International Association of Scientific Innovation and Research (IASIR)
(An Association Unifying the Sciences, Engineering, and Applied Research)

ISSN (Print): 2279-0063
ISSN (Online): 2279-0071

International Journal of Software and Web Sciences (IJSWS)
www.iasir.net

Global Navigation Satellite Systems and Their Applications

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ABSTRACT:
Global Navigation Satellite System (GNSS) plays a significant role in high precision navigation, positioning, timing, and scientific questions related to precise positioning. Ofcourse in the widest sense, this is a highly precise, continuous, all-weather and a real-time technique. This Research Article is devoted to presenting recent results and developments in GNSS theory, system, signal, receiver, method and errors sources such as multipath effects and atmospheric delays. To make it more elaborative, this varied GNSS applications are demonstrated and evaluated in hybrid positioning, multi-sensor integration, height system, Network Real Time Kinematic (NRTK), wheeled robots, status and engineering surveying. This research paper provides a good reference for GNSS designers, engineers, and scientists as well as the user market.

I. Use and Applications of Global Navigation Satellite Systems

In the year 2001, pursuant to the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE-III), the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) established the Action Team on Global Navigation Satellite Systems (GNSS) under the leadership of the United States and Italy and with the voluntary participation of 38 Member States and 15 organizations. The Action Team was one of 12 action teams established by COPUOS to implement priority recommendations of UNISPACE-III, as identified by Member States of the United Nations. As a result of the deliberations of the Action Team on GNSS had paved way for the establishment of the International Committee on GNSS (ICG) under the umbrella of the United Nations. ICG's establishment recognizes that GNSS which has become a truly international resource and demonstrates the willingness of providers and users to ensure that GNSS services continue to be available in the future for the benefit of mankind. It is noteworthy to say that ICG is a milestone in the demonstration of Member States to promote for cooperation in the use of outer space for peaceful purposes.

With a view to extend full-fledged support to the work of the ICG, the Office for Outer Space Affairs (OOSA) of the Secretariat of the United Nations was designated as the Executive Secretariat of the ICG. Keeping in view of this capacity, the OOSA through its Programme on GNSS Applications is organizing regional workshops, training courses and international meetings focusing on capacity-building in the use of GNSS-related technologies in various rapidly growing fields of applications as well as deploying instruments for the International Space Weather Initiative (ISWI). It is worth mentioning that OOSA is also on the verge of developing an in-depth GNSS education curriculum for inclusion in the training programmes at all UN-affiliated Regional Centres for Space Science and Technology Education, which also serve as ICG Information Centres. Interestingly, all these activities bring together a large number of experts, including those from developing countries, to discuss and act on issues that are also of high relevance to the ICG on an yearly basis.

Following the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), held in 1999, in its resolution 54/68, the United Nations General Assembly endorsed the "Vienna Declaration: Space Millennium for Human Development". The Vienna Declaration called for action, among other matters, to improve the efficiency and security of transport, search and rescue, geodesy and other activities by promoting the enhancement of, universal access to and compatibility of, space-based navigation and positioning systems. In response to that call, in 2001 the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) established the Action Team on Global Navigation Satellite Systems (GNSS) to carry out those actions under the chairmanship of Italy and the United States of America. The Action Team on GNSS, consisting of 38 member States and 15 inter-governmental and non-governmental organizations, recommended, among other things, that an International Committee on GNSS (ICG) should be established to promote the use of GNSS infrastructure on a global basis and to facilitate exchange of information. The Committee included this recommendation in the Plan of Action proposed in its report to the General Assembly on the review of the implementation of the recommendations of UNISPACE III. In 2004, in its resolution 59/2, the General Assembly endorsed the Plan of Action. In the same resolution, the General Assembly invited GNSS and augmentation system providers to consider establishing an ICG in order to maximize the benefits of the use and applications of GNSS to support sustainable development.

At the "United Nations International Meeting for the Establishment of the International Committee on Global Navigation Satellite Systems (ICG)" held on 1- 2 December 2005 in Vienna, Austria, the ICG was established on a voluntary basis as an informal body for the purpose of promoting cooperation, as appropriate, on matters of mutual interest related to civil satellite-based positioning, navigation, timing, and value-added services, as well as compatibility and interoperability among the GNSS systems, while increasing their use to support sustainable development, particularly in the developing countries. The participants in the meeting agreed on an establishment of the ICG information portal, to be hosted by UNOOSA, as a portal for users of GNSS services.

The United Nations General Assembly, in its resolution 60/99 of 2005,

"Notes with satisfaction the progress made, in accordance with General Assembly resolution 59/2, *by Global Navigation Satellite Systems (GNSS) and augmentation system providers to establish an international committee on GNSS….*"

In its resolution 61/111, of 14 December 2006, the General Assembly noted with appreciation that,

"the International Committee on Global Navigation Satellite Systems was established on a voluntary basis as an informal body to promote cooperation, as appropriate, on matters of mutual interest related to civil satellite-based positioning, navigation, timing and value-added services, as well as the compatibility and interoperability of global navigation satellite systems, while increasing their use to support sustainable development, particularly in developing countries."

A **satellite navigation** or **SAT NAV** system is a system of satellites that provide autonomous geo-spatial positioning with global coverage. It allows small electronic receivers to determine their location (longitude, latitude, and altitude) to within a few metres using time signals transmitted along a line-of-sight by radio from satellites. Receivers calculate the precise time as well as position, which can be used as a reference for scientific experiments. A satellite navigation system with global coverage may be termed a **global navigation satellite system** or **GNSS**.

As of October 2011, only the United States NAVSTAR Global Positioning System (GPS) and the Russian GLONASS are fully globally operational GNSSs. China is in the process of expanding its regional Beidou navigation system into the global Compass navigation system by 2020. The European Union's Galileo positioning system is a GNSS in initial deployment phase, scheduled to be fully operational by 2020 at the earliest. Several countries including France, Japan and India are in the process of developing regional navigation systems.

Global coverage for each system is generally achieved by a satellite constellation of 20–30 medium Earth orbit (MEO) satellites spread between several orbital planes. The actual systems vary, but use orbit inclinations of >50° and orbital periods of roughly twelve hours (at an altitude of about 20,000 kilometres (12,000mi).

II. CLASSIFICATION

Satellite navigation systems that provide enhanced accuracy and integrity monitoring usable for civil navigation are classified as follows:

- **GNSS-1** is the first generation system and is the combination of existing satellite navigation systems (GPS and GLONASS), with Satellite Based Augmentation Systems (SBAS) or Ground Based Augmentation Systems (GBAS). In the United States, the satellite based component is the Wide Area Augmentation System (WAAS), in Europe it is the European Geostationary Navigation Overlay Service (EGNOS), and in Japan it is the Multi-Functional Satellite Augmentation System (MSAS). Ground based augmentation is provided by systems like the Local Area Augmentation System (LAAS).

- **GNSS-2** is the second generation of systems that independently provides a full civilian satellite navigation system, exemplified by the European Galileo positioning system. These systems will provide the accuracy and integrity monitoring necessary for civil navigation. This system consists of L1 and L2 frequencies for civil use and L5 for system integrity. Development is also in progress to provide GPS with civil use L2 and L5 frequencies, making it a GNSS-2 system.

- Core Satellite navigation systems, currently GPS (U.S.), GLONASS (Russia), Compass (China), and Galileo (EU).
- Global Satellite Based Augmentation Systems (SBAS) such as Omnistar and StarFire.
- Regional SBAS including WAAS (U.S.), EGNOS (EU), MSAS (Japan) and GAGAN (India).
- Regional Satellite Navigation Systems such as China's Beidou, India's yet-to-be-operational IRNSS, and Japan's proposed QZSS.
- Continental scale Ground Based Augmentation Systems (GBAS) for example the Australian GRAS and the US Department of Transportation National Differential GPS (DGPS) service.

- Regional scale GBAS such as CORS networks.
- Local GBAS typified by a single GPS reference station operating Real Time Kinematic (RTK) corrections. [6]

III. HISTORY

It can be ascertained as a matter of fact that the early predecessors were the ground based DECCA, LORAN, GEE and Omega radio navigation systems, which used terrestrial longwave radio transmitters instead of satellites. As such positioning systems broadcast a radio pulse from a known "master" location, followed by repeated pulses from a number of "slave" stations. The occurrence of delay between the reception and sending of the signal at the slaves was carefully controlled, allowing the receivers to compare the delay between reception and the delay between sending. Mathematically, the distance to each of the slaves could be determined, providing a fix from this evaluation.

Transit was the first satellite navigation system which was a highly articulate system deployed by the US military in the 1960s. The principle of Doppler effect was employed in the case of Transit's operation. In this case, it was ascertained that the satellites travelled on well-known paths and broadcast their signals on a well known frequency. However, the received frequency will differ slightly from the broadcast frequency because of the movement of the satellite with respect to the receiver. As a result of monitoring this frequency shift over a short time interval, the receiver can determine its location to one side or the other of the satellite and several such measurements combined with a precise knowledge of the satellite's orbit can fix a particular position.

It was also accurately predicted by mathematical calculations that a part of an orbiting satellite's broadcast included its precise orbital data. With the sole purpose of ensuring accuracy, the US Naval Observatory (USNO) continuously observed the precise orbits of these satellites. Once a satellite's orbit deviated, the USNO would send the updated information to the satellite. Subsequent broadcasts from an updated satellite would contain the most recent accurate information about its orbit.

It was estimated that modern systems were more of a direct nature. In this case, the satellite broadcasts a signal that contains orbital data (from which the position of the satellite can be calculated) and the precise time the signal was transmitted. Then the orbital data is transmitted in a data message that is superimposed on a code that serves as a timing reference. In addition, the satellite uses an atomic clock to maintain synchronization of all the satellites in the constellation. The receiver compares the time of broadcast encoded in the transmission with the time of reception measured by an internal clock, thereby measuring the time-of-flight to the satellite. A variety of such accurate measurements can be made at the same time to different satellites, allowing a continual fix to be generated in real time using an adapted version of trilateration.

Every case of distance measurement, regardless of the system being used, places the receiver on a spherical shell at the measured distance from the broadcaster. Simply by considering several such measurements and then looking for a point where they meet, a fix is generated. Therefore, in the case of fast-moving receivers, the position of the signal moves as signals are received from several satellites. Also, the radio signals become slow a little bit as they pass through the ionosphere and this slowing varies with the receiver's angle to the satellite because that changes the distance through the ionosphere. Thus, the basic computation attempts to find the shortest directed line tangent to four oblate spherical shells centered on four satellites. Thereby by using combinations of signals, the Satellite navigation receivers minimise errors from multiple satellites and multiple correlators and then using techniques

IV. A GPS RECEIVER IN CIVILIAN

Automobile Use – Below

such as Kalman filtering to combine the noisy, partial and constantly changing data into a single estimate for position, time and velocity.

GNSS applications

Global Navigation Satellite System (GNSS) receivers, using the GPS, GLONASS, Galileo or Beidou system are used in many applications.

Navigation

- Automobiles can be equipped with GNSS receivers at the factory or as aftermarket equipment. Units often display moving maps and information about location, speed, direction, and nearby streets and points of interest.
- Aircraft navigation systems usually display a "moving map" and are often connected to the autopilot for en-route navigation. Cockpit-mounted GNSS receivers and glass cockpits are appearing in general aviation aircraft of all sizes, using technologies such as WAAS or LAAS to increase accuracy. Many of these systems may be certified for instrument flight rules navigation, and some can also be used for final approach and

landing operations. Glider pilots use GNSS Flight Recorders to log GNSS data verifying their arrival at turn points in gliding competitions. Flight computers installed in many gliders also use GNSS to compute wind speed aloft, and glide paths to waypoints such as alternate airports or mountain passes, to aid en route decision m aking for cross-country soaring.

- Boats **and** ships can use GNSS to navigate all of the world's lakes, seas and oceans. Maritime GNSS units include functions useful on water, such as "man overboard" (MOB) functions that allow instantly marking the location where a person has fallen overboard, which simplifies rescue efforts. GNSS may be connected to the ships self-steering gear and Chartplotters using the NMEA 0183 interface. GNSS can also improve the security of shipping traffic by enabling AIS.

. **Heavy Equipment** can use GNSS in construction, mining and precision agriculture. The blades and buckets of construction equipment are controlled automatically in GNSS-based machine guidance systems. Agricultural equipment may use GNSS to steer automatically, or as a visual aid displayed on a screen for the driver. This is very useful for controlled traffic and row crop operations and when spraying. Harvesters with yield monitors can also use GNSS to create a yield map of the paddock being harvested.[1]

- Bicycles often use GNSS in racing and touring. GNSS navigation allows cyclists to plot their course in advance and follow this course, which may include quieter, narrower streets, without having to stop frequently to refer to separate maps. Some GNSS receivers are specifically adapted for cycling with special mounts and housings.

V. A GPS unit showing basic way point and tracking information which is typically required for outdoor sport and recreational use - Below

- **Hikers and Climbers** and even ordinary pedestrians in urban or rural environments can use GNSS to determine their position, with or without reference to separate maps. In isolated areas, the ability of GNSS to provide a precise position can greatly enhance the chances of rescue when climbers or hikers are disabled or lost (if they have a means of communication with rescue workers).
- GNSS equipment for the visually impaired is available.
- Spacecraft are now beginning to use GNSS as a navigational tool. The addition of a GNSS receiver to a spacecraft allows precise orbit determination without ground tracking. This, in turn, enables autonomous spacecraft navigation, formation flying, and autonomous rendezvous. The use of GNSS in MEO, GEO, HEO, and highly elliptical orbits is feasible only if the receiver can acquire and track the much weaker (15 - 20 dB) GNSS side-lobe signals. This design constraint, and the radiation environment found in space, prevents the use of COTS receivers. Low earth orbit satellite constellations such as the one operated by Orbcomm uses GPS receivers on all satellites.[1]

Surveying and mapping

- Surveying — Survey-Grade GNSS receivers can be used to position survey markers, buildings, and road construction. These units use the signal from both the L1 and L2 GPS frequencies. Even though the L2 code data are encrypted, the signal's carrier wave enables correction of some ionospheric errors. These dual-frequency GPS receivers typically cost US$10,000 or more, but can have positioning errors on the order of one centimeter or less when used in carrier phase differential GPS mode.
- **Mapping and geographic information systems (GIS)** — Most mapping grade GNSS receivers use the carrier wave data from only the L1 frequency, but have a precise crystal oscillator which reduces errors related to receiver clock jitter. This allows positioning errors on the order of one meter or less in real-time, with a differential GNSS signal received using a separate radio receiver. By storing the carrier phase measurements and differentially post-processing the data, positioning errors on the order of 10 centimeters are possible with these receivers. Several projects, including OpenStreetMap and TierraWiki, allow users to create maps collaboratively, much like a wiki, using consumer-grade GPS receivers. [2]
- **Geophysics and geology** — High precision measurements of crustal strain can be made with differential GNSS by finding the relative displacement between GNSS sensors. Multiple stations situated around an actively deforming area (such as a volcano or fault zone) can be used to find strain and ground movement. These measurements can then be used to interpret the cause of the deformation, such as a dike or sill beneath the surface of an active volcano.
- **Archeology** — As archaeologists excavate a site, they generally make a three-dimensional map of the site, detailing where each artifact is found.
- Survey-grade GNSS receiver industry include a relatively small number of major players who specialize in the design of complex dual-frequency GNSS receivers capable of precise tracking of carrier phases for all or most of available signals in order to bring the accuracy of relative positioning down to cm-level values required by these applications. The most known companies are Javad, Leica, NovAtel, Septentrio, Topcon, Trimble.

Other uses

- **Precise time reference** — Many systems that must be accurately synchronized use GNSS as a source of accurate time. GNSS can be used as a reference clock for time code generators or Network Time Protocol (NTP) time servers. Sensors (for seismology or other monitoring application), can use GNSS as a precise time source, so events may be timed accurately. Time division multiple access (TDMA) communications networks often rely on this precise timing to synchronize RF generating equipment, network equipment, and multiplexers.
- **Mobile Satellite Communications** — Satellite communications systems use a directional antenna (usually a "dish") pointed at a satellite. The antenna on a moving ship or train, for example, must be pointed based on its current location. Modern antenna controllers usually incorporate a GNSS receiver to provide this information. [6]
- **Emergency and Location-based services** — GNSS functionality can be used by emergency services to locate

cell phones. The ability to locate a mobile phone is required in the United States by E911 emergency services legislation. However, as of September 2006 such a system is not in place in all parts of the country. GNSS is less dependent on the telecommunications network topology than radiolocation for compatible phones. Assisted GPS reduces the power requirements of the mobile phone and increases the accuracy of the location. A phone's geographic location may also be used to provide location-based services including advertising, or other location-specific information. [6]

- **Location-based games** — The availability of hand-held GNSS receivers has led to games such as Geocaching, which involves using a hand-held GNSS unit to travel to a specific longitude and latitude to search for objects hidden by other geocachers. This popular activity often includes walking or hiking to natural locations. Geodashing is an outdoor sport using waypoints.
- **Aircraft passengers** — Most airlines allow passenger use of GNSS units on their flights, except during landing and take-off when other electronic devices are also restricted. Even though consumer GNSS receivers have a minimal risk of interference, a few airlines disallow use of hand-held receivers during flight. Other airlines integrate aircraft tracking into the seat-back television entertainment system, available to all passengers even during takeoff and landing. [2]
- **Heading information** — The GNSS system can be used to determine heading information, even though it was not designed for this purpose. A "GNSS compass" uses a pair of antennas separated by about 50 cm to detect the phase difference in the carrier signal from a particular GNSS satellite. Given the positions of the satellite, the position of the antenna, and the phase difference, the orientation of the two antennas can be computed. More expensive GNSS compass systems use three antennas in a triangle to get three separate readings with respect to each satellite. A GNSS compass is not subject to magnetic declination as a magnetic compass is, and doesn't need to be reset periodically like a gyrocompass. It is, however, subject to multipath effects. [3]
- GPS tracking systems use GNSS to determine the location of a vehicle, person, pet or freight, and to record the position at regular intervals in order to create a log of movements. The data can be stored inside the unit, or sent to a remote computer by radio or cellular modem. Some systems allow the location to be viewed in real-time on the Internet with a web-browser. [2]
- Recent innovations in GPS tracking technology include its use for monitoring the whereabouts of convicted sex offenders, using GPS devices on their ankles as a condition of their parole. This passive monitoring system allows law enforcement officials to review the daily movements of offenders for a cost of only $5 or $10 per day. Real time, or instant tracking is considered too costly for GPS tracking of criminals.
- **GNSS Road Pricing systems -** charge of road users using data from GNSS sensors inside vehicles. Advocates argue that road pricing using GNSS permits a number of policies such as tolling by distance on urban roads and can be used for many other applications in parking, insurance and vehicle emissions. Critics argue that GNSS could lead to an invasion of people’s privacy.
- **Weather Prediction Improvements** — Measurement of atmospheric bending of GNSS satellite signals by specialized GNSS receivers in orbital satellites can be used to determine atmospheric conditions such as air density, temperature, moisture and electron density. Such information from a set of six micro-satellites, launched in April 2006, called the Constellation of Observing System for Meteorology, Ionosphere and Climate COSMIC has been proven to improve the accuracy of weather prediction models.
- **Photographic Geocoding** — Combining GNSS position data with photographs taken with a (typically digital) camera, allows one to view the photographs on a map or to lookup the locations where they were taken in a gazeteer. It's possible to automatically annotate the photographs with the location they depict by integrating a GNSS device into the camera so that co-ordinates are embedded into photographs as Exif metadata. Alternatively, the timestamps of pictures can be correlated with a GNSS track log.[4][5]
- **Skydiving** — Most commercial drop zones use a GNSS to aid the pilot to "spot" the plane to the correct position relative to the dropzone that will allow all skydivers on the load to be able to fly their canopies back to the landing area. The "spot" takes into account the number of groups exiting the plane and the upper winds. In areas where skydiving through cloud is permitted the GNSS can be the sole visual indicator when spotting in overcast conditions, this is referred to as a "GPS Spot".
- **Marketing** — Some market research companies have combined GIS systems and survey based research to help companies to decide where to open new branches, and to target their advertising according to the usage patterns of roads and the socio-demographic attributes of residential zones.
- **Wreck diving** — A popular variant of scuba diving is known as wreck diving. In order to locate the desired shipwreck on the bottom of the ocean floor GPS is used to navigate to the approximate location and then the shipwreck is found using an echosounder.

- **Social Networking** - A growing number of companies are marketing cellular phones equipped with GPS technology, offering the ability to pinpoint friends on custom created maps, along with alerts that inform the user when the party is within a programmed range. Not only do many of these phones offer social networking functions, they offer standard GPS navigation features such as audible voice commands for in-vehicle GPS navigation.[3]

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