Advancement in GPS Technology and Application

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Abstract

GPS (Global Positioning System) is a passive, all-weather satellite-based navigation and positioning system, which is designed to provide precise three dimensional position and velocity, as well as time information on a continuous worldwide basis. At present times, GPS is the most widely used positioning and navigation system in the world. It is due to many advancements in GPS technology and application. This paper will describe a few advancements, i.e. GPS modernization program, GPS augmentation and widening of GPS application spectrum.

1. Introduction

The Global Positioning System (GPS) is a USA satellite-based navigation and positioning system that provides reliable positioning, navigation, and timing services on a continuous worldwide basis and freely available to all [1]. It is a weather independent system, and can be used by many peoples at the same time, day and night, and anywhere in the world.

The GPS is made up of three segments (see Figure 1): space segment, control segment and user segment.

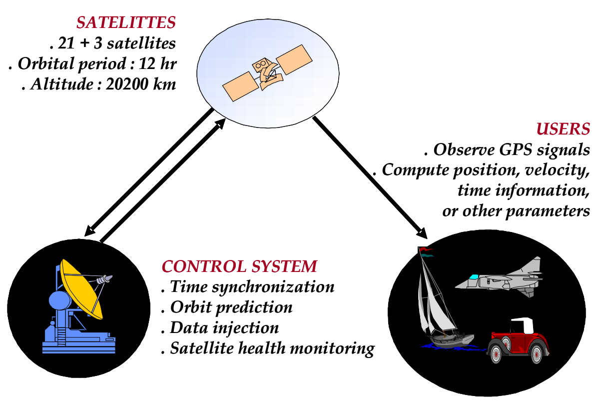

Figure 1. GPS Segments

The space segment consists of a nominal constellation of 24 operating satellites (see Figure 2) that transmit one-way signals that give the current information on GPS satellite position, time and its distance from the user. The first GPS satellite (Block I) was launched in 1978. The current GPS constellation (Feb. 2007) consists of 30 satellites: 16 Block II/IIA, 12 Block IIR and 2 Block IIR-M satellites [2].

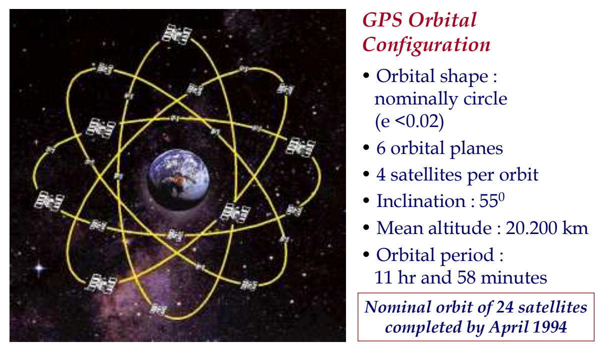

Figure 2. GPS orbital constellation

The control segment consists of worldwide monitor and control stations that maintain the satellites in their proper orbits through occasional command maneuvers, and adjust the satellite clocks. It tracks the GPS satellites, uploads updated navigational data, and maintains health and status of the satellite constellation [1].

The user segment consists of the GPS receiver equipment, which receives the signals from the GPS satellites. By observing the signals from enough number of satellites, the user can derive its position and velocity, obtain precise time information, and can also estimate other derivative parameters. In principle, GPS receivers can be categorized into three positioning types: navigation, mapping and geodetic type receiver; and also a timing receiver (see Figure 3).

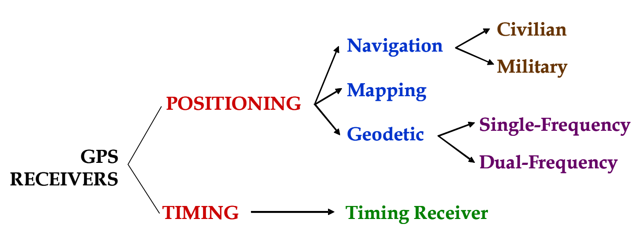

Figure 3. Classification of GPS receivers.

Nowadays, besides its military applications GPS has been used in many civilian applications such as: surveying and mapping in land and sea, construction and mining, geodynamics, and deformation studies, navigation and transportation (land, air, sea), tropospheric and ionospheric studies, cadastral survey, agriculture, forestry, photogrammetry and remote sensing, GIS (Geographic Information System), oceanographic studies (current, wave, tides), and also sport and recreative applications [3].

At present times, GPS is the most widely used positioning and navigation system in the world. It is due to many advancements in GPS technology and application. This paper will describe a few advancements, i.e. GPS modernization program, GPS augmentation and widening of GPS application spectrum.

2. GPS Modernization Program

The United States is committed to an extensive modernization program of GPS. In general, GPS modernization goals are: system-wide improvements in: accuracy, availability, integrity, and reliability; robustness against interference; improved indoor, mobile, and urban use; interoperability with other GNSS constellations; and backward compatibility [4].

Modernization on the space segment is performed by improving the Block II satellites into Block IIF and then Block III (see Figure 4); including the implementation of a second and a third civil signal on GPS satellites [1]. The second civil signal will improve the accuracy of the civilian service and supports some safety-of-life applications; and the third signal will further enhance civilian capability and is primarily designed for safety-of-life applications, such as aviation.

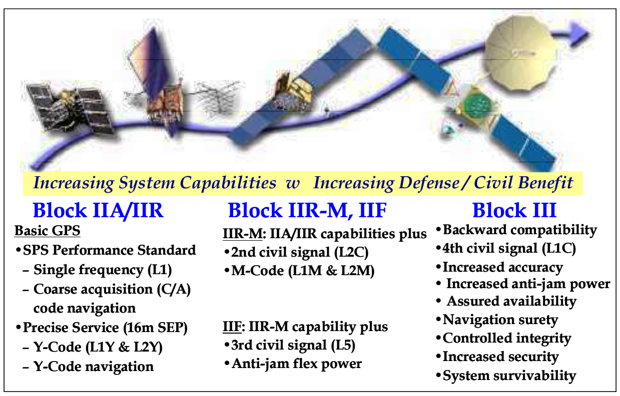

Figure 4. GPS modernization path [5].

For civil users, new signals provide: more robustness against interference, compensation for ionospheric delays, and widelaning/trilaning scheme for resolving integer ambiguities caused by cycle slips during precise carrier phase measurements. While for military users, new spectrally separated signals provide: protection of friendly use, prevention of adversary exploitation, and preservation of civil use outside area of operations. In general for both civil/military, system improvements in accuracy, availability, integrity, and reliability can be achieved.

Modernization on the control segment is conducted by enhancing the new master control station with: improved operator interfaces, IIR-M and IIF capabilities, integrated mission operations support center, and launch and early orbit anomaly resolution and disposal operations (LADO). Fully mission capable alternate master control station will also be realized. Legacy accuracy improvement initiative will be achieved by: additional information from National Geospatial-Intelligence Agency sites; doubles amount of data being used for signal integrity and constellation performance monitoring; and doubles amount of data used for satellite time and position estimation, resulting in more accurate satellite orbital position and clock data available to users [5]. In this context of GPS modernization scheme, the constellation of monitoring stations will be enhanced from 6 stations at present to at least 17 stations as shown in Figure 5.

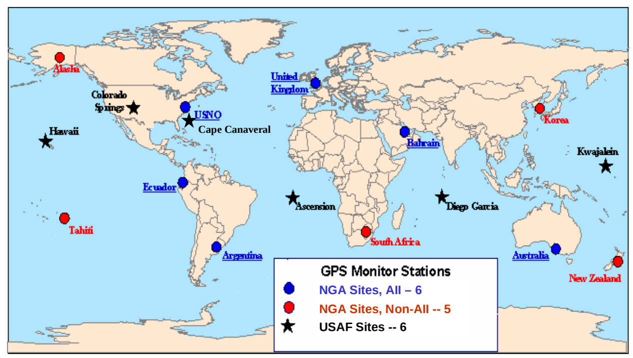

Figure 5. Future GPS Monitoring Stations [5].

3. GPS Augmentations

Although the accuracy provided by GPS is relatively high, its system integrity is relatively low. To increase its system reliability, GPS should be augmented with other external systems and a reliable integrity monitoring method. Moreover, GPS also can not be used in the places where GPS signal can not reach the antenna, as indoor, inside the tunnel, or underneath the water. To overcome this problem, GPS has to be augmented or assisted with other external systems.

To meet the specific user requirements for positioning, navigation, and timing (PNT), a number of augmentations to the Global Positioning System (GPS) are available. An augmentation is any system that aids GPS by providing accuracy, integrity, reliability, availability, or any other improvement to positioning, navigation, and timing that is not inherently part of GPS itself. Such augmentations include, but are not limited to [1]:

a. *Nationwide Differential GPS System (NDGPS):* The NDGPS is a ground-based augmentation system operated and maintained by usually the national agency, with the aim to provide increased accuracy and integrity of the GPS to users on land and water. NDGPS is built to international standards, and over 50 countries around the world have implemented similar systems. In this case, Indonesia has not yet established NDGPS.

b. Wide Area Augmentation System (WAAS): The WAAS, is a satellite-based augmentation system operated usually by the national aviation agency, to assist aircraft navigation for all phases of flight. Today, these capabilities are broadly used in other applications because their GPS-like signals can be processed by simple receivers without additional equipment. Besides the U.S. WASS, other ICAO (International Civil Aviation Organization) standard space-based augmentation systems include: Europe's European Geostationary Navigation Overlay System (EGNOS), India's GPS and Geo-Augmented Navigation System (GAGAN), and Japan's Multifunction Transport Satellite (MTSAT) Satellite Augmentation System (MSAS). All of these international implementations are based on GPS. In this case, Indonesia has not yet established its own WAAS.

c. Continuously Operating Reference Station (CORS): The CORS network archives and distributes GPS data for precision positioning and atmospheric modeling applications mainly through post-processing. CORS is being modernized to support real-time users. In Indonesia, there are partial CORS already established by BAKOSURTANAL and LIPI mainly to serve geodetic and geodynamics applications [6; 7].

d. Global Differential GPS (GDGPS): GDGPS is a high accuracy GPS augmentation system, developed by the Jet Propulsion Laboratory (JPL) to support the real-time positioning, timing, and orbit determination requirements of the U.S. National Aeronautics and Space Administration (NASA) science missions. Future NASA plans include using the Tracking and Data Relay Satellite System (TDRSS) to disseminate via satellite a real-time differential correction message. This system is referred to as the TDRSS Augmentation Service Satellites (TASS).

e. *International GNSS Service (IGS):* IGS is a network of over 350 GPS monitoring stations from 200 contributing organizations in 80 countries [8]. Its mission is to provide the highest quality data and products as the standard for Global Navigation Satellite Systems (GNSS) in support of Earth science research, multidisciplinary applications, and education, as well as to facilitate other applications benefiting society. Approximately 100 IGS stations transmit their tracking data within one hour of collection.

It should be noted that there are other augmentation systems available worldwide, both government and commercial. These systems use differential, static, or real-time techniques.

4. Widening Spectrum of GPS Applications

Nowadays, GPS applications have rapidly flourished from standard positioning, surveying and mapping applications to various more innovative commercial applications (see Figure 6). GPS has been extensively used in various land, marine, air and space applications.

Figure 6. Examples of GPS applications [9].

According to [1], GPS has become a mainstay of transportation systems worldwide, providing navigation for aviation, ground, and maritime operations. Disaster relief and emergency services depend upon GPS for location and timing capabilities in their life-saving missions. Everyday activities such as banking, mobile phone operations, and even the control of power grids, are facilitated by the accurate timing provided by GPS. Farmers, surveyors, geologists and countless others perform their work more efficiently, safely, economically, and accurately using the free and open GPS signals.

By combining GPS with the pseudolites, GPS can also be used for indoor positioning and therefore open new innovative GPS indoor applications [10]. Figure 7 shows an example of indoor and outdoor positioning using combination of GPS and Locata Lites (kind of pseudolites). Several other sensors can also assist GPS for indoor positioning.

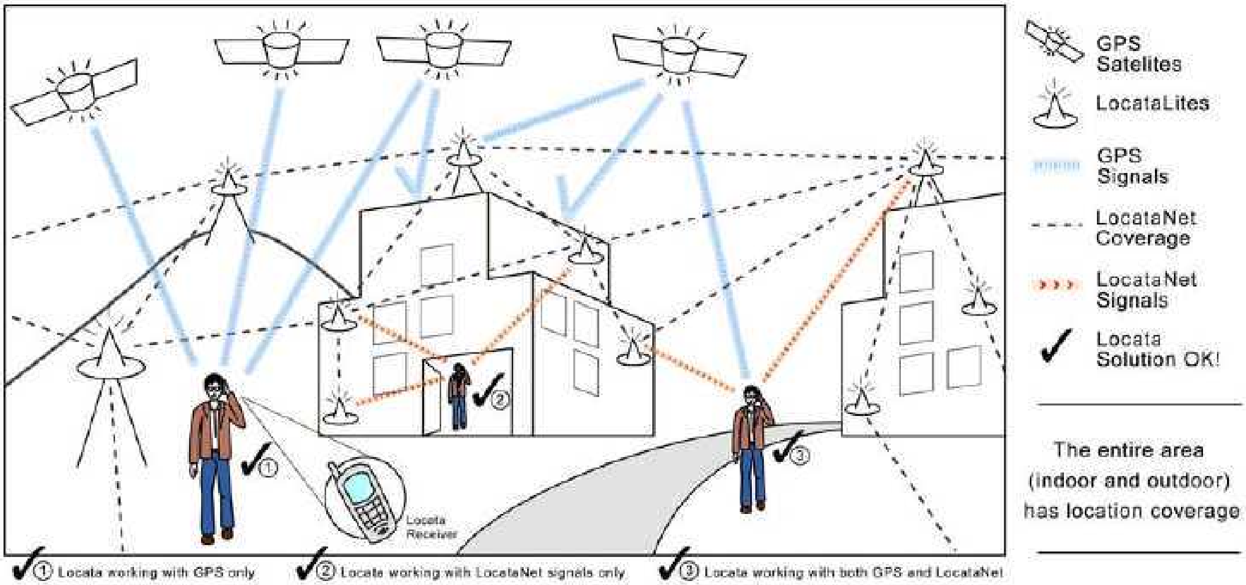

Figure7. Enhancing indoor capability of GPS positioning using Locata Lites [10].

5. GPS Applications in Indonesia

GPS is started to be used in Indonesia at the end of 1980s especially for surveying and mapping related purposes. Afterward the applications are started to increase encompassing various fields of application, from scientific to recreation and sport. Table 1 shows the example of growing GPS applications in Indonesia.

Table 1. Status of some GPS applications in Indonesia

No	Type of Activity	Status and involved Agencies and Sectors
1	Establishment of geodetic control network.	Conducted and continuing (BAKOSURTANAL)
2	Establishment of cadastral control network.	Conducted and continuing (BPN, Private)
3	Establishment of forestry control network.	Conducted and continuing (Forestry)
4	Establishment of control network for various topographic mapping.	Conducted and continuing (Public Work, Transmigration, ESDM, Private)
5	Determination and reconstruction of land parcel boundary	Conducted and continuing (BPN, Private)
6	GPS for Photogrammetry and Remote Sensing	Conducted and continuing (BAKOSURTANAL, BPN, PBB, Private)
7	Coordinating the forest boundary points.	Not yet used, planned (Forestry)
8	Positioning for various geophysical, geological and mining applications.	Conducted and continuing (ESDM, Pertamina, LEMIGAS, Private)
9	Positioning for hydro oceanographic survey and mapping	Conducted and continuing (Dishidros TNI-AL, BAKOSURTANAL, Ocean and Fishery, Private)
10	Positioning for navigation and (land, marine, air) transportation purposes	Conducted and continuing (Transportation, Army, Ocean and Fishery, BPPT, BAKOSURTANAL, ITB, Private)
11	Geodynamics study and monitoring	Conducted and continuing (BAKOSURTANAL, ITB, LIPI, Geology Agency)
12	Deformation monitoring (landslide, land subsidence, dam, bridge, oil rig etc.)	Conducted, continuing, and potential (Public Work, PLN, Pertamina, Pemda, Geology Agency, ITB, Private)
13	GPS for GIS	Conducted and continuing (BAKOSURTANAL, BPN, Forestry, KLH, BPN, PBB, ITB, Private)
14	Study and monitoring of currents, waves and offshore.	Conducted, continuing, and potential (DISHIDROS, LON-LIPI, BPPT, BAKOSURTANAL, ITB, Private)
15	GPS based volcano deformation monitoring	Conducted and continuing (DVGHM, ITB)
16	GPS Meteorology	Ongoing and potential (LAPAN, BMG, BAKOSURTANAL, ITB, Private)
17	GPS Airborne Gravimetry	Potential (BAKOSURTANAL, ESDM, Private)
18	Synchronization of electrical power plant network.	Potential (PLN)
19	Boundary determination and demarcation (district, provincial, national and international)	Conducted and continuing (BAKOSURTANAL, Dittop TNI AD, Topdam, Dishidros TNI-AL, Pemda, BPN)
20	GPS for Intelligent Transport System (ITS)	Conducted and continuing (Transportation, Private)
21	Synchronization of cellular telephone network.	Conducted and continuing (Comm. and Info, Private)

22	Establishment of the Indonesian CORS (Continuously Operating Reference Station)	Potential (BAKOSURTANAL)

6. Potential GPS Advancements in Indonesia

GPS augmentations and GPS application enhancement and diversification are two types of GPS advancements that can be conducted in Indonesia.

The Indonesian archipelago located at the junction of the Eurasia, Australia, Pacific, and Philippine Sea plates, resulting in wide spectrum topography, frequent earthquakes, and volcanism [11]. In the west, the Australia plate subducts beneath the Eurasia plate along the Java trench while to the east, the continental part to the east, the continental part of the Australia plate collides with the Banda arc and the Pacific-oceanic plate. Indonesian region is therefore prone to earthquakes, tsunamis and volcanic eruptions. Considering is rugged topography and usually heavy rainfall, landslide and flooding are also other prominent geohazards that continuously affecting Indonesia. Land subsidence moreover also affecting some large cities in Indonesia. Moreover Indonesia is a vast archipelago consisting of more than 17.000 islands and has population of more than 200 millions.

Considering the above characteristics of Indonesia, then GPS advancements in Indonesia should be better performed inline with the establishment of to the national natural hazard mitigation and transportation systems.

In order to serve the natural hazard mitigation system, Indonesia should establish the Indonesian GPS CORS (Continuously Operating Reference Station). Several GPS continuous stations that are already running in Indonesia and operated by both BAKOSURTANAL and LIPI can be a good embryo for the Indonesian CORS. BAKOSURTANAL has maintained several GPS continuous stations namely in Cibinong, Medan, Kupang, Pare-Pare, Biak, Watatu, Palu, Toboli, Tolitoli, Gunung Sitoli, and Yogyakarta. Figure 6 shows the Sumatran cGPS Array (SuGAr) network which is maintained by LIPI in co-operation with Caltech.

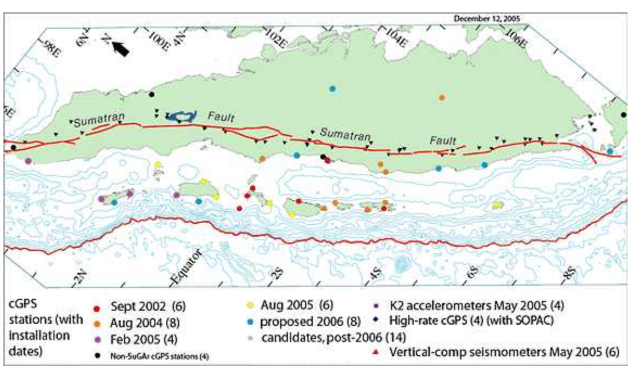

Figure 6. Existing stations of the Sumatran continuous GPS Array (SuGAr) [7].

The establishment of Indonesian CORS will actually beneficial not only for natural hazard mitigation; but it will also important for supporting surveying and mapping applications, GPS-based meteorology, and Intelligent Transport System (ITS) of Indonesia. In order to support the transportation sectors, the CORS should also have a functional capability of being as regular DGPS (Differential GPS) system [3].

The Indonesian GPS CORS can also support the Indonesian Tsunami Early Warning System (ITEWS) which is now in the process of establishment by the Indonesian government. The sensors of the ITEWS comprise seismometers, GPS instruments, tide gauges and buoys as well as ocean bottom pressure sensors as shown in Figure 7.

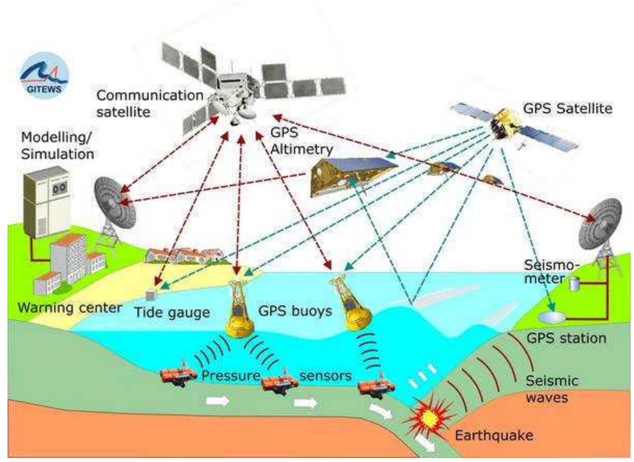

Figure 7. Components of ITEWS [12].

By locating CORS stations on specific areas on and around subduction zones, active faults and active volcanoes, the CORS system can also function as the early warning system for earthquake and volcano eruption.

It should be noted here that, considering a vast area that should be covered by the Indonesian CORS, from Sabang to Merauke, and most probably also many CORS stations will be located in secluded areas, then data communication and management will become important issues to resolve. Good and reliable communication infrastructures and supporting computer networks are important for the establishment of robust and reliable Indonesian CORS.

7. Closing Remarks

World-wide applications of GPS are increasing rapidly, due to increasing availability, accuracy, reliability and integrity of GPS systems; and also to advancements in electronics, instrumentation and control fields.

The applications of GPS in Indonesia has also steadily growing, encompassing various activities. In order to further enhance GPS applications, so it can be most beneficial for peoples and the country, then strong support from the national communities and expertise on instrumentation, control and electronics are also compulsory.

The advancements of GPS in Indonesia should also be supported by proper legal infrastructures and qualified human resources. The endorsements from related governmental agencies and high learning institutions will therefore also be crucial.

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