University of Nebraska Cooperative Extension EC 01-157

Precision AGRICULTURE

Untangling the GPS Data String

Viacheslav I. Adamchuk, Biological Systems Engineering

RESOURCES

For more information about precision agriculture research, education and demonstration programs at the University of Nebraska, visit the Web site at http://precisionagriculture.unl.edu/

Most people associate precision farming or site-specific management with the global positioning system (GPS). It is used to locate the antenna of a GPS receiver on Earth. GPS provides the opportunity to record a set of geographic coordinates that specify a particular field location. Therefore, field data collected using GPS technology is georeferenced. Processing of these data is complicated, and software packages designed for precision farming applications have built-in capabilities to interpret the GPS receiver output. However, some simple operations can be performed using standard office software. In this case, it is necessary to know the basics behind GPS data. The objective of this publication is to illustrate a way to convert GPS receiver output into linear units for georeferenced data analysis.

GPS Receiver Output

The most common ASCII output of any GPS receiver is a set of comma delimited lines (sentences) defined by National Marine Electronic Association interface standard NMEA-0183. This output can be viewed and recorded via a hyper terminal application if no other software is available. Every line follows the same pattern, as shown in the following example (Figure 1):

Comma Delimiter — Asterisk Delimiter

$GPZDA,220047.13,12,10,2000,00,00*67

Sentence ID (GPZDA), Field 1 (220047.13), Field 2 (12), Field 3 (10), Field 4 (2000), Field 5 (00), Field 6 (00), Checksum (67)

Figure 1. An example of NMEA-0183 sentence output

The checksum values are used by a receiver to verify the integrity of the data. The information expressed by each comma delimited field depends on the sentence, some of which are identified as:

- $GPALM - GPS almanac data
- $GPGGA - GPS fix data
- $GPGLL – GPS antenna position data
- $GPGRS - GPS range residuals
- $GPGSA - GPS DOP (dilution of precision) and active satellites
- $GPGST - GPS pseudorange statistics
- $GPGSV - GPS satellites in view
- $GPMSS - Beacon receiver signal status
- $GPRMC - Recommended minimum specific GPS data
- $GPVTG - Course over ground and ground speed
- $GPZDA - GPS time and date

In order to extract information related to the position of a GPS antenna, it is necessary to record at least one of three sentences: $GPGGA, $GPGLL, or $GPRMC. Each of them indicates geographical longitude and latitude of position fix and corresponding UTC time (Universal Time Coordinate). The following tables define the meaning of each field in these three sentences. The descriptions of NEMA-0183 GPS outputs are based on the AgGPS 132 Operation Manual (Trimble Navigation Limited, Sunnyvale, Calif.). The underlined values are to be used in calculations.

Table 1. $GPGGA Output Sentence
$GPGGA,180432.00,4027.027912,N,08704857070,W,2,07,1.0,212.15,M,-33.81,M,4.2,0555*73

Field	Value	Meaning
1	180432.00	UTC of position fix in hhmmss.ss format (18 hours, 4 minutes and 32.00 seconds)
2	4027.027912	Geographic latitude in ddmm.mmmmmm format (40 degrees and 27.027912 minutes)
3	N	Direction of latitude (N - North, S - South)

IANR
Cooperative Extension
Institute of Agriculture and Natural Resources
University of Nebraska

Field	Value	Meaning
4	08704.857070	Geographic longitude in dddmm.mmmmmm format (87 degrees and 4.857070 minutes)
5	W	Direction of longitude (E - East, W – West)
6	2	GPS quality indicator (0 - fix not valid, 1 - GPS fix, 2 - DGPS fix)
7	07	Number of satellites in use (00-12)
8	1.0	Horizontal DOP
9	212.15	Antenna height above MSL (mean sea level) reference (212.15 m)
10	M	Unit of altitude (meters)
11	-33.81	Geoidal separation (-33.81 m)
12	M	Unit of geoidal separation (meters)
13	4.2	Age of differential GPS data record
14	0555	Base station ID (0000-1023)

Table 2. $GPGLL Output Sentence
$GPGLL,4027.027912,N,08704.857070,W,180432.00,A,D*7A

Field	Value	Meaning
1	4027.027912	Geographic latitude in ddmm.mmmmmm format (40 degrees and 27.027912 minutes)
2	N	Direction of latitude (N - North, S - South)
3	08704.857070	Geographic longitude in dddmm.mmmmmm format (87 degrees and 4.85707 minutes)
4	W	Direction of longitude (E - East, W - West)
5	180432.00	UTC of position fix in hhmmss.ss format (18 hours, 4 minutes and 32.00 seconds)
6	A	Status (A – data valid, V – warning)
7	D	Mode indication (A - autonomous, D - differential, N - data not valid)

Table 3. $GPRMC Output Sentence
$GPRMC,180432,A,4027.027912,N,08704.857070,W,000.04, 181.9,131000,1.8,W,D*25

Field	Value	Meaning
1	180432.00	UTC of position fix in hhmmss.ss format (18 hours, 4 minutes and 32.00 seconds)
2	A	Status (A - data is valid, V - warning)
3	4027.027912	Geographic latitude in ddmm.mmmmmm format (40 degrees and 27.027912 minutes)
4	N	Direction of latitude (N - North, S – South)
5	08704.857070	Geographic longitude in dddmm.mmmmmm format (87 degrees and 4.85707 minutes)
6	W	Direction of longitude (E - East, W - West)
7	000.04	Speed over ground (0.04 knots)
8	181.9	Track made good (heading) (181.9°)
9	131000	Date in ddmmyy format (October 13, 2000)
10	1.8	Magnetic variation (1.8°)
11	W	Direction of magnetic variation (E - East, W - West)
12	D	Mode indication (A - autonomous, D - differential, N - data not valid)

Both the latitude and longitude values included in a NMEA-0183 sentence are represented in degrees, minutes and decimal minutes. Latitude is formatted as ddmm.mmmm, while longitude is represented as dddmm.mmmm in a single field. The direction of latitude and longitude are indicated as a single character in the next field ('N'- north; 'S' - south; 'E' - east; 'W' - west). Most computations that involve geographical coordinates require longitude and latitude to be expressed in decimal degrees with a corresponding sign (negative for south latitudes and west longitudes) (as shown in the Figure 2). The conversion of latitude or longitude into decimal degrees is usually done as:

$$dd.dddddd = dd + \frac{mm.mmmm}{60} \qquad (1)$$

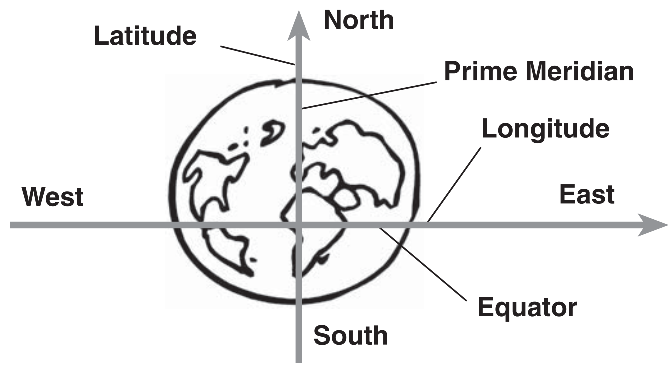

Figure 2. Latitude south of equator and longitude west of prime meridian must be negative

The UTC time that corresponds to the position fix can be used to measure the change in geographic location over time (travel speed). It is expressed in hours (00 - 23), minutes (00 - 59) and seconds (00 - 59) (decimal fraction of a second may also appear). Data computation requires time values to be continuous. This can be done by calculation of seconds from the beginning of a day (UTC reference) in the following way:

$$sssss = hh \cdot 3600 + mm \cdot 60 + ss \qquad (2)$$

As will be discussed later, the height above the ellipsoid (h) also is required to accurately process GPS data. It can be computed from $GPGGA NMEA-0183 sentence as the sum of the antenna height with respect to MSL (mean sea level) reference, and the geoidal separation. If only $GPGLL or $GPRMC sentences are available, the height above ellipsoid should be known or assumed. A value of local airport's elevation (MSL altitude) may be used as an approximation.

Longitude and Latitude Conversion

The geographical **longitude** indicates the angle between the plane of the reference (Prime or Greenwich) meridian and the meridian passing through a point of interest. The geographical **latitude** is the angle between the normal to the ellipsoid passing through the point of interest and the Equatorial plane (Figure 3). In other words, geographical longitude and latitude represent angular measures of a position on the Earth's surface. A longitude (λ) defines east-west position with respect to the prime meridian (000 - 180°), while a latitude (φ) indicates north-south position with respect to the equator (00 - 90°).

Several models have been developed in the past to represent our planet. For GPS technology, the WGS-84 (World Geodetic System 1984) has been adopted. This model assumes an ellipsoid with a semi-major axis (equatorial radius) ***a = 6,378,137 m***, and a semi-minor axis (polar radius) ***b = 6,356,752.3142 m*** (defined as 1/f = 1/298.257223563, where f = (a-b)/a).

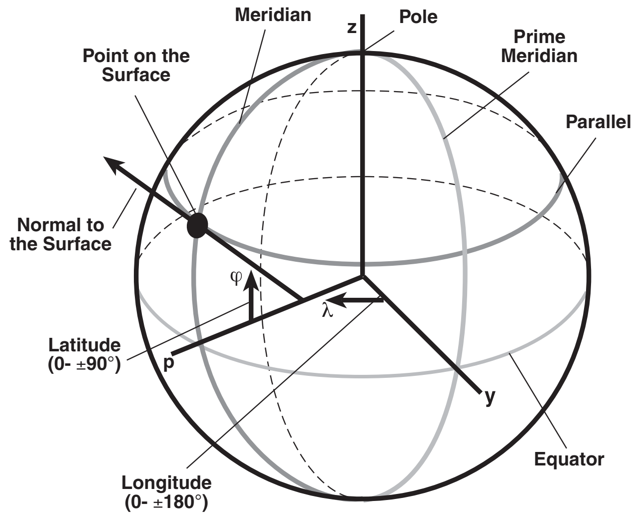

Figure 3. Definition of geographical latitude and longitude

While practicing site-specific field management, it is necessary to interpret the change in geographical coordinates in terms of distance. Conversion of longitude and latitude into linear units is complex. Since all meridians intersect at two points (the poles), the distance corresponding to a particular change of longitude depends on the latitude. On the other hand, the fact that Earth is represented by an ellipsoid model (not a sphere) suggests that a change in latitude may also correspond to different distances depending on the north-south position.

Besides geographical longitude and latitude, every point on the Earth has a third coordinate – altitude or height above the ellipsoid (h). Complex terrain causes it to differ for various land locations. It is also necessary to keep in mind that the height above the ellipsoid is not the same as the height above sea level used in aviation.

Usually, an agricultural field has a relatively small size (with respect to Earth), and may be considered as a flat surface at a particular location on Earth. Therefore, in order to convert geographic coordinates into linear units it is necessary to define the distance corresponding to a 1° change in longitude (F_{lon}) and latitude (F_{lat}) for a specific field location (average geographic latitude φ and height over ellipsoid h). These conversion factors could be computed using a set of equations.

In order to derive a pair of equations to convert decimal degrees of longitude (λ) and latitude (φ) into linear units, a meridian plane must be considered in rectangular p-z coordinates (Figure 4).

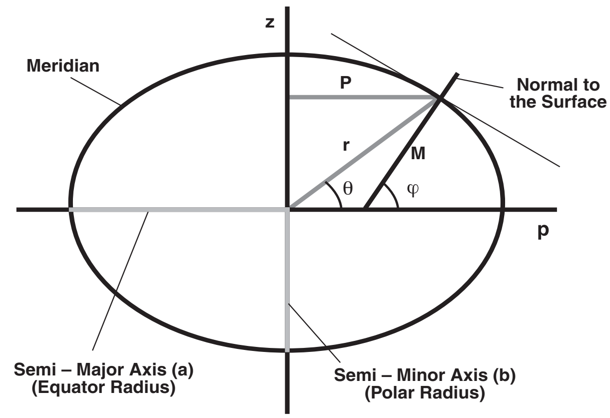

Figure 4. The Earth is represented by an ellipsoid

Since every parallel (imaginary line on the surface parallel to the Equator) represents a circle of constant latitude, its radius (P) is needed to determine the longitude conversion factor F_{lon}. On the other hand, a meridian plane has the shape of an ellipse; therefore, the point radius of curvature in the meridian plane (M) should be used to determine the conversion factor F_{lat}. Since geographical coordinates are recorded in decimal degrees, the following formulas may be used to determine the distance that corresponds to 1°:

$$F_{lon} = \frac{\pi}{180^\circ} P$$

$$F_{lat} = \frac{\pi}{180^\circ} M \qquad (3)$$

Through a sequence of mathematical manipulations the following equation can be derived to calculate radii P and M:

$$P = \frac{a^2 \cos\varphi}{\sqrt{a^2 \cos^2 \varphi + b^2 \sin^2 \varphi}} \qquad (4)$$

$$M = \frac{a^2 b^2}{(a^2 \cos^2 \varphi + b^2 \sin^2 \varphi)^{3/2}} \qquad (5)$$

Equations (4) and (5) along with (3) can be used to determine latitude and longitude conversion factors for a point located on the surface of the ellipsoid. Since a difference in altitude also affects these factors, correcting for a non zero height above ellipsoid (*h*) can be done as:

$$F_{lon} = \frac{\pi}{180^\circ} (P + h\cos\varphi) = F_{lon_{h=0}} + \left(\frac{\pi}{180^\circ} \cos\varphi\right) h$$

$$F_{lat} = \frac{\pi}{180^\circ} (M + h) = F_{lat_{h=0}} + \left(\frac{\pi}{180^\circ}\right) h \qquad (6)$$

In fact, the radius of curvature in the meridian plane M is increased by the value *h*, while the radius of a parallel P is increased by the projection of *h* onto the equatorial plane. The following equation can be used to define F_{lon} and F_{lat} for a particular latitude φ and height above ellipsoid *h*:

$$F_{lon} = \frac{\pi}{180^\circ}\left(\sqrt{\frac{a^2}{a^2\cos^2\varphi + b^2\sin^2\varphi}} + h\right)\cos\varphi \qquad (7)$$

$$F_{lat} = \frac{\pi}{180^\circ}\left(\frac{a^2 b^2}{(a^2\cos^2\varphi + b^2\sin^2\varphi)^{3/2}} + h\right)$$

The units for a, b and h define the units of conversion factors. Therefore F_{lon} and F_{lat} can be obtained both in meters and feet (a = 20,925,646 ft and b = 20,855,487 ft).

Data Usage

After the recorded data have been converted into decimal degrees with the corresponding sign, and appropriate conversion factors have been established, the analysis of georeferenced data may be conducted. The primary tasks of GPS data analysis include determination of the **distance**, **travel speed** and **heading** based on the coordinates of two points. Distance calculation can also be used to establish a local system of coordinates with easting and northing axes scaled in linear units.

The distance between two points (Figure 5) can be found using the following formula:

$$\text{Distance} = \sqrt{(F_{lat}(\varphi_1 - \varphi_2))^2 + (F_{Lon}(\lambda_1 - \lambda_2))^2} \qquad (8)$$

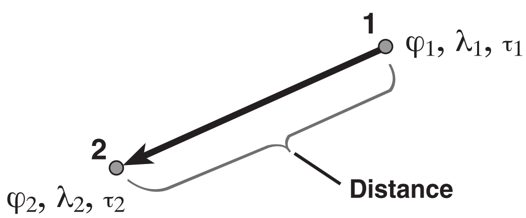

Figure 5. Distance between two points

The travel time between two recorded points is found as the difference between the corresponding UTC values ($\tau_2 - \tau_1$). Distance divided by time gives average travel speed.

Travel direction (heading) from point 1 to point 2 is also needed in many applications (Figure 6). It can be determined by using the following formula:

$$\text{if } \lambda_1 = \lambda_2 \text{ then } \begin{cases} \text{if } \varphi_1 < \varphi_2 \text{ then Heading} = 0^\circ = 360^\circ \\ \text{if } \varphi_1 > \varphi_2 \text{ then Heading} = 180^\circ \end{cases}$$

$$\text{if } \lambda_1 < \lambda_2 \text{ then} \quad \text{Heading} = 90^\circ - \tan^{-1}\left(\frac{F_{Lat}(\varphi_2 - \varphi_1)}{F_{Lon}(\lambda_2 - \lambda_1)}\right) \qquad (9)$$

$$\text{if } \lambda_1 > \lambda_2 \text{ then} \quad \text{Heading} = 270^\circ - \tan^{-1}\left(\frac{F_{Lat}(\varphi_2 - \varphi_1)}{F_{Lon}(\lambda_2 - \lambda_1)}\right)$$

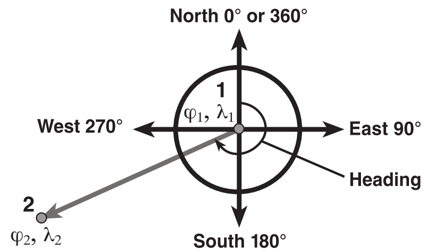

Figure 6. Determining travel direction (heading)

Sensitivity

Equation (7) is relatively easy to use in data analysis. However, some curiosity related to the sensitivity of the conversion factors to changes in coordinates may exist. The assumptions of a flat field (farm) with a relatively small change in geographical latitude may create errors in data interpretation. In addition, conversion factors calculated or obtained from a reference table for a different location may cause even more significant mistakes.

In this example, the true average latitude of a site is $\varphi = 40^\circ$ and the height above the ellipsoid is h = 2,000 ft = 610 m. The corresponding conversion factors are: F_{lon} = 85,402 m = 280,190 ft and F_{lat} = 111,045 m = 364,322 ft. If the same conversion factors are used for a site located 1° north ($\varphi = 41^\circ$), a 1.42% overestimation of a distance in the east-west direction will take place, while a distance in north-south direction will be underestimated only by 0.017%. Similarly, if a true site is located 1° south ($\varphi = 39^\circ$) a 1.50% underestimation in east-west direction and 0.017% overestimation in north-south direction will occur.

Therefore, it appears that knowing the true geographical latitude is important. However, if the site spreads 5 miles from north to south, and the average latitude is applied, a distance in the east-west direction can be affected by only 0.053%. The effect on a distance in the north-south direction is less than 0.001%. Therefore, the biggest error while measuring distance between points 10,000 ft apart is not greater than 6 ft.

On the other hand, the value of the height above the ellipsoid has even less effect on the conversion factors. Thus, if an altitude of 2,000 ft is not accounted for, the underestimation of a distance in both directions will be less than 0.01%.

This analysis shows that the significance of errors associated with the assumption of constant conversion factors for the entire site is negligibly small, but should be assessed in order to justify the reliability of the data analysis.