Abstract

This paper presents an overview of the use of GPS technology in sugarcane production. The diverse applications for which it can be used are discussed and some examples of available technology are given. Primarily a GPS is used to fix a machine or implement in 2D or 3D space that is used to collect geospatial data, control a machine, or for variable rate application. The use of GPS technology is a key component of controlled traffic farming systems where all wheeled and tracked traffic is confined to the inter-row to limit compaction and damage to sugarcane stools. Virtually all operations from land preparation to harvesting can benefit from the use of including GPS technology. Particularly precision agriculture applications are gaining in prominence. In the future, fully autonomous vehicles may become commonplace in sugarcane production.

Keywords: GPS, technology, precision agriculture, controlled traffic, machine guidance, yield mapping, UAV, land levelling.

Introduction

In recent years the use of GPS technology in agricultural production has been on the increase. More and more operations in sugarcane production are being carried out with the assistance of GPS technology. Primarily the purpose of using GPS technology is to measure or to control the position of agricultural equipment in the field.

Applications of GPS technology in sugarcane production include the following activities:

- Surveying
- Machine guidance and auto-steer
- Controlled traffic
- Land forming
- Land preparation
- Precision laying of drip lines or drainage pipes
- Planting
- Harvesting and yield mapping
- Precision agriculture applications

GPS system and components

Currently there are two fully operational GPS constellations: the GPS system belonging to the United States Department of Defence (DoD) and the GLONASS system belonging to Russia. The GPS system consists of a constellation of 31 satellites orbiting the earth at an altitude of approximately 12 600 miles. The GLONASS system has a constellation of 29 satellites orbiting at an altitude of approximately 11 900 miles. The GPS system was designed to function with a minimum of 24 satellites; four satellites in six circular orbital paths. A representation of the orbits of the satellites is shown in Figure 1. There are additional global systems in development such as the Galileo (European Union) and
COMPASS (China) that are due for completion in 2020 and regional systems in development by India, Japan, and France (Wikipedia, 2013a).

For precision applications in agricultural production the following GPS components are required: at least four satellites with good geometry; GPS rover receiver on vehicle/equipment; GPS base station receiver on a fixed, known point; and radio or network telemetry to transmit error correction signal from base station to rover or from a third party correction signal service. An example of a GPS system configuration is shown in Figure 2.

In the early days of GPS the US DoD deliberately introduced an accuracy error for civilian users that was termed Selective Availability (SA). This could result in horizontal position errors of up to 80 m and vertical errors greater than 100 m. On 1 May 2000 SA was deactivated which greatly improved accuracy to ± 10 m for both horizontal and vertical measurements (GPS.gov, 2013). The deactivation of SA allowed for the rapid development of autonomous use GPS receivers such as those contained in SatNavs and mobile devices.

Figure 1: Constellation of satellites orbiting the earth.

For high precision applications in sugarcane production, an accuracy of ± 25 mm is required. Centimetre accuracy can be achieved by using real time kinematic (RTK) correction where a correction signal is broadcast from a fixed base station to the rover units. This allows the rover to calculate its relative position with mm accuracy. The absolute position accuracy is relative to how accurately the position of the fixed base station has been determined. With RTK navigation, the accuracy degrades with distance from the base station in the range of 1 to 2 ppm (1 to 2 cm per 10 km).

In addition to operators having their own base station and correction signal there are third party correction signal services that can be subscribed to or received for free. For high accuracy results, a base station should be located within 10 km line of sight. Examples of third party service provider for correction signals are shown in Table 1.

Table 1: Examples of third party correction signals.

<table>
<thead>
<tr>
<th>Correction signal</th>
<th>Accuracy</th>
<th>Subscription fee?</th>
<th>Where available</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAAS(^1)</td>
<td>&lt; 7.5 m</td>
<td>No</td>
<td>USA/Canada</td>
</tr>
<tr>
<td>Omnistar</td>
<td>&lt; 1 m</td>
<td>Yes</td>
<td>Worldwide</td>
</tr>
<tr>
<td>EGNOS(^2)</td>
<td>&lt; 2 m</td>
<td>No</td>
<td>Europe</td>
</tr>
<tr>
<td>StarFire, John Deere</td>
<td>± 2.5 cm to ± 25 cm</td>
<td>Yes/No</td>
<td>Near local JD dealership</td>
</tr>
</tbody>
</table>

\(^1\) Wide Area Augmentation System, Federal Aviation Authority, USA.

\(^2\) European Geostationary Navigation Overlay Service, European Space Agency.
Machine guidance, auto-steer, and controlled traffic

The simplest form of machine guidance is using a light bar with coloured lights that aids the driver in steering on the correct path. A reference line, commonly called an AB line, has to been determined using GPS surveying or other surveying techniques. The AB line can be straight or curved. Most guidance units can be programmed with an offset, typically the row spacing, to automatically produce paths for the GPS to follow. An example of a Trimble in-cab controller and light bar is shown in Photo 1.

The next level of machine guidance is auto-steer where the GPS controller is responsible for guiding the machine when following the guidance paths. The steering systems can either be integrated to the hydraulic/electrical steering system or as an add-on to the steering wheel. The operator is typically there for turning on headlands and for making adjustments to the machine (eg speed and base cutter height for harvesters). The achievable accuracy with an auto-steer is better than with the light bar guidance system.

Photo 1: Example of in-cab GPS controller with light bar for guidance.
The use of auto-steer machinery is a pre-requisite for a controlled traffic system (CFS). A controlled traffic system is where the tyres/tracks of all in-field machinery are confined to a limited area of the inter-row. This minimises the chances of compaction or stool damage in the cane row. An example of a controlled traffic system is shown in Photo 2 where the harvester and the in-field cane haulage follow the same path in wet field conditions. With the traditional 1.5 m row spacing up to 97% of the field is compacted when visual guidance is used by the harvester and haulage operators. This reduces to 69% when the operations are guided by GPS. Further reductions in compacted area can be achieved by planting cane at 1.9 m row spacing. For visual guidance the compacted area is around 53% and this reduces to 35% for GPS guided machinery. By concentrating all traffic in the inter-row the trafficability in wetter soils is improved. Due to lower levels of compaction and minimal physical damage in the cane row, yields should be more sustainable and lead to longer crop cycles and reduced costs.

Photo 2: Controlled traffic system guided by auto-steer GPS.

Land preparation, land forming, drip tape laying, and drainage pipe laying

The use of GPS technology for land preparation provides the opportunity to reduce the costs of land preparation by only cultivating the soil under the cane row. This also reduces the need to cultivate the inter-row where spraying for weeds or retaining a trash blanket are preferable to mechanical cultivation. The traffic path also creates a flat, compact furrow shape that can improve the application efficiency of furrow irrigation.

GPS based land forming has performance improvements over laser levelling technology. In simple GPS systems the levelling tractor can also do the field survey and software in the on-board display can calculate single plane designs for immediate implementation. For more complex fields, the surveying is typically done with a surveying rover GPS and the designs are done in the office on dedicated software. The designs are then uploaded to the GPS controller on the tractor and the designs implemented. An example of single scraper land levelling system is shown in Photo 3. There is a GPS receiver on the post above the cutting blade to accurately fix the height of the scraper blade. In most systems there is a hydraulic control module that automatically sets the cut and fill heights of the cutting edge.
With an increase in energy costs and limitations on the availability of water for irrigation, the use of drip irrigation in sugarcane production is becoming more prevalent. An important consideration for mechanically harvesting drip irrigated sugarcane is the placement of the drip tape in the cane row. The drip tape needs to be accurately positioned so that it is not damaged by planter discs, harvester base cutter blades, fertiliser applicator discs, or during cultivation and bed maintenance operations. Drip tape is often laid with GPS guidance and auto-steer. When subsequent operations are also carried out using GPS guidance the risk to damaging drip tape in the ground is minimised. A three row drip tape laying implement is shown in Photo 4.

The use of GPS technology is also being used to install sub-surface drainage pipes. GPS receivers and hydraulic controllers are used to accurately position the drainage pipe to ensure that there is sufficient grade for water to flow down the pipes. An example of a GPS based drainage pipe laying implement is shown in Photo 5. Note that there are three receivers on the implement to accurately place the pipe in 3-dimensional space.
Precision mechanical planting

GPS guided planters are essential in fields that have sub-surface drip tape installed. The use of GPS guidance allows the setts to be placed at the correct distance and depth relative to the drip tape without damaging the drip tape. Accurate and consistent placement is required especially in light soils. A semi-mechanical dual row planter in a drip irrigated field is shown in Photo 6 on the left and the result of planting is shown on the right.

Harvesting

GPS technology in harvesting can be utilised for yield mapping and for machine guidance. There are systems available that relate the flow/mass of cane through the harvester to yield where an accurate position is obtained with a GPS receiver. The yield maps can be used to identify areas of high and low potential. An example of a yield mapping system developed in a 2005 study by Universidade Estadual de Campinas, Brazil, for a harvester is shown in Photo 7 (Cerri, 2005). A load cell on the elevator is used together with angle and speed sensor and positioning from GPS to map fields. Reliable, commercial yield monitors for sugarcane are still in development as there are accuracy and reliability issues (Jensen et al., 2010). An example of a yield map produced in the 2005 study is shown in Figure 3.

GPS guidance can also be used on harvesters to ensure accurate alignment with the cane row to improve cane pick up and to reduce cane losses. A common challenge for harvester operators is running off line or across lines, especially in high yielding fields or lodged cane or at night. GPS guidance can also be used in fields with curving rows that follow contours. GPS guidance also improves productivity, especially at night and for green cane harvesting.
Photo 7: GPS based yield mapping of sugarcane (Cerri, 2005).

Figure 3: Yield map produced by yield monitor used in the Brazilian study (Cerri, 2005).

Precision agriculture applications

Precision agriculture is defined as “the application of technologies and agronomic principles to manage spatial and temporal variability associated with all aspects of agricultural production for the purpose of improving crop performance and environmental quality” (McGraw-Hill, 2003).

The gathering of geospatially referenced data is a key component of precision agriculture operations. GPS technology is used to measure the location of a parameter being recorded as well as for determining the location of the machine or implement at the time of application or operation.

GPS technology in precision agriculture is used for the following applications and operations:

- Soil survey to fix positions of sampling points for manual and automatic soil sampling.
- GPS guidance for autonomous aerial vehicles for taking geo-referenced imagery.
- Variable rate applications of fertilisers and chemicals.
- Precision application of chemicals.
An example of precision agriculture equipment that utilises GPS technology is an automated soil sampling rig. The Verion Agricultura VSolus soil sampler is shown in Photo 8. The VSolus is towed behind an ATV or LDV and a GPS is used to guide the operator to a predetermined grid point for sampling or to record the position of an ad hoc sample. The accuracy and time efficiency of GPS surveys are typically higher than when compared with traditional survey methods. Data are also easily available in a format that is immediately useful in GIS packages that are used for precision agriculture mapping and analysis.

Photo 8: Verion Agricultura VSolus automated soil sampler.

The use of unmanned aerial vehicles (UAVs) for precision agriculture applications is a technology that has been recently adopted. The UAVs are used to capture geo-referenced imagery for aerial photography, topographic mapping, and analysis of crop growth and performance. The UAVs use GPS technology to fix the position and altitude of the imagery and to control the flight path if it is utilised in autonomous mode. Most UAVs can also be flown manually by remote control. Some examples of UAVs that are currently available are shown in Figure 4. The small and light weight drones are more suitable for sugarcane applications. The Sense Fly Swinglet CAM is being used commercially in Brazil for photographing and analysing cane growth. The Sense Fly Swinglet CAM system pictured in Figure 4 costs in the region of US$ 35 000 for a system complete with drone, remote control, autonomous guidance and telemetry, and software for analysis.

Figure 4: Examples of UAVs (clockwise from top left) Aibotix X6 Hexacopter, Trimble Gatewing X100, Sense Fly Swinglet CAM, and Sense Fly eBee.
The drones can also be fitted with cameras that capture near infrared (NIR) and parts of the visible spectrum. These images can be used for normalised difference vegetation index (NDVI) analysis. As chlorophyll absorbs red-light and reflects near-infrared light, the NDVI can be used to identify areas of rigorous growth and those with no grow. Rigorous growth is indicated by low red-light and high near-infrared reflectance. These give high NDVI values that will show up as dark green on NDVI maps. Low NDVI values indicate area with non-vegetative bare ground, rock, water, snow, ice, and clouds. The NDVI is calculated by the following equation:

$$NDVI = \frac{(NIR - VIS)}{(NIR + VIS)}$$

Where VIS and NIR stand for the spectral reflectance measurements acquired in the visible (red) and near-infrared regions. The spectral reflectance is the ratio of incoming to reflected radiation in the individual bands. The NDVI value ranges between -1 and +1 (Wikipedia, 2013c). A NDVI map produced from UAV aerial photography for a sugarcane farm is shown in Figure 5. The brown area shows the water surface of the reservoir and the dark green areas show vigorously growing cane.

**Figure 5: NDVI map for sugarcane area photographed from a UAV.**

Taking a closer look at the field on the right of Figure 5, the NDVI map and aerial photograph of the field are as shown in Figure 6. The areas indicated by the black lines are areas of less vigorous growth. These are more apparent on the NDVI map than they are in the aerial photograph. The maps help identify areas in fields that may need investigation to determine the causes of poor growth and to develop strategies for remediation.

**Figure 6: Sugarcane field with NDVI map (left) and aerial photo (right).**
Variable rate application of fertilisers and chemicals utilises GPS technology to determine the applicators position in the field relative to the variable rate map determined for the field. An on-board controller regulates the amount of fertiliser or chemical to be applied at that point in the field.

Similar GPS guidance can be used for precision application of herbicides. When fields have been prepared and planted using GPS guidance, herbicides can be applied to the inter-row by accurately controlling the position of the spray nozzle. This can also be taken further by having spray nozzles that have sensors calibrated to identify fields that only spray herbicide when necessary. This reduces the cost of application as well as the impact on the environment. If this system is utilised correctly then it is possible to use less expensive herbicides, such as Glyphosate, as the risk to the cane plant is reduced. GPS guidance can also be used for aerial crop sprayer guidance. This reduces the need to have Flag Men on the ground that greatly improves the health and safety conditions for workers.

**Conclusion**

GPS technology is currently in use in sugarcane production and the number of applications is on the increase as the technology improves and costs are reduced. In addition sugarcane is expanding into areas that are more marginal where the need for precision approaches to farming will be required to maximise the returns from the land.

Currently in development are autonomous, driverless tractors that utilise GPS technology as one of the control components. In the future it may be possible that autonomous tractors are used for sugarcane production.

**References**


