From Tremors to Insights: How AI and Big Data Are Revolutionizing Earthquake Science and Reducing Seismic Risk

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Natural disasters—particularly earthquakes—pose severe threats to human life, infrastructure, and the environment, often triggering secondary hazards such as tsunamis and fires. In recent years, the rapid advancement of artificial intelligence (AI) and big data analytics has transformed how we approach earthquake science, offering new possibilities to mitigate risks and reduce the consequences of seismic events. The availability of massive volumes of seismic data, along with complementary datasets from acoustic and electromagnetic sensors, has created an unprecedented opportunity to extract meaningful patterns and relationships that were previously inaccessible through traditional methods.

AI has emerged as a powerful framework capable of handling this enormous data volume while capturing complex spatial and temporal correlations within it. Broadly speaking, there are three key areas where AI can significantly contribute to reducing the destructive impact of earthquakes: earthquake monitoring and hazard assessment**,** early warning systems**,** and earthquake forecasting**.**

For hazard assessment, AI-powered monitoring systems can automatically detect, pick, locate, and estimate earthquake magnitudes from continuous waveform data. This automation facilitates the generation of comprehensive earthquake catalogs, which are essential for identifying active tectonic structures, assessing regional seismic hazards, and informing the design of resilient infrastructure and building codes.

In the context of early warning systems, AI models can rapidly analyze the first few seconds of a seismic signal following the arrival of the primary (P) wave to estimate the magnitude and potential impact of an earthquake before the arrival of the more destructive secondary (S) waves. This capability enables the issuance of real-time alerts that can save lives, prevent secondary disasters, and reduce overall damage.

Finally, earthquake forecasting represents the long-term and ultimate goal of seismological research. AI has shown promising potential to identify subtle patterns or precursor signals embedded within continuous seismic data and historical earthquake catalogs. These insights can enhance our understanding of earthquake preparation processes and may eventually contribute to more reliable forecasting of future events.

In conclusion, AI stands as a transformative tool in modern seismology, capable of handling massive, heterogeneous datasets and uncovering hidden features that enhance earthquake monitoring, early warning, and forecasting. The integration of AI with large-scale sensing networks and multimodal data sources marks a pivotal step toward a safer and more resilient society in the face of natural seismic hazards.

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Biography

Omar M. Saad is a Research Scientist at King Abdullah University of Science and Technology (KAUST) in Saudi Arabia and an Associate Professor at the National Research Institute of Astronomy and Geophysics (NRIAG) in Egypt. He serves as an Associate Editor for the Journal of Geophysical Research: Machine Learning (JGR: ML) and IEEE Transactions on Geoscience and Remote Sensing (TGRS). Additionally, he is part of the Young Editorial Board for the Journal of Geophysics and Engineering (JGE). Recently, Dr. Saad was elevated to IEEE Senior Member. He earned his Ph.D. from Egypt-Japan University of Science and Technology (E-JUST), complemented by his study at Kyushu University in Japan. With extensive research experience in machine learning, he held a postdoctoral position at Zhejiang University from 2019 to 2021.

With more than 100 journal and conference publications, Dr. Saad has received several notable honors, including the Geophysics Bright Spots Award (2023), the Egyptian Encouragement Award in Advanced Technology in Basic Sciences (2023), and recognition as the Best Researcher in Geophysics at NRIAG in 2021 and 2022. He also achieved first place in the AETA Earthquake Forecasting Competition (2022) and was recently listed among Stanford University's Top 2% of Scientists worldwide (2024).

Omar M. Saad actively engages in teaching and mentoring graduate students while serving as a reviewer for various scientific journals. His work focuses on artificial intelligence and deep learning applications in geophysics and seismology.