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

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Abstract

This paper presents research that integrates low-altitude CubeSats for signal telemetry while enhancing these CubeSats for the acquisition of imaging data. The objective of this study is to improve a CubeSat by incorporating a radar system, Lidar, and a fish-eye lens camera to capture high-resolution imaging data from long-range signals. This process will employ a Qutrit-based Quantum Optimization Circuit to achieve superior image reconstruction. The innovative aspect of this approach lies in a unique reconstruction technique that leverages Qutrit circuitry to enhance both the reconstruction and optimization processes. The focus of this research is on utilizing Quantum Computing to analyze geospatial imaging data obtained from a CubeSat equipped with a specialized Compute Module. Investigations into the processors within this computing framework have identified parallels with an existing patented signal processing method, which serves as a foundational model for the Compute Module. Since image construction is dependent on raw data and includes sonar, thermal, and various signal types in geospatial reconstruction, the application of Qutrits can significantly improve both the speed and quality of the process. This proposed solution aims to strengthen a lunar mission by enhancing imaging and surveying capabilities. The paper reviews the current literature on this innovative methodology and seeks to provide essential foundational support for future related experiments. Additionally, a Qubit-based grid computing architecture will be employed for quantum optimization.

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 the context of geospatial analysis, the number of unknown variables is substantial, particularly from an imaging analysis standpoint, along with the variety of data types involved. Researchers have employed Quantum Computing in Computed tomography (CT) Imaging and Sonar [2], exploring Quantum Optimization techniques, which can similarly be applied to this broader challenge. Prior studies have utilized qubit-based algorithms for clustering [3], and there is potential for employing qutrits in this domain. This approach seeks 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 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 (FQRRI), Flexible qutrit representation of quantum color image (FQRQCI), Multi channel qutrit representation for quantum image (MCQRI), and Quantum representation model of color digital images using qutrit (QRCIQ) [4], which collectively contribute to the process of Quantum Image Representation (QIR) [4]. Historically, these techniques have been predominantly utilized in generative or constructive applications rather than in reconstructive processes. Among these, 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 and necessitate the encoding of color information based on the basis states of Qubit sequences [4]. Given the necessity for deterministic principles in image analysis and the importance of the data involved, our focus will be on the QRCI model, as highlighted by prior researchers in the field in the publication Optics Communications, which is also indexed in the SAO Astrophysics Data System.

The probabilistic FQRI model is being evaluated for the gray-scale aspect, different from the QRCI model for determinism. This approach entails a significantly lower level of statistical complexity, which likely allows for reduced statistical inaccuracies compared to the complexities associated with RGB data, particularly when addressing the intricate final product of geospatial image reconstruction. Therefore, FQRI could be utilized for the grayscale section of the raw data, while RGB can be utilized via QRCI [4].

The formula:

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

represents a flexible Qutrit representation of Quantum Images [4], and can be utilized far 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 the θ_i values, where θ_i falls within the interval $[0, (\pi \setminus 2)$. In the case of an 8-bit grayscale image, the pixel values range from 0 to 255, which are subsequently scaled to fit within the range of θ [4].

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

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

The variable b denotes the bit plane number, whereas i signifies the i^n 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]. The QRCI image has been enhanced to QRCIQ, or Qutrit-based, due to 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, applying a technique for incremental imaging [1]. Initially, data will be gathered from a CubeSat operating at a low elevation, specifically between 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 utilize an innovative and 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 Kit (QSK) testkit, with the raw data being loaded in real-time.

2.1 Experimental Approach

The CubeSat module utilized for data collection employs an innovative and proprietary computational technique that emphasizes real-time data transmission throughput as a processing mechanism. This approach aims to enhance telemetry results for signal spectrums 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, 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 is 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 as close to real-time as possible, taking into account 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 raw data necessary for layering, as well as the positioning required to construct a model for the final video graphic output. If optimized effectively, this technique adopts a hybrid strategy that integrates classical (neuromorphic) computing, innovative signal processing, and Quantum Computing paradigms, all functioning seamlessly through a Software Defined Network (SDN) to establish a streamlined and efficient methodology.

Figure 1: Starkcom Global Network CubeSat v1.0

The CubeSat is designed to incorporate a solar panel to ensure continuous and efficient power generation, alongside a computing module and ground power capabilities [5]. Concurrently, a new iteration of the computing module is under development to accommodate various spectrums, 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.

2.2 Experimental Objectives

The objectives of the experiment necessitate the following steps 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. Prior research on Qubit-based cryptographic schemes that facilitate this approach was theorized in a preprint published in 2019 [8].

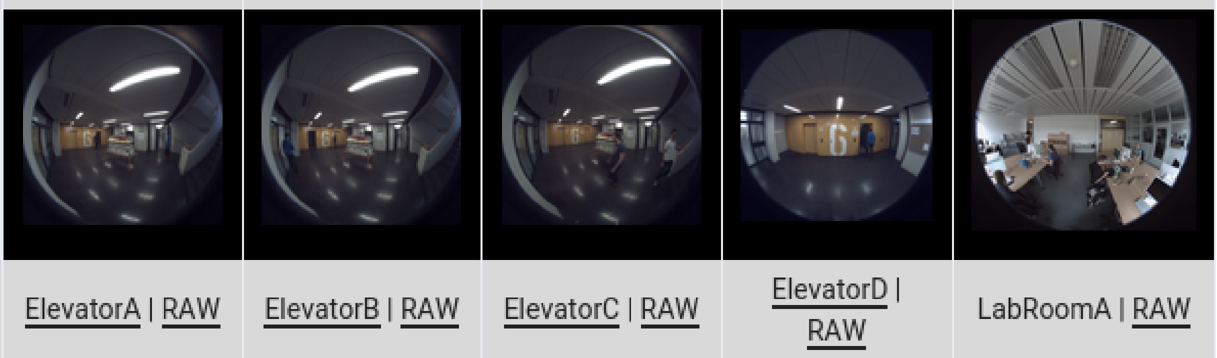

Figure 2: Raw Fish Eye Data Recomposed — Source: Andrea Eichenseer and Andre Kaup (ICASSP), pp. 1541-1545, Shanghai, China, March 2016)

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 a comprehensive geospatial analysis during a lunar exploration mission. This is particularly crucial given the unpredictable factors of the environment that is being analyzed, surveyed, and visualized.

3 Experimental Significance

This document serves as a communication and review paper intended to precede a significant experiment and aims to be submitted as part of a grant application exhibit. 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 Starkcom Compute module concerning the data being collected, which includes specifications for the lens and camera module pertinent to the captured data. The related repositories and technical documentation will be employed 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 [6], extending beyond traditional domains of image recognition and generation [6] to encompass innovative reconstructive initiatives. 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 we understand and implement Quantum Image Representation and Processing, particularly in real-time data syndication methods and strategies.

The primary objective of this work is to lay a robust foundation for a critical grant proposal, while simultaneously providing a comprehensive context for Quantum Image Representation 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 and funding opportunities.

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. Should the NASA SBIR Phase 1 funding be awarded, the repositories established as a result will be made open source, specifically concerning the 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.

Furthermore, there is a clear intention to encapsulate the findings of further experimentation and peer review in a third format, specifically a conference poster. This will provide an additional platform for disseminating results and engaging in meaningful discussions with both the scientific community and the general public. By sharing these insights widely, the research aims to stimulate interest and dialogue around the potential of Quantum technologies in image processing and beyond, 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 implements a single author.

Funding Statement

This document seeks to provide an overview of 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.

Conflict of Interest

This 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 Interest

Currently, no competing interests of the author exists.

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