FACT SHEET

Use of global positioning system and three-dimensional laser scanning in road works

1. Introduction

1.1 Global positioning system (GPS) and three-dimensional laser scanning are employed as tools for geometric surveying and modelling for road works. These technologies can accurately capture construction location and activities, thus facilitating road works project control and providing automatic GPS machine guidance[1]. This fact sheet aims to provide members of the Panel on Transport with background information on the use of GPS and three-dimensional laser scanning, including the adoption of these technologies by Wisconsin and Montana of the United States in surveying works carried out for road projects.

2. Global positioning system

2.1 GPS is a space-based satellite navigation system made up of a network of 24 satellites placed in orbit by the United States (US) government. GPS was originally intended for military applications, and the US government made the system available for civilian use when it became fully operational in 1995. GPS can provide location and time information in all weather conditions, anywhere on or near the Earth. At present, the civilian service is freely available to all users on a continuous, worldwide basis, whereas the military service is available to the US and allied armed forces as well as approved US government agencies.

[1] Automatic GPS machine guidance is a system using GPS-based technology to guide construction plant on site and through the construction process.

<u>Structure of the global positioning system</u>

2.2 GPS satellites encircle the Earth in a very precise orbit and transmit signal information to Earth. GPS receivers take this information to calculate the user's exactly location, with a number of control stations locating around the world to ensure the proper functioning of GPS satellites. As such, GPS consists of three major segments, namely the space segment, the control segment, and the user segment. The US Air Force develops, maintains and operates both the space and control segments.

2.3 The GPS space segment consists of a constellation of satellites transmitting radio signals to users. The US Air Force manages the constellation to ensure the availability of at least 24 GPS satellites for 95% of the time. GPS satellites fly in medium Earth orbit at an altitude of approximately 20 200 km. Each satellite encircles the Earth twice a day and transmits signal information to the Earth.

2.4 The GPS control segment consists of a global network of ground facilities that track the GPS satellites, monitor their transmissions, perform analyses, and send commands and data to the constellation. The current operational control segment includes a master control station, an alternate master control station, 12 command and control antennas, and 16 monitoring sites.

2.5 The user segment consists of the GPS receiver equipment, which receives, decodes and processes the signals from the GPS satellites and uses the transmitted information to calculate the user's location. GPS receivers can be carried in the user's hand[2] or installed on aircraft, ships tanks, submarine, cars and trucks. In general, GPS receivers are composed of an antenna, tuned to the frequencies transmitted by the satellites, receiver-processors, and a highly stable clock (often a crystal oscillator). They may also include a display for providing location and speed information to the user. A receiver is often described by its number of channels that signifies how many satellites it can monitor simultaneously. Originally limited to four or five, the number of channels has progressively increased over the years such that receivers typically have more than 12 channels.

[2] The typical hand-held receiver is the mobile phone with built-in GPS receiver.

Application of the global positioning system in road works

2.6 GPS has become a widely deployed and useful tool for commerce, scientific uses, tracking, and surveillance, especially for road works surveying and mapping. With the use of GPS technology, highly accurate surveying and mapping results can be rapidly obtained, thereby significantly reducing the amount of equipment and labour hours that are normally required of other conventional surveying and mapping techniques during road works. At present, it is possible for a single surveyor to accomplish in one day what used to take weeks with an entire team. GPS is unaffected by rain, wind, or reduced sunlight, and is rapidly being adopted by professional surveyors and mapping personnel throughout the world.

2.7 GPS also provides accurate three-dimensional positioning information for natural and artificial features that can be displayed on maps. The information serves as a prime input to geographic information systems, which assemble, store, manipulate, and display geographically referenced information. In particular, road construction works which requires accurate location information can benefit from the efficiency and productivity provided by the positioning capability of GPS. The benefits of adopting GPS technology in surveying and mapping include:

(a) providing significant productivity gains over traditional surveying by eliminating many of its inherent limitations, such as the requirement for a line of sight between surveying points for distance measurement;

(b) providing accurate positioning of natural and artificial features that can be used to create maps and models that are used for a wide range of services such as road works, disaster relief and public safety;

(c) giving decision-makers timely and valuable information for wise use of resources;

(d) producing highly accurate surveying results in real-time at the centimetre-level; and

(e) allowing surveyors to work uninterrupted in periods of poor weather conditions or reduced sunlight.

3. Three-dimensional laser scanning

Technology of three dimensional laser scanning

3.1 Three-dimensional laser scanning utilizes light detection and ranging to produce accurate three-dimensional representations of objects. It is similar to radio detection and ranging, commonly known as radar, but it uses light to measure range or distance instead. A laser scanner produces a light source at a specific frequency. It uses a mirror to direct the laser beam horizontally and vertically towards the object. The surface of the object then reflects the laser beam. Using the principle of pulse time of flight[3], the distance to the object can be determined by the transit time, with a precision of ±4 millimetres. The result of a scan produces a collection of points in space, commonly known as "point clouds", which can be processed and combined into accurate three-dimensional models.

3.2 Multiple scans from a single scan session can be combined into a single three-dimensional model through scan registration, data filtering and modeling. For generating a three-dimensional model, several scanning targets around the location serve as control points while edges from non-moving construction equipment or materials serve as reference points. The overlapping areas from all scanning images are stitched, or registered, together to generate a single, to-scale three-dimensional point cloud model. Three-dimensional models can then be developed for further manipulation and/or modeling purposes.

3.3 In general, the matching accuracy of three-dimensional laser scanning is affected by the following factors:

(a) the presence of moving objects, such as personnel, equipment, in the overlap zones;

(b) adjacent scans with different point spacing; and

(c) the necessity of additional scans from opposite sides of the site due to limited site access to scanning positions around the site perimeter.

3 Under the pulse time of flight principle, the distance between the sensor and an object is calculated by measuring the time interval between an emitted laser pulse and reception of the reflected pulse.

Application of the three-dimensional laser scanning in road works

3.4 Three-dimensional laser scanning provides an innovative approach to collect high-fidelity data to support engineering analyses for road works and construction. These high-fidelity data also provide the much needed precision to other civil engineering disciplines, such as geotechnical and structural engineering, for better understanding and controlling of structural or ground deformations caused by construction activities including road works.

3.5 The development of three-dimensional laser scanning has led to a wide range of applications, particularly in the domain of road works such as landslide monitoring and highway construction. It also enables engineers to acquire construction site geometry information in three dimensions, which is conducive to correlating measured ground deformations to specific construction activities.

4. Overseas experience in adoption of the global positioning system and three-dimensional laser scanning technologies in road works

Wisconsin of the United States

4.1 The Wisconsin Department of Transportation ("WisDOT") adopted static GPS positioning for project control in road works as early as the 1990's. WisDOT went further in the mid-1990s to acquire the Real-Time Kinematic GPS base and rover receivers[4]. This technology provides centimetre-level accuracies in real time, as opposed to the delayed post processing required for static GPS.

[4] Rover, which stands for Remotely Operated Video Enhanced Receiver, is a system which allows ground forces to see what an aircraft is seeing in real time by receiving images acquired by the aircraft's sensors on a laptop on the ground.

4.2 With the advance in technology in recent years, WisDOT has applied the continuously operating reference stations ("CORS") approach to support the Real-Time Kinematic GPS in providing more accurate land surveys since 2007. CORS, using the Real-Time Kinematic positioning, relay the received signals to a regional server that analyzes the data from multiple CORS, receives additional signals from rovers, calculates corrections to the signals being received at each rover, and sends to each rover corrections to the carrier phase ranges it is computing. This innovation eliminates the need for a local base station and facilitates the Real-Time Kinematic surveys that use only rovers, significantly reducing the necessary investment in equipment and simplifying logistical requirements in the field.

4.3 The impact of CORS for Real-Time Kinematic GPS surveys on GPS machine guidance[5] is significant. Contractors who adopt the technology will no longer need to operate project base stations, and can eventually reduce the required amount of local project control involved in road works.

4.4 Some Wisconsin contractors have started using GPS machine guidance for grading operations on highway projects. In such case, three-dimensional designs and models are required for GPS machine guidance. Specifically, in an operational setting, an on-board computer positions the machine within the three-dimensional model by registering coordinates for the machine, computed by the Real-Time Kinematic GPS methods, to the local co-ordinate system of the model. The position of the machine with respect to the design surface is then known and the necessary amount of cut or fill for grading operations is continuously available as the machine moves in three-dimensional space.

5 As mentioned in paragraph 1.1, GPS machine guidance is a system using GPS-based technology to guide construction plant on site and through the construction process.

Montana of the United States

4.5 The Montana Department of Transportation has been using GPS machine guidance on projects since 2002. Contractors build the necessary three-dimensional models from paper plans and are responsible for quality control on GPS machine guidance projects. This includes the configuration of project control, calibration of the GPS system to the model, and the spacing of GPS base stations. Field checks are performed by radial survey with total stations, which are electronic instruments used in surveying to read slope distances, and such technology is independent of GPS.

4.6 GPS machine guidance has been used on projects up to 10 miles in length. However, where there are issues with satellite visibility in the mountainous western part of the state, contractors may experience up to 20 minutes down time. On these occasions, GPS machine guidance is often supplemented with laser guidance technology.

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References

1. Articlesbase. (2010) *GPS application in the mearing of bridge and road construction.* Available from: http://www.articlesbase.com/gps-articles/gps-application-in-the-mearing-of-bridge-and-road-construction-2836873.html [Accessed December 2011].

2. Construction and Materials Support Center (CMSC). (2007) *Implementation of GPS Controlled Highway Construction Equipment – Final Report.* Available from: http://cmsc.engr.wisc.edu/Vonderohe2007Apr01.pdf [Accessed December 2011].

3. Construction and Materials Support Center (CMSC). (2009a) *Current Reports: 3D Technologies: Status and Plans for Implementation 3D Technologies for Design and Construction in WisDOT – Final Report.* Available from: https://mywebspace.wisc.edu/groups/CMSC/reports/WisDOT3DTechnologyImplementationReport.pdf [Accessed December 2011].

4. Construction and Materials Support Center (CMSC). (2009b) *Current Reports: Implementation of GPS Controlled Highway Construction Equipment Phase III – Final Report.* Available from: https://mywebspace.wisc.edu/groups/CMSC/reports/ImplmentationofAMG-PhaseIIIFinalReport.pdf [Accessed December 2011].

5. Construction and Materials Support Center (CMSC). (2011) *Current Reports.* Available from: http://cmsc.engr.wisc.edu/reports.html [Accessed December 2011].

6. GPS.Gov. (2011) *System: GPS.* Available from: http://www.gps.gov/ [Accessed December 2011].

7. Infomap. (2011) *GPS Machine Guidance.* Available from: http://www.infomapsurveys.co.uk/gps/gps-machine-guidance.htm [Accessed December 2011].

8. National Aeronautics and Space Administration (NASA). (undated) *GPS Overview.* Available from: http://gpshome.ssc.nasa.gov/content.aspx?s=gps [Accessed December 2011].

9. National Ocean and Atmospheric Administration (NOAA). (2010a) *NOAA Ocean Service Education: Global Positioning.* Available from: http://oceanservice.noaa.gov/education/tutorial_geodesy/ [Accessed December 2011].

10. National Ocean and Atmospheric Administration (NOAA). (2010b) *NOAA Ocean Service Education: The Global Positioning System – Geodesy.* Available from: http://oceanservice.noaa.gov/education/kits/geodesy/geo09_gps.html [Accessed December 2011].

11. National Ocean and Atmospheric Administration (NOAA). (2011) *GPS Orbits: Computing GPS Orbits.* Available from: http://www.ngs.noaa.gov/orbits/ [Accessed December 2011].

12. The Aerospace Corporation. (2007) *Figure: Elements of the Global Positioning System.* Available from: http://www.aero.org/education/primers/gps/elements.html [Accessed December 2011].

13. The official web site of the U.S. Air Force. (2010) *Factsheets: Global Positioning System.* Available from: http://www.af.mil/information/factsheets/factsheet.asp?id=119 [Accessed December 2011].

14. Trimble. (undated) *GPS Tutorial: Putting GPS to work – Mapping.* Available from: http://www.trimble.com/gps/gpswork-map.shtml [Accessed December 2011].

15. Wikipedia. (2011) *Global Positioning System*. Available from: http://en.wikipedia.org/wiki/Global_Positioning_System [Accessed December 2011].

16. WorldCat Identies. (2007) *University of Wisconsin-Madison Construction and Materials Support Center: Overview*. Available from: http://www.worldcat.org/identities/nc-university%20of%20wisconsin%20madison$construction%20and%20materials%20support%20center#linkoverview [Accessed December 2011].