Applications for GPS on Shovels and Excavators

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ABSTRACT: With GPS, high speed computers and rapid response tilt sensors it is now possible to determine the position of the bucket teeth of an excavator or shovel within a few centimeters. Applications include selective mining, bench control, precise excavation and placement of spoil, bench and ramp control, excavation of civil structures and production measurement. This paper will discuss the hardware and software capabilities and include actual case studies of applications.

1. INTRODUCTION

It has been more than 25 years since the introduction of the Global Positioning System (GPS). Uses and applications have grown rapidly and the technology is now well established and reliable. Almost all mines now use GPS for surveying. A single surveyor can now accomplish in a few hours what once took a team of people days of tedious field and office work. GPS has also been employed directly on mining machinery – most notably dozers. GPS guidance systems allow the operator to complete complex earthmoving designs without the need for field staking. More advanced systems allow for accurate real time productivity monitoring and the automatic generation of "as-builts" in the form of Digital Terrain Maps (DTMs).

GPS is also being applied to other mining equipment besides dozers – including drills, trucks, graders, loaders, dredges and so on. This paper describes the use of high precision GPS to determine the position of the bucket teeth of shovels and excavators.

2. ANTENNA PLACEMENT

GPS instruments determine the latitude, longitude and elevation of the GPS antenna. Ideally to determine the position of the bucket, the antenna would be placed right on it. However the antenna would not survive in this location, and moreover would be frequently shielded from the sky and thus not receiving satellite signals.

On top of the machinery house is a better solution. The GPS determines the position of the antenna, but a functional system requires the system to determine the orientation of the machine.

Since shovels and excavators typically stay in one position for some time and rotate in order to move material from the bank to trucks, it is possible to use one antenna offset from the centre of rotation. As the machine rotates the successive positions from the antenna can be used to calculate the position of the centre of rotation. Once knowing the centre of rotation, the orientation of the machine can be calculated as the GPS antenna moves. However this scheme has the disadvantage that the machine must be rotated through at least 120 degrees every time the machine changes position.

Using two GPS antennas and two receivers is more expensive, but gives a faster more accurate result. The preferred locations are the back corners of the machinery house.

3. ROTATION PLANE

Knowing the orientation and position of the machinery house enables the position of the boom to be calculated. However the result will be in error if the machine is not rotating in a plane parallel to the earth's geoid. It is necessary to measure the pitch and roll of the machine to correct the result for rotation in an angled plane.

4. BOOM COMPONENTS

Knowing the position of the machinery house does not get us the position of the bucket. To do that, we need to know the movements of the ropes or beams connecting the bucket to the machinery house.

This can be accomplished with a variety of instruments-:

- Tilt sensors
- Rotation encoders on rope drums
- Wire reel sensors on hydraulic cylinders
- Measurement of fluid flow through hydraulic cylinders

Tilt sensors and encoders have proven to be the most reliable and robust solutions.

5. TILT SENSORS

Many commercially available sensors work with fluid vials. These have variable sensitivities and limited ranges, and many reports in only one axis. However so called nano technology has opened up the possibility of tilt sensors based on other physical effects, such as the movement of minute gas bubbles. A tilt sensor developed for the task of tracking mining equipment must demonstrate a number of capabilities:

- Rapid response – reporting at a rate of at least 10 times per second.
- Accuracy – performance to within 0.1 degrees is essential in order to achieve centimetre level precision on mining scale equipment.
- Resistance to vibration – the sensor must be capable of filtering out vibration effects.
- Resistance to overshoot – fluid sensors tend to "slosh".
- Resistance to shock loading – the unit must be capable of withstanding the high g forces associated with large rocks landing on the boom.
- Low maintenance requirements
- Easy calibration when installed in different orientations
- Long life – at least 3 years is desirable with no drift in reported values.

6. COMPUTERS

Computers used on board mining equipment must contend with difficult environmental conditions. When the machines are unattended in the field the temperatures can range from the very cold to the very hot. When the machine is in operation, it is subject to vibration and sometimes to relatively high dust levels. To be useful to the operator it must be easy to use and be visible under varying ambient light conditions. Rotating hard disks have a short life in this application and must be replaced by solid state memory. At least 2 GB of non volatile memory is necessary to hold the operating system, system software and complex designs. The computer should have a touch screen for easy operation. It must be fast enough to compute bucket positions and update screen backgrounds in a production situation.

7. ACCURACY

Using a base station the GPS systems have an accuracy of about one centimetre. Accuracy is lost in translating the positions to the bucket, but nevertheless even on large machines it is possible to achieve accuracy within 50mm. Since the bucket teeth are at least 250 mm long and wear back, this level of accuracy is satisfactory. On smaller machines tighter tolerances can be obtained down to 25 centimetres can be obtained. Accuracy depends to some extent on the maintenance of the shovel or excavator. Slack bearings will introduce additional errors.
Accuracy also depends on the number and position of visible satellites.

8. LATENCY

Information about the position of the bucket must not only be accurate, it must be delivered rapidly enough to allow the operator to use the information while production digging. Latency is the time between the bucket reaching a certain position and the representation on the screen showing the position. To achieve satisfactorily low levels of latency, the GPS receivers and the sensors must have a rapid response, the computer must run at a high enough speed and the software must use efficient algorithms. APS has found that using GPS receivers operating at 5 Hz, sensors running at 20 Hz and a computer running at 700 MHz, latency is around 300 milliseconds – a satisfactory but still noticeable lag.

9. INITIALIZATION

High precision GPS requires the GPS receivers to measure phase differences on both code signals (L1 and L2) from each satellite and the carrier wave itself. Because the wavelength of the carrier wave signal is shorter than the resolution of the code phase, the GPS receiver must resolve the ambiguity in whole wavelengths. This requires at least five satellites and may take some time. For the user this means that after turning on the equipment there will be a delay before the equipment can define a precise position (reaches "lock"). If the delay is lengthy this can be a source of irritation. Some manufacturers' algorithms are more efficient than others and hence require less time to achieve "lock". The more satellites that are available, the shorter the time necessary to achieve "lock".

10.GLONASS

The US GPS system, (known as NAVSTAR) is well known. What is not so well known is that the Russians also have a GPS system – known as GLONASS. The Russian system has yet to reach its design capability. Currently, (February 2005) there are eleven GLONASS satellites in orbit out of a planned constellation of eighteen. By comparison the US maintains at least 24 satellites at any one time and currently has 29 active, healthy satellites. Some manufacturers offer receivers capable of accessing signals from both sets of satellites. Thus the satellite pool for these receivers is forty. Access to both sets of satellites speeds acquisition of lock and reduces downtime due to lack of satellites. This is an important consideration for mining applications where part of the sky may be blocked by pit walls.

11.TELEMETRY

Radio telemetry systems are needed to transmit GPS correction signals, to download designs to the machines and to upload as built DTMs when the job is finished. Many GPS survey units use VHF signals for GPS corrections. These radios are good for coverage but have inadequate bandwidth to transmit complex designs. UHF radios operating at 400 to 900 MHz provide enough bandwidth to transmit designs. Wireless LAN radios operating at 2.4 GHz allow machines to be connected into the mine's intranet system, or even into the internet for remote connection. Wireless LAN systems have great bandwidth but are limited to line of sight communication and distances up to 2 kilometres. Some of the limitations of wireless LAN can be overcome by meshed systems in which each machine is a repeater. Alternatively a dual system can be installed with UHF or VHF for the mission critical GPS correction factors and other data cached until the LAN connection is established.

When machines are connected to the intranet, downloading designs is a simple drag and drop process. Intranet connection also allows supervisors and engineers to log in and see exactly the screen that the operator is seeing, and thus answer any questions or concerns. Intranet connections for this purpose can be installed on supervisors' vehicles.

Internet connections allow remote trouble shooting and remote downloads of updated software.

12.DEMONSTRATED BENEFITS

The following benefits have been demonstrated on high precision guidance systems for shovel and excavator buckets:

1. Accurate selective mining of mineralized horizons.
2. Accurately finding the low wall batter line in coal stripping operations, thus reducing overdig, or lost coal.
3. Accurate representation of hazardous areas – such as loaded blast areas or areas underlain by old underground workings.
4. More even benches, thus reducing truck cycle times and wear and tear on trucks. Benches will require less dozer and grader time.
5. Accurately cut ramps – again improving tyre life and truck cycle times.
6. Selective mining of coal – ensuring high value plies are fully and cleanly recovered.
7. Completing civil works to design – improving productivity.
8. Automatic generation of as built plans, which can be used for filing statutory reports for example or pit planning.
9. Less need for surveyors in the field

13.CENTURY MINE

The Century Zinc Mine, operated by Zinifex in northern Queensland has been using high precision GPS supplied by APS on two excavators for three years. The ore zone is hosted in grey shale. Identification of ore and waste is difficult. Prior to installation of the GPS system, surveyors and geologists delineated the ore zones with spray paint. During ore loading, a geologist was continually present. The guidance system clearly shows the operator the position of the bucket relative to the ore, and even identifies the type of ore. Since implementation there has been a significant increase in the head grade of ore into the mill, resulting in increased output. The elimination of the need for personnel on foot around the loading zone also enhances safety.

Century also operates GPS systems on their Bucyrus 495B shovels used for overburden stripping. Although no selective mining is involved with these shovels, the introduction of guidance has resulted in significantly smoother benches and ramps, with a consequent reduction in spillage, improved cycle times and reduced tire wear.

14.COLLINSVILLE MINE

The Collinsville Coal Mine, owned by Xstrata Coal and operated by Thiess Contractors is a mixed coking and thermal surface coal mine in northern Queensland. Overburden stripping is accomplished by a dragline, dedicated stripping dozers and excavator and truck fleets. The mine has two Liebherr 994 excavators and two Liebherr 995s equipped with high precision guidance from APS. In a typical sequence with thirty metres of overburden, the dozers move the top eighteen metres. The excavators follow, removing the remaining twelve metres in three 4 metre benches.

The nature of dozer stripping is such that a certain amount of rehandle is inevitable. It is essential that the intersection of each excavator bench with the new spoil pile is accurately located. Overdig of the spoil results in unnecessary rehandle and extra costs. Underdig leads to possible coal loss. Because of the geometry of the pit, every 1 metre error in locating the correct coal edge leads to 16 cubic metres of unnecessary rehandle per linear metre of pit if the error is too far on the spoil side. Too far on the coal side leads to a loss of

Prior to introduction of high precision guidance, the bench limits were marked with stakes placed at 20 metre intervals. Staking is a fairly labor intensive operation, and stakes are frequently disturbed or destroyed in the course of operations.

Thiess carried out a rigorous survey of under and over excavation in pits excavated before and after the introduction of high precision guidance on the first excavator. Overburden moved in 12 pits dug prior to GPS guidance amounted to 3.2 million cubic metres and showed an average 3.86% of overdig and 1.82% of underdig. Following the introduction of guidance three pits containing 1.5 million cubic metres of excavator dug overburden showed an average overdig of 0.99% and underdig of 0.93%. The reduction in overdig was sufficient to pay for the systems within a few months.

Thiess subsequently installed guidance systems on the three other excavators at the site.

15.JD CONSTRUCTION

JD Construction is a small earthmoving company in Brisbane. JD has two excavators fitted with GPS guidance systems from APS. A typical recent job involved excavation of the foundations for a building. This job was accomplished without the need for field staking. Eliminating staking means that the surveyors don't have to spend time in the field, and also means that operators don't have to take time to read the stakes, or spend idle time waiting on surveyors to stake the next part of the job or replace damaged stakes. Company owner JD says that GPS guidance results in about a 30 percent improvement over his standard times for completing jobs.

For jobs such as canal construction, pipeline trenches, embankments and subdivision landscaping GPS guidance means faster and more accurate completion at a lower cost.

Although excavators at mine sites are typically involved in bulk digging, most mine sites use their machines for civil work from time to time. These works could include diversion channels, settling ponds, haul roads and similar projects. GPS guidance enables these chores to be completed faster so that the machines can get back to their primary purpose.

16. FUTURE DEVELOPMENTS

16.1 *Ore Grade Tracking*

The ability to determine at all times the exact position of the bucket teeth of an excavator or shovel makes it possible to track the volume and source of every bucket loaded into a haul truck. If the geological model is good enough the quality of every truckload could be defined – allowing unprecedented quality control of material headed for the mill.

16.2 *Advanced Selective Mining*

It is possible to use spectral analysis to detect high grade ore veins in the bank. If a laser scanner or stereo digital camera captures the data, the high grade veins can be spatially defined and then mined using the GPS system to guide the bucket.

16.3 *Data Transmission*

The addition of high band width LAN communications opens up the possibility of much greater data flows. For example it is possible to interrogate on board maintenance health systems via the LAN. Thus a mechanic in the workshop can determine when machines are due for maintenance based on oil pressures, bearing temperatures and suchlike factors.

17. CONCLUSIONS

GPS guidance to the bucket is available and reliable. The applications in mining are many and varied. The value of such systems is enhanced by integration into mine planning, surveying, production reporting, maintenance management and other technical and management information systems at the mine site. In order to get maximum benefit, companies should ensure that they invest in open architecture systems that can accommodate data from a variety of sources.

Photo 1 Excavator at Century Zinc Mine equipped with GPS guidance for selective mining of ore.

Photo 2 Guidance System being used for excavation of building foundation Excavator guidance from Microfyn, Software from Carlson Software.

Photo 3 Excavator at Collinsville with guidance used to find the edge of Coal.

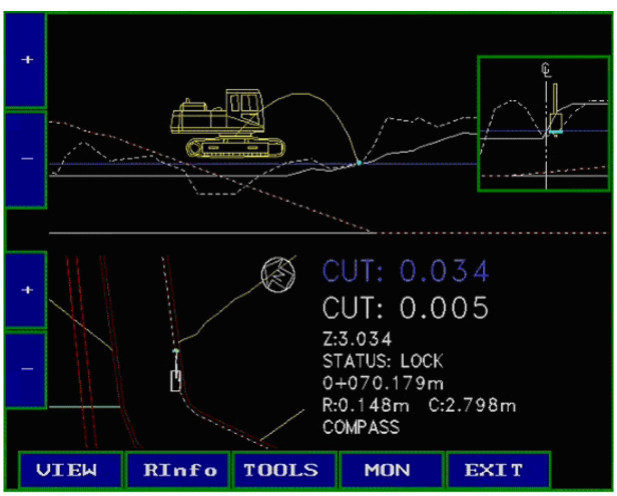

Photo 4 Screen view from Collinsville. Software from Carlson Software.

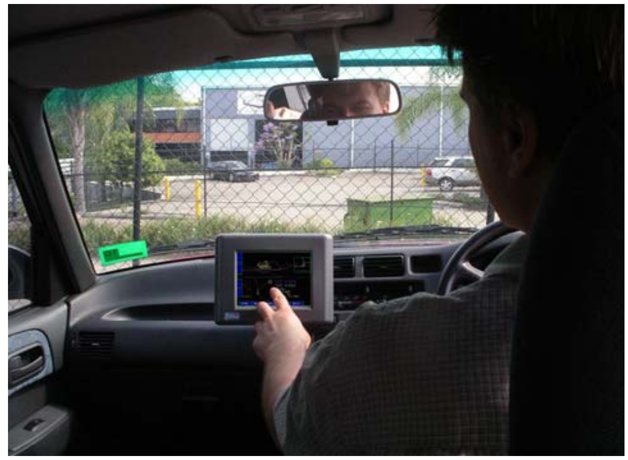

Photo 5 Foreman's vehicle system equipped with wireless LAN to duplicate Shovel operators view.

Photo 6 Tilt Sensor Installed on excavator boom.