Future Satellite Positioning and Navigation Systems

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GPS has found its way in many industrial applications, mainly as a result of its accuracy, global availability and cost effectiveness. GPS was developed by the U.S. Department of Defense in early 1970s, initially as a military system. However, it was later made available to civilians, to become a dual-use system that can be accessed by both military and civilian users. To meet the future requirements, the GPS decision makers have studied several options to adequately modify the signal structure and system architecture of the future GPS constellation. This program is known as the GPS modernization program.

In the same way, Russia developed the GLONASS satellite system, which has much in common with the GPS system. Presently, all the satellites in the GLONASS constellation are prototypes. Russia is planning to launch a new generation GLONASS satellite, called GLONASS-M, in the near future.

A third global satellite-based positioning and navigation system, known as Galileo, is proposed by Europe. Galileo is a civil-controlled satellite system, which is expected to be operational by 2008. Canada has participated in the definition phase studies of Galileo, and is expected to participate in the development and validation phase as well.

This article discusses the current status and the future developments of the three satellite systems.

The Global Positioning System (GPS)

The Global Positioning System (GPS) is an all-weather satellite-based navigation system that was developed by the U.S. Department of Defense in early 1970s. GPS consists, nominally, of a constellation of 24 operational satellites. To ensure continuous worldwide coverage, the GPS satellites are arranged so that four satellites are placed in each of six orbital planes (Figure 1). The GPS satellite orbits are nearly circular (an elliptical shape with a maximum eccentricity is about 0.01), with an inclination of about 55° to the equator. The semi-major axis of a GPS orbit is about 26560 km, i.e., the satellite altitude is about 20,200 km above the earth's surface.

Each GPS satellite transmits a microwave radio signal composed of two carrier frequencies (or sine waves) modulated by two digital codes and a navigation message. The two carrier frequencies are generated at 1575.42 MHz (referred to as L1 carrier) and 1227.60 MHz (referred to as L2 carrier). All the GPS satellites transmit the same L1 and L2 carrier frequencies. The two GPS codes are called Coarse Acquisition (or C/A-code) and Precision (or P-code). The codes consist of streams of binary digits, zeros and ones, known as bits or chips. The chipping rate of the C/A-code is 1.023 million bits per second (Mega bps). The P-code is ten times faster than the C/A-code. Each satellite is assigned a unique C/A-code, which enables the GPS receivers to identify which satellite is transmitting a particular code. Presently, the C/A-code is modulated onto the L1 carrier only, while the P-code is modulated onto both the L1 and L2 carriers. The GPS navigation message is a data stream added to both the L1 and L2 carriers, which contains, along with other information, the coordinates of the GPS satellites as a function of time.

GPS satellite constellation build-up started with a series of eleven prototype satellites known as Block I satellites. These prototype satellites were followed by the second, and more advanced, generation of the GPS satellites known as Block II/IIA satellites. A total of 28 Block II/IIA satellites were launched during the period from February 1989 to November 1997. Of these, 23 are currently in service. A new generation of GPS satellites, known as Block IIR, is currently being launched. A total of 21 Block IIR satellites are planned to be launched. The current GPS constellation (July 2001) contains 5 Block II, 18 Block IIA and 6 Block IIR satellites. This makes the total number of GPS satellites in the constellation to be 29, which exceeds the nominal 24-satellite constellation by 5 satellites.

GPS Modernization

The current GPS signal structure was designed in the early 1970s, some 30 years ago. In the next 30 years, the GPS constellation is expected to have a combination of the Block IIR satellites, which are currently being launched, and the following generations Block IIF, and possibly Block III satellites. To meet the future requirements, the GPS decision makers have studied several options to adequately modify the signal structure and system architecture of the future GPS constellation. The modernization program aims, among other things, at providing signal redundancy, improving the positioning accuracy, improving the signal availability and the system integrity.

The modernization program will include the addition of a civil code (C/A-code) on L2 frequency and two new military codes (M-codes) on both L1 and L2 frequencies. These codes will be added to the last 12 Block IIR satellites, which will be launched at the beginning of 2003. The

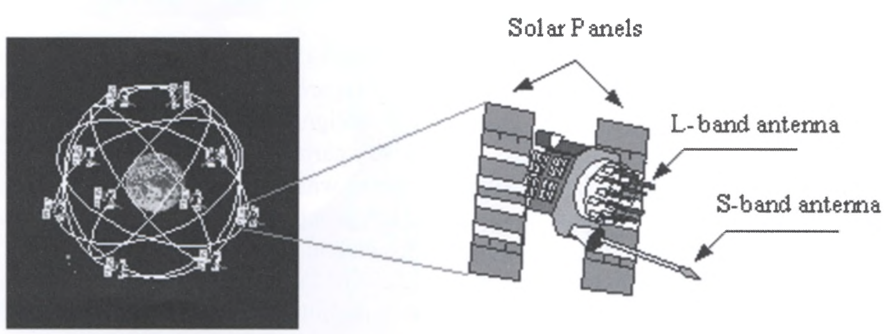

Figure 1. GPS Satellite Constellation

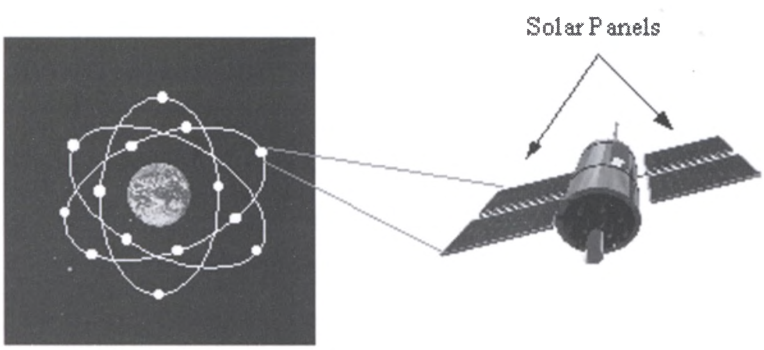

Figure 2. GLONASS Satellite Constellation
(Satellite image courtesy of Ashtech, Inc.)

availability of two civil codes (i.e. C/A-code on both L1 and L2 frequencies) allows a user with a standalone GPS receiver to correct for the effect of the ionosphere (the upper layer of the atmosphere), which is a major error source. With the termination of Selective Availability on May 1, 2000, it is expected that once a sufficient number of satellites with the new capabilities are available, the autonomous GPS horizontal accuracy will be about 8.5 m (95% of the time) or better.

The addition of the C/A-code to L2, which although improves the autonomous GPS accuracy, was found to be insufficient for use in the civil aviation safety-of-life applications. This is mainly because of the potential interference from the ground radars that operate near the GPS L2 band. As such, to satisfy aviation user requirements, a third civil signal at 1176.45 MHz (called L5) will be added to the first 12 Block IIF satellites along with the C/A-code on L2 and the M-code on L1 and L2, as part of the modernization program. This third frequency will be robust and will have a higher power level. In addition, this new L5 signal will have wide broadcast bandwidth (a minimum of 20 MHz) and a higher chipping rate (10.23 Mega bps), which provide higher accuracy under noisy and multipath conditions. The new code will be longer than the current C/A-code, which reduces the system self-interference. Finally, the broadcast navigation message of the new signal, which although contains more or less the same data as the L1 and L2 channels, will have an entirely different, more efficient structure. The first Block IIF satellite is scheduled to be launched in 2005 or shortly thereafter. The addition of these capabilities will dramatically improve the autonomous GPS positioning accuracy. As well, the real-time kinematic (RTK) users, who require centimeter-level accuracy in real-time, will be able to resolve the initial integer ambiguity parameters instantaneously.

The modernization of GPS will also include the studies for the next generation Block III satellites, which will carry GPS into the year 2030. Finally, the GPS ground control facilities will also be upgraded as a part of the GPS modernization program. With this upgrade, the expected standalone GPS horizontal accuracy will be 6 m (95% of the time) or better. This will eliminate the need for a DGPS service for many applications, particularly the GIS applications.

GLONASS Satellite System

The Global Navigation Satellite System (GLONASS) is an all-weather global navigation satellite system developed by Russia. The nominal constellation of GLONASS system consists of 21 operational satellites plus 3 spares at a nominal altitude of 19,100 km. Eight GLONASS satellites are arranged in each of 3 orbital planes (Figure 2). GLONASS orbits are approximately circular with an orbital inclination of 64.8º.

Similar to GPS, each GLONASS satellite transmits a signal that has a number of components: two L-band carriers, C/A-code on L1, P-code on both L1 and L2, and a navigation message. However, unlike GPS, each GLONASS satellite transmits its own carrier frequencies in the bands 1602-1615.5 MHz for L1 and 1246-1256.5 MHz for L2, depending on the channel number. These two bands are on their way to being shifted to 1598.0625-1604.25 MHz and 1242.9375-1247.75 MHz, respectively, to avoid interference with radio astronomers and operators of low earth orbiting (LEO) satellites. With this shift, each pair of GLONASS satellites will be assigned the same L1 and L2 frequencies. The satellite pairs, however, will be placed on the opposite sides of the earth (antipodal), which means that a user cannot see them simultaneously. GLONASS codes are the same for all the satellites. As such, GLONASS receivers use the frequency channel rather than the code to distinguish the satellites. The chipping rates for the P-code and the C/A-code are 5.11 and 0.511 Mega bits/sec, respectively. GLONASS navigation message is a 50 bps data stream, which provides, among other things, the satellite ephemeris and the channel allocation.

GLONASS system completed 24 working satellites in January 1996. Unfortunately, however, the number of usable GLONASS satellites has dropped to only 7 satellites at the present time (July 2001). It is expected that a new generation GLONASS satellite, GLONASS-M, will be launched in the near future. GLONASS-M has a lifetime of 5 years, improved onboard atomic clocks and the facility to transmit the C/A code on both L1 and L2 carrier frequencies.

GPS and GLONASS systems may be integrated to improve the geometry and the positioning accuracy, particularly under poor satellite visibility, such as in urban areas. There are, however, two problems with the GPS/GLONASS integration. The first one is that both GPS and GLONASS systems use different coordinate frames to express the position of their satellites. GPS uses the WGS 84 system while GLONASS uses the Earth Parameter System 1990 (PZ-90) system. The two systems differ by as much as 20 meters on the earth's surface. The transformation parameters between the two systems may be obtained by simultaneously observing reference points in both systems. Several research groups have developed various sets of transformation parameters. However, accurate determination of the transformation parameters is still unavailable. The second problem with the GPS/GLONASS integration is that both systems use different reference times. The offset between the two time systems changes slowly and reaches several tens of microseconds. One way of determining the time offset is by treating it as an additional variable in the receiver solution.

Future European Global Navigation System (Galileo System)

Galileo is a satellite-based global navigation system proposed by Europe. Galileo is a civil-controlled satellite system to be delivered through a public-private partnership. Three different constellation types were investigated to ensure the optimum selection of the Galileo architecture, namely: low earth orbits (LEO), medium earth orbits (MEO) and inclined geo-synchronous orbits (IGSO). Combinations of various constellation types were also studied. Following this study, the Galileo decision makers adopted a constellation of 30 medium earth orbit satellites. The satellites will be evenly distributed over 3 orbital planes at an altitude of about 23,000 km. This selection ensures that more uniform performance is obtained for all regions, i.e. independent of the region's latitude. The signal characteristics of the Galileo system are to be determined sometime in 2001.

Galileo will be compatible at the user level with the existing GPS and GLONASS systems. However, unlike GPS and GLONASS, Galileo will provide two levels of service: a basic, free of direct charge service and a chargeable service that offers additional features. Some security measures, such as withholding of the service, have been studied to ensure that the system is properly used. A European political body, independent of Galileo management, will have the authority to take the proper measures in the event of a crisis.

The target date for the gradual introduction of the Galileo operational service is 2008 or shortly thereafter. The Galileo development plan will be divided into three different phases:

The definition phase, which was concluded at the end of the year 2000.

The development and validation phase, which begins in 2001 and extends for a period of four years. This phase will comprise more detailed definition of the Galileo system, e.g. frequency allocation. As well, this phase will include the construction of the various segments of the system (space, ground and receiver). Some prototype satellites will be launched in 2004, along with the establishment of a minimal ground infrastructure, to validate the system.The constellation deployment phase is scheduled to begin in 2006 and extends until 2007. With the experience gained during the system validation phase, operational satellites will be gradually launched during this phase. In addition, ground infrastructure will be completed.

It is worth mentioning that Canada and the European Commission have established a joint working group on satellite navigation. Canada has participated in the definition phase studies of Galileo, and is expected to participate in the development and validation phase as well.

Interoperability of the Three Systems

GPS and GLONASS systems have been successfully integrated, which has improved the geometry and the positioning accuracy, particularly under poor satellite visibility. Further improvement could be achieved, provided that accurate information on the datum and time offsets between the two systems is available.

There are ongoing discussions between the USA, Russia and Europe to ensure the compatibility and interoperability of the three satellite systems. The availability of three independent and interoperable satellite systems will significantly improve the positional accuracy and reliability.

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QUESTIONS? COMMENTS?

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Historical Information

WANTED

PRESS RELEASE
Surveying - Alberta's History
September 21, 2001

The history of surveying in Alberta is the history of the province. The township system and the orderly settlement in this province are all due to the work of the early land surveyors.

The Alberta Land Surveyors' Association has retained the services of historical consultant Judy Larmour of Rimbey to write a book on the History of Surveying in Alberta. It is hoped to have it in time for Alberta's centennial in 2005.

"We know that many people probably had an uncle or a grandfather or other family member who was a surveyor or worked on a survey crew. If they had old diaries or photographs, we would certainly love to hear from them," said Historical and Biographical Committee Chairman, Bob Baker of Lethbridge.

If you, or someone you know, has stories, pictures or other information on the early days of surveying in the province, please contact the Alberta Land Surveyors' Association at:

1-800-665-2572

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