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MODERNIZATION PLAN OF GPS IN 21st CENTURY AND ITS IMPACTS ON SURVEYING APPLICATIONS

G. M. Dawod

Survey Research Institute, National Water Research Center, Egypt

ABSTRACT

The Global Positioning System (GPS) has been developed in 1970’s as a military, and partially a civilian, navigation system. Over the last three decades, GPS has become the primary tool in surveying and mapping applications worldwide with Egypt be no exception.

A new modernization plan is currently underway by the U.S. Department of Defense in order to make GPS cope with the requirements of advanced technologies in the 21st century. The first step in this strategy, carried out in May 2000, was turning off the Selective Availability (SA) accuracy degradation. Additionally, a new civil signal (called L2C) will be transmitted by modernized Block IIR (IIR-M) and all subsequent satellite starting from 2003. For military purposes, a new military code (called L2M) will be added to the L2 frequency. Furthermore, another completely new civil signal (called L5) will be transmitted on a frequency of 1176.45 MHZ as early as 2005 by the Block IIF satellites. Also, the modernization plan includes several improvements to enhance the performance of the GPS control segment. This paper presents the characteristics of each component of the GPS revolutionizing plan, and investigates its anticipated influences on surveying and mapping applications in terms of system integrity and availability, attainable positioning accuracy and reliability.

KEYWORDS
Surveying, GPS, Satellites; Signals and codes

[1] dawod_gomaa@hotmail.com

1. Introduction

Since the mid-1980s, the Global Positioning System (GPS) has been extensively utilized in a wide range of civil and military applications worldwide. Today, GPS is used almost exclusively employed by the geodesy and surveying community for a large variety of mapping projects. The GPS technology is entering a new era in the 21st century through the undergoing execution of a fifteen-year revolutionizing modernization plan. This program focuses on improving position and timing accuracy, availability, integrity monitoring support capability and enhancement to the control system. This paper aims to present the characteristics of the components of the GPS modernization strategy, and to investigate its anticipated influences on surveying applications.

2. The need for GPS Modernization

The development of GPS technology has started in the early 1970s by the U.S. Department of Defense (DoD). The first generation of GPS satellites (Block I) has been launched in space starting February 23, 1978. GPS has been officially declared "fully operational" as of April 27, 1995. However, the basic structural characteristics of GPS, i.e., satellites, transmitted signals, and even the control segment, have not been changed significantly in the last quarter of the twentieth century. This is a relatively a long time on the technology development time scale. Several reasons and motivations were behind the development of a fifteen-year modernization plan to make GPS cope with the requirements of technologies in the 21st century.

Starting in 1997, special technical meetings have been carried out by the Interagency GPS Executive Board (IGEB) to develop a new modernization strategy. Several procedures have been suggested to meet the civilian and military requirements of GPS services. The main civilian goal was to enhance the performance of the GPS Standard Positioning Service (SPS). SPS refers to the signal-in-space provided free of direct user charges for peaceful, commercial, and scientific use on a continuous, worldwide basis. It is known that only one fully accessible signal (The Course-Acquisition C/A coded signal at L1 frequency) is available for civilian applications. Moreover, the Selective Availability (SA) was implemented starting July 4, 1991 to degrade the full real-times GPS accuracy for civilian users. On a military basis, the modernization plan aims to provide another Precise Positioning Service (PPS) for U.S. military and other authorized users, and to develop measures to prevent the hostile use of GPS. Today, only the Y (encrypted precise P) code is modulated on the L2 frequency for military applications.

Some of the overall objectives of the modernization program, as described in the FRP official U.S. document, are [1]:
- Worldwide coverage.
- User-passivity.
- Resistance to interference and jamming.
- Resistance to natural disturbance and hostile attacks.
- Resistance to radio frequency (RF) interference.
- Effectiveness of real-time response.
- Existence in appropriate radionavigation bands.
- High positional accuracy.
- Continuous availability of information.
- Continuously reliable for navigation.
- Cost effectiveness.

3. Components of the modernization plan

GPS Modernization is a multi-phase effort to be executed over the next 15+ years by DoD. In order to achieve the previously mentioned objective, the modernization strategy consists of several elements. On a civilian basis, the first real step toward modernizing GPS took place on May 1, 2000 by turning off the SA error source. This step afforded GPS civil users at least a five-fold improvement in accuracy. In absence of SA, accuracy estimates would be 22 meters horizontal and 33 meters vertical (95% of the time) [2]. Another civilian component of GPS modernization is providing additional coded civil signals (L2C on the L2 frequency and a completely new signal called L5). For military applications, a new military code (known as M code) will be transmitted on both L1 and L2 frequencies. The GPS satellites will also be an important part in the innovation strategy. The IGEB has accepted a DoD recommendation to develop a new generation of satellites (Block III) that meet the military and civilian requirements through 2030. The last module of the modernization plan is upgrading the GPS operational control segment and its facilities. Each element of this revolutionizing plan will be discussed in more details in the following sections.

3.1 New GPS civilian signals

Two new codes are planned to be transmitted by GPS satellites for civilian applications. The first civilian signal, called L2C, was announced by a white house press release on March 30, 1989. L2C is a modified C/A code transmitted on the L2 frequency by the modernized block IIR (IIR-M) and all subsequent satellites. The first IIR-M satellite is scheduled to be launched in 2003. The designed structural characteristics of the L2C code, as will be discussed, prove that it will become the most widely used GPS signal of all since. The second civilian signal, called L5, has features that depart significantly from the other GPS frequencies, making it much more robust and more resistant to interference. The code transmitted on L5 has special design characteristics, and is not a replica of the other codes on the new L5 frequency.

The main key feature of L2C is that it better matches to 21st century capabilities and requirements The actual technical development of L2C has been carried out in January 2001. Two primary requirements drove the design of L2C. The first objective is to eliminate need for the semi-codeless tracking techniques now used to acquire the L2 measurements. L2C enhances tracking performance by having no data on one of its codes, and provides full-wavelength carrier phase measurements without having to resolve the phase ambiguity inherent in signals with bi-phase data modulation. The L2C signal structure consists of: (1) The CM, which is a moderate-length code contains 10,230 chips, repeats every 20 milliseconds, and is modulated with message data; and (2) The CL, which is a long-length code contains 767,250 chips, repeats every 1.5 seconds, and has no data modulation [4 and 5]. The second key objective was to let L2 lower the data modulation threshold, making it possible to read the message when barely tracking the signal. In order to achieve this goal, L2C has cross-correlation performance of 45 dB, compared to the unacceptable 21 dB cross-correlation of the L1 C/A code [6].

The second civil signal, called L5, will be transmitted on a frequency of 1176.45 MHZ by Block IIF satellites as early as 2005 [7]. The L5 band is set aside by the International Telecommunication Union for the aeronautical radionavigation service in order to satisfy the safety-of-life requirements for aircraft navigation. However, L5 also will serve as a robust third civilian signal for all users and applications. There are a lot of factors drove the design of the L5 signal based on manufactures and users' points of view. An important user requirement, affected the L5 signal design, is the request for data-free carrier component. This is a crucial demand for users perform real-time kinematic (RTK) carrier tracking operations. A data-free component provides users with a capability to track whole carrier cycles and enhances tracking the carrier at significantly lower signal-to-noise rations. A carrier component that carries the navigation data is also required, so that the L5 signal is independent of the other civil GPS signals.
The L5 signal structure was developed by the RTCA special committee SC159 working group 1 in 1999. In order to make L5 more powerful than the existing L1 and L2 signals, significant signal structural changes have been performed in terms of bandwidth, signal power, code structure, chipping rate, data structure; and data modulation. L5 is designed with a center frequency of 1176.45 MHZ, a minimum bandwidth of 20 MHZ, and a signal power four times stronger than the L1 C/A [7]. Moreover, the L5 offers two components: one with and one without a superimposed navigation data messages. Each component is

modulated with a different, but synchronized, L5 code. Different PRN codes (known as I5 and Q5) are used in the two components to prevent tracking biases by making each component completely independent of the other, except for the carrier phase. A more efficient data message structure is employed in L5 providing navigation data with integrity in a more timely manner [8].

3.2 New signal availability

It is known that since the 1974 when the first Block I satellite was launched, there have been only three navigation signals: C/A on L1, P/Y on L1; and P/Y on L2. The modernization plan will double the total number of signals by 2003. Launching the first Block IIF satellite in 2005, the number of signals will be seven. This dramatic change is illustrated in table 1. Figures 1 and 2 depict expected time line of new signals availability based on the estimated satellites launching scheme. The first Block IIR-M satellite are expected to be launched in 2003, while Block IIF satellites are anticipated to be launched starting 2005. As shown in these two figures, it is probable that by 2011 there will be 28 satellites transmit L2C signals and 18 satellites transmit L5 signal. The initial operation capability (IOC) of L2C service, i.e., 18 satellites on orbit, is planned for 2008, while the full operational capability (FOC), i.e., 24 satellites on orbit, is planned for 2010. For the L5 service, the IOC is planned for 2005, while the FOC is planned for 2014 [1].

Table 1
GPS Navigation Signals

Signals \ Year	Now: Block IIR satellites	2003: Block IIR-M satellites	2005: Block IIF satellites
C/A on L1	X	X	X
P/Y on L1	X	X	X
M on L1		X	X
L2C on L2		X	X
P/Y on L2	X	X	X
M on L2		X	X
Civil L5			X

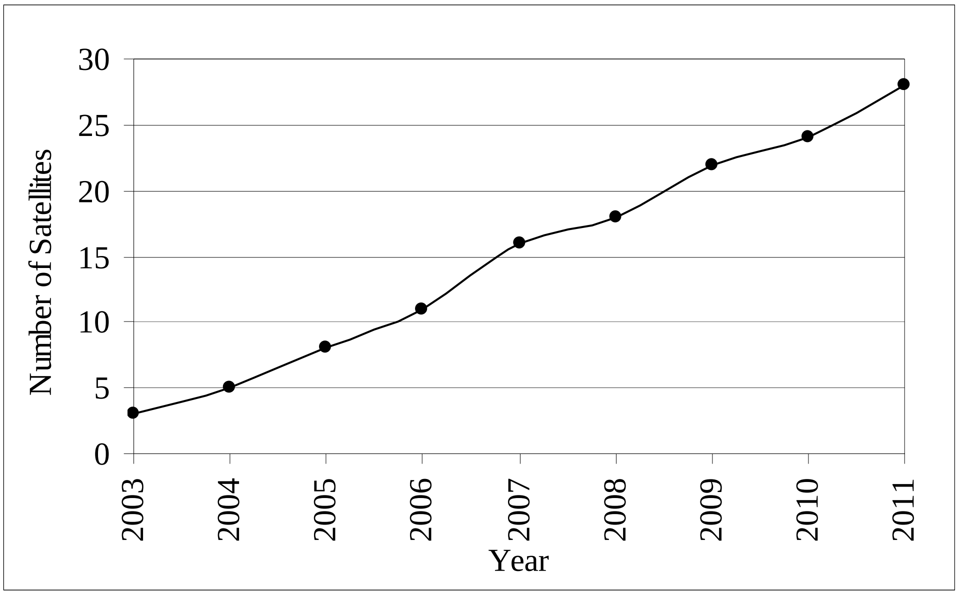

Figure 1
Planned L2C Availability Schedule

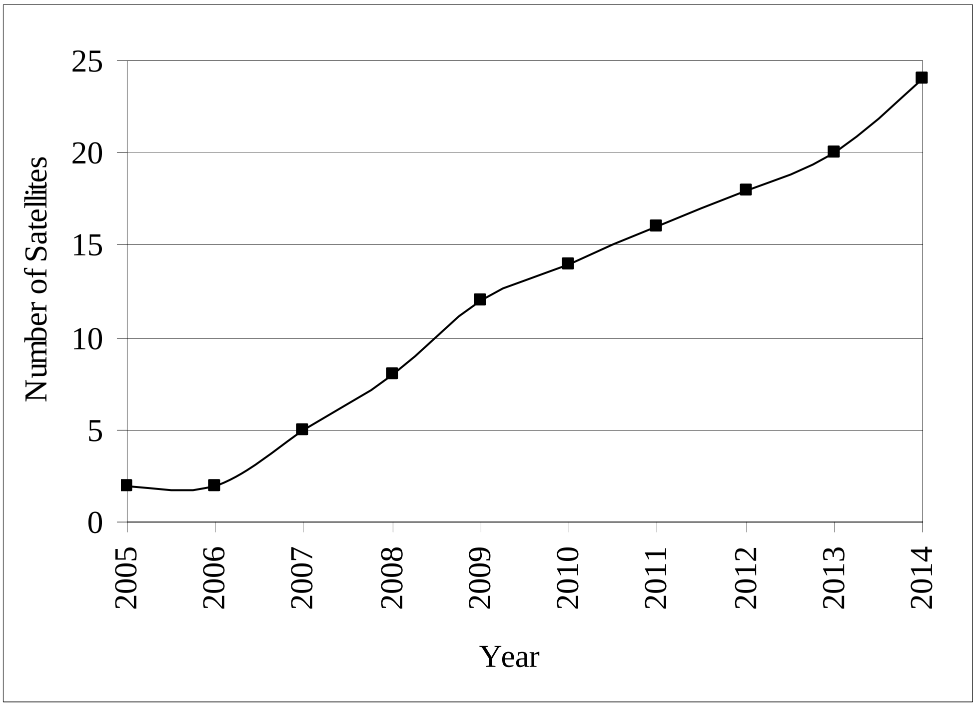

Figure 2
Estimated L5 Availability Schedule

3.3 Improvements of GPS satellites

The current GPS operation plan carries the constellation through approximately the year 2010, considering the use of 12 Block IIF satellites. To fulfill military and civilian requirements, the IGEB recommends the development of a new generation of satellites that is called Block III. In 2000, the U.S. DoD initiated a study that examines candidate acquisition and architectural concepts satisfying system requirements [8]. A crucial element of Block III satellites, from a military perspective, is the need for a higher power M code to improve resistance to intentional and unintentional signal interference. Optimized costs, high performance, risk, and technology insertion are the main elements of the undergoing development plan of Block III satellites [1].

3.4 Improvements of GPS control segment

Updating the control segment is another essential element in the GPS modernization program. Several improvements are currently being carried out to enhance the capabilities of satellite monitoring and to increase the positioning accuracy of both military and civilian services. Some of the improvement procedures are [8]:

- Upgrading the monitoring stations and ground facilities.
- Replacing existing mainframe computers with high-technology ones.
- Establishing an alternate master control station.
- Implementing new more-robust mathematical techniques for computing satellites' orbits and clock errors.
- Incorporating data from other monitor stations operated by the National Imagery and Mapping Agency, known as NIMA, to increase the accuracy of computed orbits and clock parameters.

4. Overall merits of the modernization program

The overall plan of GPS modernization intends to enhance the system performance to meet the technology requirements in 21st century. Military and civil GPS users will attain a lot of advantages. Turning off the selective availability (SA) in 2000 afforded GPS civil users accuracy of 22 meters (compared with accuracy of 100 meters under SA). With the absence of SA, the next largest error source is the signal delay caused by the Earth's atmosphere. Having a second and a third civilian code (L2C and L5) will enable the GPS civilian users to correct the ionospheric error by forming a linear combination of pseudorange measurements. This will be reflected in more accuracy in real time situation such as aircraft approaching and landing. The L2C signal will achieve more reliable and accurate positioning and navigation even in wooded areas.

The new structural design of L5 offers more robust carrier phase tracking and provides grater accuracy even in the presence of noise and multipath. The underway modernization of the control segment is expected to reduce ephemeris and clock error by approximately 50% [8]. Additionally, the new Block III satellites will improve the resistance of signal interference. The GPS modernization components will increase the horizontal accuracy estimate to be 6 meters or better for standalone GPS receivers. The modernization program will make GPS an even more powerful utility, serving the needs of civilian users well into 21st century.

5. Impacts of GPS modernization on surveying and mapping

With the GPS modernization program, the surveying and mapping applications will enter a new era. Several GPS-based 'traditional' problems and situations that faced the surveying community in the last quarter of the twentieth century will no longer exist. Even more, GPS will be efficiently utilized in new applications. The 6-meter accuracy level for non-differential (standalone) mode will make Geographic Information System (GIS) data collection less expensive and more reliable by only using hand-held cheap code receivers. The same is true for image rectification process of remote-sensing images with pixels size of five meters or larger. For static survey applications, centimeter-level accuracies will be achievable more quickly and cost effectively than is possible today. This is obtained through the existence of three frequency wide lanes (L1-L5, L1-L2, and L2-L5) to resolve integer ambiguities and making precise carrier phase measurements. Since the position accuracy is the most-crucial demand from the geodetic and mapping community, it was an objective of the modernization strategy to afford high-level of accuracy for this sector of users. Table 2 presents some estimates of the anticipated accuracy for survey applications [3]. Current civil GPS users will be able to operate at the same, or better, levels of performance that they enjoy today. It should be mentioned that in order to benefit from the advantages of the GPS modernization plan, the user have to pay non-direct use costs. Updating current hardware (receivers and software), or even purchasing new ones, will be a must to cope with the modernized components of GPS technology in 21st century.

Table 2
Anticipated achievable accuracy for survey applications
(centimeters)

Task	Absolute Accuracy		Relative Accuracy		
	Horizontal	Vertical	Horizontal	Vertical	Remarks
Static Survey	30	50	1.0	2.0	0-25 Km 30 min
Geodetic Survey	10	20	1.0	2.0	0-6000 Km 4 hours
Rapid Survey	30	50	2.0	5.0	0-20 Km 5 min
On-The-Fly Kinematic Survey	30	50	2.0	5.0	0-20 Km Real Time

6. Conclusions

Since the development of GPS technology in the early 1970s, its basic structural characteristics have not been changed significantly. A fifteen-year modernization plan is currently underway to make GPS cope with the requirements of technologies in the 21^{st} century. In 2000, the SA error source was turned off affording standalone position accuracy of 22 meters horizontal and 33 meters vertical. The modernization program includes transmitting two new civil codes: L2C and L5. L2C is a modified C/A code transmitted on the L2 frequency by the modernized block IIR satellites starting 2003. L5 will be transmitted on a new frequency of 1176.45 MHZ by Block IIF satellites as early as 2005. Additionally, a modern generation of GPS satellites, called Block III, is currently under development. Updating the control segment is another essential element in the GPS modernization program.

Through the GPS modernization program, the surveying and mapping applications will enter a new era. The expected 6-meter accuracy level for non-differential mode will make GIS and remote sensing data collection more cost-effective and more reliable. For static survey applications, centimeter-level accuracies will be achievable more quickly and cost effectively than is possible today. Even though current geodetic and surveying GPS users will be able to operate at the same, or better, levels of performance, they have to pay non-direct use costs in order to benefit from the advantages of the GPS modernization plan. Updating existing hardware (receivers and software), or even purchasing new ones, will be a must to cope with the modernized components of GPS technology in 21^{st} century.

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