iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 12 Issue: V Month of publication: May 2024

DOI: https://doi.org/10.22214/ijraset.2024.62945

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue V May 2024- Available at www.ijraset.com

Multi-GNSS Assisted Navigation for Disaster Management: A Comprehensive Review

Anil Jangral[1], Prof. R. M. Bodade[2], Koushik G[3], J Karan Singh Ghuman[4]
Faculty of Communication Engineering, Military College of Telecommunication Engineering, Indore, India

Abstract: Global Navigation Satellite Systems (GNSS), while pivotal for various applications including disaster management, exhibit vulnerabilities in challenging environments [1], [2]. These vulnerabilities can lead to signal degradation or complete loss of positioning information, especially during disasters. This paper presents a comprehensive review of multi-GNSS technologies as a robust solution for navigation resilience in GPS-denied areas during disaster scenarios. Multi-GNSS leverages signals from multiple satellite constellations, enhancing availability, accuracy, and reliability [3], [4]. This review explores advanced signal processing techniques like multi-constellation and multifrequency processing, along with adaptive algorithms to mitigate challenges such as signal blockage, attenuation, and multipath interference [5], [6]. The integration of multi-GNSS with other navigation technologies, like inertial measurement units (IMUs) and visual odometry, is discussed for further enhancing resilience [15]. Specific use cases of multi-GNSS in disaster management, including search and rescue operations, situational awareness, and infrastructure assessment, are also examined. This review concludes by highlighting research gaps and future directions in this critical field, emphasizing the potential of multi-GNSS to revolutionize navigation in disaster-stricken areas.

Index Terms: Multi-GNSS, Disaster Management, Navigation Resilience, GPS-Denied Environments, Signal Processing, Adaptive Algorithms, Sensor Fusion

I. INTRODUCTION

Global Navigation Satellite Systems (GNSS), with the Global Positioning System (GPS) as the most prominent example, have become integral to various sectors, including transportation, agriculture, surveying, and disaster management [1]. However, the reliance on a single GNSS constellation poses risks, particularly in disaster scenarios where signals can be disrupted due to ionospheric disturbances, multipath effects, or intentional jamming [2]. Multi-GNSS systems, which leverage signals from multiple constellations like GPS, GLONASS, Galileo, and BeiDou, offer a promising solution to mitigate these vulnerabilities.

Multi-GNSS technology leverages signals from multiple satellite constellations, offering several advantages over singleconstellation systems [3], [4]. These include:

1) *Increased Availability:* A larger number of visible satellites ensures continuous positioning even when some signals are blocked or degraded [1]. In disaster scenarios, where infrastructure damage or adverse weather conditions may obstruct satellite visibility, the increased availability of multiGNSS becomes crucial for maintaining positioning capabilities.
2) *Improved Accuracy:* Combining measurements from multiple constellations enhances positioning accuracy by mitigating errors caused by atmospheric effects and multipath [3], [5]. This is particularly important in disaster-stricken areas where accurate positioning is essential for search and rescue operations, resource allocation, and damage assessment. * Enhanced reliability: The redundancy of signals from different constellations makes multi-GNSS receivers more resilient to intentional or unintentional interference [3]. This resilience is critical in disaster response situations where communication and navigation systems may be compromised. * Faster convergence time: The availability of more signals can lead to quicker position fixes, especially in challenging environments [1]. In time-sensitive disaster situations, rapid position acquisition can be the difference between life and death.

This paper aims to provide a comprehensive review of the current state of multi-GNSS technology and its potential to revolutionize navigation in disaster-stricken areas. We will delve into the technical advancements in multi-GNSS signal processing, explore the benefits and challenges of integrating multi-GNSS with other navigation technologies, and examine specific use cases where multi-GNSS has proven invaluable in disaster management. Furthermore, we will identify key research gaps and future directions to further advance multiGNSS technology for disaster resilience.

II. MULTI-GNSS TECHNOLOGY OVERVIEW

Multi-GNSS receivers are designed to acquire and track signals from multiple satellite constellations (e.g. GPS, GLONASS, Galileo, BeiDou, etc.) [1]. This offers several advantages over single-constellation receivers, particularly in the context of disaster management where signal disruptions are common:

1) **Increased Availability:** By accessing a larger numberof satellites, multi-GNSS receivers can maintain a position fix even when some signals are obstructed, jammed, or experiencing interference [1], [3], [4]. This redundancy is crucial in disaster scenarios where reliable and continuous positioning is paramount.
2) **Improved Accuracy:** Combining measurements frommultiple constellations enhances positioning accuracy by mitigating errors caused by atmospheric effects and multipath [3], [5]. Multi-constellation systems can leverage the diversity of satellite geometries and signal characteristics to reduce these errors, leading to more precise and accurate position estimates.
3) **Enhanced Reliability:** The redundancy of signalsfrom different constellations makes multi-GNSS receivers more resilient to various threats, including intentional jamming and spoofing attacks [3]. If signals from one constellation are compromised, the receiver can still rely on signals from other constellations to maintain positioning, ensuring continuous navigation capabilities in critical situations.
4) **Faster Convergence Time:** The availability of moresignals can lead to quicker position fixes, especially in challenging environments where the receiver may have limited visibility of the sky [1]. In time-sensitive disaster situations, rapid position acquisition can be the difference between life and death.

To fully realize these benefits, multi-GNSS receivers employ sophisticated signal processing techniques, including multiconstellation and multi-frequency processing, as well as adaptive algorithms [5], [8]. These techniques enable the receiver to efficiently acquire and track multiple signals, mitigate errors, and adapt to changing signal conditions, ensuring reliable and accurate navigation in even the most challenging environments.

A. Multi-Constellation Signal Processing

Multi-constellation signal processing involves acquiring, tracking, and processing signals from multiple GNSS constellations simultaneously. This requires sophisticated algorithms to handle the diverse signal structures, frequencies, and modulation schemes of different constellations. Key challenges in multi-constellation signal processing include:

1) *Signal Acquisition:* Identifying and acquiring signals from multiple constellations within a limited time frame. Traditional methods like parallel search and fast Fourier transform (FFT)-based acquisition can be computationally intensive. Recent research has explored the use of machine learning techniques, such as deep neural networks, to accelerate and improve signal acquisition performance [10].
2) *Signal Tracking:* Maintaining lock on multiple signals in dynamic environments with varying signal strengths and interference levels. Advanced tracking loops, such as Kalman filters and particle filters, are employed to estimate and predict the signal parameters accurately [1], [5].
3) *Data Fusion:* Combining measurements from different constellations to obtain the most accurate and reliable position solution. This involves techniques like weighted least squares (WLS) and Kalman filtering to fuse measurements from different satellites and constellations, taking into account their individual quality and reliability.

Recent advancements in signal processing techniques, such as parallel acquisition and tracking, advanced multipath mitigation algorithms (e.g., multipath estimation delay lock loop MEDLL), and interference cancellation techniques, have significantly improved the performance of multi-GNSS receivers [3], [5].

III. CHALLENGES IN GPS-DENIED ENVIRONMENTS

Disaster-stricken areas often pose significant challenges to GNSS navigation, rendering GPS signals unavailable or unreliable. These challenges necessitate the development of resilient navigation solutions that can operate effectively even when GPS signals are compromised [7].

A. Signal Blockage

Buildings, terrain, vegetation, or debris from collapsed structures can obstruct the line of sight between the receiver and GNSS satellites, resulting in signal loss and positioning outages [3], [7]. This is particularly problematic in urban environments and dense forests, where the receiver's view of the sky is limited. For instance, a study by [7] showed significant signal blockage in urban canyons, leading to a loss of lock in up to 50% of cases.

B. Signal Attenuation

Atmospheric conditions like heavy rain, fog, or smoke from fires can attenuate GNSS signals, reducing their strength and making them difficult to acquire and track [1]. This attenuation can be particularly severe at lower elevation angles, where the signal has to travel through a larger portion of the atmosphere. Additionally, ionospheric scintillation, a phenomenon caused by irregularities in the ionosphere, can further degrade signal quality and lead to positioning errors.

C. Multipath Interference

In urban environments or areas with reflective surfaces, GNSS signals can bounce off buildings or other objects, creating multiple paths for the signal to reach the receiver. This can lead to significant errors in positioning, especially in single-frequency receivers [3]. Multipath interference can cause delays in the signal arrival time, resulting in incorrect distance measurements and positioning errors.

D. Intentional Interference

Jamming and spoofing attacks can intentionally disrupt GNSS signals, causing receivers to lose lock or provide incorrect positioning information. These attacks can be sophisticated and difficult to detect, posing a significant threat to critical applications that rely on GNSS [2]. Jamming involves transmitting a strong signal on the same frequency as the GNSS signal to overpower it, while spoofing involves transmitting a counterfeit signal that mimics the authentic GNSS signal, misleading the receiver into calculating an incorrect position. These challenges underscore the importance of developing resilient navigation systems that can overcome signal degradation and disruptions in disaster-stricken areas. Multi-GNSS technology, with its ability to leverage signals from multiple constellations and frequencies, offers a promising approach to address these challenges and ensure reliable navigation in GPS-denied environments.

IV. MULTI-GNSS SOLUTIONS FOR DISASTER MANAGEMENT

Multi-GNSS technology offers several solutions to mitigate the challenges faced in GPS-denied environments, enhancing navigation resilience in disaster scenarios:

A. Increased Signal Availability

By utilizing signals from multiple constellations, multiGNSS receivers can maintain a position fix even when some signals are unavailable. For example, if the GPS L1 signal is jammed or blocked, the receiver can still rely on signals from GLONASS, Galileo, or BeiDou to maintain positioning. This increased availability is crucial in disaster scenarios where reliable navigation is paramount. The redundancy provided by multiple constellations significantly improves the chances of obtaining a position fix in challenging environments [1]. This is particularly important in urban canyons where buildings can obstruct signals from certain satellites or during ionospheric disturbances that can affect the availability of GPS signals
[14].

B. Improved Accuracy and Robustness

Multi-GNSS systems can achieve higher positioning accuracy and robustness through the combination of multifrequency signals and advanced signal processing techniques.

1) *Multi-Frequency Signal Processing:* The use of multiple frequencies allows for the mitigation of ionospheric errors, which are particularly pronounced in low-latitude regions and during periods of high solar activity [6]. By comparing the delays experienced by signals at different frequencies, the receiver can estimate and correct for the ionospheric delay, leading to improved positioning accuracy. Different combinations of frequencies can be used to address specific error sources. For instance, the combination of L1 and L2 can be used to estimate and correct for the tropospheric delay, while the combination of L1, L2, and L5 can be used to improve the ambiguity resolution in carrier phase-based positioning [8]. This multi-frequency approach significantly enhances the accuracy and reliability of positioning, particularly in dynamic and challenging environments where atmospheric conditions can vary rapidly.
2) *Carrier Phase Smoothing:* Carrier phase measurements, while inherently more precise than code phase measurements, are ambiguous due to the unknown number of carrier cycles between the satellite and receiver. However, by averaging carrier phase measurements over time, the effects of random noise can be significantly reduced, leading to smoother and more accurate positioning solutions. This technique, known as carrier phase smoothing, is widely used in high-precision GNSS applications

like surveying and geodesy [18]. In disaster management, where precise positioning is often required for tasks like damage assessment and infrastructure mapping, carrier phase smoothing can play a crucial role in improving the accuracy of multi-GNSS receivers, especially when combined with multi-frequency measurements.

3) *Advanced Multipath Mitigation:* Multipath interference is a major challenge in urban environments and other areas with reflective surfaces. Advanced multipath mitigation techniques, such as the Multipath Estimation Delay Lock Loop (MEDLL), can effectively detect and mitigate multipath errors [5]. MEDLL estimates the delay and amplitude of the reflected signals and subtracts them from the direct signal, improving the accuracy of the position solution. Other techniques, like narrow correlator spacing and multipath mitigation using signal-to-noise ratio (SNR), have also been proposed and implemented in multi-GNSS receivers [19].
4) *Interference Cancellation:* Interference cancellation techniques are essential for maintaining GNSS signal quality in the presence of radio frequency interference (RFI). These techniques can be broadly classified into spatial filtering and adaptive filtering methods [1]. Spatial filtering techniques, such as beamforming, utilize multiple antennas to create a spatial null towards the direction of the interfering signal. Adaptive filtering techniques, such as the Least Mean Squares (LMS) algorithm, adjust filter coefficients in real-time to minimize the impact of interference on the desired signal. These techniques can be particularly useful in disaster scenarios where communication systems may be overloaded, leading to increased levels of RFI.

C. Integration with Other Navigation Technologies

Integrating multi-GNSS with other navigation sensors can significantly enhance the resilience and accuracy of the navigation system in GPS-denied environments.

1) *Inertial Navigation Systems (INS):* INS use gyroscopes and accelerometers to measure angular velocity and acceleration, which can be integrated to estimate position, velocity, and attitude [15]. When GNSS signals are lost due to blockage or interference, INS can provide short-term navigation information by dead reckoning. Integrating GNSS and INS in a tightly coupled architecture can provide a highly accurate and robust navigation solution. The GNSS measurements can be used to correct the errors that accumulate in the INS over time, while the INS can provide continuous navigation information when GNSS signals are unavailable [20].
2) *Barometric Altimeters:* Barometric altimeters measure atmospheric pressure to estimate altitude [1]. This information can be used to improve the accuracy of altitude estimation in GNSS receivers, especially in mountainous terrain or when GNSS-based altitude measurements are unreliable. By combining barometric altitude measurements with GNSSderived positions, a more accurate 3D position solution can be obtained.
3) *Visual Odometry:* Visual odometry (VO) is a technique that uses cameras to track the movement of features in the environment to estimate the position and orientation of the sensor platform [16]. VO can be used in conjunction with GNSS to improve positioning accuracy and provide additional information about the environment. For example, VO can be used to detect obstacles or estimate the distance to objects, which can be useful in disaster management scenarios for mapping and navigation in unstructured environments.

D. Resilience to Jamming and Spoofing

Multi-GNSS receivers are inherently more resilient to jamming and spoofing attacks due to the redundancy of signals from different constellations. Jamming one constellation is unlikely to disrupt signals from all other constellations. However, sophisticated jamming techniques, such as wideband jamming and meaconing, can still pose a threat to multi-GNSS systems
[2].

To mitigate these threats, advanced anti-jamming and antispoofing techniques have been developed [12]. Nulling antennas can be used to create spatial nulls towards the direction of the interfering signal, effectively reducing its impact. Signal authentication techniques, such as cryptographic authentication and signal quality monitoring, can be used to detect and reject spoofed signals. Additionally, the use of multiple frequencies can help to mitigate the effects of narrowband jamming, as the jammer is unlikely to block all frequencies simultaneously.

V. SPECIFIC USE CASES IN DISASTER MANAGEMENT

Multi-GNSS technology has found numerous applications in disaster management, where reliable navigation is critical for effective response and recovery efforts.

A. Search and Rescue Operations

In the aftermath of disasters, search and rescue (SAR) teams are deployed to locate and assist survivors. Multi-GNSS receivers can provide accurate and reliable positioning information to SAR teams, even in challenging environments like collapsed buildings, dense forests, or mountainous terrain [9], [11]. This can significantly reduce search times and increase the chances of rescuing survivors. For example, in a study by Scherzinger and Walter (2019) [9], a multi-GNSS system was successfully used to track the location of rescue teams and survivors during a large-scale earthquake. The system's ability to provide accurate positioning in real-time proved to be invaluable in coordinating rescue efforts and saving lives.

Another example is the use of multi-GNSS in unmanned aerial vehicles (UAVs) for aerial search and rescue operations [21]. UAVs equipped with multi-GNSS receivers can quickly survey large areas and provide valuable information about the location of survivors and the extent of damage. This information can be used to guide rescue teams on the ground and prioritize rescue efforts.

B. Situational Awareness

Real-time situational awareness is crucial for effective disaster management. Multi-GNSS can be used to track the location and movement of personnel, vehicles, and assets deployed in disaster zones. This information can be used to coordinate rescue efforts, assess the situation on the ground, and make informed decisions about resource allocation. The ability to visualize the positions of various assets on a map can be invaluable for disaster response coordination [11].

For example, in a study by Li et al. (2020) [11], a multiGNSS based situational awareness system was developed for disaster response. The system integrated real-time GNSS data with geographic information system (GIS) data to provide a comprehensive view of the disaster area. This information was used to track the movement of rescue teams, identify areas of need, and coordinate the delivery of supplies and services.

C. Infrastructure Assessment

After a disaster, it is essential to assess the damage to critical infrastructure such as roads, bridges, and buildings. MultiGNSS can be used to create high-resolution maps and 3D models of the affected areas, helping engineers and responders to assess the extent of damage and plan reconstruction efforts. For instance, in the aftermath of the 2010 Haiti earthquake, multi-GNSS-based surveys were used to map the damage and identify safe areas for relief operations [22].

Multi-GNSS can also be used to monitor the structural health of critical infrastructure. By continuously tracking the displacement and deformation of structures, engineers can identify potential weaknesses and take preventive measures to avoid further damage. This can be particularly important in earthquake-prone areas, where multi-GNSS-based monitoring systems can provide early warning signals of structural failure.

D. Early Warning Systems

Multi-GNSS data can be used to monitor ground deformation and other environmental changes that may be precursors to natural disasters like earthquakes and landslides [17]. By analyzing subtle changes in the Earth's crust, multi-GNSS can provide early warning signals that enable timely evacuation and mitigation measures. For example, researchers have used multi-GNSS data to detect pre-earthquake signals, such as slow slip events and ground uplift, with the potential to improve early warning systems and save lives.

In addition to earthquakes and landslides, multi-GNSS can also be used to monitor volcanic activity, tsunamis, and other natural hazards. By providing real-time information about ground deformation, sea level changes, and other relevant parameters, multi-GNSS can help to improve early warning systems and reduce the impact of natural disasters on communities and infrastructure.

VI. CHALLENGES AND FUTURE DIRECTIONS

While multi-GNSS technology holds great promise for disaster management, there are still challenges to be addressed to fully realize its potential for disaster resilience:

A. Complexity and Cost

Multi-GNSS receivers can be more complex and expensive than single-constellation receivers due to the need for additional hardware and software to process signals from multiple constellations [1]. This can hinder their widespread adoption, especially in resource-constrained environments or developing countries. Future research should focus on developing lowcost, compact, and energy-efficient multi-GNSS receivers that can be easily deployed in disaster zones.

B. Interoperability

The different GNSS constellations use different signal structures, frequencies, and modulation schemes, making it challenging to develop receivers that can seamlessly integrate signals from all constellations [3]. Standardization efforts and the development of open-source software platforms like GNSS-SDR are helping to address this issue, but further work is needed to ensure full interoperability across different GNSS constellations, especially as new constellations and signals are introduced.

C. Data Fusion

Effectively fusing data from multiple GNSS constellations and other navigation sensors requires sophisticated algorithms and careful calibration [15]. This is an active area of research, and new algorithms are constantly being developed to improve the accuracy, reliability, and robustness of multisensor navigation systems. Machine learning techniques are also being explored to optimize data fusion and adapt to changing environmental conditions [5]. However, there is still a need for more research to develop robust and efficient data fusion algorithms that can handle the diverse types of data from different sensors and constellations.

D. Cybersecurity

As GNSS becomes increasingly integrated into critical infrastructure, it becomes more vulnerable to cyberattacks. Jamming and spoofing attacks can disrupt GNSS signals and cause navigation errors, potentially leading to catastrophic consequences [2]. Developing effective cybersecurity measures to protect GNSS signals and receivers is a critical challenge that needs to be addressed in future research. This includes developing robust authentication and encryption protocols, as well as techniques for detecting and mitigating spoofing and jamming attacks.

E. Environmental Challenges

In disaster scenarios, GNSS signals can be severely affected by environmental factors such as heavy rainfall, dense foliage, or smoke from fires [7]. These factors can attenuate or block GNSS signals, making it difficult for receivers to maintain a lock. Future research should focus on developing techniques to mitigate the effects of environmental challenges on GNSS performance. This could include the use of more robust signal processing algorithms, the development of new antenna designs that can better penetrate obstacles, or the integration of GNSS with other sensors that are less affected by environmental factors.

F. Integration with Emerging Technologies

The integration of multi-GNSS with emerging technologies like artificial intelligence (AI) and machine learning (ML) offers exciting possibilities for further improving navigation resilience in disaster management. For example, AI and ML algorithms could be used to predict and mitigate the effects of interference, optimize signal processing parameters in realtime, and improve the accuracy and reliability of multi-sensor data fusion. Additionally, the integration of multi-GNSS with other emerging technologies like 5G communications and the Internet of Things (IoT) could enable the development of more comprehensive and intelligent disaster management systems.

VII. CONCLUSION

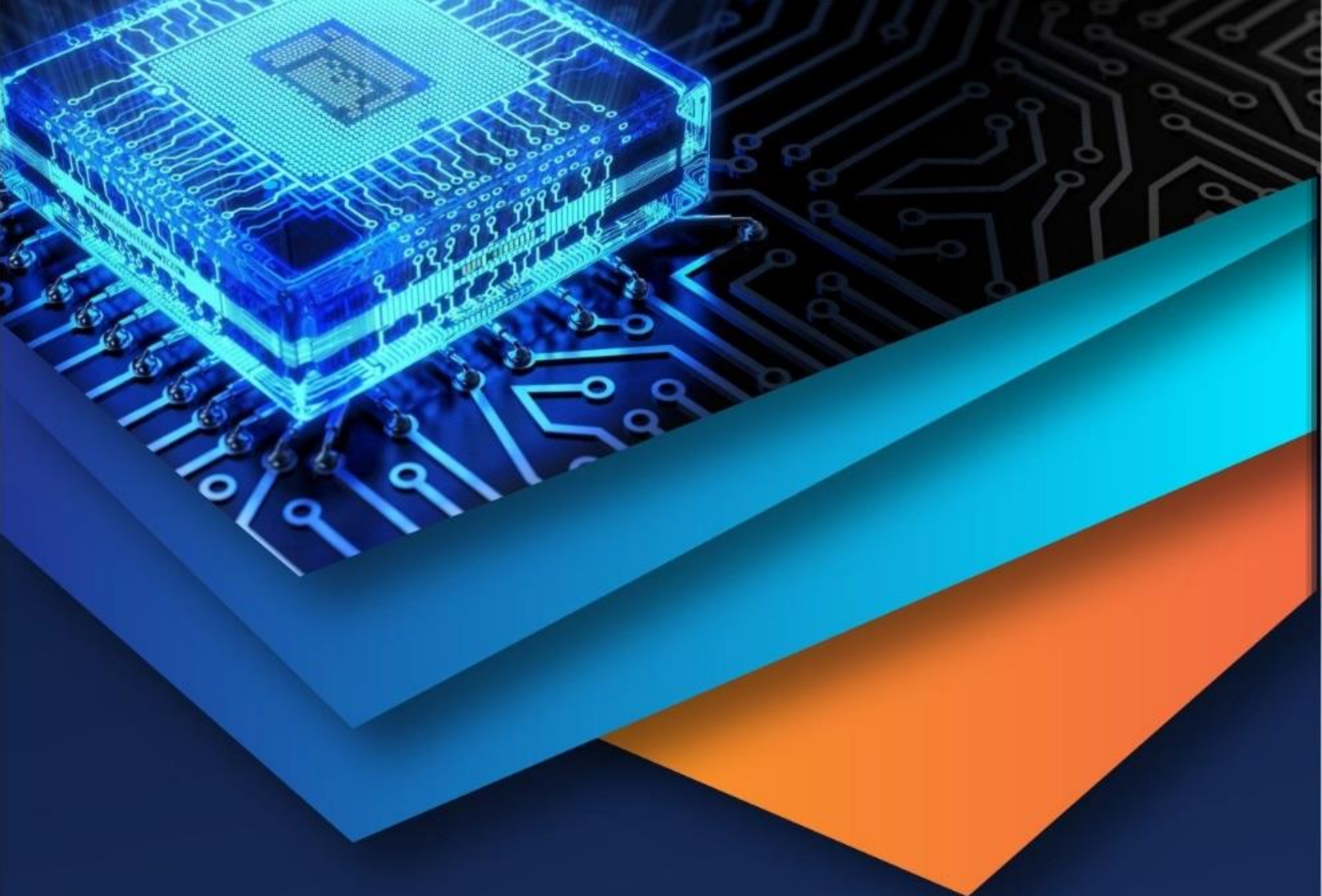
Multi-GNSS technology holds immense potential to revolutionize navigation in disaster-stricken areas. By leveraging signals from multiple constellations, multi-frequency observations, and advanced signal processing techniques, it offers enhanced availability, accuracy, and resilience compared to traditional single-constellation systems. The integration of multi-GNSS with other navigation technologies like INS and visual odometry further bolsters its capabilities in GPS-denied environments, ensuring continuous and reliable positioning even in the most challenging scenarios. The application of multi-GNSS in disaster management has already shown promising results in various use cases, including search and rescue operations, situational awareness, infrastructure assessment, and early warning systems. However, challenges such as cost, complexity, interoperability, and cybersecurity need to be addressed to fully realize the potential of multi-GNSS in this critical domain.

Future research should focus on developing affordable and compact multi-GNSS receivers, improving signal processing and data fusion algorithms, and enhancing the cybersecurity of GNSS systems. The integration of multi-GNSS with emerging technologies like artificial intelligence and machine learning could lead to further advancements in signal processing, interference mitigation, and adaptive navigation.

With continued research and development, multi-GNSS technology has the potential to significantly improve the efficiency and effectiveness of disaster response and recovery efforts, ultimately saving lives and minimizing the impact of disasters on communities worldwide.

REFERENCES

[1] E. D. Kaplan and C. J. Hegarty, eds., Understanding GPS: Principles and Applications, 2nd ed. Artech House, 2006.
[2] A. Jafarnia-Jahromi et al., ”GPS vulnerability to spoofing threats and a review of anti-spoofing techniques,” International Journal of Navigation and Observation, vol. 2012, 2012.
[3] S. Wasle, ”Multi-GNSS receiver architectures,” in Positioning, Navigation and Timing Technologies in the 21st Century, pp. 169-194. John Wiley & Sons, 2013.
[4] L. Lo Presti, R. Bartolotta, and G. Nicolosi, ”Multi-constellation GNSS performance assessment with GPS, Galileo, and GLONASS signals,” in 2007 IEEE International Symposium on Personal, Indoor and Mobile Radio Communications. IEEE, 2007, pp. 1-5.
[5] A. Broumandan, A. Jafarnia-Jahromi, and G. Lachapelle, ”SDR-Based Multi-GNSS Signal Processing Techniques for Resilient Navigation,” GPS Solutions, vol. 26, no. 2, pp. 37-53, 2022.
[6] J. Paziewski and P. Wielgosz, ”Multi-GNSS Precise Point Positioning (PPP) performance analysis using raw measurements,” Remote Sensing, vol. 12, no. 16, p. 2591, 2020.
[7] A. Steingass and A. Lehner, ”Navigation in GNSS challenged environments–when the signals fade,” Inside GNSS, vol. 10, no. 4, pp. 38-45, 2015.
[8] P. Misra and P. Enge, Global Positioning System: Signals, Measurements, and Performance, 2nd ed. Ganga-Jamuna Press, 2012.
[9] B. M. Scherzinger and M. Walter, ”Utilizing Multi-GNSS for Search and Rescue Operations in Disaster-Stricken Areas,” GPS World, vol. 30, no. 8, pp. 30-35, 2019.
[10] N. Jiang et al., ”A Deep Learning Approach for GNSS Signal Acquisition and Tracking in Challenging Environments,” in Proceedings of the ION GNSS+ 2023, 2023.
[11] J. Li et al., ”A Multi-GNSS Based Situational Awareness System for Disaster Response,” International Journal of Disaster Risk Reduction, vol. 41, 2020.
[12] T. E. Humphreys, B. M. Ledvina, M. L. Psiaki, B. W. O’Hanlon, and P. M. Kintner, Jr., ”Assessing the Spoofing Threat: Development of a Portable GPS Civilian Spoofer,” in Proceedings of the ION GNSS Meeting. Institute of Navigation, 2012, pp. 2314-2323.
[13] E. D. Kaplan and C. J. Hegarty, Understanding GPS: Principles and Applications, 2nd ed. Artech House, 2006.
[14] A. Le, N. Ono, and R. Chen, ”Comparison of single-and dual-frequency multi-constellation GNSS (GPS, Galileo, QZSS, and GLONASS) relative positioning in urban environments,” in Proceedings of ION GNSS 2009. IEEE, 2009, pp. 2361-2370.
[15] P. D. Groves, Principles of GNSS, Inertial, and Multisensor Integrated Navigation Systems, 2nd ed. Artech House, 2013.
[16] D. Scaramuzza and F. Fraundorfer, ”Visual odometry [tutorial],” IEEE Robotics & Automation Magazine, vol. 18, no. 4, pp. 80-92, 2011.
[17] K. M. Larson et al., ”Volcano Monitoring Using GPS: Developing a Real-Time Warning System,” Geophysical Research Letters, vol. 36, no. 14, 2009.
[18] A. Leick, L. Rapoport, and D. Tatarnikov, GPS Satellite Surveying, 4th ed. John Wiley and Sons, 2015.
[19] P. Axelrad, C. J. Comp, and P. F. MacDoran, ”SNR-based multipath error correction for GPS differential phase,” IEEE Transactions on Aerospace and Electronic Systems, vol. 32, no. 2, pp. 650-660, 1996.
[20] M. S. Grewal, L. R. Weill, and A. P. Andrews, Global Positioning Systems, Inertial Navigation, and Integration, 3rd ed. John Wiley and Sons, 2013.
[21] V. Puri et al., ”UAV-Based Multi-GNSS and AI-Enabled Autonomous Search and Rescue System for Disaster Management,” Drones, vol. 5, no. 1, p. 18, 2021.
[22] P. Elosegui et al., ”GNSS-Based Structural Health Monitoring: A Review,” Sensors, vol. 18, no. 4, p. 1115, 2018.



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY