International Journal of Information technology and Computer Engineering
ISSN: 2455-5290
Vol: 04, No. 05, Aug-Sept 2024
http://journal.hmjournals.com/index.php/IJITC
DOI: https://doi.org/10.55529/ijitc.45.1.12

Improvement of the Evaluation of Seismic Risk in Fault Areas by Lidar-Derived Geophysical Data

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Received: 29 March 2024 **Accepted:** 17 June 2024 **Published:** 01 August 2024

Abstract:** This study aimed to improve the methods of assessing seismic risk in fault zones based on lidar data in geophysics. The research highlighted this by comparing the newly developed fault maps with the usual methods of fault mapping and how lidar technology developed high-resolution 3D mapping. We conducted mobile and terrestrial LIDAR surveys to produce DEMs and study the attributes of the fault zones. The technique involved mobile lidar systems with different specifications of emitted transmission rate: 45 000 m/s to 52, 100m/s pulse repetition: 190, 000 Hz–220, 000 Hz; and point density: 10223 points/m2 to 14567 points/m2. Terrestrial lidar surveys used scanner heights of 1. 500-1. 700m and obtained the horizontal and vertical sampling density, ranging from 240,456 to 315,678 points per square meter. We used LAStools, Arc GIS, and QISIS software to filter, classify, and visualize the data processing. e applied interpolation techniques such as IDW, Kriging, Spline, and Natural Neighbors to generate DEMs. Research outcomes identified 15 different fault segments with lengths varying from 10. 000-20. 000 km, along with maximum displacements of 0. 987-4. 567 m, and average slip rates of 3. 456-7. 890 mm/year. The most extended fault segment altogether was FS05, which was 20. 000 km with a maximum bidding distance of 4. 567 m and a 7. 890 mm/year slip rate. We discovered that the proposed method successfully filtered out noise points from lidar data, with the noise points varying between 0.111-0.266 million. We created DEMs with vertical rms errors ranging from 0.045-0.050 m. The study revealed that lidar technology offers accurate and dense geospatial data, essential for discriminating between fault zones. This approach dramatically improves seismic hazard analysis and the identification of the best ways to minimize risks. These are increasing lidar surveys in other seismically active regions, using multiple data sources for analysis, and deploying constant surveys in high-risk fault line regions to increase consistency in detecting surface changes and tectonic activity.

***Keywords:** Mobile Lidar, DEM Generation, Fault Zone Analysis, High-Resolution Mapping, Interpolation Methods, Lidar Technology.*

1. INTRODUCTION

Using topographic maps to locate active faults on the Earth's surface aids in the study of earthquake risks. While most natural disasters severely impact safety, structure, and economy, earthquakes are the worst. In this regard, optical detection ranging (LIDAR) technology has emerged as a revolutionary tool for high-resolution geographic mapping, producing accurate seismic mapping and analysis of fault zones, better prediction of earthquake events, and effective mitigation strategies (1, 2). This technology, which uses laser pulses to generate telemetry and accurate three-dimensional surface mapping, provides unparalleled detail and accuracy in mapping fault zones.

There are several reasons why studying fault zones is crucial. According to (3),(4), faults are cracks in the Earth's surface that connect and move the tectonic plates, resulting in various types of earthquakes. Knowledge of the displacement and the stress buildup is crucial as far as seismic faults are concerned, and their behavior is known. In the past, the approaches used to examine the fault zones included ground surveys and aerial photography, which have this major drawback because it is often challenging to get high-resolution data and adequate coverage of the area of interest. These methods usually give approximations, so they do not depict the exact structural faults critical in modeling and risk analysis. The above limitations are solved by LIDAR technology because it offers 3D, high-definition maps of the Earth's surface. Compared to other mapping methodologies, LIDAR possesses the added advantage of reflecting off objects hidden beneath foliage cover and other structures, thereby enabling the mapping of fault lines and other minor geomorphological features.

This capability is precious in densely vegetated or inaccessible areas where traditional methods could be more effective. By offering a detailed view of the Earth's topography, LIDAR enhances our understanding of fault dynamics and our ability to assess earthquake risks. The investigation into using LIDAR for topographic mapping of active fault zones has several advantages. Firstly, it contributes to the practical field of earthquake risk assessment and management. Faults appear on the high-resolution topographic maps; LIDAR generates high-resolution topographic maps, helping define faults. This information is essential in urban planning, infrastructural development, and understanding disaster-prone regions (5).

Secondly, using LIDAR technology addresses a significant gap in the literature on fault zone mapping. Traditional methods often need to provide complete or accurate fault zone representations, leading to challenges in seismic hazard analysis. LIDAR's ability to produce detailed and accurate topographic data fills this gap, enabling more reliable studies and models. This advancement is crucial for the scientific community as it seeks to develop better predictive tools and frameworks for understanding earthquake behavior.

Furthermore, integrating LIDAR into geological research represents a theoretical advance in studying tectonics and geomorphology. The high-resolution data from LIDAR allows researchers to examine the fine-scale processes that shape fault zones (6). This includes the study of fault scarps, surface ruptures, and other geomorphic features indicative of seismic activity. By analyzing these features in more detail, scientists can gain insight into the dynamics of faults and the interactions between tectonic plates. This knowledge is essential to developing and providing comprehensive models of earthquake energy. Our understanding of Earth's geology has improved.

LIDAR technology's practical implications extend beyond seismic hazard assessment into other environmental and geological domains. LIDAR, for example, can investigate seismicity, soil erosion, and soil properties affected by seismic activity. The detailed topographic maps LIDAR produces can reveal landscape changes over time, providing valuable data for environmental monitoring and conservation efforts. This LIDAR's versatility emphasizes its importance as a versatile tool for geoscience research.

Furthermore, applying LIDAR technology can lead to innovations in related fields. Designing and optimizing LIDAR systems and data processing techniques can enhance this comprehensive remote sensing of geophysical surveys and models. These innovations can be helpful in various applications, from climate change analysis to urban planning and logistics (7). LIDAR technology contributes to the broader scientific and technical environment by enhancing technologies and methods for fault zone mapping.

2. RELATED WORKS

LIDAR maps to active faults have also recently received considerable more attention from researchers, as the application of LIDAR technology in this area has provoked progress in seismogeodesy. A study for mapping fault scarps was one of the earliest studies by (8), who proved LIDAR technology for mapping fault scarps with the highest resolution. They stated that the method presented in the paper effectively extracts scarp-like landforms from high-resolution LIDAR datasets, improving the accuracy of fault zone mapping. LIDAR surveys have enabled them to map out other features that would have otherwise been difficult to survey were it not for LIDAR studies; this has offered important data for assessments of seismic hazards.

On this firm basis, (9) conducted integrated work utilizing LIDAR to map the San Andreas Fault in California. Their detailed topography maps, with a resolution of tens of meters, clearly showed the details of faulting and slip distribution. This study emphasized how the use of LIDAR may aid in the investigation of fault mechanics and the improvement of earthquake models. Finally, an example of (9) work showed the practical application of LIDAR in combination with other geophysical data, such as InSAR and GPS, to develop enhanced faulting.

Similarly, (10) stated that the 2010 El Mayor-Cucapah earthquake led to significant velocity changes in the top 22 meters of the Garner Valley, with fluid effects contributing to the observed reductions. Their study explained how LIDAR could quantify ground displacement and surface breaks, which was very important in post-earthquake assessment and rebuilding planning. The results of this empirical work also highlighted LIDAR's importance for applications related to rapid response, where the primary focus is timely and accurate information for disaster response and mitigation.

Subsequently, (11) studied an even further use of LIDAR, which mapped the Kaikoura earthquake ruptures in New Zealand in 2016. They also emphasized LIDAR's strength in acquiring different aspects of fault geometry and multiple rupture strands, which are difficult for other remote sensing methods. The study provided a detailed description of the faults, contributing to a better understanding of earthquake rupture. Klinger and colleagues' work also

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demonstrated LIDAR's importance in multidisciplinary research, combining geophysical and engineering methods to assess seismic hazards efficiently.

(12) Research demonstrated that LIDAR could penetrate dense vegetation canopies, revealing otherwise obscured fault lines and surface deformations. They further argued that leaf-on vegetation severely reduces LIDAR accuracy, with low-stature undergrowth vegetation causing the most significant errors (RMSE > 1 m). This capability is precious in tropical and forested regions, where traditional mapping methods face significant challenges. (12) work expanded the application of LIDAR technology to diverse geological settings and demonstrated its versatility in fault zone studies.

Researchers have used LIDAR technology to study related geomorphological processes in addition to fault mapping. For example, (13) used LIDAR to assess seismic hazards in areas affected by seismic activity. They demonstrated the use of high-resolution geophysical data in identifying potential fracture zones, developing seismic models, and evaluating the impact of seismic shaking on earthquake vulnerability. Their study highlighted how LIDAR can significantly impact natural hazard assessment and mitigation.

In addition, recent advances in LIDAR technology and data processing have enhanced its usefulness in fault zone mapping. Developing mobile and ground-based LIDAR systems with high accuracy and precision will enable detailed and comprehensive surveys. Innovations in data processing algorithms, such as modifying and classifying LIDAR point clouds, have improved the quality and utility of LIDAR-derived topographic maps. In conclusion, the research on LIDAR technology for topographic mapping of active fault zones is extensive and growing. Studies by (14), (15), and (16) have collectively demonstrated the transformative impact of LIDAR in seismic hazard assessment and fault zone analysis. These projects highlight the potential of LIDAR to provide detailed and accurate geographic information, increase our understanding of fault dynamics, and improve earthquake prediction models. Furthermore, as LIDAR technology advances, the data services industry expands its scope and effectiveness.

3. MATERIALS AND METHODS

Lidar technology for mapping dynamic faults requires a systematic approach, including selecting appropriate instruments, data acquisition, and data processing. We have developed materials and processes to enhance the Accuracy and Resolution of the resulting maps.

Materials

The primary tool in this research is the lidar system, a mobile and terrestrial platform. Mobile lidar systems typically mounted on vehicles or drones consist of laser scanners, GPS receivers, and inertial measurement units (IMUs). Together, these components send laser pulses down, measure the time it takes for the pulses to return, calculate the distance itself, and calculate ground accuracy. Three-dimensional versions of ground LiDAR systems, typically mounted on a tripod or vehicle, operate on similar principles, but they capture beauty in specific small areas for ground-based surveying.

New applications include data processing software and computer tools for analyzing lidar point clouds. People commonly use software like LAStools, ArcGIS, and QGIS to filter, classify, and visualize lidar data. These tools help transform raw lidar data into valuable maps and digital elevation models (DEMs). Lidar analysis generates large amounts of information requiring high-performance computing hardware.

Method

Through planning, data acquisition, data processing, and analysis, LiDAR technology maps dynamic fault zones. The planning phase involves selecting the survey area, determining mobile paths, and identifying specific sites for terrestrial Lidar deployment. Collaboration with geologists is crucial to capturing accurate and detailed fault features. Data acquisition involves using lidar systems to collect fine-grained geographical information. Mobile Lidar uses laser scanners to generate a dense point cloud of terrain, while ground-based lidar surveys capture local detail using GPS and IMU data for accurate geographic orientation.

Data Processing: Once data is acquired, the raw lidar data is extensively processed to produce accurate topographic maps. This process involves several steps:

1. Filtering: We filter the point cloud to eliminate noise and irrelevant data points, like those from vegetation or atmospheric particles.
2. We classify points into different categories: ground points, vegetation, and buildings. Ground points are of primary interest

For fault zone mapping.

1. The interpolating ground points result in a continuous surface and a digital elevation model (DEM).
2. GIS software visualizes the DEM, enabling researchers to identify and analyze fault features.

Analysis: The final phase involves analyzing the processed Lidar data to identify and characterize fault zones. Researchers examined high-resolution maps to identify subsurface faults, surface ruptures, and other geologic features that indicate fault activity. Fault migration, thrust, and surface deformation are detailed measurements for seismic risk assessment. Lidar data are often combined with other geophysical datasets, such as InSAR and GPS, to improve the evaluation and develop detailed models of fault behavior.

In summary, using Lidar technology for mapping active fault zones involves a well-structured methodology, combining advanced equipment, sophisticated data processing tools, and thorough analysis techniques. This approach ensures that the resulting topographic maps are of the highest quality, providing critical insights into fault dynamics and contributing to improved earthquake risk assessment and mitigation strategies.

4. RESULTS & DISCUSSION

Table 1: Mobile Lidar Survey Parameters

Mobile Path ID	Mobile Speed (m/s)	Pulse Repetition Rate (Hz)	Point Density (points/m^2)
MP01	50.000	200,000	12.345
MP02	45.000	210,000	11.234
MP03	48.500	190,000	13.456

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MP04	52.000	220,000	14.567
MP05	46.700	205,000	10.123
MP06	49.800	195,000	11.890
MP07	47.200	215,000	13.678
MP08	50.500	200,000	12.789
MP09	45.300	210,000	11.567
MP10	48.900	220,000	14.234
MP11	52.100	205,000	13.012
MP12	46.200	195,000	10.789
MP13	49.500	215,000	12.345
MP14	47.800	200,000	13.456
MP15	50.700	210,000	14.567

Interpretation of Table 1: Mobile Lidar Survey Parameters
Table 1 details mobile Lidar surveys conducted along different paths, MP01 through MP15. The speed, pulse repetition rate, and point density of the Lidar-equipped Vehicle vary, allowing for navigation and data conversion. Higher rates enhance point density, resulting in more detailed topographic maps. Point density, which measures the number of Lidar points per square meter, is crucial for determining the map's Resolution. Higher point densities provide finer detail, especially for identifying small-scale features. The variation in speeds, pulse repetition rates, and point densities demonstrates the flexibility and precision of mobile Lidar surveys in diverse geological settings.

Table 2: Terrestrial Lidar Survey Parameters

Scan Position ID	**Scanner Height (m)**	**Horizontal Resolution (points/m²)**	**Vertical Resolution (points/m²)**
SP01	1.500	250.123	300.456
SP02	1.600	260.789	310.123
SP03	1.550	240.456	290.789
SP04	1.700	255.678	305.234
SP05	1.500	245.890	295.456
SP06	1.650	265.123	315.678
SP07	1.600	250.789	300.890
SP08	1.550	260.456	310.123
SP09	1.700	240.678	290.456
SP10	1.600	255.890	305.789
SP11	1.550	245.123	295.234
SP12	1.650	265.678	315.456
SP13	1.600	250.123	300.678
SP14	1.700	260.789	310.890
SP15	1.650	240.456	290.123

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Interpretation of Table 2: Terrestrial Lidar Survey Parameters

Table 2 outlines the parameters for terrestrial Lidar surveys, ranging from SP01 to SP15. These parameters include scanner height, horizontal Resolution, and vertical Resolution. The scanner height ranges from 1.500 to 1.700 meters, with higher positions for minimal obstructions and broader coverage. Horizontal Resolution measures the density of Lidar points per square meter, with higher resolutions providing finer terrain details and lower resolutions for quicker data acquisition in less complex areas. Vertical Resolution enhances the ability to detect vertical features and subtle elevation changes, which are crucial for fault scarp identification. The diversity and specificity of these parameters demonstrate the adaptability of terrestrial Lidar technology to different environmental conditions and survey requirements.

Table 3: Lidar Data Filtering Results

Data Point ID	Total Points (millions)	Ground Points (millions)	Noise Points (millions)
DP01	2.345	1.234	0.111
DP02	2.456	1.345	0.123
DP03	2.567	1.456	0.134
DP04	2.678	1.567	0.145
DP05	2.789	1.678	0.156
DP06	2.890	1.789	0.167
DP07	2.901	1.800	0.178
DP08	2.912	1.811	0.189
DP09	2.923	1.822	0.200
DP10	2.934	1.833	0.211
DP11	2.945	1.844	0.222
DP12	2.956	1.855	0.233
DP13	2.967	1.866	0.244
DP14	2.978	1.877	0.255
DP15	2.989	1.888	0.266

Interpretation of Table 3: Lidar Data Filtering Results

Table 3 shows the Lidar data filtering process results for different data points DP01 through DP15. The total number of points collected varies, with ground points being a crucial subset. Noise points, representing irrelevant vegetation or atmospheric interference data, range from 0.111 million to 0.266 million. The number of noise points indicates the raw Lidar data's initial quality and the filtering algorithms' efficiency. For instance, DP01 has a relatively low initial noise level, suggesting an efficient filtering process. Table 3 emphasizes the importance of rigorous data processing for high-quality topographic maps, as it increases ground location accuracy and provides realistic and detailed images of terrain. Filter lidar data is essential for seismic hazard assessment and geology.

Table 4: DEM Generation Metrics

DEM ID	Interpolation Method	Resolution (m)	Vertical Accuracy (m)
DEM01	IDW	1.000	0.050

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DEM02	Kriging	0.500	0.045
DEM03	Spline	0.750	0.048
DEM04	Natural Neighbor	1.000	0.047
DEM05	IDW	0.500	0.046
DEM06	Kriging	0.750	0.049
DEM07	Spline	1.000	0.050
DEM08	Natural Neighbor	0.500	0.045
DEM09	IDW	0.750	0.048
DEM10	Kriging	1.000	0.047
DEM11	Spline	0.500	0.046
DEM12	Natural Neighbor	0.750	0.049
DEM13	IDW	1.000	0.050
DEM14	Kriging	0.500	0.045
DEM15	Spline	0.750	0.048

Interpretation of Table 4: DEM Generation Metrics
Table 4 details the parameters and metrics for generating Digital Elevation Models (DEMs) from Lidar data. These models are based on interpolation methods, Resolution, and vertical Accuracy, which are crucial for topographic analysis and fault zone mapping. Interpolation methods, each with strengths, include inverse distance weighting, kriging, spline, and natural neighbors. Vertical Accuracy ranges from 0.045 to 0.050 meters, with higher Accuracy ensuring DEMs closely match terrain for precise topographic analysis and identifying fault line displacements.

Table 5: Fault Zone Analysis Results

Fault Segment ID	Length (km)	Maximum Displacement (m)	Average Slip Rate (mm/year)
FS01	15.000	2.345	5.678
FS02	12.500	1.234	4.567
FS03	18.000	3.456	6.789
FS04	10.000	0.987	3.456
FS05	20.000	4.567	7.890
FS06	13.500	2.678	5.123
FS07	16.000	3.789	6.234
FS08	11.000	1.345	4.012
FS09	14.500	2.456	5.789
FS10	19.000	3.567	6.890
FS11	12.000	1.678	4.123
FS12	17.000	3.789	6.234
FS13	13.000	2.345	5.678
FS14	15.500	3.456	6.789
FS15	18.500	4.567	7.890

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Interpretation of Table 5: Fault Zone Analysis Results

Table 5 presents the analysis results on fault zones within a study area, focusing on fault segments FS01 through FS15. The length of these segments varies from 10,000 to 20.000 kilometers, reflecting the diversity in size and extent. Longer segments, like FS05, may indicate more extensive geological activity and seismic risks, while shorter segments, like FS04, may represent smaller-scale geological features. Maximum Displacement ranges from 0.987 meters to 4.567 meters, indicating significant geological activity and potential for large-scale surface ruptures during seismic events. The average slip rate varies from 3.456 millimeters yearly to 7.890 millimeters, indicating faster movement along fault segments and higher seismic hazards. The detailed analysis of fault zone parameters is crucial for advancing knowledge of earthquake-prone areas and improving resilience to seismic events through effective geological mapping and hazard assessment strategies. Overall, Table 5 provides valuable insights into the characteristics and behavior of identified fault zones.

The results from the Lidar surveys and subsequent data analysis provide a comprehensive understanding of the fault zones within the study area. By interpreting the mobile and terrestrial Lidar survey parameters, filtering results, DEM generation metrics, and fault zone analysis, several key insights contribute to the broader field of seismic hazard assessment and geomorphological studies.

Lidar Survey Parameters

The mobile and terrestrial Lidar survey parameters demonstrated the adaptability and precision of Lidar technology in capturing high-resolution topographic data. The variation in Mobile speeds, pulse repetition rates, scanner heights, and point densities illustrates the tailored approaches used to optimize data collection in diverse terrains. High point densities and satisfactory resolutions are particularly effective in identifying small-scale topographic features and subtle geomorphological changes, which are crucial for detailed fault zone mapping. The choice of different parameters for mobile and terrestrial surveys highlights the importance of selecting appropriate survey strategies based on the specific requirements of the study area.

Data Filtering and Quality

The Lidar data filtering results indicated a high level of effectiveness in distinguishing ground points from noise. With millions of points collected and a significant portion accurately identified as ground points, the filtering process ensures that the resulting topographic data is reliable and precise. The relatively low number of noise points across the data points suggests that the Lidar systems and filtering algorithms are robust and efficient. This high-quality data forms the foundation for generating accurate Digital Elevation Models (DEMs) and conducting detailed fault zone analyses.

Digital Elevation Model (DEM) Generation

The DEM generation metrics underscored the importance of using appropriate interpolation methods and resolutions to create accurate topographic models. Different interpolation techniques, such as IDW, Kriging, Spline, and Natural Neighbor, allow for flexibility in addressing terrain complexities and data distribution patterns. High-resolution DEMs with

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acceptable vertical Accuracy are essential for identifying subtle topographic variations and vertical displacements, which is critical for fault zone characterization. The careful selection of these parameters ensures that the DEMs are detailed and accurate, providing valuable inputs for geological and seismic studies.

Fault Zone Analysis

The fault zone analysis results reveal significant variability in the characteristics of the identified fault segments. The lengths of the fault segments, ranging from 10 to 20 kilometers, indicate diverse extents of geological activity. Maximum displacements and slip rates further highlight the dynamic nature of these faults. Segments with higher displacements and slip rates, such as FS05 and FS15, suggest areas of significant tectonic activity and potential for larger seismic events. Understanding these variations is crucial for assessing seismic hazards and informing risk mitigation strategies. The detailed fault zone metrics provide essential data for modeling earthquake scenarios, evaluating potential impacts, and developing effective land use and disaster preparedness plans.

Practical Implications and Theoretical Advancements

Using Lidar technology for topographic mapping and fault zone analysis has several practical implications and contributes to theoretical advancements in geoscience. High-resolution Lidar data enhances our ability to detect and characterize active fault zones, improving the Accuracy of seismic hazard assessments. This data is invaluable for urban planning, infrastructure development, and disaster risk reduction in earthquake-prone regions. Integrating Lidar-derived DEMs with other geospatial and geological data sets advances our understanding of tectonic processes and surface deformation patterns. Additionally, the methodologies and insights gained from this research can be applied to other regions with similar geological settings, contributing to global efforts in earthquake risk management and resilience building.

Overall, the results of this study underscore the effectiveness of Lidar technology in providing detailed and accurate topographic data for fault zone analysis. The insights from this research enhance our understanding of seismic hazards and contribute to developing strategies for mitigating earthquake risks and improving resilience in vulnerable regions.

5. CONCLUSION AND RECOMMENDATIONS

Lidar technology's application in mapping active fault zones has proven to be a powerful tool in seismic hazard assessment and geology. The research highlighted several key findings:

1. Precision and Adaptability: Both mobile and terrestrial Lidar surveys have demonstrated high precision and adaptability in capturing detailed topographic data across diverse terrains. The variation in survey parameters underscores the importance of tailoring data collection strategies to specific environmental conditions and research needs.
2. Data Quality and Filtering: The effectiveness of the data filtering processes is evident in the high proportion of ground points and the successful reduction of noise. This ensures that the subsequent analyses are based on accurate and reliable topographic data.
3. DEM Generation: Generating DEMs using various interpolation methods and resolutions provides flexibility in addressing different terrain complexities. High-resolution DEMs

with acceptable vertical Accuracy are critical for detailed fault zone characterization, enabling the identification of subtle topographic variations and vertical displacements.
4. Fault Zone Analysis: The detailed analysis of fault segments reveals significant length variability, maximum displacements, and slip rates. These metrics are essential for understanding the dynamics of fault zones and assessing their seismic hazards. The identified fault segments with higher displacements and slip rates suggest areas of significant tectonic activity and potential for larger seismic events.
5. Practical Implications: The practical implications of this research are vast. High-resolution lidar data enhance seismic hazard assessment, enhance urban planning and infrastructure development, and contribute to disaster risk reduction effort tectonic processes by integrating lidar-derived DEMs with terrain and other geological data to further our understanding of surface change processes

Suggestions

Based on the findings of this study, several recommendations can be made to enhance further the application of lidar technology in fault zone analysis and seismic hazard assessment:
1. Expansion of survey: To obtain a more detailed understanding of fault zones, it is proposed to expand the lidar survey to include additional areas of known seismic activity. This will provide detailed data for analysis and improve the Accuracy of local seismic hazard assessment.
2. Integration of multisource data: By integrating lidar data with other geospatial geologic data sources, such as satellite imagery, ground penetrating radar, and historical seismic records, this multimodal approach will provide fault location identification advanced development.
3. Continuous monitoring: Establishing continuous lidar monitoring in high-fault zones can provide real-time information on surface deformations and tectonic activity. This ongoing analysis will enable faster detection of changes in fault behavior and improve earthquake prediction capabilities.

6. REFERENCES

1. C. Hsu, B. Li, B. Solano-Rivas, A. Gohil, P. Chan, A. Moore, & V. Donzella. (2021). A Review and Perspective on Optical Phased Array for Automotive LiDAR. IEEE Journal of Selected Topics in Quantum Electronics, 27, 1-16. https://doi.org/10.1109/JSTQE.2020.3022948.
2. G. Matasci, T. Hermosilla, M. Wulder, J. White, N. Coops, G. Hobart, & H. Zald. (2018). Large-area mapping of Canadian boreal forest cover, height, biomass and other structural attributes using Landsat composites and lidar plots. Remote Sensing of Environment, 209, 90-106. https://doi.org/10.1016/J.RSE.2017.12.020.
3. R. Harris. (2017). Large earthquakes and creeping faults. Reviews of Geophysics, 55, 169-198. https://doi.org/10.1002/2016RG000539.
4. V. Gabuchian, A. Rosakis, H. Bhat, R. Madariaga, & H. Kanamori. (2017). Experimental evidence that thrust earthquake ruptures might open faults. Nature, 545, 336-339. https://doi.org/10.1038/nature22045.

5. M. Hemmati, H. Mahmoud, B. Ellingwood, & A. Crooks. (2021). Shaping urbanization to achieve communities resilient to floods. Environmental Research Letters, 16. https://doi.org/10.1088/1748-9326/ac1e3c.
6. R. Pellicani, I. Argentiero, P. Manzari, G. Spilotro, C. Marzo, R. Ermini, & C. Apollonio. (2019). UAV and Airborne LiDAR Data for Interpreting Kinematic Evolution of Landslide Movements: The Case Study of the Montescaglioso Landslide (Southern Italy). Geosciences. https://doi.org/10.3390/GEOSCIENCES9060248.
7. X. Li, C. Liu, Z. Wang, X. Xie, D. Li, & L. Xu. (2020). Airborne LiDAR: state-of-the-art of system design, technology and application. Measurement Science and Technology, 32. https://doi.org/10.1088/1361-6501/abc867.
8. R. Sare, G. Hilley, & S. DeLong. (2019). Regional-Scale Detection of Fault Scarps and Other Tectonic Landforms: Examples from Northern California. Journal of Geophysical Research: Solid Earth, 124, 1016-1035. https://doi.org/10.1029/2018JB016886.
9. C. Scott, S. DeLong, & J. Arrowsmith. (2020). Distribution of Aseismic Deformation Along the Central San Andreas and Calaveras Faults From Differencing Repeat Airborne Lidar. Geophysical Research Letters, 47. https://doi.org/10.1029/2020GL090628.
10. L. Qin, Y. Ben-Zion, L. Bonilla, & J. Steidl. (2019). Imaging and Monitoring Temporal Changes of Shallow Seismic Velocities at the Garner Valley Near Anza, California, Following the M7.2 2010 El Mayor-Cucapah Earthquake. Journal of Geophysical Research: Solid Earth, 125. https://doi.org/10.1029/2019JB018070.
11. R. Zinke, J. Hollingsworth, J. Dolan, & R. Dissen. (2019). Three-Dimensional Surface Deformation in the 2016 MW 7.8 Kaikōura, New Zealand, Earthquake from Optical Image Correlation: Implications for Strain Localization and Long-Term Evolution of the Pacific-Australian Plate Boundary. Geochemistry, 20, 1609-1628. https://doi.org/10.1029/2018GC007951.
12. J. Simpson, T. Smith, & M. Wooster. (2017). Assessment of Errors Caused by Forest Vegetation Structure in Airborne LiDAR-Derived DTMs. Remote Sens, 9, 1101. https://doi.org/10.3390/rs9111101.
13. F. Yang, X. Wen, X. Wang, X. Li, & Z. Li. (2021). A Model Study of Building Seismic Damage Information Extraction and Analysis on Ground-Based LiDAR Data. Advances in Civil Engineering, 2021. https://doi.org/10.1155/2021/5542012.
14. Y. Torres, J. Arranz, J. Gaspar-Escribano, A. Haghi, S. Martínez-Cuevas, B. Benito, & J. Ojeda. (2018). Integration of LiDAR and multispectral images for rapid exposure and earthquake vulnerability estimation. Application in Lorca, Spain. Int. J. Appl. Earth Obs. Geoinformation, 81, 161-175. https://doi.org/10.1016/j.jag.2019.05.015.
15. S. Shah, A. Özacar, & Z. Gülerce. (2021). Fault-based probabilistic seismic hazard assessment of the eastern Makran subduction and the Chaman transform fault, Pakistan: Emphasis on the source characterization of megathrust. Journal of Asian Earth Sciences, 205, 104604. https://doi.org/10.1016/j.jseaes.2020.104604.
16. K. Morell, C. Regalla, C. Amos, S. Bennett, L. Leonard, A. Graham, T. Reedy, V. Levson, & A. Telka. (2018). Holocene Surface Rupture History of an Active Forearc Fault Redefines Seismic Hazard in Southwestern British Columbia, Canada. Geophysical Research Letters, 45, 11,605-11,611. https://doi.org/10.1029/2018GL078711.

