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ABSTRACT

The Field Grid Sense system was adapted to locate and record crop yield in the field. Accurate measurement of yield in spatially variable fields is needed to achieve maximum profitability in crop production. The harvester system is composed of a laptop computer, data acquisition system, fifth wheel, and an ultrasonic level sensor assembled on a combine. The fifth wheel, in combination with travel lanes, is used to identify yield with position where yield is determined by the change of grain volume in the combine hopper. Yield maps can be generated from the collected data and then used as a production management tool in conjunction with other field characteristic information.

INTRODUCTION

PURPOSE - Accurate measurements of yield and other field characteristics are needed to achieve maximum profitability in crop production. The Field Grid Sense (FGS) system provides a means of yield mapping. Locating yield variations in the field and making comparisons to soil maps and fertilizer application rates can be advantageous for determining possible production problems.

Crop production efficiency can be increased by knowing the site specific yield and grain moisture contents. Over several years a data base can be compiled with FGS and prescription farming can be used to increase profitability. Expensive fertilizers and herbicides can be applied at varying rates based on yield and other site specific data to insure that these products are used as efficiently as possible.

The FGS harvester system could also be used to eliminate discrepancies between landlords and tenants over sharecrop amounts. The system is also functional for test plot yield determinations and showing the yield fluctuation across the plot. Benefits of accurate yield maps displaying the yield variations due to spatial variability of the field are noticeable both economically and environmentally.

The benefits of yield mapping are noticeable from past research done by several parties and their varying yield determination methods. A grain flow sensor was developed using piezo-film (1)¹. The film was mounted under the combine sieves to correlate an impact rate to a harvesting grain flow. This flow was then converted to a yield for the development of yield maps. Field tests and laboratory tests were performed. For better accuracy a larger area of the sieve needed to be covered with the impact sensor.

Yield was mapped according to grain flow determined by a Claydon Yield-o-Meter manufactured by Shelbourne Reynolds Engineering in England. The flowmeter mounted on the discharge side of the grain bin auger, consisted of a paddle wheel and grain flow was sensed as a function of the rotation of the paddle wheel. The researchers concluded that the system showed the yield variability across the field with reasonable accuracy. However, in low grain yield areas the yield was overestimated by the system due to smoothing of the data (2).

In another method, the amperage was measured to a motor which drove the clean grain auger to determine the

1. Numbers in parenthesis refer to the references listed at the end of the manuscript.

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grain flow into a combine (3). The greatest error in grain flow measurements in an auger was due to variations in the grain moisture content (4). The change in momentum occurring from a direction change of the grain was used as an indication of grain flow. A force derived from the combination of friction and impact caused by the flowing grain could be filtered so that yields could be mapped (5). A capacitance grain flowmeter and a nucleonic grain flowmeter were also researched (6).

The combine causes many problems in determining grain flow throughout the machine. The time interval as the grain flows from the head to the flow sensor is called the transportation delay. The redistribution of grain within the combine is represented by a time constant. Combining these terms results in a model using a first order time delay (2).

Locating position for a particular grain yield within the field can be done in several ways. Some of these methods include dead reckoning, radio wave triangulation, and global positioning. Construction of traffic lanes takes some initial preparation (7). However, it is a low investment, and does perform satisfactory. Radio location, such as triangulation, can be used in many cropping practices (2). An emerging technology, Global Positioning Systems, (GPS), is fast becoming an alternative to other techniques of positioning. With decreasing costs and improving accuracies, it may soon replace other methods (8).

BENEFITS - Grain yield mapping systems are restricted by many factors present in the field or on the combine. Some of these factors include the space available on the machine, physical variables of the grain, machine vibration and electrical noise, topography, and environmental conditions. The system we selected to generate instantaneous yield maps minimizes the unwanted effects from the factors mentioned above. The FGS combine system provides maps of both the grain yield and grain moisture content at a specific point in the field. The system also generates topography maps of the field. The system includes temperature and grain moisture affects in determining the yield. This insures that all compensations are performed before the yield map is generated and the consumer can gather the needed information directly from the map. The information collected can then be used for locating last season's crop production mistakes and fine tuning next season's crop inputs.

Correct chemical applications based on yield and soil characteristics can be beneficial to everyone. The producer saves money by applying variable rates which correspond to the needs of the crop and the soil. This ensures that the products applied were correctly prescribed and used, therefore leaving no chemicals present to contaminate other parts of the environment. Agricultural practices can contaminate the surface waters and groundwater, and a top priority of prescription farming is to minimize agriculture's effects on the environment (9). An accurate measure of yield specific to the location in the field is mandatory for this method of farming. Safe use and correct methods of farming can decrease the chances

of damage to all the resources present within the environment.

OBJECTIVES - The information collected could improve crop production efficiencies obtained by fine tuning crop production techniques to fit the environment, equipment, and the producer.

Therefore, research was initiated with the following objectives:

1. Adapt QLANE software and the FGS mapping and control system for use with the combine so that it performs instantaneous yield mapping, grain moisture mapping, and topography mapping controlled by a laptop computer.
2. Evaluate the described FGS combine system based on performance of the components.

MATERIALS AND METHODS

The FGS harvester system was designed to document the location of crop performance in the field. This performance is based upon moisture corrected grain yield. The yield mapping system consists of eight parts: distance sensor, laptop computer, data logger, control box, a file containing the field map, ultrasonic level sensor, and two electronic clinometers. These components were mounted on a TR 86 New Holland Combine. The computer collected and recorded all pertinent information from the sensors listed above.

The yield mapping system used controlled travel lanes established earlier during preplanting operations. Lanes are numbered and can be harvested in any order. Therefore field location is determined by the lane being harvested and the distance traveled down the lane. At the start of a new lane the number of the lane is entered and the initial distance is zero. Grain moisture content, pitch, roll, yield, and distance are recorded by the data acquisition system. This information is available for viewing by the user. The system records the data from the above sensors during field operation from a given field, which is broken up into grids. These grids are approximately 12.2 meters long and the width is equal to the width of the combine head currently being used. This grid size is large enough to notice topography, grain moisture, and yield changes, and yet small enough to eliminate the possibility of missing important fluctuations in one or more of these factors. After harvesting a field, a map can be generated. This map will display the changes in yield and grain moisture content throughout the field. The map depicts fluctuations in the factors noted above in grids equal to or larger than the size described. Therefore the smallest grid would be 12.2 meters by the width of the head, and the largest grid for a particular lane could be the width of the head by the entire length of the lane.

The time delay corresponding to the time at which the grain is cut until it reaches the yield sensor was determined and used as an average of 22.5 seconds. The transportation delay ranges from 20 to 25 seconds for this combine (10). More research is needed so that more

reliable values can be used to determine this delay based on combine ground speed and the thickness of the crop. It is noticed that the delay is larger when leaving the crop than when entering. This is an important problem that needs to be addressed further if the accuracy of spatial yield maps is to be improved.

SYSTEM COMPONENT DESCRIPTION - The developed instrumentation system controls various components of the system and records the field data necessary to meet the objectives of the research. The instrumentation configuration is shown schematically in Figure 1.

Figure 1. Diagram depicting the main components used to collect the data to develop field maps.

Microcomputer - A 640K IBM compatible Zenith SuperSport laptop computer controls the various components of the system and stores the data collected onto disk. An RS-232 serial port interface was used to link a Campbell Scientific 21X Micrologger to the laptop computer. Two 3 1/2 inch disk drives were used by the system. Drive A contained the diskette with the FGS software and combine programs. Drive B stored all pertinent field data for a given field. This configuration kept the main program safe from possible damage and allowed the user to easily store and retrieve records for specific fields.

Within the environmentally controlled climate of the combine cab the laptop computer performs the functions required to operate the system. The laptop is placed on a shelf next to the operator's right shoulder.

This placement permits the freedom of operation of the other controls and still makes the computer available for viewing and keying in functions (Figure 2). The portability of a laptop allows for many uses by the farmer other than just field data acquisition, such as business record keeping and forecasting management decisions.

Figure 2. This laptop position in the combine cab provides for viewing and access to other controls.

Data Acquisition - A Campbell Scientific 21x Micrologger receives signals from either the sensors or from the control box. From here the signals are relayed to the laptop computer. A program was constructed to control the acquisition of the signals from the various sensors. This allows the laptop to use its capabilities for other functions rather than communicating with the sensors and waiting for processing functions to be completed. The micrologger also acts as a data backup valve by storing the data from the field in its internal memory in raw form. If a diskette or the laptop malfunctions the backup data is still present in the micrologger, if this device is also not turned off.

The micrologger is powered through the control box and receives signals from the sensors in the form of voltage differentials or pulse inputs. The voltage differentials are confined to a ± 5 vDC, and the pulse inputs are collected in terms of number of counts. Position of the data logger is shown in figure 3.

Figure 3. Milltronics MultiRanger Plus Ultrasonic driver box on lower shelf, control box on left side of top shelf, and data logger on right half of top shelf.

Interface Control Box - A control box was designed and built to contain the electronic circuits needed to convert signals, regulate voltages, power sensors and equipment, and house system control switches (Figure 3.)

Within the control box the ultrasonic 4-20 mA signal is converted to a voltage output for the data logger with the use of a quarter bridge. The grain moisture and temperature signals are processed with the use of voltage divider circuits to establish signals within the ± 5 vDC range tolerable by the data logger.

Power is sent and regulated at 5 vDC to the magnetic pickup and electronic clinometers with the use of a voltage regulator.

The control box contains a master power switch which turns on or off the power to all components, except the laptop computer. Also located on the control box are two toggle switches. The first toggle is a "hold" switch, when on allows a corresponding voltage which instructs the computer to hold all functions. This is useful when the operator needs to stop the machine for some minor adjustments. The second toggle is a "change lane" switch and is used to inform the computer at the completion of a harvested lane. At this point data for the finished lane is saved onto a diskette and a new lane to be harvested can be selected.

Ultrasonic Level Sensor - An ultrasonic level sensor from Milltronics was used to measure the depth of the grain in the combine hopper (Figure 4). This measurement of depth corresponds to a volume of grain, given that the dimensions of the tank are precisely known. The change in volume over a given distance traveled by the combine yields a value representing the grain yield present for the area just harvested.

It was assumed that one depth measurement was sufficient in determining the depth of the grain. An optimum placement of the sensor over the grain was determined in a manner similar to grain depth in a circular grain bin. If the grain is peaked at the center of the bin, measuring the depth at one-half the radius would approximately correspond to the depth if the grain was leveled. Starting with this concept and through testing, this sensor placement was determined for the combine used. Machine vibration and grain moisture content do affect the accuracy of the depth measured. However, initial research began with the most simple configuration, a one point measurement, and developed from there.

Basic ultrasonic operations involve the principles of using the time required for a transmitted electronic pulse to be echoed back from a material or surface. Milltronics uses an advanced version of this technology by continually storing an updated ultrasound profile in memory. This technique, called echo enhancement, increases the degree of reliability of ultrasonics.

The MultiRanger Plus, as used during this research, consists of a driver box containing the electronics and components which control the ultrasonic signal, and removable programmer for specific programming needs. Easy setup and programming allow for fast installation and use of this device. All parameters describing the task for which the device is to be used are entered by keying in codes with the removable programmer. Alterations in the program are quick and results can be viewed at once on the LCD display located on the driver box (Figure 3).

Resolution of the ultrasonic system, as provided by the manufacturer is 0.1% of range, while accuracy is 0.25% of full range. The device can be operated in temperatures of -20 to 60 degrees Celsius, with temperature correction available if large temperature changes occur during operation. The electronics also contain a MK2 "Fuzz" Filter to smooth small variations in level from surface waves. An agitator filter can also be used to remove unwanted effects on the signal caused by the agitators or crossbracing.

The MultiRanger Plus is used to drive the ultrasonic signal, while the 21x and the laptop computer do the processing necessary to store the data in proper format.

Figure 4. Location of the ultrasonic level sensor over the combine tank for yield determination purposes.

Grain Moisture and Temperature Sensor - Grain moisture content is needed to determine the yield on the go based on number two corn. To account for temperature differences of grain occurring during the harvesting season a temperature transducer is included in the system. Change in temperature affects the actual moisture content of the grain.

The transducer selected was built by David Manufacturing Company. This sensor includes a capacitance sensitive moisture sensor fin, and a current sensitive temperature transducer, or monolithic type. However, the response time of the temperature transducer to notice temperature changes was not what was required by this system, and therefore the data from this part of the apparatus was not included in determining the grain moisture content. A thermocouple might be a better choice for this need, if temperature considerations are needed to determine grain moisture contents precisely.

The sensor, named Cale-U-Dri, consists of a plastic box containing a stainless steel capacitance sensitive fin and a current sensitive temperature transducer. The sensor is mounted in the grain hopper fill auger, therefore most of the grain flows past the sensor, yielding a representative sampling of the grain for moisture content (Figure 5).

The capacitance fin operates at a frequency of 1 MHz, which allows almost instantaneous reading of the moisture content of the grain passing through the auger. This moisture reading corresponds to the grain that just entered the tank. Therefore, this moisture can be used to determine the corrected yield. A calibration curve was

Figure 5. Placement of the grain moisture and temperature sensor on the hopper fill auger.

supplied by DMC which was used as a starting point for programming of the moisture signal.

Fifth Wheel and Position Sensing - To measure the ground speed of the combine and the distance traveled down the lane a fifth wheel was used. This was the same device used for the fertilizer and direct injection spraying FGS projects conducted at SDSU (11).

The fifth wheel consists of a bicycle fork attached to a parallel linkage which mounts to the combine's frame. The wheel was placed directly behind the path of the left front drive wheel. The drive wheel crushed stalks and other debris allowing the fifth wheel to ride over a conditioned path. To maintain constant contact between the wheel and ground a spring was attached to the fifth wheel configuration (Figure 6). This reduces slippage, excessive vertical motion, or jumping. Six equally spaced blot heads are welded on the rim of the fifth wheel. An Airpax Magnetic pickup, attached to the fork of the apparatus, generates a voltage spike which correspond to a count recorded by the micrologger. Every six counts is one rotation of the wheel. The speed of the counts generated yields the ground speed and the number of counts indicates the distance traveled.

Schumacher, found that the median rolling circumference is 1.554m (5.097 ft) for this fifth wheel. Extensive tests on varying soil conditions were conducted to determine this result.

Figure 6. Fifth wheel Configuration with magnetic pickup placed in the path of the combine drive wheel.

Electronic Clinometers - With the use of an AccuStar Electronic Clinometer an accurate angle measurement of the surface of the field can be taken. These measurements are used to create a topographic map of the field. Two clinometers are mounted on the combine to measure the change of slope in two directions. The pitch and roll of the combine were used to measure these angle changes.

The clinometers consist of a two inch diameter metal casing which houses a capacitor based sensor. A center plate etched to form two linear variable capacitors is placed between the housing halves. The device is half filled with a dielectric liquid and an inert gas. The rotation of the sensor produces a linear output in capacitance and with a conversion a ratiometric voltage output.

The electronic clinometer is a ratiometric device with 5 vDC power required. This produces an output of 2.5 vDC and a ± 0.016 volts per degree of rotation. Total range of the device is ± 60 degrees, linear range is ± 45 degrees, with a resolution of 0.001 degree, and the time constant is 0.3 seconds. Linearity of the device changes with the ranges of the angle. From 0 to 10 degrees linearity is $\pm 0.1\%$, 10 to 45 degrees $\pm 1\%$ of the angle, and from 45 to 60 degrees the signal is monotone. This device's operation range is large enough for field purposes and the resolution is greater than that needed to create topography maps. Operating temperatures are -40 to 65 degrees Celsius, and a small adjustment for temperatures out of this range is 0.008 degrees per degree Celsius.

One of the clinometers was mounted on the rear

axle of the combine to measure the roll which indicates the change in slope of the field in the direction perpendicular to travel. The other clinometer was mounted above the front axle to measure the pitch of the combine which corresponds to the change in slope of the field in its direction parallel to travel (Figure 7). With this data a map depicting the topography of the field can be created and used as a production management tool.

Figure 7. Location of the electronic clinometer, (right of laptop), to measure the pitch of the combine indicating a change in topography.

Software - A software program entitled QLANE™, controls the FGS system. This program was originally written by Schumacher and Froehlich, to control the application of granular fertilizer via a laptop computer (11). The software was modified to control and record field operations of a direct injection module in conjunction with a liquid chemical field sprayer (12). Further modifications were made to apply the software to the harvester system. Similar program format is maintained throughout each modification, however programming functions vary depending on the application.

This program links the data logger to the laptop computer and records the field data pertinent to the objectives of the research. This data is yield, grain moisture content, ground speed, distance, pitch, and roll. All data is saved onto a three and one-half inch diskette. All data can be viewed later at the office and field maps can be produced. The variables can be monitored on the computer screen during harvest. The software divides the screen into sections. The sections contain program commands, system operations, and field data. Instructions that the user responds to include the field name, the date

of harvest, lane number, type of material being harvested, and some program control functions.

The software calls for and receives information from the data logger or interface control box. The voltages or pulses from these devices have had some signal conditioning and programming alterations before entering the software. This allows more of the laptop's time to be free for other operating functions. The signals received by the software are then processed into a desirable output form. The current form allows data to be imported into spreadsheets and mapping software. After mapping, the information is used as a crop management tool.

FIELD OPERATION

An instantaneous yield mapping system was designed, built, and tested based upon the need for spatial variable farming practices (Figure 1). The components require some setup and operation instructions. A description of the operating procedure is as follows:

1. A combine is fitted with a bracket to mount the ultrasonic sensor over the hopper of the combine. The hopper is calibrated by corresponding a volume for a given depth of the grain (Figure 4).
2. The ultrasonic sensor is connected to the hopper bracket. The fifth wheel, clinometers, and grain moisture and temperature sensors are mounted on the combine. The laptop computer, RS-232 interface, Campbell Scientific 21x Micrologger, control box, and ultrasonic driver box are placed in the combine cab (Figure 3).
3. All sensors are connected to the control box or data logger. The data logger communicates with the laptop via the RS-232. The control box is connected to the combine's 12 vDC battery. All power is regulated by the control box before being supplied to the other components.
4. The operator drives the combine to the first lane of the field to be harvested. A program disk in Drive A and a field disk is placed in Drive B of the laptop. Disk B will contain the data only for one field, therefore a new disk is needed for each field.
5. The operator flips the power switch on, located on the control box, and flips the hold switch to the on position.
6. At the A prompt the operator types the name of the program "QB Combine." The program loads and a program is also downloaded to the data logger. The system is now ready for operation.
7. The operator now answers questions describing the field's situation. This includes the longest lane, width of combine head, name of the field, and type of operation.
8. The operator types in the lane to start combining, engages the harvesting system, switches the hold switch to

the off position, and starts harvesting.

9. During harvesting the operator can observe the yield, grain moisture content, ground speed, and distance traveled down the lane on the computer screen. All sensor output voltages are present on the screen during research for monitoring considerations. Yields and grain moisture readings are recorded every 12.2 meters so that the data can be used to produce yield maps. If combine or data acquisition system problems arise the hold switch can be flipped on. This "holds" all the current readings of the sensors and position in the field until the problem is solved. Then the switch is flipped off and harvesting can continue.

10. At the end of the lane the operator switches the change lane switch on. This saves the data from that lane automatically onto the disk in Drive B. The operator can now unload the combine hopper or select a new lane to harvest. Upon selecting a new lane, the operator drives to the lane, engages the harvesting system, and switches the change lane switch off while entering the new lane. From this point on the operation of harvesting continues with the same procedure.

11. After the field is harvested all the data should already be stored onto the diskette in Drive B. At the office the operator can view the data (Figure 8), in raw form or a print out of a yield map (Figure 9,10). The map can display the yield, grain moisture contents, date of harvest, and field name. This makes an excellent reference for next years crop production needs, and an instantaneous tabulation of each field's yields.

Yield	Moist.	Temp.	Slope1	Slope2	Speed	Dist.	Lane
(mV)	(mV)	(mV)	(mV)	(mV)	(counts/s)	(m)	#
2204	40	2743	2679	2697	4	45	7
2204	46	2742	2678	2706	3	80	7
2205	48	2742	2662	2681	4	120	7
2208	41	2742	2671	2686	4	163	7
2206	54	2742	2649	2673	5	211	7
2188	53	2741	2644	2689	4	241	7
2245	45	2741	2654	2700	4	288	7
2257	51	2742	2681	2707	4	331	7
2256	56	2741	2666	2722	4	366	7
2250	51	2741	2688	2725	4	408	7
2256	44	2742	2673	2720	4	442	7
2299	45	2742	2686	2707	4	484	7
2269	46	2741	2687	2709	4	526	7
2299	45	2742	2677	2720	4	560	7
2237	41	2742	2705	2708	5	603	7
2241	41	2741	2691	2702	4	645	7
2254	43	2741	2677	2708	4	691	7

Figure 8. Typical data recorded with the FGS harvester system.

Figure 9. Field map displaying the yield of a particular field. Areas of zero yield are due to downed corn.

DISCUSSION AND SUMMARY

The FGS system and QLANE™ software were adapted for the use with a combine to perform yield, grain moisture, and topography mapping. The system components, controlled with a laptop computer, have proven to be functional in laboratory and field evaluations. Accomplishments of the project are as follows:

1. Components needed to create the harvester system were selected and researched based on cost, operating principles, and adaption to harvesting systems.
2. An operational data collection harvester system, controlled with a laptop computer was designed and developed, and tested. A combine, laptop computer, and transducers were assembled to perform the system's objectives. The system was operated in the laboratory and in the field through common harvesting procedures. The system performed the desired objectives.
3. The programmable software, QLANE™, was adapted for recording data necessary for evaluating the system and mapping the grain yield, grain moisture content, and topography.
4. Actual field maps depicting the grain yield, grain moisture content, and topography were generated with the collected data, (Figures 10, 11, and 12). These maps can be used as crop management tools in conjunction with other site specific information.

Figure 10. Topographic display of the yield with interpolation methods employed.

Figure 11. Map displaying the varying corn moisture contents throughout the field.

Figure 12. Map displaying the topography of the test field.

CONCLUSIONS AND RECOMMENDATIONS

Yield mapping of grain was effectively performed with the measurement of position, lane width, grain moisture content, and depth of grain within the combine hopper.

Ultrasonic level sensing proved feasible as a method of determining the grain yield. However, improvements need to be made. These may consist of making several level readings in the combine hopper rather than at one location. An ideal system would create a topographic image of the surface of the grain in the combine hopper, therefore insuring an exact known volume in the hopper. In general, using ultrasonics is a simple approach to a complex problem so that site specific farming can be employed.

The position sensing system was a simple and accurate method of determining location within a field. Currently this method is feasible for research and many farming operations. However, with technological advancements in other methods, such as GPS, new and better methods might soon be more applicable.

The capacitance moisture sensor performed well and was reliable, but small problems still exist with sensing moisture of a moving medium and further research is needed.

The electronic clinometers performed satisfactory in producing data for the generation of useable topographic maps. More extensive research might show more promising possibilities.

Further research is needed in the site specific data

collection area. Site specific yield is considered a key component to farming spatially and further developments would be appreciated by many in this technological and agricultural spectrum. Continuing research in technology, economics, and agronomics of spatial variable systems is a must to the development of a feasible and compatible spatially variable management system.

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