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Research Article

Exploring GPS Data for Operational Analysis of Farm Machinery

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Abstract: Global Positioning System (GPS) has made a great evolution in different aspects of modern agricultural sectors. Today, a growing number of crop producers are using GPS and other modern electronic and computer equipments to practice Site Specific Management (SSM) and precision agriculture. This technology has the potential in agricultural mechanization by providing farmers with a sophisticated tool to measure yield on much smaller scales as well as precisely determination and automatic storing of variables such as field time, working area, machine travel distance and speed, fuel consumption and yield information. This study focuses on how to interpret and process raw GPS data for operational analysis of farm machinery. Exact determinations of field activities using GPS data along with accurate measurements and records of yield provide an integrated tool to calculate field efficiency and field machine index which in turn increases machine productivity and labor saving. The results can also provide graphical tools for visualizing machine operator's performance as well as making decision on field and machine size and selection.

Keywords: Field efficiency, field machine index, GPS, precision agriculture

INTRODUCTION

Traditionally farmers measure crop yield for whole field or for large sections. This so called 'collect-and-weigh' method ignores variations that exist in soil, environment and crop. The Global Positioning System (GPS) has made possible great developments in agriculture and Site Specific Management (SSM) as a response to the variability in the field. Shibusawa (1998) conceptualized SSM as a system approach to re-organize the total system of agriculture towards a low-input, high efficiency, sustainable agriculture. This new farming approach mainly benefits from the emergence and convergence of several technologies, including GPS, Geographic Information System (GIS), miniaturized computer components, automatic control, remote sensing, mobile computing, advanced information processing and telecommunications (Gibbons, 2000). These technologies and improvements now made it possible to measure yield on much smaller scales. In addition, GPS is used widely in precision agriculture with specific applications in crop scouting, yield mapping, field boundary mapping, soil sampling and soil property mapping, weeds and pest control and mapping, vehicle's guidance, navigation control and so on. In determining instantaneous grain crop yield, farmer must know three things, namely, grain flow rate (mass/sec), combine's travel speed and cutting width of the header or swath. Grain flow rate can be measured using grain flow sensors. Combine's ground speed can be determined precisely from GPS receiver that includes latitude, longitude and vehicle heading. A typical yield monitor is usually designed to record the GPS data and the collected harvesting mass information every second. The yield monitoring should be programmed in a way that it properly interprets the data sentence in order to effectively use GPS as a supply of ground speed data. This instantaneous yield data can be geo-referenced with coordinates of the corresponding yield data points using computer programs and create a data base to create yield map. This process produces a huge number of data in an entire harvesting season. Collected data are then sent to engineering laboratories for further interpretation in order to generate yield table for Geographic Information System (GIS) software and yield map creation. Yield maps reveal the harvested mass per unit area.

Yield variability in a farm that is presented in the yield map depends not only on agricultural and biological variables (such as soil nutrition and property) but also machine operator's performance. Farm machinery indexes play important roles in agricultural mechanization and technical managements especially during the busy pick periods when timing becomes an issue. Shortening machine operation time while keeping work quality is desired to produce optimum output. It is therefore important to know about important principles of GPS for agricultural application.

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The objective of this study is to provide illustrations about fundamentals behind geo-referenced data and their application in site specific and farm machinery management for increasing field productivity. The uniform terminology for agricultural machinery management published by the American Society of Agricultural Engineering (ASAE Standards, 2006a, b), has been followed in this article in order to refer to the corresponding technical terms.

METHODOLOGY

Global positioning and coordinate system: At least 24 GPS satellites orbit the earth twice a day in a specific pattern, travelling approximately 7000 miles per hour about 12000 miles above the earth's surface (Yeung and Lo, 2002). The satellites are spaced so that they follow six orbital paths, with four satellites in each path as shown in Fig. 1. This satellite arrangement guarantees that GPS receiver anywhere in the world can receive signals from at least four of them. The GPS receiver collects signals from GPS satellites that are in view and uses triangulation to calculate its position, usually expressed as latitude, longitude and altitude. The signals are radio waves and travel at the speed of light. It only takes between 65 and 85 milliseconds for a signal to travel from a GPS satellite to a GPS receiver. This satellite based navigation system defines Position, Velocity and Time, (PVT), under any climate condition 24 h a day anywhere in the world, for free.

Interpretation of GPS data requires a basic understanding of the coordinate systems and different data formats. There are several ways to locate a geographical point on the surface of the Earth. The three most used coordinate systems are latitude-longitude (Lat/Long), Universal Transverse Mercatur (UTM) and State Plane Coordinates (SPC).

Latitude and longitude is the most common way to locate points on the surface of the earth and are recorded in angular units of degrees, minutes and seconds. This represents angular distanced calculated from the center of the earth. One second of latitude is equal to about 30 meters on earth and indicates north-south position with respect to the equator ranging from 0 to 90°. Longitude defines east-west position with respect to the prime meridian, ranging from 0 to 180 degrees. The Lat/Long coordinate system uses a grid or network of latitude and longitude line, superimposed on the surface of earth as shown in Fig. 2. Expressing these points on a plane as a systematic representation of all or part of the surface of the Earth is called map projection. Some projections treat the earth as sphere, ellipsoid or both. The U.S. Geological Survey (USGS) uses several different projections. For GPS technology, the World Geodetic System 1984 (WGS-84) earth model has been adopted. Depending on the projection used, there can be different coordinate systems. Other representations of latitude and longitude coordinate are degrees decimal format and degrees-and-decimal minutes.

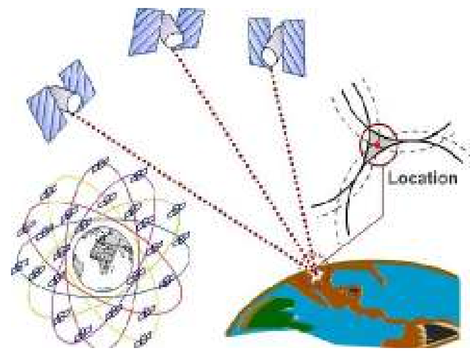

Fig. 1: Orbital planes and satellite system representation

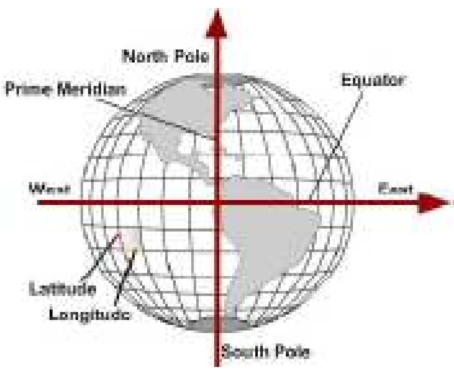

Fig. 2: Grid of latitude and longitude line, superimposed on the surface of earth

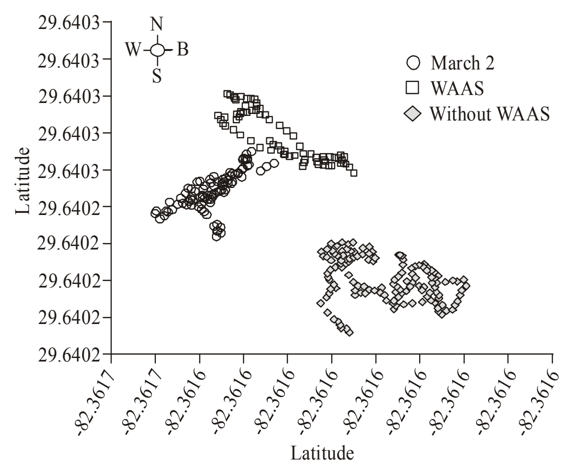

Fig. 3: Comparison between accuracy of March2 DGPS receiver and two Garmin GPS map 76 receivers with WAAS enabled and without WAAS

UTM is a widely used projection for larger scale maps. Coordinate values in UTM are given in meters

Table 1: Conversions of latitude and longitude

	Decimal degrees (dd. dd ... d)	Radian
Deg, minutes and decimal minutes lat = ddmm. mm ... m long = dddmm. mm ... m	$\mathrm{dd.dd\ldots d = dd + \frac{mm.mm\ldots m}{60}}$	$\mathrm{rad = (dd + \frac{mm.mm\ldots m}{60})(\frac{\pi}{180})}$
Deg, minutes and seconds dd° , mm′, ss. ss"	$\mathrm{dd.dd\ldots d = dd + \frac{mm'}{60} + \frac{ss.ss''}{3600}}$	$\mathrm{rad = (dd + \frac{mm'}{60} + \frac{ss.ss''}{3600})(\frac{\pi}{180})}$

with the vertical axis called northing and horizontal axis called easting. SPC coordinates are similar to UTM but are generally in units of feet. Coordinate systems are convertible to each other through some simple calculations or using ready available programs. It is suggested that farmers have a uniform coordinate system in order to line up different field maps (yield maps, soil property map, etc.,) and to be able to overlay various layers of information.

Data accuracy: The accuracy of GPS is degraded by several sources of errors such as satellite clocks, satellite orbits, earth's atmosphere, multipath errors and the receiver itself. This error is normally distributed around its mean. The one-standard-deviation or 68% of GPS measuring error is equivalent to the radius of a circle in which 50% of the measurements are expected to fall. To reduce this error, methods of improving GPS accuracy are used. The most widely used and accepted method is called differential corrections or DGPS. Three sources of differential correction available to most civilian in the United States are U.S. Coast Guard (known as Nationwide DGPS), local FM signals (user provided) and satellite-based differential corrections (such as WAAS, Omni STAR, Star fire, etc.,). Typical position error of original GPS (without correction) is about 100m. This error is about 1 to 3 m for NDGPS and 1 to 2 m for WAAS in horizontal direction. As general reference GPS receivers with better clocks, more precision mathematical algorithm and less internal noise are more expensive and produce less error.

To experiment positioning accuracy, GPS data were collected for five minutes using the base station along with March II DGPS receiver and two Garmin GPS map 76 receivers with WAAS enabled and without WAAS. The scatter plot of the three data sets was created using MATLAB and is shown in Fig. 3. It can be observed that the March II data points are very close to each other and are more centralized which indicate higher accuracy compared to the two Garmin GPS receivers. The data points from Garmin GPS with WAAS are more scattered than March II data points. The radius dispersion of data points from Garmin GPS without WAAS is observed larger than the other two data points which mean it has the least accuracy among all the three data points.

GPS communication and data interpretation: GPS receiver communication is defined within an electrical

Table 2: A sample of GPRMC sentence and its description

$GPRMC,151739,A,2721.0310,N,08109.3878,W,001.1,343.4,101208,005.3,W*72

RMC	Recommended minimum sentence C
151739	Fix taken at 15:17:39 UTC
A	Status A=active or V=Void
2721.0310,N	Latitude 27 deg 21.0310' N
08109.3878,W	Longitude 81 deg 9.3878' W
001.1	Speed over the ground in knots
343.4	Track angle in degrees True
101208	Date – 10th of December 2008
005.3, W	Magnetic Variation
*7D	The checksum data, always begins with *

Table 3: A sample of GPGGA sentence and its description

$GPGGA,152242.00,2938.4299131,N,08221.6896220,W,2,10,0.9,28.91,M,-31.11,M,5.0,0193*47

$GPGGA	Global positioning system fix data
152242.00	Time 15:22:42 coordinated universal time (UTC)
938.4299131,N	Latitude 29 deg 38.4299131' North
08221.6896220,W	Longitude 82 deg 21.6896220' West
2	Fix quality
10	Number of satellites being tracked
0.9	Horizontal dilution of position (HOD)
28.91,M	Altitude, Meters, above mean sea level
-31.11,M	Height of Geoid (mean sea level) above WGS84 ellipsoid
5.0	Time in seconds since last DGPS update
0193	DGPS station ID number
*47	The checksum data, always begins with *

data transmission standard protocol called The National Marine Electronics Association (NMEA). The output is an ASCII file which contains data called sentence or string, each of which including the PVT computed by the GPS receiver. The data within a single line are separated by a comma and the line ends with a carriage return/line feed sequence and can be no longer than 80 characters. Different brands and categories of GPS may use different types of NMEA sentence, but all of the standard sentences always start with a '$' (dollar) sign at the beginning of the line follows by GP which refers to GPS and a three letter suffix that defines the sentence contents. Common NMEA sentences used in agriculture are RMC and GGA. The format of latitude and longitude in both arrangements is recorded in degrees-and-decimal minutes (dddmm. mm ... m). Another way of expressing latitude and longitude is in angular units of degrees, minutes and seconds ($dd°, mm', ss.ss''$). It is usually necessary to convert these formats to decimal degrees or radians for geometric computational purposes. This conversion is illustrated in Table 1. Interpretation of each part of GGA and RMC sentence are provided in Table 2 and 3.

Once the information about different points of a field is known, parameters such as distance between points, velocity and surrounded area between three or more points can be calculated. It should be noted that for small size areas, surface of the earth can be assumed flat and distance between two points can be calculated using the customary math procedure, however spherical shape of the earth should be taken into account when two points are significantly far from each other. In this case, mathematical representation of earth model should be used.

RESULTS AND DISCUSSION

Mechanical power was adopted for farm use in the late 1800's and is a vital element in today's modern agriculture. As the primary source of power in field, farm machinery should be used to the best possible advantage. This is an important issue as agriculture moves towards mechanization. With growth in average farm size, faster and higher capacity machines are demanded to accomplish farm tasks in a shorter time. Since larger machines are more expensive, their time lost such as field adjustments, loading seed and fertilizer and row ends turnings becomes more critical and more costly during annual operational hours.

Operational analysis is an approach to increase machine capacity and obtain efficient machine utilization. Driver's performance and field condition affect total operation costs, such as fuel, lubricants and repairs, especially in larger machinery which have higher hourly costs. Another issue that is important in any farm operation and may affect farm machinery is timeliness. This parameter refers to the ability of manager to complete a farm activity at such a time that crop return (quantity and quality) is optimized. Better management strategies to improve planning and scheduling such as motion-and-time study management will reduce peak machinery demand and maintain a more stable machine force on the farm, leading to increase yield and profitability. Insufficient machine capacity may prevent completion of a field operation and create economic penalties. In some cases, the quality of field crops, including grains and hays, or horticultural crops, including vegetables and fruits are affected by the dates of planting and harvesting which represents a hidden cost associated with farm machinery. Therefore, obtaining accurate time record of all activities for a specific machine operation is always the first step in operation analysis. GPS receivers and data loggers can easily generate and store time and position information. The second step is to divide the time recorded into primary and support functions. For example, in a planting operation, placing seed in the ground is the primary function. Support functions include turning, adjustments and adding seed, chemical and fertilizer. Each component of operation is expresses as a percent of total field time. GPS mounted equipments and computer algorithms can provide managers with essential information for analyzing machine performance, including effective operation time.

The third step is to provide details analysis of the information obtained in the steps one and two. This includes examination of each segment of the operation to determine if the time may appear to be excessive when compared to average values from reasonably efficient operations. Computer programs such as GIS software can be used to visualize this analysis and make decision for those segments which show the greatest possibility for improving the efficiency of the total operation.

Track-and-record of farm machinery: Increasing machine productivity can be achieved through optimizing effective field capacity (Hanna, 2001) which at the end, translates into lower unit cost of production. Two parameters play an important role in effective field machine capacity. First, machine management which refers to the mechanical condition of the machine and indicate where, when and how the machine is used on field. Second, physical condition of the field which includes field size and shape, topography, terrace layout, row length and arrangement, row-end turning space and field surface. Since a particular machine has a fixed theoretical field capacity, therefore, new technology such as GPS/GIS and wireless communication for real-time data increase machine productivity not in terms of acres per hour, but by utilizing machine and operator's time more effectively.

Track-and-record of machinery location in field using GPS is the first step in precision analysis of farm machinery operation. Processing such raw data provides useful information and document changes in machine field speed and field time that can help growers to create decision support systems for a better farm and machinery management. For example, precise determinations of time lost using GPS data along with accurate measurements and records of field speed provide an integrated tool to calculate field efficiency and machine capacity as well as visualizing driver's performance. These results can be used to make decision on machine size and selection.

Field efficiency, field machine index and scheduling efficiency: Effective time of machine operation is total field time minus time lost. The percentage of machine's time lost should be considered in operational analysis. Field efficiency is the ratio between the productivity of a machine under field condition and theoretical productivity. This parameter accounts for time loses of operation, management policy and field characteristic. Time loses can be influenced by row end turning, machine adjustment, lubrication and refueling, material handling (seed, fertilizer, chemicals, water, harvested material, etc.) and equipment cleaning. Field efficiency is not constant for a particular machine and varies with the size and shape of the field, crop yield, field pattern and other conditions. It can be increased by reducing time lost, such as row end turning. Turning time greatly influences machine capacity.

Once the information about different points of a field is known, parameters such as distance between points, travel speed and the surrounded area between points can be calculated. In addition to that, having a GPS receiver mounted on a particular machine like a grain combine, citrus mechanical harvester, chemical sprayers, etc. and collecting the PVT and other relevant operational data such as the harvested mass or the amount of applied chemical, it will be possible to determine additional parameters that are used in analyzing farm machinery management or in creating yield map (Lotz, 1997; Parsons *et al*., 2000), soil map, land field boundary map, etc.

Field Machine Index (FMI) is an indication of how well a specific field is adapted for the use of machinery on it. This index includes the influence of row-end turning conditions and row length on actual field production time and total row end turning time. In the other words, FMI is the ratio of the productive machine time to the sum of productive machine time plus the row-end turning time. Time loses refers to the time used for support functions, such as making adjustment and fueling. The maximum possible value for FMI is 100%. The higher field machine index, the better field adapted to machine use. Three basic items of information are needed to determine FMI, namely, total field time (T_f), total support function time (T_s) and total turning time (T_r). All of these items can be calculated accurately from raw GPS data. The FMI can be calculated as follows:

$$\text{FMI} = \frac{T_f - T_s - T_r}{T_f - T_s} \times 100 \tag{1}$$

FMI is useful in predicting machine capacity and for determining machinery needs and hours of use. An interesting point is that FMI for a specific machine on a particular field is almost the same for other machines used on that same field. For example, if FMI is low for one machine operation, it turns out to be low for other operations on the same field.

Effective field capacity is a function of field Speed (S), machine working Width (W), field efficiency (η_f) and unit yield of the field and is expressed by area capacity (C_a) and material capacity (C_m), they are given by the following equations in ASABE:

$$C_a = \frac{S.W.\eta_f}{10} \tag{2}$$

$$C_a = \frac{S.W.\eta_f}{10} Y \tag{3}$$

Field speed and field efficiency can be determined directly from GPS data. Instantaneous yield is defined as the harvested mass per unit area and can be calculated as:

$$\text{Yield}\left(\frac{kg}{m^2}\right) = \frac{\text{Mass}}{\text{Area}} = \frac{\text{Mass}}{\text{Distance.Width}}$$

or

$$= \frac{\text{Flow rate.Time}}{\text{Speed.Time.Width}} = \frac{\text{Flow rate}}{\text{S.W}}$$

Flow rate is measured using mass flow sensors such as impact force sensor (load-cell based), plate displacement sensors (potentiometer devices), radiometric systems or image processing applications. Calculating field efficiency from raw GPS data require computer algorithms to determine machine time loses, which is a result of row end turnings, machine adjustment (unclogging of spray nozzles), lubrication and refueling, material handling (seed, fertilizer, chemicals, water, harvested material, etc.,) and equipment cleaning. Time losses that are either proportional or non-proportional to the area should be determined from collected GPS data and filtered out from the effective harvesting time in order to calculate field efficiency according to the following equations:

$$\eta_f = \frac{T_t}{T_e + T_h + T_a} \tag{4}$$

where,

T_t = The theoretical time to perform operation
T_e = The Effective operating time
T_h = The Time losses (not proportional to area)
T_a = The Time losses (proportional to area)

These results can also be used to determine scheduling efficiency which is the ratio of effective operating time to the total workday hours and indicates the ability of farm manager to utilize working hours and employees. This is also a useful parameter for making decision on machinery size selection Eq. (5):

$$C_i = \frac{A}{B.G} \tag{5}$$

where,

C_i = The required machine capacity (ha/h)
A = The area (ha)
B = The number of days to finish the operation
G = The expected time available for field work each day (h/day)

Other parameters of interest that GPS data can be used directly or indirectly in their calculation are the unit price of machinery Eq. (6), fuel consumption cost, labor cost, annual timeliness cost for an operation Eq. (7) and optimum machine capacity Eq. (8):

$$K_p = \frac{10P_w}{S.\eta_f} \tag{6}$$

$$W = \frac{K_3 A^2 Y.V}{Z.G.C_i} \tag{7}$$

$$M_{oc} = \sqrt{\frac{100A}{C_o K_p}\left(L_c + T_{fc} + \frac{K_3 A.Y.V}{Z.G}\right)} \tag{8}$$

where,

K_p = The unit price function (dollars/ha-h)
P_w = The price per unit width of increased of machine (dollars/m)
W = The annual timeliness cost (dollars)
K_3 = The timeliness coefficient obtained from ASAE D497, clause 8
V = The value per yield (dollars/ton)
Z = Equal to 4 if the operation can be balanced evenly about the optimum time and a value of 2 if the operation either commence or terminates at the optimum time
G = The expected time available for field work each day (h)
M_{oc} = The optimum capacity of a machine (ha/h)
C_o = The ownership cost percentage (%)
L_c = The labor cost (dollars/ha)
T_{fc} = The machine ownership cost (dollars/ha)

CONCLUSION

GPS technology is the foundation of site specific management and precision agriculture for sustainable use of farm resources. With the enlargement of fields and intensive farming practices, it has become more difficult to take account of their local field variability manually without a revolutionary development in technologies (Stafford, 2000). In precision agriculture, GPS data are mainly used in determining some parameters of interests as in yield mapping, soil mapping, field boundary mapping, etc. The potential application of GPS data to accurately identify and record field location and operation time of farm machinery was discussed in this study. Data of this kind are usually huge. For example, a yield monitoring system that collects data every second generates up to tenth of thousand yield data points in a 100 acre field. This is far too much to interpret manually using paper and pencil. Computers and Geographic Information Systems (GIS) provides farmers with a powerful and exciting tool to enter, store, manipulate and display GPS collected data and associates with other data values, such as yield or soil type. These geo-referenced data afford an excellent means of SSM to reduce production cost (Edwards, 2009) and increase benefits.

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