

Qutrit Ternary Image Circuits for Geospatial GIS Lunar Surveying Utilizing a Novel Technique

^{1*}Andrew M.K. Nassief

¹*Riemann Computing Inc., Research, Quantum Computing, Troy, MI, USA*

Abstract

This paper explores the integration of low-altitude CubeSats for signal telemetry while enhancing them for the acquisition of imaging data, with a focus on lunar surveying and high-resolution image reconstruction. The proposed framework involves enhancing a CubeSat with multimodal sensing capabilities, including radar, lidar, and optical imaging (with a fish-eye lens camera) to capture high-resolution imaging data from long-range signals. To address the computational challenges associated with reconstructing geospatial imagery from such data, this work investigates the use of qutrit-based quantum optimization circuits for image reconstruction. The core contribution is a qutrit-based reconstruction technique designed for both improved reconstruction fidelity and optimization of grayscale and color geospatial images. The approach leverages quantum image representation methods and integrates a specialized onboard compute module informed by existing signal processing methods. By applying qutrit-based processing to raw geospatial data derived from multiple signal types, the framework aims to enhance reconstruction performance in terms of speed and image quality, alongside a qubit-based grid computing architecture for quantum optimization. The proposed methodology is situated within the current related literature, providing foundational support for subsequent experiments aimed at improving lunar surveying and imaging capabilities.

Keywords CubeSats; CT imaging; imaging data compression; quantum computing; qubits; quantum optimization; image reconstruction; quantum correction

1 Introduction

The level of detail required in geospatial imaging analysis is directly correlated with the complexity of the visualization paradigm [1]. In geospatial analysis, the number of unknown variables is substantial, as is the variety of data types involved, particularly from the perspective of imaging analysis. Researchers have used quantum computing in computed tomography (CT) imaging and sonar [2] to explore quantum optimization techniques, and it can similarly be applied to this broader challenge. Previous studies have used qubit-based algorithms for clustering [3], and there is potential to employ qutrits in this domain. The approach presented here is intended to leverage these advances for an experimental use case focused on a modified CubeSat designed for low-altitude geospatial analysis.

Existing methodologies for quantum image representation and reconstruction mechanisms have been well-established for some time. A review of the literature identifies

five primary techniques [4]: flexible representation of quantum images (FQRI), flexible qutrit representation of RGB quantum images (FQRRRI), flexible qutrit representation of quantum color images (FQRQCI), multichannel qutrit representation for quantum images (MCQRI), and the quantum representation model of color digital images using qutrits (QRCIQ) [4]. These techniques collectively contribute to the process of quantum image representation (QIR) [4]. Historically, they have been predominantly utilized in generative or constructive applications rather than in reconstructive processes. FQRI is designed for grayscale images and is optimized for raw data prior to the application of color coding [4], while the other techniques employ red, green, and blue (RGB) color models. Notably, QRCIQ stands out as the only non-probabilistic method, operating deterministically. The QRCI and QRCIQ methods represent a novel quantum framework for color digital images, necessitating the encoding of color information based on the basis states of qubit sequences [4]. Given the necessity of deterministic principles in image analysis and the importance of the data involved, as highlighted by prior researchers in the field, our focus will be on the QRCI model. The probabilistic FQRI model is evaluated for the grayscale aspect, unlike the QRCI model, which is evaluated for determinism. This approach entails a significantly lower level of statistical complexity, which likely allows for reduced statistical inaccuracies compared with the complexities associated with RGB data—particularly when addressing the intricate final product of geospatial image reconstruction. Therefore, FQRI can be utilized for the grayscale section of raw data, while RGB can be utilized via QRCI [4].

The formula

$$|I(\theta)\rangle = \frac{1}{3^n} \sum_{i=0}^{3^{2n}-1} (\cos \theta_i |0\rangle + \sin \theta_i |1\rangle + 0|2\rangle) \otimes |i\rangle \quad (1)$$

represents a flexible qutrit representation of quantum images [4], and it can be utilized for grayscale data encoding as a problematic method of determination. To encode a $3n \times 3n$ image, a total of $2n + 1$ qutrits are necessary. Of these, $2n$ qutrits are allocated for encoding the location information, while the additional qutrit is designated for encoding the pixel values. The pixel values are represented by θ_i , where θ_i falls within the interval $[0\pi/2)$. In the case of an 8-bit grayscale image, the pixel values range from 0 to 255, and they are subsequently scaled to fit within the range of θ [4].

For QRCI, we utilize the following equation [4]:

$$|I\rangle = \frac{1}{3^{n+1}} \sum_{b=0}^5 \sum_{i=0}^{3^{2n}-1} |R_b^i G_b^i B_b^i\rangle \otimes |i\rangle \quad (2)$$

The variable b denotes the bit plane number, whereas i signifies the i -th pixel [4]. The RGB values correspond to the RGB encoding utilized for an 8-bit image. This method can be adapted as a color encoding technique and utilized for purposes beyond mere reconstruction [4]. QRCI images have been enhanced to QRCIQ images, or qutrit-based images, in the existing literature and research in this domain [4].

2 Materials and Methods

We are proposing an experiment related to geospatial analysis that employs a specific method of image reconstruction. This approach involves the use of raw data and radar data, with the application of a technique for incremental imaging [1]. Initially, data will be gathered from a CubeSat operating at a low elevation, specifically from 4000 to 5000 feet or lower, to facilitate targeted imaging [5]. The CubeSat will be equipped accordingly,

and the raw data will be compiled through a real-time signaling process combined with an intensive image collection methodology. This targeted data acquisition will be carried out using a proprietary signal computing framework designed for the CubeSat. Subsequently, the raw data will be organized and processed across multiple qubits arranged in a grid format [3]. The initial layers of raw data will undergo reconstruction using FQRI, followed by the application of QRCI [6] for RGB processing. This process is intended to be executed on a Rigetti quantum computer [6] or a quantum software developer test kit (QSK), with the raw data being loaded in real time.

2.1 Experimental Approach

The CubeSat module to be utilized for data collection employs an innovative and proprietary computational technique that emphasizes real-time data transmission throughput as a processing mechanism. This approach is intended to enhance telemetry results for signal spectra in low-elevation [5], lower-range environments, where numerous signals often reflect. Concurrently, a proprietary lossless data compression mechanism is implemented for the network packets. The signal processing framework and methodology of this CubeSat are well-suited for real-time networking and communications through software-defined networking (SDN) techniques. Additionally, modifications can be made to the CubeSat's computing module to integrate with radar systems, lidar systems, and fish-eye cameras, thereby enabling the collection of associated imaging data, extending its functionality beyond telecommunications. The imaging data captured by the fish-eye lens [7] will be collected in a static and traditional raw format for subsequent analysis and processing. Global positioning systems are employed to track coordinates, and the data are transmitted and analyzed to create geospatial image compositions.

The fish-eye lens [7], combined with a specific video-capturing technique, produces 8-bit RGB sequences that are layered to create final outputs. These layers undergo optimization through quantum circuits. The initial phase involves FQIR, which converts raw data to grayscale, followed by QCIR, which transforms grayscale into color [4]. The objective of quantum optimization is to achieve results that are as close to real time as possible, while considering polynomial time complexity and the challenges associated with compiling numerous layers on a probabilistic basis before generating a deterministic color output based on a set number of layers. To facilitate this process, we intend to employ a Lorentz transformation for referenced coordinate planes and curvature paths. This approach enables the implementation of a matrix for both image and time coordinates, allowing for the acquisition of the raw data necessary for layering, as well as the positioning required to construct a model for the final videographic output. If optimized effectively, this technique adopts a hybrid strategy that integrates classical (neuromorphic) computing, innovative signal processing, and quantum computing paradigms, all of which function seamlessly through an SDN to establish a streamlined and efficient methodology.

The CubeSat is designed to incorporate a solar panel to ensure continuous and efficient power generation, as well as a computing module and ground power capabilities [5]. Currently, a new iteration of the computing module is under development to accommodate various spectra, while a new CubeSat is being constructed for data collection and surveying purposes. To replicate the necessary experiment, the CubeSats in development are integrated into the Starkcom Global network [5] and will utilize its IP blocks or leased IP blocks during the anticipated experiment.



Figure 1: Starkcom Global Network CubeSat v1.0

2.2 Experimental Objectives

In the experiment, the following steps are required for the proposed software-defined networking (SDN): 1) real-time connectivity, 2) layering and tracking, and 3) optimization and processing. To enhance the speed of optimization and processing, a qubit-based grid computing [8] or clustering method will be employed. Previous research on qubit-based cryptographic schemes that facilitate this approach was theorized in a preprint published in 2019 [8].

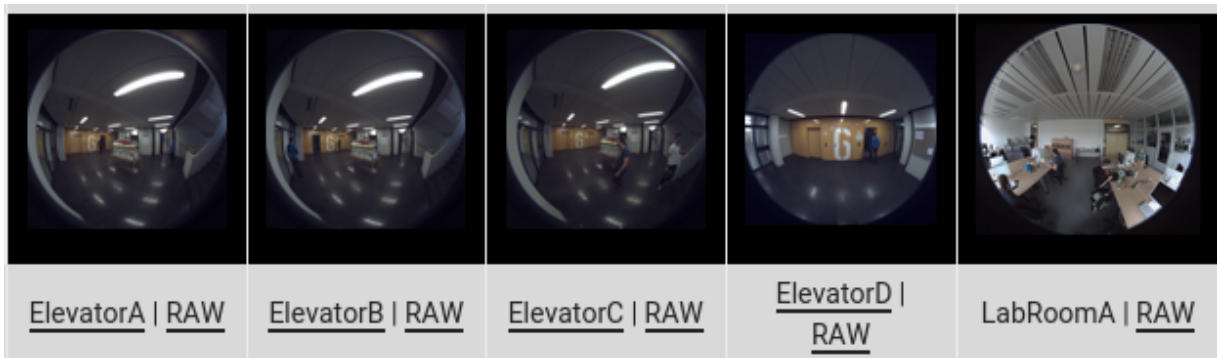


Figure 2: Raw fish-eye data recomposed. Source: [7], Shanghai, China, March 2016.

The ongoing experiment and the nature of the data necessitate the optimization of each position and layer to achieve a variation of the image that is as close to static, non-stationary, and undistorted as possible. The reconstruction, along with the associated signal data, will facilitate comprehensive geospatial analysis during lunar exploration missions. This is particularly crucial given the unpredictable factors of the environment being analyzed, surveyed, and visualized.

3 Experimental Significance

One of the initial instances of employing qubits in quantum computing, characterized by a multiple states and a multi-faceted approach to quantum complexity, was quantum

complexity theory [9]. This theory presented the Bernstein–Vazirani algorithm as a means of achieving a quantum advantage exponentially over conventional classical computing [10]. Since that time, quantum computing has been explored using the framework of multiple states across qubits, which has been proposed as a method of theoretically enhancing the quantum advantage in various fields. A notable application of this is in image construction, where classical sparse coding is used as a technique [11]. Additional instances have included quantum-inspired algorithms and training for simulations in quantum circuits, as well as the application of AI methods such as XGBoost [12]. Quantum-inspired algorithms, together with the innovative use of qutrits for exponential benefits, are gaining traction within the quantum computing industry as a whole. Furthermore, the introduction of the ParaQuantum Neural Net is intended to reduce the noisiness associated with pure quantum states, a concept that researchers have theorized [13].

This document serves as a review of relevant qutrit-based quantum image representation methods and introduces a reconstruction framework for geospatial imaging using CubeSat-acquired data. The outcomes of this experiment will necessitate the establishment of a repository for the raw data hex, a separate repository for the output data, and a comprehensive summary of the Rigetti Computing instance along with the associated quantum circuit steps. Additionally, it will require configurations related to the Stark-com compute module concerning the data being collected, including the specifications for the lens and camera module pertinent to the captured data. The related repositories and technical documentation will be used for a subsequent publication that will summarize the experimental findings.

4 Anticipated Data

The significance and originality of this research will serve to illuminate the multifaceted applications of quantum representation, extending beyond traditional domains of image recognition and generation to encompass innovative reconstructive initiatives [6]. By exploring the intersection of quantum technologies and advanced imaging techniques, this study aims to reveal new pathways for leveraging quantum principles in practical applications, thereby contributing to the broader field of quantum engineering.

Moreover, this research will emphasize the importance of hybrid software-defined networking architectures that integrate diverse computing paradigms and data processing methodologies. By doing so, it seeks to achieve optimal outcomes that are not only efficient but also pioneering within the context of quantum engineering. This novel approach is poised to redefine how QIR and processing are understood and implemented, particularly in real-time data syndication methods and strategies.

The primary objective of this work is to provide a comprehensive context for QIR and processing. This includes an exploration of real-time data syndication techniques that are essential for advancing the field. The insights gained from this research will be instrumental in shaping future initiatives.

Discussions surrounding these topics will be presented in a subsequent peer review, which will be contingent upon the completion of a follow-up paper detailing the processed experiments. Future work will include the public release of input and output RGB data. This transparency will be crucial for fostering collaboration and enabling other researchers to replicate and build upon the processing techniques developed in this study, ultimately contributing to the advancement of knowledge in this exciting and rapidly evolving field.

Patents

The patents [US10965315B2] and [US12002348B2], along with subsequent intellectual property, have served as a foundational inspiration for the research presented in this paper by Riemann Computing Inc. It is anticipated that this paper will lead to the development of a novel algorithmic architecture and quantum circuit, which will likely result in the filing of new patents following the experimental phase due to the innovations achieved.

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Author Contributions

Not applicable, as this paper has a single author.

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This document seeks to provide an overview of the previous literature and efforts related to an experiment that will serve as a foundation for a NASA SBIR Phase 1 Proposal concerning lunar missions. Should funding be secured, this research may be applied to the exploration, surveying, and mapping of the lunar surface. Additionally, external financial support for the CubeSats and this research will be provided by Riemann Computing Inc., which also sponsored the creation of this document and intends to fund the forthcoming experiment.

Conflicts of Interest

The author is the innovator responsible for [US10965315B2] and [US12002348B2], as well as the founder of Riemann Computing Inc. They hold ownership of the Starkcom Global Network and are the creator of the Stark Compute Modules series.

Competing Interests

Currently, the author has no competing interests.

Institutional Review Board Statement

Not applicable.

Data Availability

Not applicable at this point in time.

Consortia

Not applicable at this point in time.

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Supplementary Materials

[Figure 1]: Starkcom Global. Source: <https://starkcom.io>

[Figure 2]: Raw Fish Eye Data Recomposed. Source: <https://lms.tf.fau.eu>