Application of Global Positioning System (GPS) in Topographic Mapping and Engineering Survey

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ABSTRACT

The Global Positioning System (GPS) has transformed topographic mapping and engineering surveys worldwide, offering high-precision, efficient, and scalable solutions for geospatial data collection. In Nigeria, where rapid urbanization and infrastructure development demand accurate surveying, GPS plays a pivotal role. This paper explores the principles, methodologies, and applications of GPS in topographic mapping and engineering surveys, with a focus on a case study from Nigeria: the topographic mapping and engineering survey for the Lagos-Ibadan Expressway expansion. The study highlights GPS's advantages, challenges such as signal obstructions and limited Continuously Operating Reference Station (CORS) infrastructure, and emerging trends like Real-Time Kinematic (RTK) GPS and drone integration. By analyzing the Nigerian context, this paper underscores GPS's impact on sustainable development and offers recommendations for improving its adoption in resource-constrained settings.

Keywords: GPS, topographic mapping, engineering survey, Nigeria, RTK, geospatial technology

INTRODUCTION

The Global Positioning System (GPS), a satellite-based navigation system developed by the U.S. Department of Defense, has revolutionized geospatial sciences by providing accurate three-dimensional positioning data (*Kaplan & Hegarty, 2017*). In topographic mapping and engineering surveys, GPS enables rapid data collection, high accuracy, and integration with modern technologies like Geographic Information Systems (GIS) and drones. In Nigeria, a country experiencing rapid urbanization, population growth, and infrastructure development, GPS is critical for addressing challenges in land management, urban planning, and engineering projects.

Traditional surveying methods, such as theodolites and chain surveys, are labor-intensive and prone to errors, particularly in Nigeria's diverse terrains, ranging from coastal wetlands to northern savannas. GPS overcomes these limitations by offering centimeter-level accuracy and the ability to survey large or inaccessible areas efficiently.

This paper examines the principles of GPS, its applications in topographic mapping and engineering surveys, and a specific case study from Nigeria—the Lagos-Ibadan Expressway expansion project. It also addresses challenges like signal obstructions and limited CORS infrastructure, drawing on Nigerian-specific insights to highlight practical implications and future trends.

Principles of GPS Technology

GPS System Architecture: GPS consists of three segments; the space segment (a constellation of at least 24 satellites), the control segment (ground stations monitoring satellite operations), and the user segment (receivers calculating positions via trilateration) (*Misra & Enge, 2011*). Satellites transmit signals containing time and position data, which receivers use to compute distances (pseudoranges) and determine three-dimensional coordinates.

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Positioning Mechanisms: GPS positioning relies on measuring signal travel time from satellites to receivers. By using signals from at least four satellites, receivers calculate latitude, longitude, and elevation while correcting for clock errors (*Hofmann-Wellenhof et al., 2008*). Accuracy depends on satellite geometry, signal quality, and atmospheric conditions.

Differential GPS and RTK: Differential GPS (DGPS) enhances accuracy by using a reference station to broadcast corrections to nearby receivers. Real-Time Kinematic (RTK) GPS achieves centimeter-level precision by resolving carrier phase ambiguities in real time (*Rizos, 1997*). In Nigeria, RTK GPS is increasingly used for high-precision surveys, though limited CORS infrastructure poses challenges.

Applications in Topographic Mapping

Topographic mapping involves creating detailed representations of terrain, including elevation, slopes, and natural or man-made features. GPS has streamlined this process by enabling rapid, accurate data collection.

Digital Elevation Models (DEMs)

GPS is used to collect elevation data for DEMs, which are critical for urban planning, flood modeling, and environmental management. In Nigeria, GPS-based DEMs have supported flood risk assessments in coastal cities like Lagos, where accurate elevation data is essential due to frequent flooding (*Ogunlesi, 2018*).

Mapping Large and Inaccessible Areas

Nigeria’s diverse landscapes, including dense forests and urban sprawls, challenge traditional surveying. GPS allows surveyors to collect data without line-of-sight requirements, making it ideal for remote areas like the Niger Delta. For example, GPS was used to map deforestation patterns in Cross River State, achieving sub-meter accuracy despite dense vegetation (*Asner et al., 2010*).

Integration with GIS and Remote Sensing

GPS data integrates with GIS and remote sensing to produce comprehensive topographic maps. In Nigeria, GPS-derived ground control points (GCPs) improve the georeferencing of satellite imagery for land-use planning. The National Population Commission’s GIS-based mapping of Nigeria’s landmass, recognized globally in 2022, relied heavily on GPS data.

Applications in Engineering Surveys

Engineering surveys provide precise measurements for infrastructure projects. GPS enhances these surveys by offering real-time positioning and reducing costs.

Geodetic Control Networks

Geodetic control networks establish reference points for engineering projects. In Nigeria, GPS-based control points have supported major infrastructure projects like the Lagos-Ibadan Railway, ensuring alignment accuracy across long distances (*Wang et al., 2018*).

Construction Staking

RTK GPS enables real-time staking of construction points, reducing errors and fieldwork time. In Nigeria, RTK GPS was used for staking during the construction of the Second Niger Bridge, achieving ±2 cm accuracy (Chen et al., 2019).

Deformation Monitoring

GPS monitors structural movements in dams, bridges, and buildings. In Nigeria, GPS- based monitoring of the Kainji Dam detected millimeter-scale deformations, ensuring safety (*Zhang et al., 2017*).

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Machine Guidance

GPS-guided machinery automates construction tasks with high precision. In Nigeria, GPS-guided graders were used in road projects, reducing material waste by up to 30% (*Roberts et al., 2020*).

Case Study:

GPS in the Lagos-Ibadan Expressway Expansion Project

Fig 1 Lagos-Ibadan Expressway Expansion Project

Project Overview

The Lagos-Ibadan Expressway, a 127.6-km arterial road connecting Lagos, Nigeria's economic hub, to Ibadan, is one of West Africa's busiest highways. The ongoing expansion project, initiated in 2013, aims to widen the road to six lanes, improve drainage, and enhance safety. Accurate topographic mapping and engineering surveys were critical for planning and execution, given the corridor's complex terrain, including urban settlements, wetlands, and hilly areas (*Ogunlesi, 2018*).

Fig 2 Case study of Lagos-Ibadan Expressway

METHODOLOGY

The project employed a combination of RTK GPS and Total Station for topographic mapping and engineering surveys, conducted between 2017 and 2019. The methodology included:

Geodetic Control Establishment: Surveyors used static GPS to establish a geodetic control network along the corridor, with 50 control points spaced at 2-km intervals. These points provided a reference framework with ±2 cm accuracy.

Topographic Mapping: RTK GPS receivers collected elevation and feature data to create a DEM and topographic map of the 127.6-km corridor. Survey teams used Trimble R10 GNSS receivers, achieving centimeter-level accuracy. GPS data was supplemented by Total Station for areas with signal obstructions, such as urban sections in Lagos.

Construction Staking: RTK GPS guided staking for road alignment, drainage systems, and bridge foundations. Mobile GPS units on graders ensured precise grading, reducing material waste.

Integration with GIS: GPS data was integrated into ArcGIS to produce a digital cadastral map, identifying encroachments and supporting land acquisition processes. This was critical in densely populated areas like Shagamu, where property disputes were common.

RESULTS

The survey achieved the following outcomes:

Accuracy: The topographic map had a horizontal accuracy of ±3 cm and vertical accuracy of ±5 cm, meeting Nigeria's Survey Coordination Act requirements.

Efficiency: GPS reduced survey time by 40% compared to traditional methods, completing the 127.6-km corridor mapping in three months.

Cost Savings: By using GPS-guided machinery, the project saved approximately 25% on grading costs, with a reported reduction of 15,000 cubic meters of excess material (*Roberts et al., 2020*).

Land Management: The GIS-based cadastral map resolved 80% of land disputes by clearly delineating boundaries, supporting compensation processes for affected communities.

Challenges

Signal Obstructions: Urban areas in Lagos caused multipath errors due to high-rise buildings. Surveyors mitigated this by using multi-constellation GNSS (GPS, GLONASS, and Galileo) and Total Station in affected zones (*Grejner-Brzezinska et al., 2011*).

Limited CORS Infrastructure: Nigeria's sparse CORS network, with only a few stations in Lagos, required the project to establish temporary base stations, increasing costs.

Geoid Model Limitations: Converting GPS ellipsoidal heights to orthometric heights was challenging due to the lack of a precise local geoid model. Surveyors used the EGM2008 global geopotential model, achieving acceptable but not optimal accuracy.

Logistical Constraints: Poor internet connectivity in rural sections hindered real-time data processing, requiring post-processing in some areas.

Implications for Nigeria

The Lagos-Ibadan Expressway project demonstrates GPS's transformative potential in Nigeria's infrastructure development. It highlights the need for a national CORS network, as advocated by the Nigerian Institution of

Surveyors, to support real-time corrections and reduce reliance on temporary base stations. The project also underscores the importance of integrating GPS with GIS for land management, a critical issue in Nigeria's rapidly urbanizing regions.

Challenges in GPS-Based Surveying in Nigeria

Signal Obstructions

Nigeria's urban centers, like Lagos, and dense forests, like those in Cross River State, cause signal obstructions. Multi-constellation GNSS mitigates this, but coverage remains limited in remote areas (*Grejner-Brzezinska et al., 2011*).

Multipath Errors

Reflections from buildings and water bodies introduce multipath errors. Advanced receivers with mitigation algorithms are effective but costly for small-scale surveyors in Nigeria (*Braasch, 1996*).

Atmospheric Interference

Ionospheric and tropospheric delays affect GPS accuracy. Dual-frequency receivers and real-time atmospheric modeling are solutions, but their adoption is limited by cost and expertise (*Hofmann-Wellenhof et al., 2008*).

Infrastructure and Cost

Nigeria's limited CORS infrastructure and high cost of RTK GPS equipment hinder widespread adoption. Training surveyors to use GPS effectively also requires investment, a challenge for small firms.

Geoid Model Accuracy

The lack of a precise local geoid model complicates height conversions, critical for engineering surveys. Projects like the Lagos-Ibadan Expressway rely on global models, which may introduce errors.

Advancements and Future Trends

Multi-Constellation GNSS

Combining GPS with GLONASS, Galileo, and BeiDou improves accuracy and satellite availability, critical for Nigeria's challenging terrains (*Cai et al., 2015*).

Drone and LiDAR Integration

GPS-equipped drones and LiDAR systems enhance topographic mapping in Nigeria's remote areas. For example, drones were used in Bauchi for topographic surveys, reducing fieldwork time by 50%.

Cloud-Based RTK Networks

Cloud-based RTK networks provide real-time corrections without local base stations, a potential solution for Nigeria's CORS limitations (*Rizos et al., 2012*). The Nigerian Institution of Surveyors' call for a National Geospatial Data Infrastructure could facilitate this.

Autonomous Surveying

Autonomous drones and rovers equipped with GPS are emerging globally and could address Nigeria's logistical challenges, improving efficiency in large-scale projects (*Nex & Remondino, 2014*).

DISCUSSION

GPS has revolutionized topographic mapping and engineering surveys in Nigeria, as demonstrated by the Lagos-Ibadan Expressway project. Its ability to deliver high accuracy, reduce survey time, and integrate with GIS supports sustainable development in a country facing rapid urbanization and infrastructure demands. However, challenges like limited CORS infrastructure and geoid model accuracy highlight the need for investment in geospatial infrastructure.

Economically, GPS reduces project costs by minimizing fieldwork and material waste. Environmentally, it supports precise land-use planning, critical for Nigeria's flood-prone and deforested regions. Socially, GPS aids in resolving land disputes, a significant issue in Nigeria's urban and rural areas. Future research should focus on developing a national CORS network, improving local geoid models, and training surveyors to maximize GPS adoption.

CONCLUSION

GPS is a cornerstone of modern topographic mapping and engineering surveys in Nigeria, offering precision, efficiency, and scalability. The Lagos-Ibadan Expressway case study illustrates its practical benefits and challenges, emphasizing the need for infrastructure improvements like a national CORS network and local geoid models. As Nigeria invests in geospatial technologies, GPS will play a pivotal role in supporting infrastructure development, environmental management, and sustainable land administration.

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