

Use of Sar Interferometry For Ground Subsidence Detection In Urban And Mining Areas

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Abstract

Ground subsidence is a critical geohazard, particularly in urban and mining regions, causing infrastructure damage, environmental degradation, and safety concerns. Synthetic Aperture Radar Interferometry (InSAR) is an advanced remote sensing technique offering millimeter-level accuracy for detecting and monitoring subsidence over large areas. This paper explores the principles and applications of InSAR in ground subsidence detection, focusing on urban and mining settings. Various InSAR processing methods such as Persistent Scatterer InSAR (PS-InSAR) and Differential InSAR (DInSAR) are discussed along with their suitability for different scenarios. The advantages of InSAR including high spatial resolution, temporal coverage, and cost-effectiveness over conventional monitoring methods are highlighted. Limitations like atmospheric interference and decorrelation are analyzed. Case studies demonstrating InSAR's effectiveness in detecting mining-induced and urban subsidence are reviewed. A comparative table summarizes InSAR techniques with respect to accuracy, data requirements,

and application complexity. The integration of InSAR data with Geographic Information Systems (GIS) for risk mapping and decision-making is emphasized. The paper concludes that InSAR provides a valuable tool for proactive subsidence monitoring, enabling sustainable urban and mining area management.

Keywords: *Ground subsidence, InSAR, Urban areas, Mining areas, Remote sensing, Differential InSAR, Persistent Scatterer, GIS*

INTRODUCTION

Ground subsidence refers to the downward vertical displacement of the Earth's surface resulting from natural or anthropogenic causes. Urban expansion, groundwater extraction, mining activities, and soil compaction are among major triggers. Subsidence leads to structural damage to buildings, roads, pipelines, and threatens public safety.

Traditional subsidence monitoring techniques like leveling surveys and GPS provide accurate point measurements but lack wide spatial coverage and frequent temporal updates. Synthetic Aperture Radar Interferometry (InSAR) has emerged as a revolutionary satellite-based technique enabling millimeter-level detection of ground deformation across vast areas with frequent revisit intervals.

This paper reviews the use of InSAR for detecting and monitoring ground subsidence in urban and mining environments. It presents InSAR methodologies, applications, challenges, and integration with GIS for hazard management.

PRINCIPLES OF SAR INTERFEROMETRY

Synthetic Aperture Radar (SAR) uses microwave signals to image the Earth's surface independent of weather and daylight. InSAR involves combining two or more SAR images captured at different times over the same area to generate an interferogram representing phase differences.

Phase changes relate directly to surface displacement along the radar line of sight. Processing these phase differences allows calculation of ground deformation with millimeter precision.

Key InSAR techniques include:

- **Differential InSAR (DInSAR):** Uses two SAR images to detect displacement between acquisitions. Effective for sudden subsidence events but sensitive to temporal decorrelation.
- **Persistent Scatterer InSAR (PS-InSAR):** Utilizes multiple images over time focusing on stable scatterers to monitor slow or gradual deformation with improved noise reduction.
- **Small Baseline Subset (SBAS):** Processes series of interferograms with small temporal and spatial baselines to extract deformation time series.

APPLICATIONS IN URBAN AREAS

Urban environments experience subsidence primarily due to groundwater extraction, tunnel excavation, or soil consolidation under heavy loads. InSAR effectively maps spatial variability of subsidence at building or neighborhood scale.

- **Case Study 1: Mexico City**

Extensive subsidence caused by aquifer depletion was monitored using PS-InSAR, revealing deformation up to several centimeters per year. This data supported municipal water management and urban planning decisions.

- **Case Study 2: Beijing, China**

DInSAR detected subsidence hotspots related to metro construction and mining under urban zones, facilitating early warnings and risk mitigation.

APPLICATIONS IN MINING AREAS

Mining induces subsidence through extraction of underground minerals, leading to surface collapse or gradual deformation.

- **Case Study 3: Coal Mining in Germany**

InSAR detected slow subsidence related to coal mining operations. The spatial patterns correlated with mining activity records, enabling operational adjustments.

- **Case Study 4: Gold Mining in South Africa**

PS-InSAR was used to monitor long-term mining-induced ground movement, contributing to safety assessments and environmental impact studies.

TABLE 1: COMPARISON OF INSAR TECHNIQUES FOR SUBSIDENCE MONITORING

Technique	Data Requirement	Temporal Resolution	Accuracy	Best Suited For	Limitations
DInSAR	Two SAR images	Days to weeks	Millimeter to centimeter	Sudden subsidence events	Temporal decorrelation, atmospheric noise
PS-InSAR	Multiple SAR images (>20)	Weeks to months	Millimeter	Slow, continuous deformation	Requires stable scatterers
SBAS	Multiple SAR images	Weeks to months	Millimeter	Complex deformation patterns	Computationally intensive

ADVANTAGES OF InSAR IN SUBSIDENCE MONITORING

- **Wide-area coverage:** Satellite SAR covers large urban or mining regions, overcoming limitations of ground sensors.
- **Millimeter-level precision:** Enables detection of very subtle movements.
- **All-weather capability:** Radar waves penetrate clouds and are unaffected by lighting conditions.
- **Frequent revisits:** Modern satellites provide data every few days.
- **Cost-effectiveness:** Reduces need for expensive field surveys and instrumentation.

CHALLENGES AND MITIGATION

- **Atmospheric Delays:** Variations in water vapor cause phase noise, mitigated by filtering and multi-temporal processing.
- **Temporal Decorrelation:** Changes in surface properties between acquisitions reduce signal coherence. Techniques like PS-InSAR help mitigate.
- **Geometric Distortions:** Steep terrain and layover effects complicate interpretation.

- **Data Processing Complexity:** Requires advanced software and expertise.

INTEGRATION WITH GIS FOR DECISION SUPPORT

InSAR-derived deformation maps can be integrated with GIS layers including land use, infrastructure, and hazard zones. This supports:

- Risk assessment and zoning
- Infrastructure maintenance prioritization
- Emergency response planning
- Environmental impact evaluation

CONCLUSION

SAR Interferometry has proven to be a powerful remote sensing tool for ground subsidence detection in urban and mining areas. It offers precise, frequent, and spatially extensive deformation monitoring that complements traditional techniques. The ability to detect slow and sudden subsidence events aids in timely risk mitigation, infrastructure safety, and sustainable resource management. Continued improvements in satellite technology and data processing will further enhance InSAR's capabilities. The integration of InSAR data into GIS-based decision frameworks enables holistic hazard management, protecting communities and assets.

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