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Prospects of the Global Navigation Satellite System Application in Improving Civil Engineering Performance and Efficiency

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ABSTRACT: The Global Navigation Satellite System (GNSS) such as the Global Positioning System (GPS) is a satellite tool for acquiring earth-related location and information about time. The GNSS-based determination of coordinates is achieved by measuring intermediate distances from GNSS satellites. Numerous studies show that the efficiency and accuracy of civil engineering or construction work can be significantly increased by using GNSS for location determination. Thus, this study is a review of recent research finding on the prospects of GNSS application in improving civil engineering performance and efficiency. First, the relevant papers were carefully selected based on hierarchical topic after a logical search of previous studies in the academic electronic databases. In addition, the items selected from the search results were thoroughly reviewed and analyzed. The specific areas of GNSS application in construction activities were examined. Summarily, the review shows that satellite technology for navigation and positioning can provide users with accurate three-dimensional locations, high speed and precise time as compared to the traditional navigation and positioning techniques.

Keywords: Accurate, Construction, DGPS, Pseudoranges, Satellite, Stakeout.

INTRODUCTION

The construction sector is considered to be one of the main factors in the socio-economic development of several nations as it provides infrastructure and employment opportunities. Unfortunately, all of this is fraught with inefficiency and low productivity in many places. To meet these challenges, it is necessary to change or adjust the conventional methods of conducting the various operations in the industry. Overall, there is an increased global awareness of the need to make the world a better place. For example, Industry 4.0 deals with combining modern tools into manufacturing and other industries (Rojko, 2017). Likewise, the fourth revolution in construction (construction 4.0) is aimed at integrating similar tools into construction (Sawhney *et al.*, 2020) sector or operation. This includes digital systems and sophisticated instruments that can reduce errors and ensure high accuracy. Generally, sustainable growth can be attained with the modern improvement in any sector (Pundir *et al*., 2019).

In the process of engineering construction many geodetic devices are constantly evolving, which are used to determine the plane coordinates and heights accurately. These include total stations, Terrestrial Laser Scanners (TLS), optical and digital levels, Unmanned Aerial Vehicle (UAV), LiDAR, GNSS, and others (Sestras, 2021). The GNSS in combination with the Total Station and TLS is useful for volume computation with a main effort on achieving the result close to actual (Amar and Arpita 2021). The conventional surveying method is being superseded by the application of modern technologies such as the GNSS (e.g., GPS). Of course, methods in modern construction enhances the various construction elements. Some prominent examples of these elements are productivity, fulfilment, environmental performance, quality, sustainable development, and probability of the project's timely delivery (Ajugiya *et al*., 2017; Ahmad and Sharma 2020).

The GPS is routinely used in a variety of scientific and engineering applications such as engineering surveying, marine and aeronautical positioning, climatology, geodynamic studies and location-based application of Internet of Things (IoT) technology. Of course, IoT depends on the Internet as a platform that combines many areas of science and technology, including cloud computing, and location (Kanade *et al.*, 2024). The location of objects is a function of determining the object's coordinates (Hagemans *et al.*, 2022), which may be achieved with the use of a GPS device (Safrei *et al*., 2018). It is usually done with at least two GPS receivers where one is for measuring the baseline while the other is for measuring the actual distance and the object's location (Meng, 2020).

The GPS is a digital satellite-based tool that affords geo-positioning and navigation with worldwide coverage (Jackson *et al.*, 2018) based on transmission of signals. The strength of the signal received is measured at the antenna of the receiver (Igbonoba and Bankole 2023). Also, it delivers an accurate location on Earth (Chaturvedi, 2018) and consists of three main segments which include space (satellites), earth (ground control points) and user (GPS receivers). The use of GPS in surveying and engineering has clear advantages over the use of traditional tools. For example, it can be used to obtain 24-hour observation time and year-round global positioning. Bonforte *et al*. (2016) suggested that (i) GPS does not require survey points to be visible from one another, as in previous techniques, (ii) offers a wide variety of surveying methods to adopt the most appropriate one for a given task, and (iii) is easier to use. GPS also affords increasing productivity and safety in construction activities (Pravinath and Abd Sukor 2022). Using the GPS for engineering surveys is more cost-effective than the traditional surveying approach. The field cost reduction naturally comes from the fact that the number of survey team members can be reduced in GPS surveying. Furthermore, it eliminates the need for frequent instrument set up.

The GNSS technology is used for design preparation and tracking purposes in the construction field. Its implementation, especially in high-rising building construction is continuously improving. Of course, the GNSS and other sensor systems will continue to be relevant in the construction industry. Its importance has become the basis of many studies. Fei (2014) analyzed the composition, advantages and usage of GPS with focus on technical problems and their solutions. Similarly, Zhanwu (2020) studied the GPS positioning with a particular utilization of mechanical positioning tool to the measurement procedure in construction. Generally, a high level of accuracy can be achieved when the GPS is used to measure the coordinates of geographic objects and in collecting space-based data (Merebashvili, 2024). Shedekar and Brown (2017) gave an example of how to plan, design, and manage drainage systems using GIS and GPS. The use of GPS technology in engineering surveying has also been demonstrated by Jiang and Zhao (2023) to continuously enhance the effectiveness and caliber of engineering data collection. Additionally, it can save money and time while improving data verification. Li *et al.* (2016) demonstrated in another study that GPS technologies are crucial to construction law, including the completion of architectural documentation. Roberts *et al.* (2014) tracked bridge deflections using the GNSS.

It is clear from the above that there are numerous studies on the use of GNSS in construction operations. Nevertheless, there is a dearth of research on the topic's recent developments. Presenting the most recent techniques on the potential of GNSS application to enhance civil engineering performance and efficiency was the aim of this review.

MATERIAL AND METHODS

The focus of this study is to review recent research papers on the prospects of GNSS application for improving civil engineering performance and efficiency. Literature search for English-language sources was conducted through academic databases including Web of Science and Scopus. Of course, Scopus is by far the most comprehensive summary and citation database covering science-related research and it contains over 87 million articles. This justifies its suitability for research on GNSS or GPS technology and civil engineering.

The relevant keywords were selected and search command was created. The search command builds on previous research related to GNSS or GPS and its application in civil engineering. The Boolean operation was employed consisting of 2 parts. One part was concerned with the GPS while the second part was about civil engineering. The search was performed using specific search terms including ("GNSS* OR GPS* OR "*Global Positioning System or "Satellite-based Positioning*") AND ("Civil Engineering OR "Construction*"). Sources published in the last ten years were given preference. Furthermore, a few of the viewpoints presented in this review were derived from first-hand experience. With this method, recently published papers and documents were collected, reviewed and analysed.

RESULTS AND DISCUSSION

A. Planning the GPS survey

GPS is a satellite-based positioning system that primarily uses time propagation and triangulation as its measurement principles. The GPS signal receiver records the arrival time of each satellite signal while concurrently receiving signals from several satellites (Pau *et al.*, 2019). The basic principle of differential positioning technology (Tampubolon *et al.*, 2021) is to use one GPS receiver as a reference station and then compare the measurement results of the other receivers with that of the reference station (Liu and Wu 2021).

As a preliminary consideration, it is important to note that a new high-accuracy GPS survey needs to be connected to existing near control point. When choosing the survey methods, it should be understood that the GPS surveys are normally undertaken using either of two main techniques including the relative and absolute or Precise Point Positioning (PPP). The relative positioning method (Magalhães *et al.,* 2021) is aimed at obtaining the location's coordinates relative to another point. The relative mode requires two or more GPS receivers to be used for observing the same satellites simultaneously and therefore remove various errors. On the other hand, the PPP GPS surveys use single GPS receiver (Wang *et al.*, 2021) to determine the absolute coordinates of the GPS antenna (cantered over a survey station). Furthermore, variations or modifications of the two main aforementioned methods have culminated in the emergence of several techniques as follows:

i. Differential GPS Survey
ii. Kinematic GPS Survey
iii. Static GPS Survey
iv. Rapid Static GPS Survey
v. Real-Time Kinematic GPS Survey
vi. Post-Processing Kinematic GPS Survey
vii. Pseudo-Kinematic GPS Survey

Prior to land surveying, the measurement area must be investigated, the measuring apparatus inspected, the measurement area's cadastral data queried, the geographic coordinate data processing software debugged, and the weather conditions examined (Ulziisaikhan and Oyuntsetseg 2020).

It should also be noted that the existing nearby control points and new stations (especially in control survey) should be located on paper. This is followed by a reconnaissance trip to the site to check the selected observation site for the following:

(a) overhead obstructions that rise above 10°-15° from the horizon
(b) reflecting surfaces that can cause multipathing
(c) nearby electrical installations that can interfere with the satellite signal, and
(d) other potential problems

If it is discovered during the reconnaissance that any selected point locations are unsatisfactory, it is essential to make adjustment in the position.

B. GPS application in construction operation

There are numerous applications of GPS and GNSS in civil engineering, which replicate to some extent the traditional nature of static engineering surveying, such as coordinating control points, deformation monitoring, setting out or detail surveys. There are also dynamic applications such as deflection monitoring of large structures (Roberts *et al.*, 2014) positioning and controlling construction plant such as bulldozers, graders, piling rigs, mining plant, drilling rigs and excavators (Ritter *et al.*, 2014). Typically such GNSS results are integrated with other sensors. The excavator, for example, has its body coordinated and orientated using the two GNSS antennas. The bucket is then coordinated relative to the body, using gravity sensors or angle encoders placed on the three moving arm and bucket sections.

Advances in GPS technology have made it possible to collect highly accurate and reliable data while reducing physical effort. In addition, the revolution resulting from the introduction and deployment of GNSS through the CORS (Continuously Operating Reference Stations) has improved surveying in general and engineering surveying in particular. CORSs are infrastructure used to store, and process geospatial data (Peter and Oliver 2017). These include levels 1, 2, and 3, with level 3 being suitable for general purposes. CORS is considered a Reliable, Accurate, Robust, and Economical (RARE) positioning service. They are characterized with real-time and high-precision positioning (Naibbi and Ibrahim 2014) for monitoring high rising building, dredging activities, surface and underground pipeline, construction management (Ayodele *et al.*, 2017), large-scale social infrastructures such as dams and bridges, and others. Also, concrete slabs, which are used for building floors, walls, roof decks, foundations and bridge decks (Nyong *et al.*, 2023) can be accurately positioned with high-precision positioning based on GPS application. In general, both kinematic and static techniques have been used successfully on construction sites. Of course, real-time kinematic GPS can be used for survey with centimetre accuracy and higher accuracy can be achieved in static mode. Thus, they are applicable in the design of survey traverses for line features including roads, railways, and pipeline, and also for monitoring deformation of structures. Details of some specific areas of GPS application in civil engineering are presented in the following subsections.

1. Control survey. The control points are survey monument serving as reference points with known 3-dimensional position upon which other survey jobs can be referenced (Akpata and Ono 2018). In the process of land surveying, the first step is to locate control piles that can be served as control points. Before using these piles it is necessary to determine if additional ones are required. If not, the control piles can be directly used as the control points for setting up a reference station. However, if additional piles are needed, the points will be remeasured to obtain accurate coordinates. After verifying the results of this remeasurement, new piles are added and recorded (Karpinskyi and Lazorenko-Hevel 2020).

Dawod *et al.* (2021) analyzed four open-source global digital elevation models and compared them on two nearly flat and hills regions. The article briefly introduced the GPS positioning principle and the land surveying process using GPS technology. Then, it conducted a case analysis on Anyi Street, Yanhu District, Yuncheng City, Shanxi Province. Firstly, control points were established, followed by measuring boundary points based on the control network formed by these control points. Finally, a map was created. Control surveys are essential in the construction of various projects including roads, pipelines, underground utility systems, tunnels, and others. Many studies have been conducted on the GPS-based establishment of geodetic controls and to validate the prospects of multi-constellation observations for both the static and kinematic data acquisition for enhancing the convergence of PPP solutions (Angrisano *et al.*, 2020).

2. Topographic survey and mapping. Modelling the terrain or the environment is very important in civil engineering because the terrain is essential for comprehending the Earth surface topography. But achieving perfect environmental models are not probable in most cases and they need to adapt to uncertainties (Pandey and Mandal 2023). It is worth noting that achieving enhanced spatial model of the topography is a function of how accurate the instruments employed in topographic surveying. The more precise the equipment used in topographical surveys, the better the representation of space will be (Guimarães *et al.*, 2020). While there are many techniques and tools available for conducting topographical surveys, total stations and GNSS are the most commonly used instrument. For instance, El-Shouny *et al.* (2017) used Post Processing Kinematic (PPK) GPS to produce topographic maps of the Rosetta region of Egypt's central delta. Stott *et al.* (2020) used RTK-GNSS Unmanned Aerial Vehicle and SfM Photogrammetry to carry out ground control point distribution for accurate kilometre-scale topographic mapping. Topographic information is critical for major infrastructure project such as dams, canals, railroads and highways. Also, the selection of method of water abstraction is based on information on the topography among others (Uche *et al.*, 2023). Of course, that information is essential for establishing the parameters needed to choose and plan irrigation supply network, irrigation distribution, and the drainage systems.

Topographic information can come from existing topographic maps, satellite data, and field surveys. Topographic surveying is an important means of getting relevant data about the earth's topography. When a topographic survey representing a construction area is precise, the result is usually a productive investment (Idris, 2019). Topographic surveys for geodetic height determination using the conventional equipment such as dumpy level, and theodolite are costly, time-consuming, and strenuous. Thus, determination of orthometric heights of points can be achieved with ease using the GPS (Herbert and Okiemute 2021). In GPS-based topographic surveys (or detailing), a GPS receiver determines the coordinates of the place where the receiver antenna is located. It saves the data to a file, and it is usually downloaded for further processing. A practical approach to lessen errors in GPS-based topographic surveys is to apply Network Real-Time Kinematic (NRTK) technique or dual frequency GPS and GLONASS system.

3. Layout and setting out of features. It must be ensured that layout and setting out of the designed structure are productive. With this, cost can be relatively reduced, guidance and expertise can be provided to builders, design assumptions can be verified, and hazards can be reduced (Berk and Ferlan 2018). Setting out is concerned with locating either 2-dimensional or 3-dimensional position of features on ground based on the construction specification. Setting out or detailing is one of the most common applications of GPS in civil engineering. There are also GPS-based dynamic applications, especially in large structures deflection studies (Roberts *et al.*, 2015), as well as construction plant positioning and controlling. Studies have shown how real-time and precise positioning of railway vehicles can be achieved, and thus the rail track axis trajectory and coordinates may be determined (Koc *et al.*, 2021). Railways have to do a lot of work to improve its quality of service to the rail users and to develop capacity in such a manner that it is always ahead of demand (Jahan *et al.*, 2014). Mayunga and Bakaone (2021) combined GPS and Linear Variable Differential Transducers (LVDTs) for monitoring bridge loading. In the study, GPS was used to determine the horizontal locations, while LVDT technology was used to determine the vertical displacements, accelerations, and strains. The maximum displacements and deflections were determined between zero and different epochs. Also, the correlation coefficient of the measurements was determined by the authors at 0.679 while the x and y standard deviations were 0.0168 and 0.0254 respectively. Thus, it was clear that there is slight deviation in the horizontal component of the bridge. Similarly, Specht *et al.* (2020) determined the suitability of GNSS for performing geodetic and civil works in railway construction in the Polish Tri-city area. Observations were made on three sections of the railway line with different topography, which limit the access to satellite signals for mobile railroad surveys.

With the Kinematic GPS survey, it is possible to acquire data at selected epoch (typically 5-10 seconds). Thus, cross-sections and locations can be obtained quickly in respect of linear features including break lines, drainages, and roads, etc. Generally, GPS application has proven to be more efficient in the layout and setting out of structures. However, Ali (2017) suggested that using the total station for ground survey will produce better accuracy in position fixing. This is corroborated by Sestras (2021) who recommended the use of total station for layout and accurate construction surveying. Of course, the use of total stations can yield precise surveying, and therefore remain an essential instrument for different surveying projects including constructions.

4. As-built survey and mapping. The construction activities require two very crucial operations including production of the current map in preparation for construction design and conducting as-built inventory at completion of a project. As-built survey and mapping is aimed at determining the conformity between the design and what is built (Lewińska and Pargieła 2018). The precision of as-built position of structures is important and it will significantly help in the management of the site and structures (Masiri *et al.*, 2020). A high accuracy in as-built survey is obtainable by employing the RTK-GPS surveying method. A Real Time Kinematic Differential Global Positioning system (DGPS) collects data for “As Built” survey cost effectively (Roberts and Tang 2015). Yet, longer lengths of baseline (base-to-rover range) produce results of lower precision in RTK method. The reason is that distance-related errors such as atmosphere and satellite orbits affect the initialization, and solution precision. The desire to overcome this limitation gave birth to the idea of Real Time Network (RTN).

The primary difference between the RTN and RTK approaches is that RTK utilized the reference station that have permanent or semi-permanent location while computed or "virtual" reference stations are used in RTN surveying. The GNSS-RTN is a satellite-based system for positioning utilizing a network of receivers (base stations, reference stations, or CORSs) for enhancing the accuracy of corrections in positioning data. RTN has found applications in construction engineering projects, municipal infrastructure (Al-Kaisy *et al.*, 2021), and many applications as the positioning accuracy continue to improve with technological advancements.

CONCLUSIONS

This review indicates that the GPS develops rapidly, and it is playing a significant role in civil engineering. The GPS can serve global and continuous 3-d navigation/positioning function irrespective of the weather condition. At the same time, the GPS is characterized by powerful confidentiality and anti-interference performance. The foremost application of GPS positioning method for civil engineering activities comprises both static and dynamic relative positioning. Its application in the construction sector has increased in recent times, and it has demonstrated a good improvement in effectiveness as compared to the conventional approach. Besides reducing workload, the GPS is essential in construction management, decision-making and the implementation of such decisions. Despite all its advantages, the GPS is characterized by some notable shortcomings in practical application. For instance, its utilization is restricted in places with an obscured horizon. Also, an unfavourable location of the satellites usually leads to suspension of the measurement pending when their geometry changes.

FUTURE SCOPE

By and large, the development of new satellites will continue to expand the application of GPS while the use of the traditional instrument will continue to decrease. The reason is that the satellite positioning is characterized by ease, high speed, and high accuracies. Furthermore, it is anticipated that there will be enhancement in the future regarding the acquisition of signal and positioning. For instance, canopy condition will likely be unable to prevent the penetration of signals from all satellite positioning systems. With this, satellite positioning may be achieved from within buildings.

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