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College of Engineering • Department of Electrical Engineering

Methods and Frameworks for Quantum State Preparation in Modern Quantum Systems

presented by

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ABSTRACT

This thesis studies the exact, deterministic preparation of arbitrary dense n-qubit quantum states, which is the fundamental data-loading step in quantum signal and image processing. Most notably, this thesis evaluates the Quantum Signal-induced Heap Transform (QsiHT) using the fast path, a recent state-preparation method built on the Discrete Signal-induced Heap Transform (DsiHT), against the established field on a common baseline. It is implemented as an explicit gate circuit, with its uniformly controlled rotations modified to hardware-native gates through the Gray-code decomposition, and benchmarked alongside the standard constructions. Because the cost of loading a generic dense amplitude vector is bounded below by an exponential number of two-qubit (CNOT) gates, the work first fixes a single framework of resource metrics (gate count, CNOT count, circuit depth, compilation time, and fidelity) together with the parameter-counting lower bound, and uses it to compare the principal exact constructions: the Möttönen uniformly controlled rotation cascade, the Iten isometry method, the general isometry primitive, multiplexor-based preparation, the Plesch-Brukner Schmidt/singular value decomposition (SVD) scheme, and the Quantum Shannon Decomposition (QSD). Every method is then re-implemented from its underlying construction in NumPy and elementary Qiskit gates, rather than invoked through a black-box library routine, so that the realized circuits are exactly those analyzed. These are all benchmarked through one measurement framework on identical real and complex Haar-random dense targets. The evaluation reports exactness (state fidelity), gate-count and depth scaling, transpiled cost across eight representative Noisy Intermediate-Scale Quantum (NISQ) native gate sets, and finite-shot and noisy sampled error represented as the fidelity error (infidelity) and the mean-square error. The noisy comparison is additionally run on two real IBM Quantum processors, where the exact frontier stays well separated from the quadratic-cost QSD. The benchmark confirms that all methods are exact to machine precision and that they separate by cost rather than capability: the Möttönen, Iten, isometry, multiplexor, Plesch-Brukner, and QsiHT methods occupy the $\Theta(2^n)$ entangling-gate frontier, while QSD pays a quadratic $\Theta(4^n)$ penalty for synthesizing an entire unitary, and under a noise model the realized error tracks the CNOT count almost exactly. Among the frontier methods, Plesch-Brukner attains the best constant on complex data by exploiting the Schmidt rank, whereas the QsiHT fast path matches the frontier on complex data and is the cheapest of the field on real (sign-bearing) data, using $2^n - 2$ CNOTs by folding amplitude signs into a single rotation cascade. It also offers the fastest, most numerically robust angle generation, making it an ideal loader for the dense real-valued data typical of signal and image processing on NISQ devices.

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