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Road Network Selection Based on Quantum Weighted PageRank Algorithm

Huayu Fu [a,b,c], Jianchen Zhang [a,b,c,d,*], Heying Li [a,b,c,d], Guangxia Wang [a,b,c,d], Jiayao Wang [a,b,c,d], Pengyu Zhao [a,b]

[a] *State Key Laboratory of Spatial Datum, College of Remote Sensing and Geoinformatics Engineering, Faculty of Geographical Science and Engineering, Henan University, Zhengzhou, 450046, China, hyfu@henu.edu.cn, jczhang@vip.henu.edu.cn, 10130155@vip.henu.edu.cn, wgx@henu.edu.cn, 10130141@vip.henu.edu.cn, pyzhao00@163.com*

[b] *Henan Industrial Technology Academy of Spatiotemporal Big Data (Henan University), Zhengzhou, 450046, China, hyfu@henu.edu.cn, jczhang@vip.henu.edu.cn, 10130155@vip.henu.edu.cn, wgx@henu.edu.cn, 10130141@vip.henu.edu.cn, pyzhao00@163.com*

[c] *College of Geographical Sciences, Faculty of Geographical Science and Engineering, Henan University, Zhengzhou, 450046, China, hyfu@henu.edu.cn, jczhang@vip.henu.edu.cn, 10130155@vip.henu.edu.cn, wgx@henu.edu.cn, 10130141@vip.henu.edu.cn*

[d] *Key Laboratory of Geospatial Technology for the Middle and Lower Yellow River Regions, Ministry of Education, Henan University, Kaifeng, 475004, China, jczhang@vip.henu.edu.cn, 10130155@vip.henu.edu.cn, wgx@henu.edu.cn, 10130141@vip.henu.edu.cn*

* Corresponding author

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Abstract:

Automatic road network selection constitutes a significant research domain in cartographic generalization, with increasing application of machine learning to automate road network tasks. Existing intelligent selection methods predominantly rely on supervised learning, which necessitates substantial labeled data and training samples at specific scales; they are susceptible to data deficiencies and annotation cost constraints in unstructured or large-scale road network scenarios. Although classical weighted PageRank algorithms can automatically identify patterns and structures in data as an unsupervised approach, they exhibit limited capability in recognizing secondary hub nodes, which can degrade low-importance nodes, and they require substantial computational resources and time when processing large-scale complex road networks.

To address these challenges, this paper proposes a quantum-weighted PageRank framework for automatic road network selection. By leveraging quantum superposition and entanglement, the algorithm enables parallel exploration of multiple paths, accelerates probability propagation, and enhances ranking precision, thereby providing refined decision support for urban arterial road identification and road priority assessment. During the dual graph transformation phase, multidimensional attributes—including road length, hierarchical classification, and traffic flow—are integrated to derive comprehensive node weights via multi-attribute fusion. In quantum algorithm design, auxiliary qubits and local initial-state designs are introduced, and unitary evolution operators are adjusted to efficiently integrate damping-coefficient encoding with quantum walks, accompanied by corresponding quantum circuit modules. To comprehensively evaluate framework performance, this study designs multiple evaluation metrics, including network robustness, connectivity preservation rate, path efficiency variation ratio, and structural similarity, and conducts comparative experiments on road networks with various topologies. Experimental results demonstrate that the quantum-weighted PageRank algorithm outperforms its classical counterpart across multiple evaluation metrics, achieving more accurate hub and secondary-node identification and validating its feasibility on simulation platforms. Future work will include practical performance evaluations on cloud-based quantum hardware to reveal its acceleration potential on physical quantum devices.

The primary contributions of this study are summarized in four main aspects:

(a) Unsupervised Multi-Attribute Fusion Framework. Using Stroke-based dual graph transformation, the original road geometry and intersection structures are mapped into nodes and edges, and multidimensional attributes—including road length, functional hierarchy, and traffic flow—are integrated to construct normalized weight vectors embedded into the initial states of the quantum-weighted PageRank algorithm; this enables quantum walks and measurements through unitary evolution operators in Hilbert space, directly obtaining the relative importance of road units without manual annotation or training datasets.

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(b) Refined Hub-Node Evaluation. Auxiliary qubits and local initial-state designs are introduced during quantum walks to dynamically encode damping coefficients and adjust superposition-entanglement strategies, allowing the algorithm to explore multiple paths in parallel and adaptively focus on critical connections, significantly improving importance-ranking accuracy for mid- and low-level road nodes and resolving the degradation issue of classical algorithms in secondary hub identification.

(c) Algorithm and Quantum Circuit Implementation. A quantum circuit module incorporating multi-controlled rotation gates, reflection operators, and auxiliary qubits is constructed for attribute weighting and probability propagation control; comprehensive workflows for global and local initial-state superposition are designed, with functional correctness of each module verified on simulation platforms, establishing a feasible technical foundation for future deployment on real quantum hardware.

(d) Deployment Feasibility and Engineering Challenges Analysis. We systematically analyze resource requirements and process integration in GPU-accelerated simulation and cloud quantum-hardware environments—including parallel computing resource allocation, quantum state encoding/decoding workflows for road network data, and precision impacts induced by qubit noise and decoherence—and propose preliminary solutions for integrating hybrid classical–quantum computing within GIS platforms, providing strategic guidance for cross-platform deployment and optimization in subsequent research stages.

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