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Quantum Edge Detection: A Technical Survey of Methods and Approaches

Abstract
Context: Edge detection is critical in image-based diagnostics where intensity variations must be resolved under low resolution and noisy conditions. Quantum image processing, using superposition and interference, offers alternative approaches to classical gradient-based methods.
Purpose: This study surveys quantum Hadamard-based and classical edge detection techniques, explicitly motivated by diagnostic tasks where accurate boundary identification from detector images is essential.
Methods: A classically simulated quantum model is applied to 8×8 binary images using amplitude encoding, single-qubit Hadamard operations, and permutation unitaries to highlight intensity transitions. Classical methods (Canny, Sobel, Laplacian) are applied independently. The workflow—image selection, quantum encoding, circuit simulation, and post-processing—is implemented in Python using Jupyter Notebook, Google Colab, and IBM Quantum simulators.
Findings: Quantum detection captures subtle boundaries via interference, even at low resolution. Orthogonal scans provide complementary features forming coherent edge maps. Canny detection localizes edges precisely with noise suppression, Sobel captures general patterns, and Laplacian highlights rapid changes but introduces spurious responses. Quantum simulations require moderate resources; classical methods are efficient on standard hardware.
Significance: Quantum and classical methods have complementary strengths, suggesting hybrid approaches could enhance edge continuity, robustness, and interpretability in precision imaging. This provides a foundation for future hybrid pipelines and large-scale, error-mitigated quantum-assisted analysis.
Keywords: Quantum image processing; quantum edge detection; hybrid quantum–classical methods; interference-based imaging; diagnostic image analysis

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