Postprint: Intelligent Prediction of Rockburst Risk Based on Heterogeneous Graph Transformer

Authors: Ran Xiangdong, Zhang Yu, Wang Junchao

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Abstract

Rockburst, as a typical dynamic hazard in underground engineering, is governed by occurrence mechanisms that are jointly influenced by multiple spatially heterogeneous factors and potential long-range coupling relationships. Although traditional Graph Neural Networks can process local structural information, they still exhibit significant limitations in modeling long-range dependencies, cross-type semantic interactions, and dynamic data variations. To address these challenges, this paper proposes an intelligent prediction method for rockburst risk based on Heterogeneous Graph Transformer (HGT), which innovatively introduces the Transformer architecture to enhance high-order semantic modeling between different node types and the expression of long-range feature dependencies. In the modeling process, this work embeds information such as rock physical parameters, geological structures, microseismic events, stress monitoring points, and construction disturbances as multi-type nodes, constructing a heterogeneous graph with multiple relational edges (e.g., geological adjacency, temporal evolution, structural coupling). The proposed HGT model employs type-specific projection mechanisms and attention weight allocation strategies, enabling efficient interaction between different node types within a unified representation space. Simultaneously, Structural Positional Encoding is introduced to enhance the model's understanding of topological structures and global node positions. During training, combined with a multi-task loss function, the model not only predicts rockburst occurrence probability but also outputs its spatial location distribution and potential affected areas, thereby achieving enhanced interpretability of prediction results. Through validation on multiple real-world tunnel and mining engineering datasets, the results demonstrate that this method outperforms existing GCN, GAT, and LSTM-based multimodal models in terms of prediction accuracy, early warning capability, and generalization performance in complex structural scenarios, showing broad prospects for engineering applications.

Full Text

Intelligent Rockburst Risk Prediction Based on Heterogeneous Graph Transformer

Xiangdong Ran[1], **Yu Zhang**[1,2], **Junchao Wang**[1]

[1]School of Intelligence Science and Technology & Beijing Key Laboratory of Super Intelligent Technology for Urban Architecture, Beijing University of Civil Engineering and Architecture, Beijing 102616, China
[2]State Key Laboratory for GeoMechanics and Deep Underground Engineering, China University of Mining & Technology, Beijing 100083, China

Abstract

Rockburst, as a typical dynamic disaster in underground engineering, is influenced by multiple spatially heterogeneous factors and potential long-range coupling relationships. Although traditional graph neural networks can process local structural information, they still exhibit significant limitations in modeling long-range dependencies, cross-type semantic interactions, and dynamic data variations.

To address these challenges, this paper proposes an intelligent rockburst risk prediction method based on Heterogeneous Graph Transformer (HGT), which innovatively incorporates the Transformer architecture to enhance high-order semantic modeling and long-range feature dependency expression among different node types. During the modeling process, we embed information such as rock physical parameters, geological structures, microseismic events, stress monitoring points, and construction disturbances as multi-type nodes, constructing a heterogeneous graph with various relational edges (e.g., geological adjacency, temporal evolution, structural coupling).

The proposed HGT model employs type-specific projection mechanisms and attention weight allocation strategies, enabling efficient interaction between different node types within a unified representation space. Simultaneously, we introduce Structural Positional Encoding to enhance the model's understanding of topological structures and global node positions.

During training, we incorporate a multi-task loss function that not only predicts the probability of rockburst occurrence but also outputs its spatial location distribution and potential impact areas, thereby enhancing the interpretability of prediction results. Through validation on multiple real-world tunnel and mining engineering datasets, the results demonstrate that our method outperforms existing GCN, GAT, and LSTM-based multimodal models in terms of prediction accuracy, early warning capability, and generalization in complex structural scenarios, showing promising prospects for engineering applications.

Keywords: rockburst prediction; heterogeneous graph neural networks; Transformer; structural positional encoding; rock mechanics; intelligent underground

engineering

Note: Figure translations are in progress. See original paper for figures.