 1992).

The acquisition of DGPS and salinity information has been described previously by Lachapelle et al (1992a. 1993) and Cannon et al (1994). An EM meter installed in a non-magnetic sleigh is typically pulled by an All-Terrain-Vehicle (ATV). Figure 2 shows a typical salinity map for one of the test sites. Field sample locations were also positioned using GPS so that a consistent reference system could be used. The field is approximately 80 acres and a four-hour survey was required to collect the data needed to produce the map. The number of sample points is approximately 2400, which if collected conventionally, would have taken several days. In addition, the operator had the flexibility to densify the data collection around areas that indicated potential high variations.



Salinitg Map - Mundare Test Site
Figure 2

Another important component of the system is a GIS database to organize and collate the variety of data collected from year to year. Various layers of information can be draped (using surfacing routines) over each other through the DGPS position. It is then possible to overlay crop yields with salinity and draw conclusions based on that relationship (i.e., high salinity results in low yield). Further, predictions can be made on how to handle these regions when it is time to fertilize and/or seed. Figure 3 shows the GIS concept as applied to agricultural yield monitoring. The GIS can also be updated with external information such as aerial photography or remote sensing. Current information layers of topography, salinity, soil type, nutrients, and crop yields were collected for the 1993 harvest.

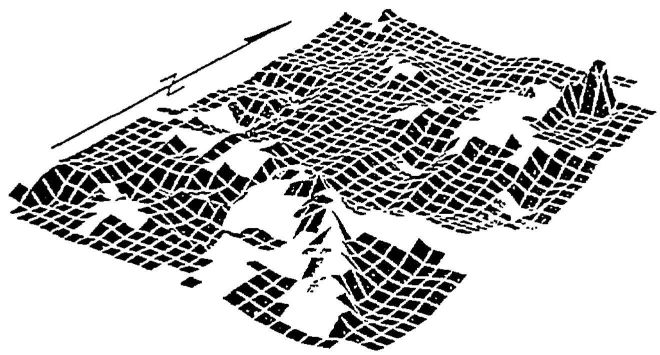


Geographical Information System (GIS)
Figure 3

PRELIMINARY YIELD RESULTS

The goal of the precision farming project is to optimize the yield-input relationship for any given field. Since this is the first harvest season of the project, results to date only give an indication of the variation within the field for this year, with the condition that it has been treated equally in the past. To view the yield variations, a surfacing routine called GRASS is used, and the result is shown in Figure 4 for a subset of the Hussar test site. The figure clearly shows that the field is not homogeneous in yield. Surface analysis of crop yields allows agricultural researchers to identify problem areas and to maintain data quality by detecting results such as the sudden peak in the NE comer of the field.

The peak in the NE comer of the subset looks like an outlier even though it passed the data sorting quality control. This is most likely caused by high moisture in the swath which returns a false reading from the yield sensor. The ridge in the SE comer, which runs into the middle of the image, coincides with a 90” comer in the swath. At this point, the speed of the swather decreases and lays a more dense swath on the comers. The combine appears to pick up crop in a smaller area, hence giving a higher false yield reading. The magnitude of this error **is** a function of the terrain in the test area. Variations of this type can be detected by draping the yield map over the topography map while spikes can be smoothed out. If false readings are associated with the combine turning, each turn can be removed by using software to analyze the DGPS data.



Yield **Map (3rd Dimension is Yield)**
Hussar Site Subset
Figure 4

In order to check the yield monitoring system, periodic samples in the field were taken and compared to the raw field data. For example, the total yield that is harvested from a given field is known when the field has been completed. The total yield is then calculated from the DGPS and yield monitor and a direct comparison is made. The difference in the two values is the sum of the errors in the sensor systems and the errors in the sensor calibration. In these early stages of the project, a scale factor is used to force the raw data to conform to the truth. All of the data is formatted and layered into a GIS for overlay capabilities.

Once all of the necessary data has been sorted into their respective layers, relationships and effects between each layer can be determined.

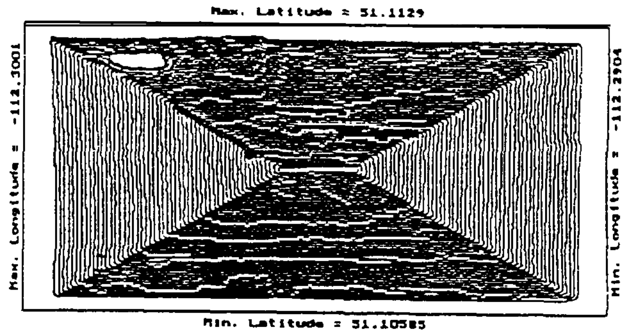
This information can be used to optimize the field potential by treating the field based on the specific sub-class of different sections. A field may have several distinct classes of soil that should have different quantities and mixtures of fertilizers applied to it in order to get maximum yield. The variable rate application would also take into account other variables such as salinity, topography and history of previous crops and applications.

DGPS ACCURACY & Repeatability

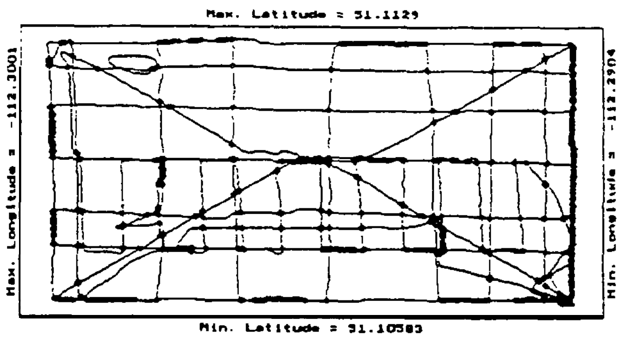
This project is expected to last approximately five years. In order for the yearly results to be meaningful, there must be some standards set for position requirements so that the results and relationships from year to year will become a history of the field performance and variation. Repeatable accuracies of 0.5 m in horizontal positioning and 1.0 m in the vertical component have been deemed adequate. To investigate if these requirements were met under operating conditions, a series of tests were performed on the data from the first harvest.

Two approaches were used to process the data, namely a carrier phase smoothing of the code approach, implemented in C³NAV™ (Cannon & Lachapelle 1992), and an OTF ambiguity resolution approach, implemented in FLYKIN™ (Lachapelle et al 1992b). The second method, which yield an accuracy at the cm-level, can then be used to assess the performance of the first method more reliably. Multipath was minimized through the use of a chokering at the reference station. No chokering was used on the moving platforms due to space consuaints.

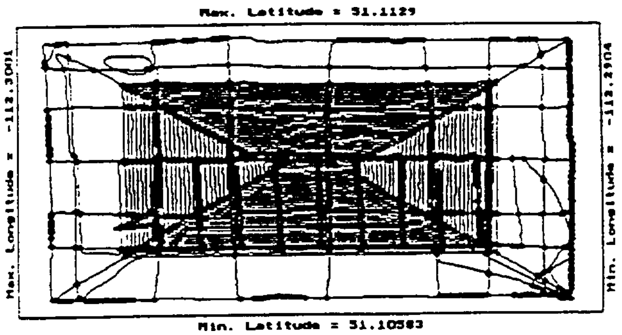
Results are presented here for the Hussar test site, the location of which is shown in Figure 1. The field consists of gently rolling hills with a steep north facing hill in the middle. The reference station was installed near the field and the moving platform was operating within a few km from the reference station. The crop was harvested on September 20 and 21 and the combine tracks are shown in Figure 5. On November 9, soil samples were taken at various locations and the tracks of the ATV used for this task are shown in Figure 6. The ambiguities OTF could be resolved on September 21 and November 9 using typically 10 to 15 minutes of data. This is to be expected when using single frequency data The portion of the field which was harvested on September 20 in shown in Figure 7. On each day, a minimum of six satellites were tracked and the theoretical PDOP was always smaller than 3. Data was collected at a rate of 1 Hz. Although cycle slips were occasionally detected on low satellites, the tracking stability of the GPSCard™ was fully satisfactory.



Combine Grid Pattern and Crossover Points - Sep 20 and 21
Figure 5



ATV Grid Pattern and Crossover Points - Nov 9
Figure 6



Cross-over points Between Sep 21 and Nov 9
Figure 7

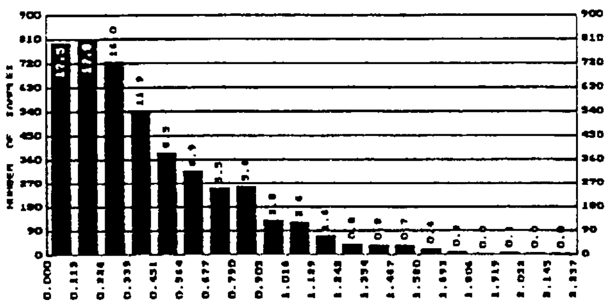
The height repeatability was first assessed by comparing the heights at crossover points between tracks observed on the same day and on different days. A cross point occurs when two points from different tracks lie within a specified radius. In the case of tracks observed on the same day, a minimum observation time difference of 10 minutes is used in order to decorrelate the positions and ensure that the crossover point is the result of the crossing of two separate tracks. An horizontal radial search distance of 3 m is used. Over such a distance, real height variations of over 10 cm might occur. The dots in Figures 5, 6 and 7 show the crossover points which were detected when the above criterion were satisfied. Some crossover points may not detected due to the vehicle traveling at speeds greater than 3 m/s. Since several hundred crossovers points were detected in each case, the sample is sufficiently large to be statistically significant.

Table 1 summarizes the rms height differences at the crossover points on each day and between the two days. The carrier phase smoothing of the code approach yields rms differences of 25 to 56 cm. In order to obtain the rms accuracy (lo) of any one height determination, the above rms differences are divided by $\sqrt{2}$. This yields a rms accuracy of between 18 and 40 cm, which is well below the 1 meter level required. Also, this rms accuracy contains the effect of real height variations within the 3 m radius used to define a crossover point. An histogram of the height differences between September 21 and November 9 using the carrier phase smoothing approach is shown in Figure 8. As expected, the rms height differences are yet smaller using the OTF approach. The reason why a decimeter level accuracy is obtained instead of a cm-level accuracy is the effect of the real height variation within the 3-m crossover point radius described above. For either solution, no bias between the two days are detected which shows the excellent repeatability of GPS.

Table 1
RMS Height Agreement at Crossover Points Using Carrier Phase Smoothing and OTF Solutions

Date	Carrier[1] Smoothing (m)	0TF2 (m)
Sept. 21	0.25	0.07
Nov. 9	0.56	0.08
Sept. 21 vs Nov. 9	0.43	0.14

1 Using C[3]NAV™
2 Using FLYKIN™



Histogram of Height Differences Between Sep 21 and Nov 9 Using a Carrier Phase Smoothing Approach
Figure 8

The carrier phase smoothing approach can also be assessed by comparing the coordinates obtained at each epoch with those obtained with the OTF ambiguity resolution approach. In this case, the comparison can be made along. the entire trajectory and over 10,000 comparison points are used. Histograms of the easting, horthing and height differences between the carrier phase smoothing and OTF ambiguity resolution solutions for September 21 are shown in Figure 9. The rms differences in each of the three coordinate components are given in Table 2 for both days. While the rms differences in latitude and longitude are at the 25 cm level, those in height are at the 50 to 70 cm level. Since the OTF ambiguity resolution method is practically error free, the rms differences represent the accuracy of the carrier phase smoothing approach. The accuracy estimate for the height component is slightly higher but more reliable than the 18 to 40 cm estimate obtained through crossover point analysis. Future tests will be based on the use of a chokering groundplane on the moving platform to assess if the above accuracy can be further enhanced.

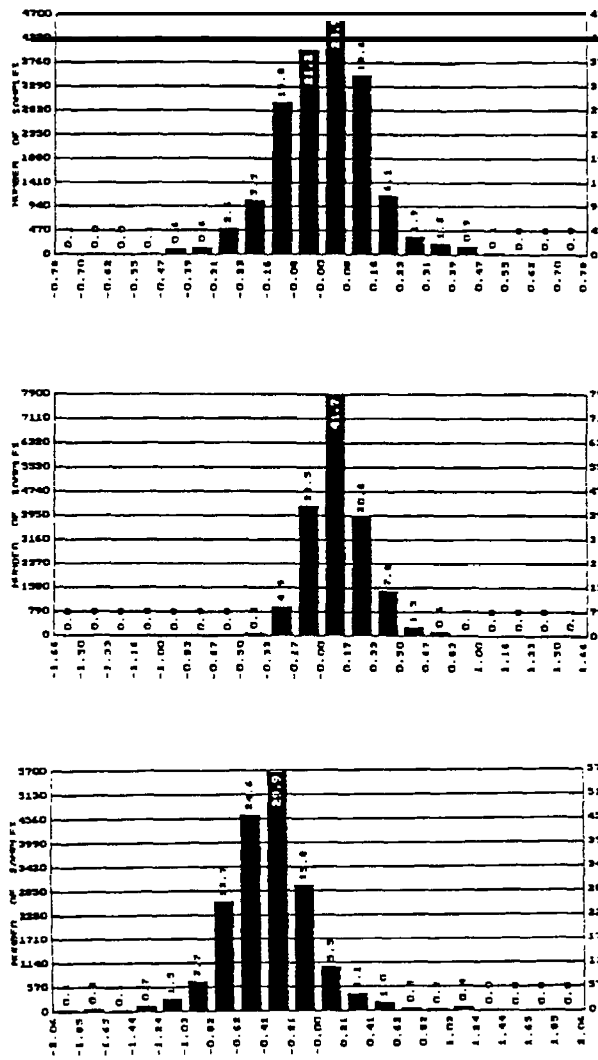
The accuracy performance obtained at the Hussar test site were also obtained at the other test sites.

Table 2
RMS Agreement Between Carrier Phase Smoothing and OTF Solutions at Crossover Points

Date	**RMS of Differences**		
	East (m)	North (m)	Height (m)
Sept. 21	0.14	0.21	0.51
Nov. 9	0.14	**0.26**	**0.66**

VARIABLE RATE FERTILIZER APPLICATION

Fertilizer application requires DGPS operating in real time along with a pre-defined prescription map with the sub-class boundaries clearly marked. An additional advantage to using real-time DGPS is that it can also assist the operator in maintaining tracks which reduce overlaps and gaps. Figure 10 shows a hypothetical representation of a prescription map. The fertilizer spreader would be guided by real-time DGPS. The prescription map can be raster-based, such that the pixel value of the screen will dictate the action, or vector-based so the zone is determined and the appropriate response is taken. The initial procedure in the project is to use a raster-based map so polygon searching will not have to be performed. The shortcoming to this approach is that the field resolution **is** a function of the pixel resolution of the map (i.e. ground resolution is a function of the field size).



Histogram of Coordinate Differences Between Carrier Phase Smoothing and OTF Ambiguity Resolution Solutions for September 21
Figure 9

Position information will be fed into the GIS database which will return the necessary instructions for fertilization at that particular location. In turn, the computer connolled variable rate spreader will adjust the outputs accordingly. This approach also allows researchers to treat any part of the field in any manner and to then analyze the success rates based on the yields returned from each sub-class. The applications can then be modified to account for the shortcomings in yields. The procedure becomes self-learning.

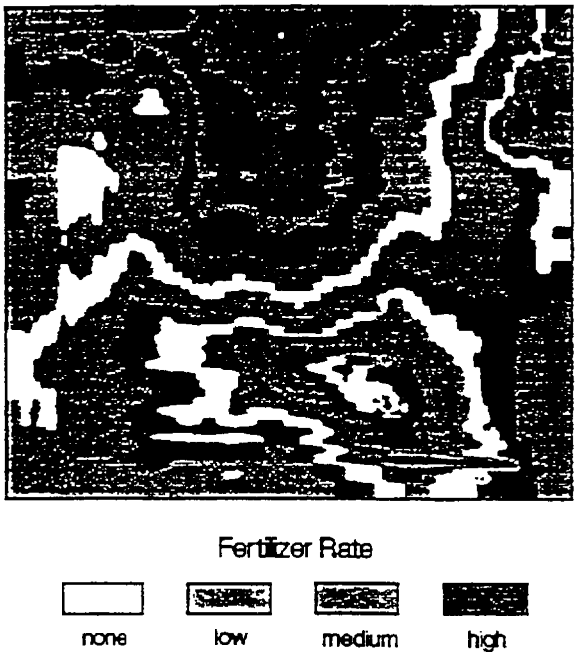


Figure 10
Hypothetical Prescription Map of a Test Site

CONCLUSIONS

This paper has outlined the precision farming objective of optimizing field potential based on the information known about the field. Integrated systems to collect this data and to form a GIS have been described. Phase I of the project is currently operational and results were presented. The ability of GPS to provide better than 50 cm horizontally and 70 cm vertically has been demonstrated using a robust carrier phase smoothing of the code approach.

The second phase of the project has been outlined. This phase will begin in Spring 94. A return to the test area in the second year of the project will provide a measure of success in the project.

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