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Perspectives on AI-assisted GPS/GNSS Research: Trends, Challenges, and Opportunities

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Abstract

Artificial Intelligence (AI) is playing a more important role in improving Global Positioning System (GPS)/Global Navigation Satellite System (GNSS) technology. Regular GPS/GNSS has issues like signal blockage, noise interference (e.g., multipath), and being easily tricked, especially in cities or inside buildings. Using machine learning, deep learning and various tools, AI offers powerful resources to comprehend, resolve, and predict the functioning of GPS in complicated scenarios. This discussion provides a comprehensive overview of AI-enhanced GPS research, covering topics such as signal prediction, spoofing detection, sensor fusion, and trajectory forecasting. With the domain of Recurrent Neural Networks (RNNs), LSTM (Long Short-Term Memory) networks can aid trajectory prediction of satellites and receivers with high accuracy. Furthermore, this paper highlights the challenges and future research avenues in the application of AI to geolocation systems.

Discipline: GPS Engineering, Spatial Technology, AI Application.

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1 Introduction

The Global Positioning System (GPS) is a modern technology transmitting signals for geolocation, navigation, and timing. A Global Navigation Satellite System (GNSS) is a combination of multiple satellite systems (Anantakarn & Witchayangkoon, 2019). In other words, GNSS may be a combination of two or more systems of US GPS, Russian GLONASS, European Galileo, Chinese BeiDou Compass, and Japanese QZSS systems. To pinpoint a location, four or more navigation satellites are required. At any geo-point, GNSS gives more available satellites than a single navigation system alone. Therefore, as with GPS, having more GNSS signals, receivers can fix their locations faster with even higher accuracy when compared to a single navigation system.

1.1 Constraints of Traditional GPS Techniques

To determine the user's location, conventional GPS depends on satellite signals utilizing the measurement of signals' travel time measured from the epoch of transmitting from in-view satellites to the epoch of receiving by a receiver. The GPS receiver employs this data to establish the user's position, speed, and time.

Although this technology has become widespread in smartphones, automobiles, and supply chain management, many limitations remain:

- Signal blockage (like urban canyons, tunnels, and thick forests)
- Multipath interference (when signals reflect off surfaces)
- Limited accuracy (about 5 meters for civilian uses based on civilian signals)
- Vulnerability to spoofing and jamming
- Dependence on satellite visibility

GPS/GNSS signals can sometimes be weak or affected by atmospheric interference. Also, in urban or indoor environments, many factors affect GPS/GNSS signals, such as satellite signal strength, multipath effects, and other random noise errors.

1.2 AI-Enhanced GPS/GNSS Research

From the above discussion, these constraints are really important in situations such as autonomous navigation or drone deliveries, where even small inaccuracies can lead to mission failure or safety risks. To increase reliability, accuracy, and strength of GPS/GNSS, AI and Machine Learning (ML) can provide tools to do so (Liu & Yang, 2019). This is particularly important for applications like emergency services and accurate mapping and surveying applications.

This research examines how AI technologies are changing GPS and navigation systems. The merging of AI and GPS/GNSS enhances precision, reliability. Also, this gives an understanding of the integration of multiple sensors. This can be applied to areas like self-driving cars, robotics, city planning, farming, and military applications.

This study looks into how AI is being used in GPS/GNSS research, focusing on important topics like signal/position prediction, detecting spoofing, sensor fusion, orbital interpolations/satellite positions and correction algorithms. Also, this study discusses the advantages, challenges, and future directions of AI-Aided GPS/GNSS.

2 Applications of AI in GPS/GNSS

AI-powered GPS methods use AI Machine Learning (ML) algorithms to analyze GPS data and enhance the precision of location identification. Various AI-powered GPS methods include:

2.1 GPS/GNSS Signal/Position Prediction

AI models can learn the time-based and location-based patterns from the analysis of GPS signals (Zheng, et al. 2018). Having this ability, it helps to predict where you might experience signal loss, like when you are in a tunnel or surrounded by tall buildings (urban canyons) (Ebrahimi et al. 2024). This can be used in situations like autonomous car driving, drone navigation, and tracking assets. Dabiri et al. (2019) applied semi-supervised deep learning technique based on GPS trajectory data.

2.2 Spoofing and Jamming Detection

Ahmed & Ahmed (2021) used Deep Learning (DL) techniques for GPS spoofing detection. Machine learning (ML) classifiers like Random Forest and Convolutional Neural Networks (CNNs) can identify unusual patterns in GNSS/GPS signals caused by spoofing or jamming. For instance, ML can identify fake signal injections that try to confuse navigation systems (Ghanbarzade & Soleimani, 2025).

2.3 GPS/GNSS + KF/EKF + Sensor Fusion + AI

Sensor fusion combines data from different sensors, including GPS/GNSS, accelerometers, and gyroscopes, to enhance the accuracy of the determined location (Groves, 2013). With Kalman Filters (KF) (Welch & Bishop, 1995)/Extended Kalman Filters (EKF) enhanced with Recurrent Neural Networks (RNNs), Deep Learning (DL) architectures can integrate GNSS/GPS data with inertial sensor data to enhance positioning accuracy in difficult environments (Chen & Pan, 2024; Xue, 2025). For instance, combined sensors using GNSS/GPS and AI help with indoor navigation for pedestrians. KF/EKF is a mathematical method that uses a series of prediction and correction steps to estimate a system's state from noisy GPS/GNSS data (Witchayangkoon, 2000). In GPS technology, KF/EKF improves the accuracy of location calculations by combining GPS data with other sensor information, such as readings from accelerometers and gyroscopes. DL algorithms, like neural networks and CNNs, can analyze GPS data to enhance the accuracy of the computed location. For example, a neural network can be trained on a dataset of GPS/GNSS measurements to learn the relationship between the GPS/GNSS data and the user's actual location.

2.4 Orbital Interpolations/Satellite Positions

Knowing precise satellite positions is important for positioning with GPS/GNSS. For general users, satellite positions are calculated from the satellite transmitted navigation message using the algorithm given in the Interface Control Document (ICD)/Interface Specification (IS-GPS-200D). Precise satellite is normally interpolated from the given epochs' IGS (International GNSS Service) ephemeris using the 9-point Lagrange Interpolation technique (Witchayangkoon, 2000). Recurrent Neural Networks (RNNs) excel at handling sequential/time series data, where the order of elements is crucial for understanding the information. With AI, deep learning, and LSTM (Long Short-Term Memory) networks can be used for satellite trajectory prediction to higher accuracy. LSTM is a type of RNNs.

2.5 GPS Error Correction

AI can learn from past GPS/GNSS data combined with correction signals like Differential Global Positioning System (DGPS) and Real Time Kinematic (RTK) to forecast and fix errors in real-time for high precision positioning, including precise point positioning (PPP) technology (Zhu, 2025; Witchayangkoon, 2000). Also, with AI, it is possible to delimit traditional correction methods (ionospheric models, tropospheric models, multipath, and other random noise errors).

3 Advantages of AI-Aided GPS/GNSS

AI-assisted GPS/GNSS research has gained significant attention in recent years, with various perspectives on its potential benefits. Some of the key perspectives are discussed.

To enhance accuracy, research on AI-assisted GPS/GNSS could boost the accuracy of GPS/GNSS location calculations by integrating GPS/GNSS data with additional sensor information, like accelerometer and gyroscope readings (Welch & Bishop, 2004).

For greater resilience, AI-assisted GPS research can enhance the resilience of GPS systems by mitigating the impact of satellite signal strength, multipath effects, and interference from various sources (Liu & Yang, 2019).

To improve effectiveness, AI-assisted GPS research can enhance the effectiveness of GPS systems by minimizing the necessity for manual calibration and refining the accuracy of location calculations (Zhang & Li, 2020).

Samanta et al. (2025) use the ESP32 CAM, a GPS module, and TinyML to find the location of natural disasters or emergencies in real-time.

4 Challenges in AI-Aided GPS/GNSS

For AI-aided GPS/GNSS, there are challenges to consider. In terms of data quality, it is crucial to have high-quality data to properly train and validate ML models. This is challenging in areas with limited satellite coverage (Li & Zhang, 2020a).

For interpretability, AI-assisted GPS research is difficult with complex ML models. This makes it hard to understand the fundamental mechanisms and decision-making processes (Samek & Montavon, 2019). For security, Research on AI-assisted GPS is likely to introduce new security risks, such as the potential for hacking and spoofing GPS signals (Li & Zhang, 2020b).

Almadhor et al. (2025) used a compact tiny deep learning architecture (CTDNN-Spoof) to identify and classify multiple types of GPS spoofing attacks in small UAVs. The findings emphasize how effective the model is at reducing GPS spoofing risks in UAVs. Their creative method offers a scalable, real-time way to improve UAV security, outperforming conventional techniques in accuracy and flexibility. More research is still needed.

Table 1 highlights several challenges in AI-aided GPS/GNSS. Table 2 emphasizes AI-aided GPS/GNSS technology.

Table 1: Challenges in AI-aided GPS/GNSS.

Challenge	Description
Data Quality	GPS/GNSS data may be incomplete or noisy; preprocessing is critical.
Ground Truth	Accurate positioning data is needed for supervised learning models.
Real-Time Processing	AI models must run efficiently for real-time GPS/GNSS applications.
Generalization	Models must function well across diverse environments (urban, forest, rural, etc.).
Explainability	Interpretable AI models are crucial for safety-critical GPS/GNSS applications.

Table 2: AI-aided GPS/GNSS.

Area	Role of AI	Methods
Signal Prediction	Fill in GPS/GNSS gaps or future positions	LSTM, GRU, Transformers
Spoofing/Jamming Detection	Detect malicious or fake GPS signals	CNNs, Anomaly Detection, CTDNN-Spoof
Sensor Fusion	Merge GPS/GNSS with IMU/Visual data for accurate positioning	Kalman Filter + Deep RNN
Error Correction	Compensate for multipath or ionospheric delay errors	Autoencoders, Time Series

5 Future Directions on AI-assisted GPS/GNSS Research

There are directions of AI-assisted GPS/GNSS research. AI can aid in GPS/GNSS constellation management, such as predicting satellite visibility, optimizing coverage dynamically. In terms of combining with other sensors, research on AI-assisted GPS can work together with other sensors (multimodal fusion) like cameras/drones, visual odometry, LiDAR, radar, IMU, and visual SLAM to enhance the accuracy and reliability in a complicated environment (Zhu 2025; Zhang & Li, 2020b). Also, with the creation of new algorithms and methods with AI, this can boost the accuracy and performance of GPS/GNSS systems (Liu & Yang, 2019b). AI can also help GPS/GNSS in new areas like self-driving cars and drones to enhance their navigation and control (Li & Zhang, 2020c). It can do self-supervised GPS/GNSS learning based on contrastive learning or sequence modeling without labeled ground truth. A lightweight AI model that requires low computation and power will make it more possible for real-time uses (Zhu 2025).

According to Zhu (2025), to boost the model's adaptability and ability to generalize to new environments, the system applies meta-learning and unsupervised learning. Additionally, cloud computing will be utilized to offer precise correction models, with the implementation of lightweight AI models to cut down on delays and lessen dependence on the cloud.

AI with 6G communication technology and cellular networks, as technology goes further from 5G, the ultra-low latency and high bandwidth features of the 6G network lay the groundwork for the low-cost real-time application of AI error correction algorithms, greatly enhancing positioning performance and system reliability in dynamic environments (Säily et al. 2021).

6 Conclusion

Artificial Intelligence is changing GPS/GNSS technology by making positioning systems smarter, more adaptable, and more resilient. It helps with things like predicting trajectories, detecting spoofing, and combining data from other sensors, which enhances both accuracy and reliability. This research examines the application of AI in GPS/GNSS studies, highlighting key areas such as signal and position forecasting, spoofing detection, sensor integration, orbital interpolation, satellite positioning, and correction algorithms.

Additionally, the study addresses the benefits, challenges, and prospects of AI-enhanced GPS/GNSS. Yet, to fully harness its capabilities, we need to tackle issues related to data, computing power, and understanding how it works.

7 Availability of Data and Materials

Data can be made available by contacting the corresponding authors.

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