GPS-SINGLE POINT POSITIONING WITHOUT SELECTIVE AVAILABILITY

Dr. Reha Metin ALKAN

Department of Geodesy and Photogrammetry Eng.,
Istanbul Technical University, Turkey.

Abstract

The Global Positioning System (*GPS*) is widely used for civilian navigation, positioning, surveying and scientific applications. If coordinate determination procedure is performed with single *GPS* receiver, single point positioning procedure has to be taken into account. However, Selective Availability (*SA*) is the main reason for reduction of the accuracy of single point positioning. It may be varied at times within the design specifications. This degradation affects either the satellite positions broadcast by the *GPS* satellites (the broadcast ephemerides) or the timing used to determine the satellite-receiver distance (which in turn is used to determine the receiver's position). Prior to midnight May 1, 2000 the *GPS* specifications stated that under conditions of *SA* a single horizontal *GPS* positioning had had an uncertainty of 100 meters at 95% confidence level. However, at midnight May 1, 2000, the United States Government was set the *SA* to zero. So the pinpoint positioning accuracy is incredibly increased up to order of between 15 to 25 meters. In this study, first, how the navigation coordinates are varied without *SA* in time is examined and second, what the *GPS* without *SA* gain to *GPS* users in addition to the opportunities already in use and what kind of new user profiles this development provided is searched. At the end, the reflection of this development onto the marine applications is also handled.

1. Introduction

GPS is a satellite based navigation system developed by the United States Department of Defense (DoD). Because of the advantages such as being independent of weather conditions, having no requirement of surveying points seeing each other, being able to manage surveying during the night, and having availability of using both offshore and inshore surveying, this satellite based method is densely used for civilian 3D positioning for surveying and scientific applications. There are two types of service in GPS available for civil and military users. The first service for civilian users is called Standard Positioning Service (*SPS*) and the second service for only authorized users is called Precise Positioning Service (*PPS*). The main difference of these services is their navigation accuracy because of the some limitations, which are Anti Spoofing (*AS*) and Selective Availability (*SA*). The *SA* was the deliberate degradation by the US Defense Department of the *GPS* signal through both the predicted ephemeris and the timing. *SA* is one of the most important error source in GPS and when it is activated, it causes error in positioning up to 100 meters. The former President Clinton announced that the US Government has stopped the intentional degradation of the *GPS* signals a few minutes past midnight EDT after the end of May 1, 2000. In other words, after this time, the *SA* was set to zero. In this way, the accuracy of the single point positioning is reduced from 100 meters to 15-25 meters (Divis, 2000). Removal of the *SA* not only enhances the performance of single point positioning but also expands the application area of single *GPS* receivers in addition to already in use.

In this study, first, how the navigation coordinates are varied without *SA* in time is examined. For this purpose, some measurements are realized on the geodetic control point which is established and coordinated previously on the University roof with an inexpensive hand-held *GPS* receiver. At the end, how the stand-alone *GPS* receivers in their present form expands the usage areas of the hydrographic surveying which are already in use in the low accuracy required measurements is searched.

2. A Brief Review of GPS Measurement

The satellite based positioning had been performed with *TRANSIT* system before the *GPS* was developed. This earlier system had two major shortcomings: the large time gaps in coverage and relatively low navigation accuracy. *GPS* was developed to replace the *TRANSIT* system for to overcome these drawbacks (Hofmann-Wellenhof *et al.*, 1992). Today, *GPS* provides continuous 24 hours a day and 365 days a year 3-Dimensional positioning whether real-time or post-processing at any location all over the world.

GPS is based on the pseudorange measurements. Pseudorange is a distance between the satellite and the receiver. Any person anywhere on the earth could determine his own 3D position which is expressed by ellipsoidal latitude, longitude and height (or cartesian coordinates). This procedure is accomplished by the simple resection process using the distance measured to satellites. The receiver clock is not synchronized with the satellite clock. This synchronization is the reason for the term pseudorange (Seeber, 1993). So, at least four satellites have to be observed at the same time to determine the 3D position (Figure 1).

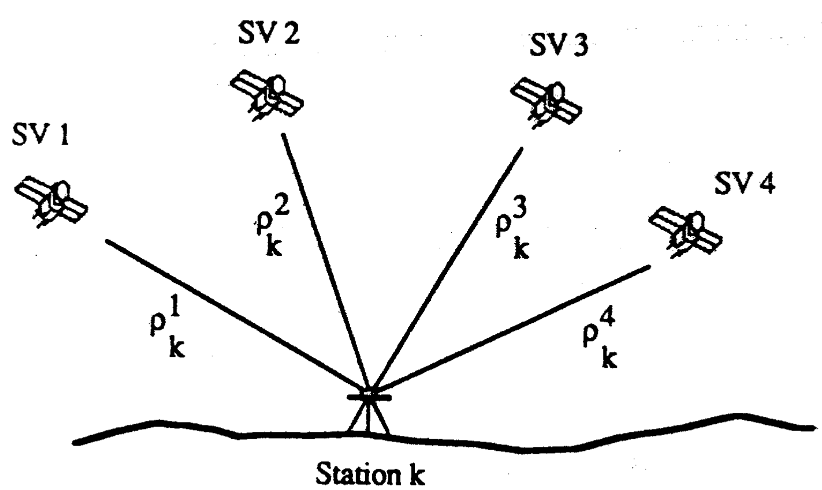

Fig. 1. Single Point Positioning

The pseudorange is measured via code and/or carrier phase. Meter level accuracy can be performed by the code ranges whereas millimeter level accuracy by the carrier phases (Leick, 1995). *GPS* error sources are summarized in the Table 1 (Holloway, 1997).

Table 1. *GPS* Error Source and their Magnitudes

Error Source	**Stand-alone GPS (m)**	**DGPS (m)**
Satellite Clocks	3.0	0.0
Orbit Errors	2.7	0.0
Ionosphere	8.2	0.4
Troposphere	1.8	0.2
Receiver Noise	0.3	0.3
Multipath	0.6	0.6
SA (now not active)	30.0	0.0
User Equivalent Range Error	± 31.4 (SA on) ± 9.4 (SA off)	± 0.9

It is clearly seen from the Table 1 that, *SA* was one of the major error source in the total user equivalent errors before May 2000. *SA* occurs when the *DoD* intentionally degrades the accuracy of *GPS* signals by introducing artificial clock and ephemeris errors, and when it is turned on its' effect reaches up to 100 meters in absolute positioning.

SA was first introduced in March 1990. It was disabled again in August 2, 1990 due to the Gulf Crisis. It became effective again in July 1991. Finally former President Clinton announced that the US government has stopped the *SA* at midnight May 1, 2000 (White House Web Site, 2000). The White House press announcement is given in Appendix-II. As part of the 1996 Presidential Decision Directive goals for *GPS*, former President Clinton committed to continuing the use of *SA* by 2006. Thus, *SA* is removed from *GPS* signals six years earlier than originally planned (Trimble Web Site, 2001). From now on, civilian users of *GPS* will be able to pinpoint locations up to ten times more accurately then they did before. It should be keep into mind that, *GPS* satellites are capable to turned back on as quickly as it was turned off. *GPS* users could obtain their position with an accuracy of approximately 15-25 meters with an inexpensive C/A code receiver in real time (Divis, 2000). On the other hand, if any user require better than 20 meter accuracy, he still need to use Differential *GPS* (*DGPS*) or Wide Area Differential *GPS* (*WADGPS*) corrections to remove the longer term errors in the system such as orbit and satellite clock errors, atmospheric and receiver noise.

3. Single Point Positioning without SA; Hydrographic Applications Perspective

Nowadays, *GPS* technique can be used in a wide array of application areas for conventional terrestrial and hydrographic surveying. Position accuracies obtained from *GPS* method are summarized in Table 2.

Table 2. General Positioning Accuracy of *GPS* Technique

Application Technique	Limitation	Observation Time	Accuracy
Point Positioning and Navigation	Everywhere	Seconds	±(15-25) m
DGPS or WADGPS	100s km	Seconds	±(0.5-10) m
Static Differential	About 100 km	Hours	±[5 mm $+ (1\, ppm * baseline)$]
True Kinematic	About 20 km	Seconds (after initialization)	±[10 mm $+ (1\, ppm * baseline)$]

Positioning at sea is an essential operation for various marine activities. Some of the possible applications are summarized in the Figure 2 (Nakiboglu, 1993).

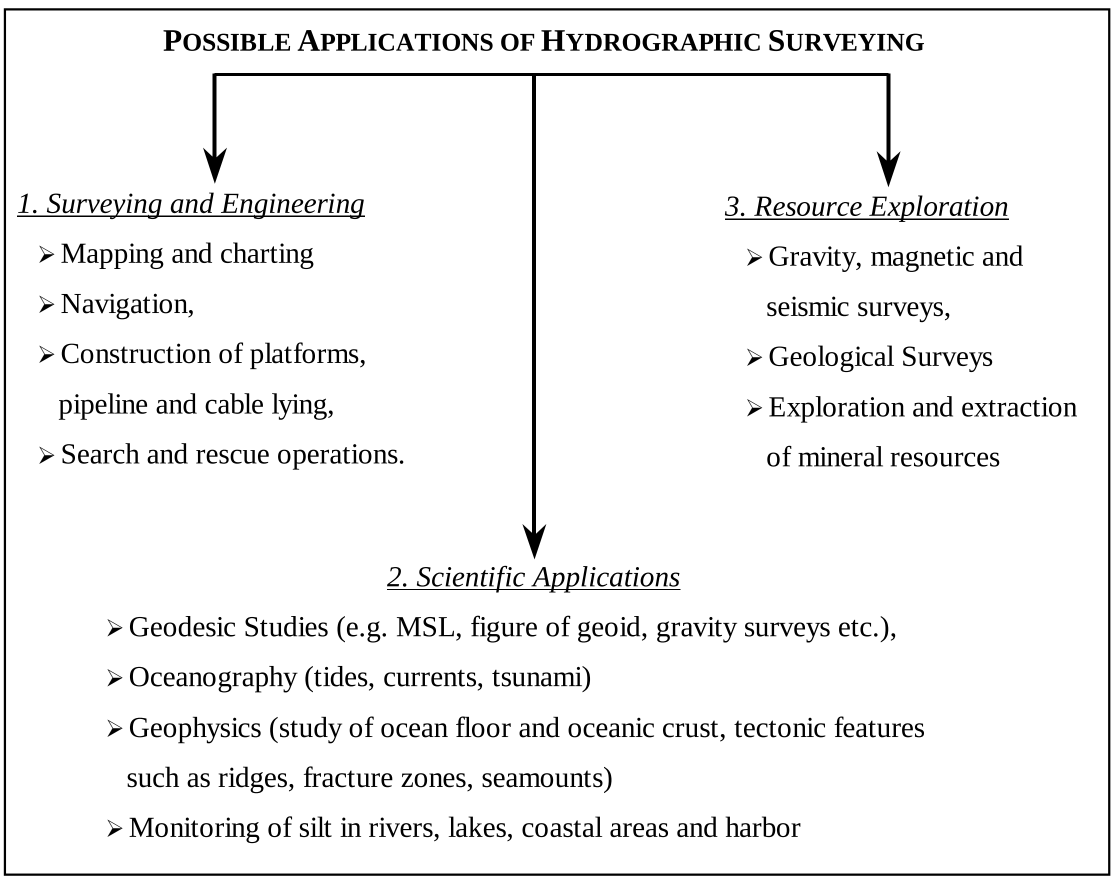

Fig. 2. Hydrographic Surveying Application Scopes

Each application requires different position accuracy. For example, 1 to 5 km accuracy might be sufficient for the navigation in open waters whereas it is necessary to reach up to 0.1 to 10 meter accuracy for shallow water hydrographic surveying. The characteristic factors are no doubt the working scale and aim of the study. The hydrographic applications may be categorized with respect to accuracy requirements as *Low Accuracy*, *Medium Accuracy* and *High Accuracy*. The first one requires ±100 m in position. The second one requires ±(1 to 10) m in position and the accuracy required for the last one is ±0.1 m in position (Seeber, 1993). Some application examples are listed below;

a-) Low Accuracy Marine Positioning: Navigation in open waters, oceanographic research, small-scale gravimetric and magnetic charting studies.

b-) Medium Accuracy Marine Positioning: Precise 3D seismic surveys, navigation in coastal areas, hydrographic surveying, calibration of transponder systems, positioning of underwater sensors and samplers in marine prospecting for mineral resources, continental shelf and territorial boundaries, installation of drilling sites and offshore structure.

c-) High Accuracy Marine Positioning: Precise hydrographic surveying, monitoring of silt in rivers, lakes, coastal areas and harbor, real-time dredge guidance and control, marine geodynamics.

Some exact accuracy criteria for the mentioned samples above are given in the Table 3.

Table 3. Expected Accuracy for Hydrographic Positioning

Possible Application Area	**Accuracy**
Geodynamics Research for Ocean Floor Motion and Deformation Studies	< ±0.1 m
Large Scale Hydrographic Charting Surveying	±(0.3-1) m
Sea Floor Control Points	±1 m
Drilling Holes	±(3-5) m
Marine Cadastre	±5 m
Pipelines	±(1-8) m
Continental Shelf and Territorial Boundaries	±(1-10) m
Marine Mining	±10 m
Oil and Gas	±(10-20) m
Oceanographic and Geophysical Studies	±(50-100) m

On the other side, there are other accuracy standards which are described by the International Hydrographic Organisation (*IHO*). The third edition of the *IHO* accuracy standards specified that soundings should be coordinated, relative to shore control, within a circle of radius 1.5 mm at the scale of the survey (Mills, 1998). The current 'minimum standards for positioning' described by *IHO* is given in Table 4 (IHO, 1997).

Table 4. Summary of Minimum Horizontal Accuracy Standards for Hydrographic Surveys Described by IHO (with 95% Confidence Level)

	Examples of Typical Areas	***Accuracy***
Order-1	Critical channels, berthing areas,	± 2 m
Order-2	Navigation channels, recommended tracks, harbours and harbour approaches (depth<100 m),	± 5 m
Order-3	Coastal areas not described in Order-1 or 2, or areas up to 200 m water depth,	± 20 m
Order-4	Offshore areas not described in Order 1, 2 or 3.	± 150 m

4. Civilian Benefits of Discontinuing SA

Today, *GPS* systems not only used in scientific, professional application areas but also in a lot of other civilian applications such as air, land, marine, railway vehicles navigation, telecommunications, mining, agriculture, outdoor sports activities. Therefore, *GPS* users are increasing enormously all over the world. Some examples of "what gain any civilian users in his live with *GPS* without *SA*?" are given below (IGEB Web Page, 2001).

Vehicles equipped with *GPS* system will be able to transmit their location to the monitoring center more accurately. Companies managing fleets of vehicles such as taxicabs, buses, commercial trucks, and rental cars will enjoy increases in efficiency as their ability to track and route individual vehicles improves. Transportation or courier services will benefit from better real-time tracking and management of assets. Any vehicle will be able to identify on which side of the road it is. When any vehicle such as car, truck is stolen, it will be easy find out where it is (of course if it has a *GPS* receiver and it is registered to any vessel monitoring system). If any car breaks down, driver will be able to tell the tow truck where he is. It might be very important in some cases if the road is divided by a barrier or a concrete divider.

Firemen, policemen, ambulance drivers etc., now will determine their position with higher accuracy according to the destination. In fact, in such life-threatening situations, every second is important. *GPS* with present status will become a more powerful and helpful for rescue teams which search for individuals lost at sea, on mountains or ski slopes, in deserts and in wilderness environment. The list of improvements for *SPS* users goes on and on.

5. Trial Measurement

To determine the effect of *SA* on the single point positioning, some measurements were realized on a geodetic point which is established on our University roof with an inexpensive hand-held GPS receiver. Measurements were performed by Garmin *e*Map hand-held *GPS* receiver on 25 February, 2001(GPS Day 56). While the real-time surveying, ellipsoidal latitude, longitude and heights are recorded at every 10 minutes between 11:00 am and 19:00 pm (*UTC*+2h). The collected coordinates are compared with known coordinates. The differences (instantaneous errors) are given in Figure 3.

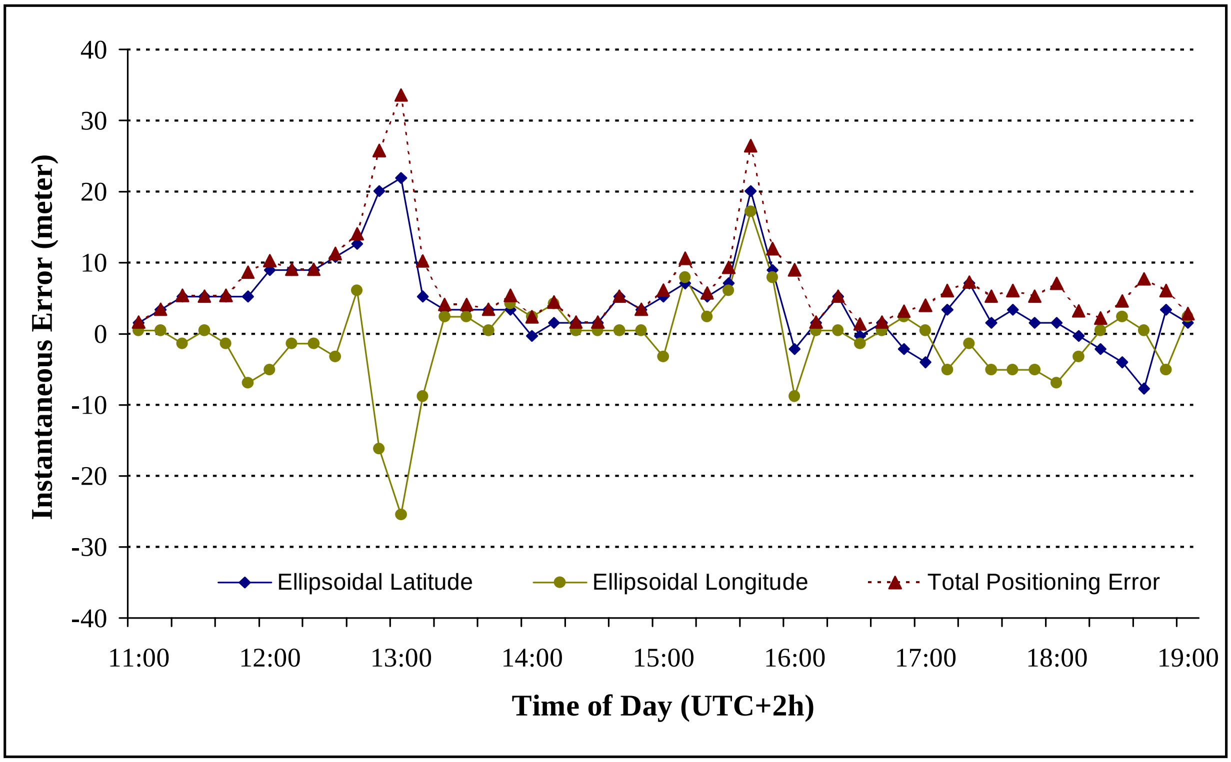

Fig. 3. Differences for Ellipsoidal Latitude and Longitude Collected by Hand-held Receiver

As a result of the application, 86% of the recorded data without *SA* reach the accuracy of under 10 meter level. The accuracy of 8% of the recorded data range between 10 and 20 meters. Finally, only 6% of the recorded data varies from their known value more than 20-meter.

6. Conclusions and Suggestions

The result of this study shows that, the positioning could be done about to ten times more accurately then we do until May 2000 with single *GPS* code receivers. It could be said that, removal of *SA* not only enhanced the performance of *GPS SPS* but also expand the application area of a single *GPS* receivers. Furthermore, it creates some new application areas which have not been used until midnight May 1, 2000.

From the point of view of hydrographic surveying, single *GPS* positioning without *SA* now well enough some of the marine applications which are sampled previous section. For example, the current accuracy is sufficient for the '*Low Accuracy Marine Positioning*' applications. In the aspects of the *IHO* standards, it can be said that reducing the positioning error from 100 meters to 20 meters or better will make the single *GPS* receivers well enough for the '*Order-3*' and '*Order-4*' applications.

In some cases, usage of an augmentation system such as *DGPS* or *WADGPS* methods should be unavoidable for the more higher accuracy required applications. In generally, if *GPS* user require better than 15-20 meter accuracy, he should continue to use augmentation systems. Turning off the *SA* would reduce the need for augmentation systems in some applications. However, especially for the high accuracy marine positioning, neither *GPS* without *SA* nor *WADGPS* and/or *DGPS* do not respond the requirement. In this case, only carrier phase measurements should provide such accuracy.

Appendix I. References

Divis, D.A. (2000). SA: Going the Way of the Dinosaur. *GPS World*, **11**(6).

Hofman-Wellenhof, B., Lichtenegger, H. and Collins, J. (1992). *GPS Theory and Practice*, Springer-Verlag.

Holloway, R. (1997). An Australia Wide, Real-time DGPS System. *Geomatic Info Magazine*, **11**(2).

IHO. (1997). *IHO Standards for Hydrographic Surveys*, Special Publication, No:44, 4th Ed., Monaco.

Leick, A. (1995). *GPS Satellite Surveying*. A Wiley-Interscience Publication, Second Edition; USA.

Mills, G. (1998). International Hydrographic Survey Standards, *International Hydrographic Review*, Monaco, **LXXV**(2), pp. 79-85.

Nakiboglu, M. S. (1993). *Hydrographic Surveying*, Unpublished Lecture Notes, King Saud University, Riyadh, Saudi Arabia.

Seeber, G. (1993). *Satellite Geodesy, Foundations, Methods, and Applications*. Berlin, New York: de Gruyter.

President Ends Intentional Degradation of GPS. The Interagency GPS Executive Board (IGEB).
24 February 2001 <http://www.igeb.gov>

The White House Office of the Press Secretary Announscment. The White House.
24 October 2000 <http://www.whitehouse.gov>

U.S. Government Turns Off Selective Availability. Trimble Navigation Limited. 24 February 2001 <http://www.trimble.com>

Appendix II. White House Press Announcement (http://www.whitehouse.gov)

THE WHITE HOUSE
Office of the Press Secretary

For Immediate Release May 1, 2000

STATEMENT BY THE PRESIDENT REGARDING THE UNITED STATES' DECISION TO STOP DEGRADING GLOBAL POSITIONING SYSTEM ACCURACY

Today, I am pleased to announce that the United States will stop the intentional degradation of the Global Positioning System (GPS) signals available to the public beginning at midnight tonight. We call this degradation feature Selective Availability (SA). This will mean that civilian users of GPS will be able to pinpoint locations up to ten times more accurately than they do now. GPS is a dual-use, satellite-based system that provides accurate location and timing data to users worldwide. My March 1996 Presidential Decision Directive included in the goals for GPS to: "encourage acceptance and integration of GPS into peaceful civil, commercial and scientific applications worldwide; and to encourage private sector investment in and use of U.S. GPS technologies and services." To meet these goals, I committed the U.S. to discontinuing the use of SA by 2006 with an annual assessment of its continued use beginning this year.

The decision to discontinue SA is the latest measure in an on-going effort to make GPS more responsive to civil and commercial users worldwide. Last year, Vice President Gore announced our plans to modernize GPS by adding two new civilian signals to enhance the civil and commercial service. This initiative is on-track and the budget further advances modernization by incorporating some of the new features on up to 18 additional satellites that are already awaiting launch or are in production. We will continue to provide all of these capabilities to worldwide users free of charge.

My decision to discontinue SA was based upon a recommendation by the Secretary of Defense in coordination with the Departments of State, Transportation, Commerce, the Director of Central Intelligence, and other Executive Branch Departments and Agencies. They realized that worldwide *transportation safety, scientific, and commercial interests could best be served by discontinuation of SA. Along with our commitment to enhance GPS for peaceful applications, my administration is committed to preserving fully the military utility of GPS. The decision to discontinue SA is coupled with our continuing efforts to upgrade the military utility of our systems that use GPS, and is supported by threat assessments which conclude that setting SA to zero at this time would have minimal impact on national security. Additionally, we have demonstrated the capability to selectively deny GPS signals on a regional basis when our national security is threatened. This regional approach to denying navigation services is consistent with the 1996 plan to discontinue the degradation of civil and commercial GPS service globally through the SA technique.*

Originally developed by the Department of Defense as a military system, GPS has become a global utility. It benefits users around the world in many different applications, including air, road, marine, and rail navigation, telecommunications, emergency response, oil exploration, mining, and many more. Civilian users will realize a dramatic improvement in GPS accuracy with the discontinuation of SA. For example, emergency teams responding to a cry for help can now determine what side of the highway they must respond to, thereby saving precious minutes. This increase in accuracy will allow new GPS applications to emerge and continue to enhance the lives of people around the world.