CHAPTER

20

c0020 Application of GPS and GNSS technology in geosciences

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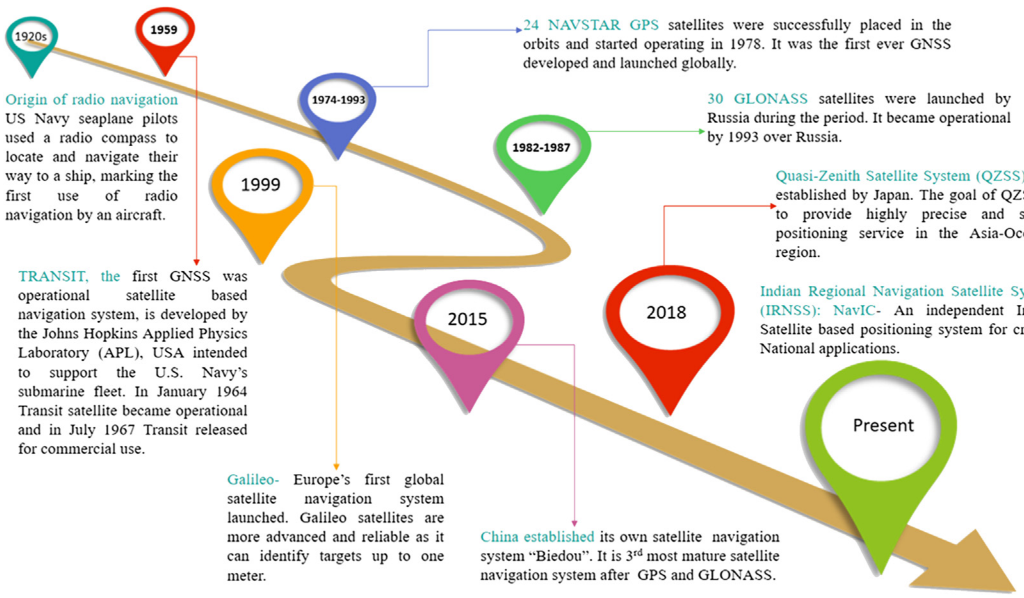
s0010 1. Introduction

p0010 Satellite navigation system is a system of artificial satellites capable of providing geospecific positioning everywhere in the world. With the help of this system, small electronic receivers calculate their position, including latitude, longitude, and height from the mean sea level with utmost precision. The framework can be utilized for providing position [3,9,13,17]. The signals additionally enable the electronic receiver to calculate the current local time to high accuracy, which permits time synchronization [49]. These utilizations are on the whole known as Positioning, Navigation, and Timing (PNT). Satellite navigation frameworks autonomously of any telephonic, however, these innovations can enhance the helpfulness of the positioning information [18].

p0015 A satellite navigation framework with worldwide coverage might be named a Global Navigation Satellite System (GNSS) and is shown in Fig. 20.1. GNSS systems provide enhanced accuracy and integrity in monitoring and are usable for civil navigation. GNSS-1 is the first-generation combination of existing satellite navigation systems (GPS and GLONASS), with Ground-based Augmentation Systems or Satellite-based Augmentation Systems (SBAS). GNSS-2 is the second generation of systems that independently provide a full civilian satellite navigation system, exemplified by the European Galileo positioning system [21,22]. GNSS-2 contained only upper L-band frequency sets.

p0020 Global Positioning System (GPS) developed by the Department of Defense (DoD) of the United States, Russia's GLONASS launched by the European GNSS Agency of the European



f0010 **FIGURE 20.1** Framework for strategic and sustainable development of global navigation.

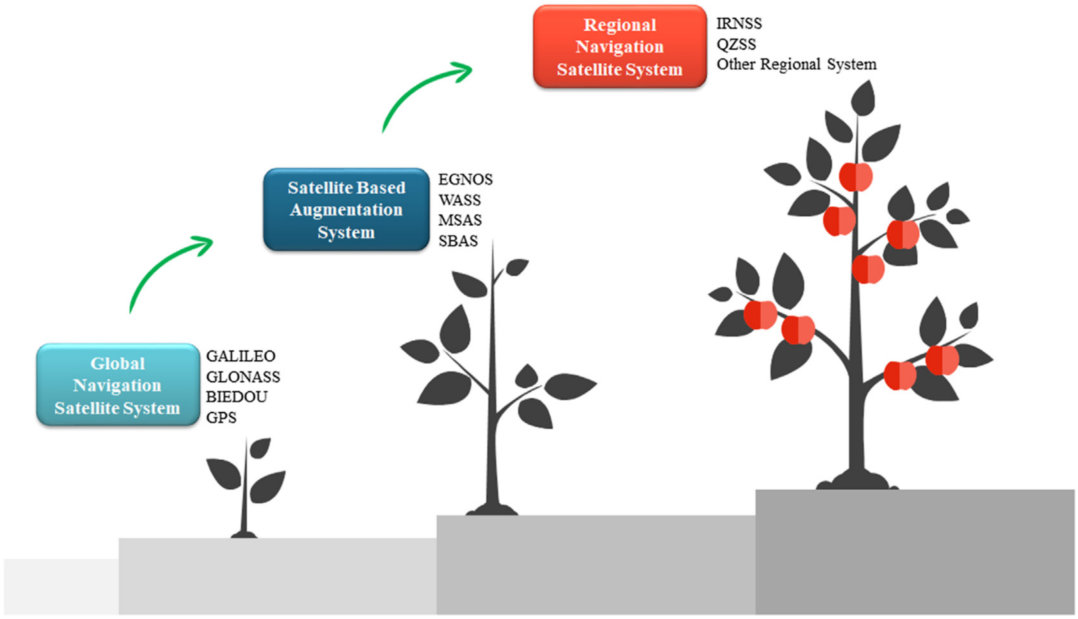
Union, and China's BeiDou Navigation Satellite System (BDS) are completely operational GNSS [27]. The European Geostationary Navigation Overlay Service was developed by the European Space Agency, and the Wide Area Augmentation System is an air navigation aid developed by the Federal Aviation Administration [38,39]. The Multi-functional Satellite Augmentation System is the Japanese SBAS that is fully operational. Indian Regional Navigation Satellite System (IRNSS) and Japan's Quasi-Zenith Satellite System are Regional Navigation Satellite Systems (RNSSs) (Fig. 20.2).

s0015 2. Global navigation satellite system

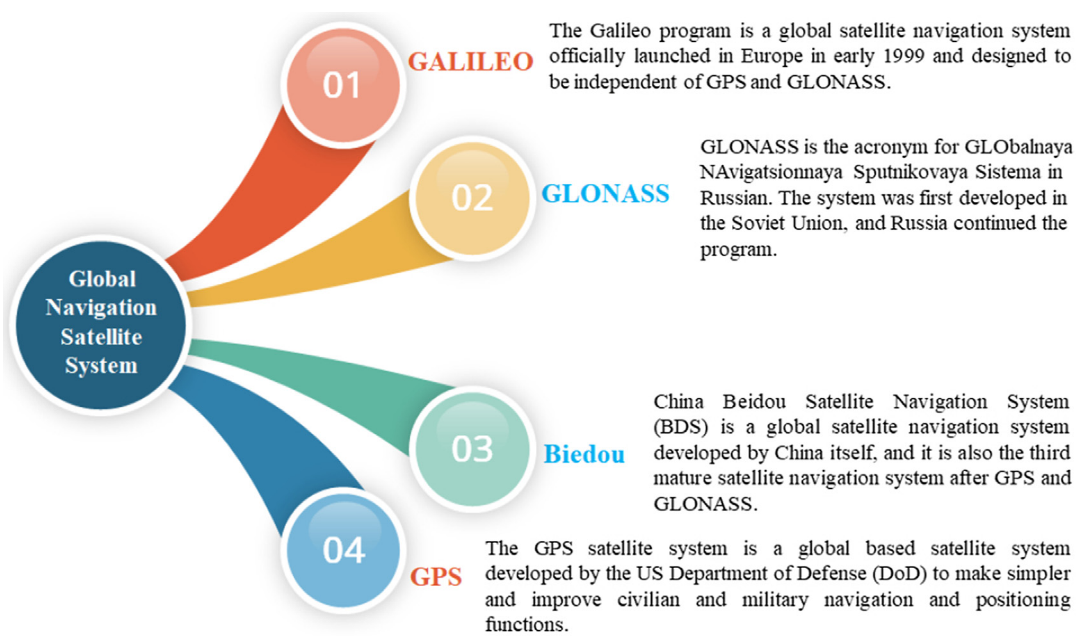
p0025 GNSS framework is one of the four major positioning systems in the world. The four positioning systems are namely US GPS, Russian GLONASS, European Galileo Global Navigation Satellite System (GNSS), and China's BeiDou navigation system [37] (Fig. 20.3).

s0020 2.1 Galileo

p0030 The Galileo program is a GNSS officially launched by Europe in early 1999 and designed to be independent of GPS and GLONASS. The US GPS is the navigation and positioning system that is used throughout the world, which Europeans consider unsafe. The Galileo system is a new generation of civil global satellite navigation system developed by the European Union to establish a civilian global navigation positioning system controlled by Europe, costing more than three billion euros [19]. The system consists of two ground control centers



f0015 FIGURE 20.2 A satellite navigation framework with worldwide coverage with three satellite system.



f0020 FIGURE 20.3 GNSS framework with four major positioning systems in the world.

and 30 satellites, of which 27 are working satellites and 3 are for backup. The satellite orbit has an altitude of about 24,000 km and is located in three orbital planes with an inclination of 56 degrees.

p0035 On July 23, 1996, the European Parliament and the Council of Ministers of Transport of the European Union formulated a common framework for the construction of a European intermodal transport network, which for the first time raised the issue of establishing a European autonomous positioning and navigation system [45]. This common program became the basis for the future "Galileo Plan." On January 13, 1999, the European Parliament approved a report submitted by the European Commission entitled "Establishing a European Intermodal Positioning and Navigation Network: A European Global Navigation Satellite System Development Strategy." On February 10, 1999, the European Commission first proposed the "Galileo Project" in its report entitled "Galileo-Europe's Participation in a New Generation of Satellite Navigation Services." The plan is divided into four stages: demonstration stage (2000–01), i.e., demonstration of the necessity, feasibility of the plan, and implementation of specific implementation measures; system development and on-orbit verification stage (2001–05); constellation deployment stage (2006–07); and the operation phase (from 2008) for which the tasks are system maintenance, providing operational services, updating satellites, etc., as planned. The initial goal of the system was to launch in 2008, but it was extended to 2011 due to technical issues. In early 2010, the European Commission again announced that the Galileo system would be put into operation until 2014 [6].

p0040 Compared with the US GPS, the Galileo system is more advanced and more reliable. The satellite signals provided by the US GPS to other countries can only find objects about 10 m long on the ground, whereas Galileo's satellites can find targets that are 1 m long. A military expert metaphorically said that GPS can only find streets, whereas Galileo can find homes [41,44]. The Galileo plan is of crucial significance to the European Union. It will not only make people's lives more convenient but also bring considerable economic benefits to the European Union's industry and commerce. More importantly, the European Union will now have its global satellite navigation system, which will help break the monopoly position of the US GPS navigation system, thereby gaining a favorable position in the global high-tech competition and creating conditions for the future construction of European independent defense. As a European Union–led project, Galileo did not exclude foreign participation [6]. China, South Korea, Japan, Argentina, Australia, Russia, and other countries also participated in the program and provided financial and technical support. After the Galileo satellite navigation system is completed, it will form the world's four major satellite navigation systems with the US GPS, Russian "Glonus" (i.e., GLONASS), and the Chinese BeiDou satellite navigation system, providing users with more efficient and accurate services [46–48].

s0025 2.2 GLONASS

p0045 GLONASS is the acronym for GLObalnaya NAvigatsionnaya Sputnikovaya Sistema in Russian. The role of the GLONASS satellite navigation system is similar to the GPS of the United States, the Galileo satellite positioning system of Europe, and the BeiDou satellite navigation system of China [1]. The system was first developed in the Soviet Union, and Russia continued the program. The development of GLONASS began in the Soviet Union in 1976.

From October 12, 1982, to 1995, several satellites were incorporated into the system through multiple rocket launches, but unfortunately, after this, the country's economy collapsed and so the condition of this system also weakened. The restoration of this system, under the chairmanship of Vladimir Putin in the early 2000s, was accorded a top government priority and a substantial increase in funding. Currently, GLONASS is the most expensive program of the Russian Federal Space Agency [4,11]. GLONASS had achieved the capacity to cover almost 100% of the Russian territory by 2010. As in February 2011, the satellite group had 22 operational satellites, which was short of the 24 satellites required to provide continuous global coverage, and this shortfall was expected to be met during 2011. The design of GLONASS satellites have been renewed several times with the most recent version being GLONASS-K. GLONASS satellites have been placed in a midcircular orbit at 19,100 km altitude with a tilt of 64.8 degrees and a duration of 11 h 15 min. These satellite groups are operated in three orbital planes, each of which has eight satellites at equal distances in the plane. A fully functional satellite group with global coverage has 24 satellites, while 18 satellites are needed to cover the Russian territories [15].

p0050 The GLONASS project is a project that was initiated by the Soviet Union in 1976. The GLONASS system uses 24 satellites to achieve global positioning services, which provides high-precision three-dimensional (3D) space and velocity information, as well as timely service. In contrast to GPS frameworks, the GLONASS framework utilizes a frequency-division multiple access strategy. Each GLONASS satellite broadcasts L1-frequencies ($L1 = 1602 + 0.5625 * k$ (MHz), with $k = 1$ 24) and L2-frequencies ($L2 = 1246 + 0.4375 * k$ (MHz)) signals.

p0055 Between 1982 and 1985, three simulated stars and 18 prototype satellites were launched for testing. The life of these test satellites by the Soviet Union was only 1 year, and the true average on-orbit life is only 14 months. The construction of the GLONASS system began in 1985 [26,32], and till 1986, six real GLONASS satellites were launched. These satellites improved the timing and frequency standards of the prototype satellites and enhanced the frequency stability. Their life span is still poor, with an average life span of about 16 months. Since then, 12 satellites that were continually improved had been launched, but half of the satellites were lost due to launch accidents. These new satellites had a designed life of 2 years and an actual average life of 22 months.

p0060 Thus, in 1987, the GLONASS system launched a total of 30 satellites, including early prototype satellites. Nine satellites were available in orbit, and the prospects were bright. The satellite launched in 1988 was a further improved version, which was commonly known as the GLONASS satellite. These satellites weigh 1400 kg and use triaxial stabilization technology and precision cesium atomic clocks, and their design life had been further increased to 3 years. Between 1988 and 2000, this version of the GLONASS satellite launched as many as 54 satellites. These satellites were launched into orbit using a proton rocket from the Baikonur launch center.

p0065 All three of the first-generation GLONASS (also known as Uragan) satellites were axial stationary vehicles that typically weighed 1250 kg and had a modest propulsion system for transfer within the satellite group. Over time, they were upgraded into block IIAs, IIBs, and IIV vehicles, each of which was undergoing evolutionary improvement. The development of GLONASS-M began in 1990 and was launched for the first time in 2003. The life span of these satellites was quite 7 years, and they weighed a little over 1480 kg. Their diameters were approximately 2.4 m and height 3.7 m. The GLONASS-K is much better than its previous generation. It is the first nonpressurized GLONASS satellite, with a much smaller mass (just 750 kg compared to the GLONASS-M with a mass of 1450 kg). Its operating life span is 10 years, which is more than the 7-year life span of the second-generation GLONASS-M.

s0030 2.3 BieDou

p0070 Recently, China's BeiDou satellite navigation system has started global services. China's BDS is a global satellite navigation system developed by China itself, and it is also the third mature satellite navigation system after GPS and GLONASS. BDS, US GPS, Russian GLONASS, and European Union Galileo are recognized suppliers of the United Nations Satellite Navigation Commission [10]. The ability has preliminary capabilities of regional navigation, positioning, and timing; positioning accuracy of 10 m; the speed measurement accuracy of 0.2 m/s; and timing accuracy of 10 ns.

p0075 BeiDou satellite navigation system is one of the world's four major satellite navigation core suppliers, with 39 satellites in orbit. Beginning at the end of 2017, the construction of the BeiDou III system has entered an ultra−high-density launch [50]. The BeiDou system officially provides RNSS services to the world, with a total of 39 satellites in orbit. After launching five to seven more satellites in 2019 and two to four satellites in 2020, the construction of the BeiDou Global System will be fully completed. Pakistan will be the first foreign nation to use China's navigation system.

p0080 BDS is an independently constructed and independently operated satellite navigation system focusing on economy, national security, and social development needs. It provides global users with all-weather, high-precision positioning, all-time, and navigation important national space infrastructure for time services [31,42]. With the improvement of BeiDou framework development and service capabilities, related products have been widely used in emergency search and rescue, meteorological forecasting, hydrological monitoring, forest fire prevention, transportation, marine and geographic mapping, power dispatching, disaster relief, communication timing, etc.

p0085 China always upholds and practices the developmental concept of “China's BeiDou, the world's BeiDou” serves the “Belt and Road” construction and development, and actively promotes international cooperation in the BeiDou system [23,35]. Development goals build a world-class satellite navigation system to meet the needs of national security, economic, and social development and provide continuous, stable, and reliable services for global users.

s0035 3. Global positioning system

p0090 The GPS is a system for point measurement using artificial Earth satellites. It is widely used in sea and air navigation, missile guidance, dynamic observation, time transmission, speed measurement, vehicle guidance, and other fields. In terms of surveying, mapping technology, and engineering construction, it is not only used in the establishment of Earth control networks, global Earth parameter measurement, plate motion monitoring, aerospace

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parameter determination, establishment of land and ocean geodetic survey benchmarks, etc. but are also increasingly used in several other areas [2,5]. The GPS satellite consists of three parts: satellites in orbit, and control on the Earth, monitoring stations, and the user's GPS receiver. GPS satellites broadcast signals from the air that are picked by the GPS receivers and they confirm these signals. Each GPS receiver provides 3D (latitude, longitude, and altitude) positioning and timing. GPS has guided dirty air, ground, and maritime transportation and has become the backbone technology of the global transportation system, disaster reduction, and emergency services in life rescue operations [7].

s0040 3.1 History and development

p0095 The GPS satellite system is a global-based satellite system developed by the US DoD to improve civilian and military navigation and positioning functions. In the 1960s, the United States Air Force has developed a system consisting of several satellites with precise time, which can help people determine the position of vehicles walking on land and aircraft flying in the air. In 1973, the Navy's and Air Force's plans were integrated [8,12]. The plan eventually developed into a NAVASTAR (Navigation Star) plan from Navigation Technology Plan. The Russians also developed a GPS called GLONASS. The European Union approved an R&D financing for a GPS called Galileo. The system started working around 2010 with the launch of the first GPS satellite in 1974. The system has undergone a series of developments and trials [14,20].

p0100 These GPS satellites launched by the United States Air Force were manufactured by Rockwell Collins. These tests continued until the 1980s. These GPS satellites were sent to space by NASA-made space shuttle. Because of the 1986 "*Challenge*" space shuttle accident, the GPS program has suffered severe setbacks [24]. A few years later, the situation changed with the launch of the "Delta II" rocket carrying GPS satellites. The full operation of the GPS and the provision of services began on December 8, 1993. At that time, the constellation had 24 satellites, of which 21 satellites operate and 3 satellites are backed up.

s0045 *3.1.1 Space segment*

p0105 The complete GPS space segment includes 24 satellites at a distance of 20,200 km from the Earth. The satellites have a fixed position around the Earth every 12 h along the orbit. So we can be anywhere on the Earth and receive signals at any time. The system is divided into six levels. There are nominally four satellites in each orbit, which are equally divided (60 degrees apart), tilted at an angle of about 55 degrees to the equatorial plane. These satellites are equipped with very precise clocks for maintaining accuracy.

s0050 *3.1.2 Control section*

p0110 The control section includes a global tracking and surveillance ground station system. The main control facility at Falcon Air Force Base in Colorado Springs, Colorado, USA, measures the signals sent from GPS satellites and transfers the information they collected to the main control station. The master control station uses these data to calculate an accurate orbit model for the GPS constellation, and this information is then compiled into real-time updated navigation information for each satellite.

s0055 *3.1.3 User segment*

p0115 The user segment includes GPS receivers, processors, and positioning and timing squall lines (for civilian or military use). The concept of GPS operation is based on the satellite's line of sight. Users measure their distance from a group of satellites in space to determine their location on the Earth. Each GPS satellite transmits a precise position and time signal. The delay of reaching the receiver is determined by the distance of four points in space, and the GPS receiver determines the 3D position by triangulation.

s0060 3.2 Operational principle of GPS

p0120 The GPS is designed with 21 satellites. The life cycle of each satellite is approximately 7.5–15 years. Replacement satellites are usually backed up in orbit to ensure that at least 24 satellites are functioning. To receive GPS signals, the device used is called a receiver. It provides a civilian user their location and comes in the form of handheld or a watch-type device. The GPS receiver can also be installed on cars and ships. GPS requires an atomic clock.

s0065 *3.2.1 Basic principles*

p0125 The basic principle of GPS operation is the method of triangulation or the trilateral measurement method. We can take the following steps to determine the position: use a satellite to determine the distance and the positioning detector (GPS receiver), the second satellite can determine the receiver on the intersection of the two spheres, and the third satellite intersects the intersection of the two spheres to form two intersections, which are located on the Earth [30,34]. The intersection of the ball and the receiver is the precise location of the receiver. The fourth atomic clock carried by the guard provides accurate time for positioning.

s0070 *3.2.2 Navigation signals*

p0130 Each satellite sends its navigation information through at least two distinct spreading codes: one is the coarse code (C/A code) and another is precise code (P-code). The C/A code is freely available to the public, and the P-code is usually used for encryption. It is especially used for military applications. The C/A code is a pseudorandom code of 1023 chips and the chip rate is 1023 Mchip/s. Each satellite has its own C/A code so that it can be recognized separately. It can be received separately from the signals transmitted by other satellites on the same frequency. When the "antispoofing" mode is turned on, the precise code is encrypted and the code is encrypted to generate the love code P (Y) code [36]. This code can only be decrypted with a valid secret device coarse code or love code P (Y) and can pass accurate time to the user.

p0135 The frequencies used in the GPS segment range from L1 to L5. L1 (1575.42 N1Hz) includes navigation information through L1 Civilian (L1C) and Military (M) code. L2 (1227.60 NI Hz) is an unmodulated carrier through L2 Civilian (L2C) code and Military (M) code. L3 (1381.05 MHz) is used for nuclear explosion detection system load (NDS), for detecting signals from nuclear firecrackers and other high-energy infrared radiation events. L4 (1379.913 MHz) is used for additional ionosphere correction studies, and L5 (1176.45 MHz) is proposed for civilian life-saving signals [43]. This frequency is included in the scope of international protection. It is used for flight navigation to ensure that there is no interference with this signal in any environment or minimize dry strokes.

s0075 3.3 GPS applications

p0140 GPS technology has been widely used in the fields of agriculture, geological application, mineral exploration, cadastral surveying and mapping, oceanography, aviation, environmental monitoring, and so on. The application of GPS in various fields has been described below with suitable utilizations.

s0080 *3.3.1 Agriculture*

p0145 The advancement and execution of precision agriculture or site-explicit cultivation has been made conceivable by joining the GPS and geographic information system (GIS). These innovations empower the coupling of ongoing information assortment with precise position data, prompting the effective control and analysis of a huge amount of geospatial information. GPS-based applications in precision agriculture are being utilized for agriculture planning, field planning, soil examination, crop exploration, variable rate applications, and yield mapping. GPS permits peasants to work during low-visibility field conditions, for example, downpour, residue, haze, and obscurity.

s0085 *3.3.2 Environment*

p0150 Requirement of better understanding and decision making with additional updated data is to support and sustain the Earth's environment while adjusting human needs. Collection of precise and convenient data has been perhaps the biggest challenge for both government and private associations that should take decisions about it. The GPS assists us with real-time information to address these needs. GPS data can be immediately dissected without the fundamental necessity for field information interpretation into a digitized structure. Precise tracking of environmental hazards, for example, flames and oil slicks, can be led more efficiently. Exact location information from GPS can help researchers in crustal and seismic observations. Conservation and monitoring of endangered species can be encouraged through GPS tracking and plotting.

s0090 *3.3.3 Oceanography*

p0155 Sailors and oceanographers are progressively utilizing GPS information for surveying in the depth of oceans, buoy placement, and navigational peril area and planning. GPS is being used to locate and map various geological exploration sites within the deep oceans by the researchers and the scientific community. Commercial fishing ships use GPS to explore ideal fishing areas, track fish movements, and guarantee compliance with territorial guidelines.

s0095 *3.3.4 Surveying and mapping*

p0160 The community of surveyors and mappers was one of the first to exploit GPS since it significantly expanded productivity and brought about increasingly precise and dependable information. When utilized by talented professionals, GPS gives surveying and planning information of the most noteworthy precision. GPS-based information assortment is a lot quicker than conventional surveying and planning procedures, decreasing the measure of equipment and work required. GPS helps in the precise planning and simulation of the physical world from mountains and streams to boulevards and structures to utility lines and different resources. Land features measured with GPS can be shown on maps and in GISs that store, control, and show geologically referenced information.

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s0100 *3.3.5 Rescue and relief projects*

p0165 GPS has assumed an essential job in relief and rescue projects for worldwide disasters, for example, Hurricanes Katrina and Rita that unleashed destruction in the Gulf of Mexico in 2005, the tsunami that impacted the Indian Ocean area in 2004, and the Nepal—India earthquake in 2015. Another significant area of disaster alleviation is in the monitoring and management of fires of the forest. To stop and control fires in forests, airplanes consolidate GPS with infrared scanners to distinguish fire limits and "problem areas."

p0170 Even in our daily life, taxi, car rental services, logistics, and other industries use GPS technology to track, dispatch, and manage vehicles; reasonably distribute the vehicles; and respond to users' ride or delivery requests at the fastest speed, reducing energy consumption and saving operating costs. GPS plays an important role in vehicle navigation [25,28]. It establishes digital traffic radio stations in cities and broadcasts urban traffic information in real time. Vehicle-mounted equipment uses GPS to accurately locate and combine electronic maps and real-time traffic conditions to automatically match the optimal path [16], and carry out the autonomous navigation of vehicles. Civil aviation transportation uses GPS receiving equipment to enable the pilot to accurately align the runway when landing, and at the same time, to make the aircraft compact, improve the utilization rate of the airport, and guide the aircraft to safely enter and leave the field.

p0175 Using GPS technology, emergency dispatch of fire alarms, ambulances, and police can be done to improve the response efficiency of emergency handling departments to emergencies such as fires, crime scenes, traffic accidents, and traffic jams. Special vehicles (such as banknote transport vehicles) can alert and locate emergencies to minimize losses. With the help of GPS, rescuers can carry out effective search and rescue of missing persons in inaccessible and harsh seas, mountains, and deserts. When a fishing boat equipped with a GPS device is in danger, it can be located and can alarm in time, so that it can get rescue more quickly and evenly [29,33].

p0180 At present, developed countries have begun to introduce GPS technology into agricultural production, the so-called "precision agricultural farming." This method uses GPS to locate farmland information, including yield monitoring and soil sample collection. The computer system determines the management measures of farmland plots by analyzing and processing the data. The yield and soil status information are loaded into sprayer, to accurately fertilize and spray agricultural land. By implementing precision farming, agricultural production costs can be reduced without reducing production as much as possible, effectively avoiding waste of resources, and reducing environmental pollution caused by fertilization and insect removal.

p0185 The United States proposes that the basic purpose of GPS modernization is to meet the needs of the development of the United States defense modernization in the 21st century. This is the first and fundamental of GPS modernization. Specifically, GPS modernization is to provide better support and guarantee military operations [40]. To quote an American general who said: "In military operations, or dangerous or threatening environments, it is required that GPS can provide better support to combat members, combat effectiveness and provide more secure protection for their lives." It can help all kinds of weapons play a more effective role.

s0105

4. Discussion

p0190 GPS is a satellite-based navigation system that provides mainly three types of services location, navigation, and time-related services. These services are received with the help of satellites orbiting the Earth. More than 20 satellites are required to ensure the global reach and accuracy of the abovementioned services. Such satellite-based navigation systems are operated by other countries, such as GLONASS of Russia, Galileo of the European Union, Baidu of China, etc. The global navigational system used for general purpose is used in general positioning, navigational, or other types of tasks. There are some errors in the signals received from them, which reduces the precision. Services of satellite navigation systems that provide more accurate signals and information are often used by military departments. India has also given IRNSS for self-reliance in this direction. It is a regional navigation system based on just seven satellites, extending over 1500 km not only in India but also outside the Indian Territory.

s0110

5. Conclusion

p0195 Satellite navigation system is a system of artificial satellites capable of providing geospecific positioning everywhere in the world. With the help of this system, small electronic receivers calculate their position, including latitude, longitude, and height from the mean sea level with utmost precision. The framework can be utilized for providing position. GPS technology has been widely used in the fields of geodesy, resource exploration, crustal movement, cadastral survey, and so on.

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Non-Print Items

Abstract
Global Positioning System (GPS) is a global navigational satellite system developed by the United States Department of Defense. This technology is available only with America, Russia (GLONASS), China (BeiDou), and Japan (Quasi-Zenith Satellite System). In this, the navigation systems of America and Russia are global, while countries like China and Japan are using it regionally. The European Union has also completed preparations to start its navigation system. In terms of surveying, mapping technology, and engineering construction, it is used not only in the establishment of Earth control networks but also in the establishment of land and ocean geodetic survey benchmarks. Global Navigation Satellite System (GNSS) framework is one of the four major positioning systems, mainly GPS, GLONASS, GNS, and BeiDou, in the world. This chapter describes the application of GPS and GNSS Technology in Geosciences like rescue and relief projects, agriculture, dynamic observation, time transmission, speed measurement, vehicle guidance, and other fields.

Keywords:
BeiDou; Geosciences; GLONASS; GNS; GPS.