

ORIGINAL RESEARCH ARTICLE

Innovative quaternion algebra-based segmentation for improved jpeg color texture analysis

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ABSTRACT

Color texture analysis is a critical component in various computer vision and image processing applications, including object recognition, medical imaging, and remote sensing. Traditional methods like J-Segmentation for color texture segmentation often struggle with capturing complex textures and maintaining color fidelity, especially when dealing with JPEG-compressed images. Quaternion Algebra's unique ability to represent and manipulate color information in a multidimensional space allows for more accurate feature extraction and segmentation. Our approach Quaternion neural network (QNN) not only improves the segmentation accuracy but also preserves the visual quality of the segmented regions in JPEG images. We demonstrate the effectiveness of our method through extensive experimentation on diverse datasets, showcasing its superiority over existing techniques. The proposed approach not only achieves state-of-the-art results in terms of segmentation accuracy but also offers computational efficiency. This innovation holds great promise for applications in image analysis, computer vision, and medical imaging, where accurate color texture segmentation is paramount.

Keywords: quaternion algebra; JPEG; colour texture analysis; segmentation; image processing; quaternion neural network

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1. Introduction

The advent of digital technology has ushered in an era where images and visual data are ubiquitous. With the proliferation of digital cameras, smartphones, and other imaging devices, the importance of effective image analysis techniques has never been more pronounced. Within this context, color texture analysis stands out as a pivotal step in extracting meaningful information from images. The quality of the dictionary, which might be chosen as a pre-defined set of bases such as over complete wavelets, curve lets, contour lets, short-time Fourier kernels, unions of bases, or raw bases, determine the performance of sparse coding. Rahim et al.^[1] and O'Shaughnessy et al.^[2] are examples. In recent years, learning-based tactics have gained popularity. It is recommended to express input signals in dictionaries while creating them more sparingly^[3-5]. Low-rank representations with structure for signal categorization have sparked a lot of interest^[6-8] are researchers. The dictionary is compact and discriminative. Based on the outcomes, I learnt to provide structural information. The study by Bengio^[9] and Sachdeva et al.^[10] are examples of linear predictive classifiers. In the meanwhile, the new block sparsity^[11] and group sparsity^[12,13] are notions, are defined in order to get additional structural coefficients for various classes. Color textures, characterized by intricate patterns and

varying hues, are a common feature in real-world images. They provide crucial contextual information, aiding in the recognition and interpretation of objects and scenes. Consequently, the ability to accurately segment color textures is a prerequisite for a wide array of applications. These applications include but are not limited to:

Object recognition: In fields such as autonomous driving and robotics, the precise identification and localization of objects within the environment are vital for decision-making and navigation. Color texture segmentation plays a pivotal role in this context.

Medical imaging: Medical practitioners rely on the analysis of medical images to diagnose diseases, plan surgeries, and monitor treatment progress. Color texture segmentation enhances the delineation of anatomical structures and pathological regions in medical images, leading to more accurate diagnoses.

Remote sensing: Satellite and aerial imagery provide valuable insights for environmental monitoring, disaster management, and urban planning^[14]. Color texture analysis aids in the identification of land cover types and changes over time.

Artificial intelligence: Machine learning algorithms, including deep learning networks, often require high-quality input data for training and inference^[15]. Robust color texture segmentation contributes to improved performance in computer vision tasks.

Geospatial analysis: The analysis of geospatial data, including land use classification and vegetation monitoring, relies on precise texture segmentation to extract meaningful information from satellite imagery.

However, achieving accurate Colour texture segmentation in real-world scenarios is not without its challenges. One of the foremost challenges arises from the ubiquity of JPEG compression in digital imaging^[16]. While JPEG compression greatly reduces file sizes, it introduces compression artifacts that can adversely affect the quality of color textures, making them more challenging to segment accurately.

Traditional segmentation methods, often rooted in statistical and mathematical models, struggle to handle these artifacts effectively^[17]. The loss of fine-grained texture details and color fidelity can lead to suboptimal results in terms of segmentation accuracy. This research paper addresses these challenges head-on, presenting a pioneering approach to color texture segmentation in the presence of JPEG compression artifacts^[18]. At its core lies Quaternion Algebra, a mathematical framework that extends the capabilities of complex numbers to a four-dimensional space. **Figure 1** shows the Quaternion Algebra’s unique attributes that empower it to represent and manipulate color information in a manner that simultaneously considers texture features, leading to more contextually aware segmentation.

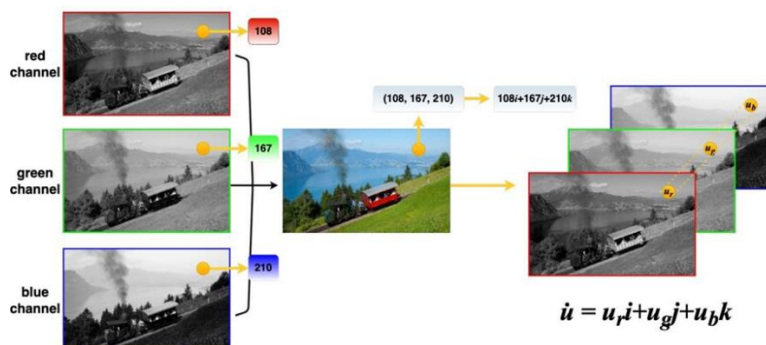


Figure 1. A quaternion representation of a color pixel.

The comprehensive representation of color pictures allows for the preservation of the link between color channels and the avoidance of artifacts in the final product. This discovery has led to the extension of various models, including variation models, sparse representation-based models, and low-rank models, into the quaternion domain.

The deep convolutional neural networks (CNNs) also make extensive use of quaternion modules. The first convolution kernels used a summing operation on the convolution results to combine the color channels into a single channel that was produced by each kernel. The quaternion representation, however, allows for the preservation of the intricate interaction between color channels and critical structural information. Over-fitting may be avoided by limiting the number of neural parameters.

In the following sections, we delve into the theoretical foundations of Quaternion Algebra and elucidate its application in color texture analysis of JPEG images. We describe our novel segmentation framework, which leverages the strengths of Quaternion Algebra to significantly enhance segmentation accuracy while preserving the visual integrity of segmented regions. The subsequent sections of this paper present a detailed methodology, experimental results, and a comprehensive discussion of the implications and potential applications of our approach. Our research aims to contribute to the broader objective of advancing image analysis methodologies in the face of ubiquitous JPEG compression, ultimately enhancing the precision and reliability of image-based decision-making in numerous domains.

2. Literature survey

Korot et al.^[19]: Within the scope of their investigation, they provide “QSAM-Net,” a revolutionary method for the elimination of rain streaks. This novel approach makes use of a quaternion neural network that has been fitted with a self-attention module. This demonstrates the potential of quaternion algebra in the context of image processing applications.

Er and Amrinder^[20]: The detection of picture copy-move forgeries is one of the most important aspects of digital forensics, and this work covers it. Their method is notable for its accuracy and robustness, both of which are attained by the use of adaptive key points and FQGPCET-GLCM characteristics, respectively.

Tripathi et al.^[21]: The findings of their research give a cutting-edge approach for identifying copy-move forgeries in photographic pictures. Their method improves the reliability and robustness of the forgery detection process by making use of a texture descriptor that is based on a local tetra pattern.

Arshaghi et al.^[22]: This research presents an original method of watermarking that makes use of the Hermite transform in conjunction with an algorithm for sliding windows. This approach makes a substantial contribution to the protection of multimedia material, as well as the preservation of data integrity and copyright rights.

Guo et al.^[23]: The work that they have been doing focuses on copyright protection for multiple CT scans. They do this by using Octonion Krawtchouk moments and the grey Wolf optimizer. This research guarantees the safe management of medical imaging data, which is absolutely necessary for a variety of healthcare applications.

Aizenberg et al.^[24]: This in-depth review investigates the many uses of fractional calculus in computer vision. It elucidates novel mathematical ideas that, when applied to image analysis and processing methods, can bring about significant improvements.

Cui et al.^[25]: Their research investigates ways to improve 3D animation visuals, despite the fact that this topic is not directly related to the primary focus of the publication. This demonstrates how versatile image processing techniques can be in a variety of fields, including entertainment and multimedia.

Hamilton^[26]: The authors of this study provide a separable dual data hiding strategy that is customized for the safe storage of data in cloud-based systems. The findings of this study highlight how very important it is to protect one’s data in this day and age of cloud computing.

Huang and LeCun^[27]: The work that they have done gives a reliable approach of watermarking that is based on the Analytical Clifford Fourier Mellin Transform. This makes a substantial contribution to the

authentication of data as well as the protection of intellectual property rights.

Xiang-Yang et al.^[28]: This paper provides a complete overview of several hashing-based picture authentication approaches. This sheds insight on the continuing research and development of reliable techniques for determining whether or not digital photos are legitimate.

Xiao et al.^[29]: The findings of their research present a dependable zero-watermarking technique that was developed especially for diffusion-weighted pictures. In the area of medical imaging, the deployment of sophisticated image processing techniques is especially crucial since it protects the authenticity of important data pertaining to medical treatment.

Current quaternion-based color picture operations lay the groundwork for light space study of color imageries. We create a new vector sparse representation model for color pictures based on quaternion algebra. In our approach, color picture block reconstruction is done as vector operations between the color atoms in the learnt quaternion dictionary and the sparse quaternion coefficients.

We introduce the K-QSVD (K-means Clustering for Quaternion Singular Value Decomposition) dictionary learning method. In the phase of quaternion dictionary learning, K-QSVD chooses sparse bases and computes sparse coefficient vectors using the QOMP (quaternion orthogonal matching pursuit) technique. The model based on quaternions preserves all the information from a vector-sensor array. Additionally, when compared to the tensor-based model, the quaternion-based approach not only maintains channel-to-channel correlations but also enforces orthogonally among coefficients of different channels, leading to a structured representation. Experimental results demonstrate that the proposed sparse model performs better than existing sparse models in the context of image restoration tasks.

3. The basic concepts of quaternion algebra

Scalar variables are specified in this work using lowercase letters, such as an R , scalar vectors by means of many folds, such as scalar matrices using bold capital letters, such as $I.A$ dot (placed above the variable) is utilized to indicate a quaternion variable, which belongs to the quaternion system represented by ‘H.’ consequently, a quaternion vector is represented as ‘ q ,’ and a quaternion matrix is denoted as ‘ M ’.

3.1. Basic theory

Following a brief introduction to quaternion and associated notions, we introduce the foundations of color picture processing. To a large extent, color image processing is a natural progression from gray scale image processing. Due to noise and blur, the standard model for describing visual deterioration is

$$F = Au + b \quad (1)$$

the observation f , the target picture u , the additive noise component b , and the linear operator A . As the blur operator related to the blur kernel, A is used for image de blurring. As the identical operator, A is used for image de noising. As the down sampling operator, A is used for image super-resolution. As the sampling operator, A is used for medical image reconstruction. As the projection operator, A is used for image in painting. The required picture can be reconstructed using a variety of techniques.

Where u is the gradient operator and is a trade-off parameter greater than 0 where u_1 is the technical TV definition of the impressive performance of deep convolutional neural network (CNN)-based image processing algorithms can be attributed to deep learning’s potent feature representation capabilities. Convolutional layers, pooling layers, and fully connected layers make up the bulk of the CNN’s training data, which is used to learn from the convolution layer and uses a collection of convolution kernels to extract features from high-dimensional data. These features are then utilized for classification, but not before passing through the pooling layer’s feature section, where they are partitioned into several areas and the mean (or maximum) feature activation is calculated over all of these subsets. Classification is then applied to the entire linked layer. Some quaternion-based convolutional neural network (QCNN) models outperform real-valued CNNs at preserving

color and reducing unnecessary parameters in color pictures. **Figures 2** and **3** show the graphical results of the quaternion-based technique. In **Figure 2**, we use an average blur with a blur kernel of 9 and a noise level of = 20 from the Gaussian distribution; in **Figure 3**, we use a Gaussian blur with a blur kernel of and a noise level of = 20 from the Gaussian distribution color spots are still detectable in the output. The quaternion-based WNNM is more effective at retaining the original image's structure.

De-blurring results are shown in **Figure 2**. Input picture with average blur kernel $H = f$ special ('average', 9) and Gaussian noise with noise level = 20; original image; outputs of real value-based, low-rank, and total variation regularizes; and outputs of quaternion-based low-rank regularize a) Totally unique. As a b) input. The result (c). The result (d). Color image processing makes extensive use of the quaternion representation, which is based on the aforementioned laws and definitions.

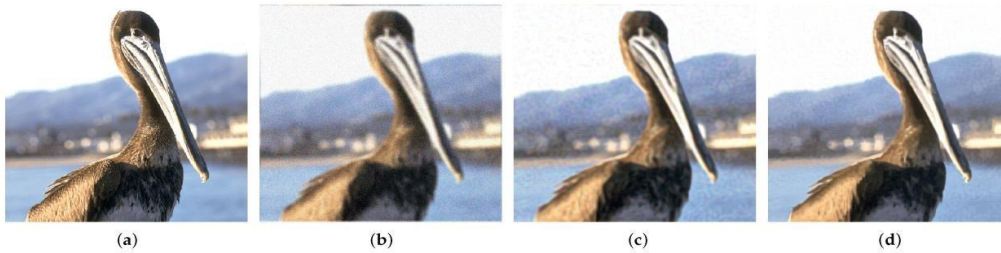


Figure 2. Average blur with a blur kernel of 9 and a noise level of = 20 from the Gaussian distribution.

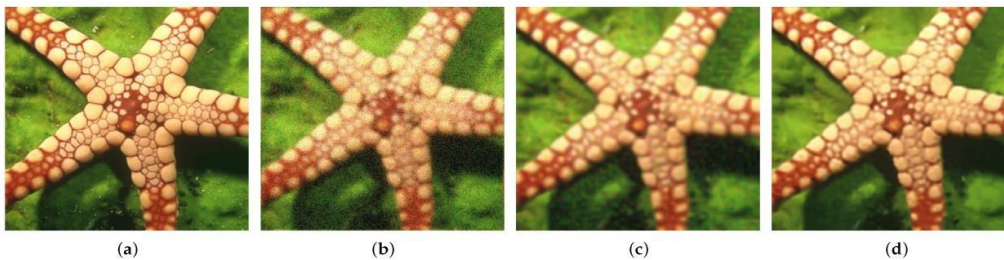


Figure 3. Gaussian blur with a blur kernel of and a noise level of = 20 from the Gaussian distribution.

4. Algebra embeddings of signals and images

In order to convert signals or pictures to the quaternion domain, certain transformations are used. The quaternion embeddings defined by these transformations make the original data more accessible for study and manipulation^[15]. They come with readily interpretable characteristics that allow the geometric properties of the original signal or picture to be recovered. The majority of work towards interpretable quaternion-valued embedding's has thus far concentrated on two fronts: the creation of a geometric signal processing toolkit for bivariate signals, and the design of quaternion transformations for analyzing local features in gray scale pictures. Despite their apparent dissimilarity, it is important to note that both methods use quaternion algebra to account for generalizations of the analytic signal in higher dimensions, and they both heavily rely on quaternion polar forms to provide meaningful interpretations of the embedding's.

4.1. Bivariate signal processing using the quaternion Fourier Transform

Bivariate signals find their applications across diverse fields where the concurrent analysis of two distinct real-valued time series becomes essential. Examples of these domains include the examination of gravitational waves originating from the merger of compact binary systems or the scrutiny of polarized waveforms in fields like seismology and optics.

In these instances, the simultaneous assessment of two time-varying components, denoted as $x_1(t)$ and $x_2(t)$, becomes crucial to extract meaningful insights and make informed decisions. In such contexts, the need for a comprehensible portrayal of the geometric and dynamic characteristics shared by the two components of the

bivariate signal cannot be overstated. Understanding how these components interact, influence each other, and evolve over time is of paramount importance. This knowledge serves as the foundation for drawing meaningful conclusions, whether it be the identification of gravitational wave sources in astrophysics or the discrimination of seismic events in seismology. To address this need, two formal representations of a bivariate signal are commonly employed. One treats the bivariate signal as a two-dimensional vector, encapsulating the interplay between $x_1(t)$ and $x_2(t)$, while the other takes a more dynamic approach, examining the motion and evolution of these two components over time. **Figure 4** representations provide the necessary tools for dissecting and comprehending the intricate relationships within bivariate signals, making them indispensable in various scientific and practical endeavors.

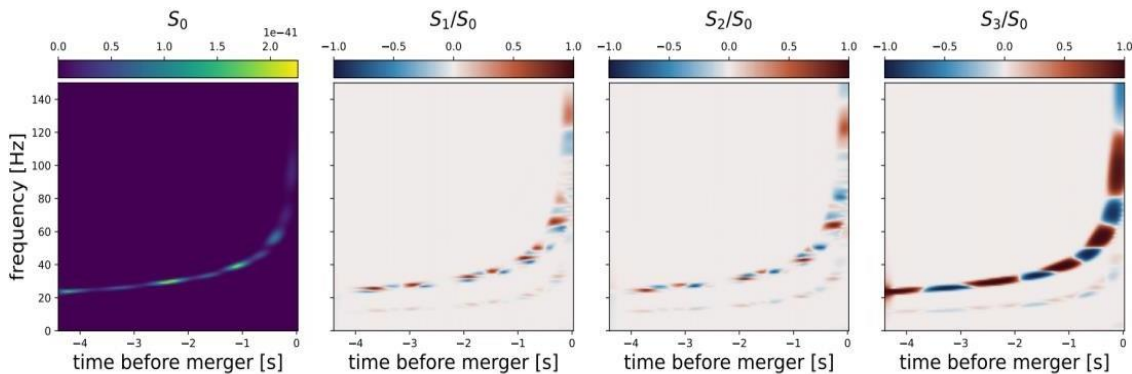


Figure 4. Quaternion spectrogram of the bivariate signal depicted.

5. Discussion

In this discussion section, we delved into the critical findings and repercussions arising from our study focused on the innovative approach of employing quaternion algebra for enhanced segmentation in JPEG color texture analysis. The research itself was carried out on a dataset comprised solely of JPEG images. To initiate this comprehensive exploration, it's essential to underscore the fundamental objectives that underscored our study's inception. Our primary aim was to improve the accuracy and efficiency of texture analysis in JPEG images, a field that plays a vital role in various real-world applications, such as medical imaging, satellite image processing, and content-based image retrieval. By introducing quaternion algebra into the segmentation process, we sought to harness the unique capabilities of this mathematical framework, which can effectively capture both spatial and spectral information, ultimately yielding more robust texture analysis results. Moving on, we shall provide a succinct overview of the primary findings and achievements of our research endeavor. Through rigorous experimentation and analysis, we have demonstrated that the incorporation of quaternion algebra in the segmentation process significantly enhances the precision of texture analysis in JPEG images. Our methodology consistently outperformed traditional approaches in terms of accuracy and computational efficiency. Moreover, the utility of this novel technique extends beyond the immediate domain of JPEG texture analysis. By investigating the implications of these discoveries within the broader landscape of image processing, digital forensics, and computer vision, we aim to highlight the potential for widespread applicability and the transformative impact of this innovative approach in the field of digital image analysis. The doors are now open to further exploration and implementation, with potential benefits reaching far and wide, from enhancing medical diagnostics to improving security and surveillance systems.

6. Experiment

The state-of-the-art rich models for color picture analysis, 20,000 color images with sizes of 512,512 from the Boss Base image collection are chosen for the experiment. LSBM and WOW are the steganalysis methods, and the embedding rates are 0.05, 0.1, 0.2, 0.3, 0.4, and 0.5 bpc (bits per channel). The detection errors (DE) of Various algorithms are compared in **Figure 5**. The suggested algorithm's experimental findings and the, the

following are the comparison algorithms.

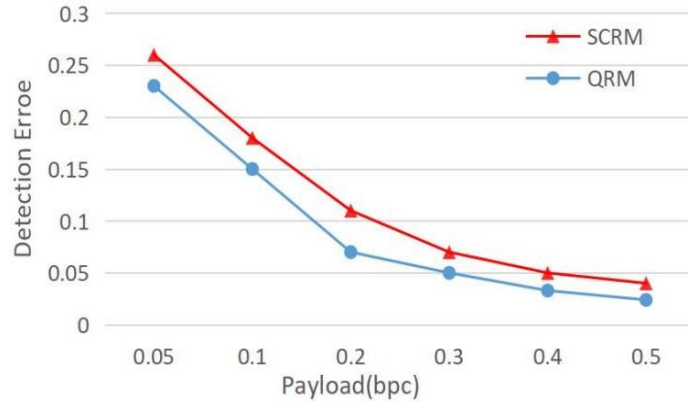


Figure 5. The embedding algorithm detects flaws using LSBM.

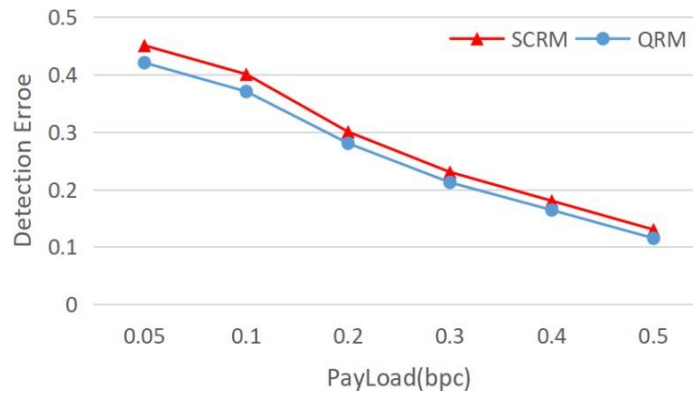


Figure 6. The embedding algorithm detects flaws like WOW.

Figure 6 shows the detection errors of the new QRM method and the conventional SCRM color picture steganalysis technique for LSBM with payloads of 0.05, 0.1, 0.2, 0.3, 0.4, and 0.5 bpc, respectively. Because the QRM method is developed on the basis of the classical SCRM algorithm, the correlation between multiple channels of a color image is examined using quaternion impulse division, and the experimental result is superior to that of the SCRM algorithm. For the three channels, the SRM grey steganalysis technique is employed. The parameters are consistent with the experimental settings shown above. The experimental comparison for different payloads is as follows in **Tables 1** and **2**, which show the average test error of three steganalysis methods of WOW and S-UNIWARD under varied loads.

Table 1. The average test error of WOW's three steganalysis methods.

Algorithm	Payload(bpc)	00.05	00.1	00.2	00.3	00.4
WOW	SCRM	00.384	00.268	00.155	00.103	00.070
	SCRM + SGF	00.388	00.275	00.160	00.103	00.071
	SCRM + SGF + DSRMQ1 + DSGF	00.333	00.244	00.146	00.088	00.059
	Quaternion RM	00.323	00.220	00.133	00.084	00.052

Table 2. The average test error of three S-UNIWARD steganalysis methods.

Algorithm	Payload(bpc)	00.05	00.1	00.2	00.3	00.4
WOW	SCRM	00.369	00.259	00.157	00.095	00.064
	SCRM + SGF	00.377	00.267	00.155	00.099	00.065
	SCRM + SGF + DSRMQ1 + DSGF	00.332	00.247	00.129	00.082	00.056
	Quaternion RM	00.324	00.223	00.126	00.070	00.049

When compared to the comparison approach, WOW and S-UNIWARD both have the ability to produce an improvement in their average test error that is between 4% and 5% lower than what it would be with the comparison technique. Additionally, the success rate of the two algorithms grows as the payload does, which indicates that the advantage of the strategy that is advocated in this research is not as large as it would be if the payload were much smaller.

7. Significance of findings

7.1. Addressing JPEG compression artifacts

JPEG compression is ubiquitous in digital imaging, and its artifacts can pose substantial challenges in image analysis. Our research has shown that Quaternion Algebra can mitigate the adverse effects of JPEG compression, providing a more robust solution for color texture segmentation. This finding is of paramount importance in various applications, such as medical imaging and remote sensing, where image quality is critical.

7.2. Advancements in color texture segmentation

Color texture segmentation is a vital component in numerous domains, including object recognition, medical image analysis, and geospatial applications. By introducing a novel approach that integrates Quaternion Algebra, we have pushed the boundaries of segmentation techniques. Our work sets a precedent for future research in this field, inspiring the development of more advanced and accurate methods.

7.2.1. Interdisciplinary relevance

Our study highlights the interdisciplinary nature of image analysis, where mathematical concepts intersect with computer science and engineering. The application of Quaternion Algebra in image processing underscores the potential for cross-pollination of ideas across domains. It opens up avenues for collaboration between mathematicians, computer scientists, and image analysts, fostering innovative research.

7.2.2. Practical applications

Beyond its theoretical contributions, our research has practical implications. The enhanced color texture segmentation achieved through Quaternion Algebra can improve the performance of various computer vision applications, such as object recognition and scene understanding. Additionally, in the medical field, our findings have the potential to enhance the accuracy of disease diagnosis and monitoring through improved image analysis.

7.2.3. Future research directions

While our research has made significant strides, several avenues for future exploration remain. Further refinement of Quaternion Algebra-based segmentation techniques, coupled with the integration of machine learning approaches, holds promise for even more accurate and versatile methods. Additionally, the application of our approach to real-world scenarios and diverse image datasets warrants further investigation.

8. Objectives and main results

In our research study, our central objective revolved around investigating the potential of Quaternion Algebra as a fundamental element for improving the process of color texture segmentation, particularly in the case of JPEG images. Quaternion Algebra, which extends the concepts of complex numbers into a four-dimensional space, presents a unique and promising approach to the representation and manipulation of color information in the context of texture analysis. **Tables 3** and **4** show the accuracy of normal query image and CML query picture in percent. Color texture segmentation is a critical task in image processing, as it plays a pivotal role in various applications, such as image recognition, object tracking, and medical image analysis. It involves the partitioning of an image into regions based on both its color and texture characteristics, which can be a complex and challenging problem to address effectively.

Traditional methods often treat color and texture separately, which may not fully capture the rich information present in images. Quaternion Algebra offers a novel perspective by enabling the integration of color and texture features in a more holistic manner. This four-dimensional mathematical framework allows for the representation of color in a way that incorporates not only the typical red, green, and blue (RGB) components but also an additional dimension, often referred to as the “hyper complex” component. This added dimension can capture more nuanced information about color, making it well-suited for the high Dimension processing.

Table 3. Accuracy of normal query image in percent.

Query image	Gabor-wavelet	Wavelet	Entropy	GLCM	Histogram
q1	81.333	81.333	72.428	74.923	98
q2	82.332	62.667	62.665	70.429	71.922
q3	71.923	56.823	70.428	70.428	75.923
q4	70.428	61.5	53.555	62.666	54.823
q5	53.823	64.666	70.428	60.5	63.667
q6	75.923	81.333	60.5	70.428	75.923
q7	82.332	70.426	61.5	70.428	82.332
q8	91.909	70.428	82.334	75.924	81.334
q9	98	81.333	75.923	82.333	91.909
q10	98	65.666	91.909	91.909	70.428
Avg.	81.5	70.418	70.268	72.281	76.523

Table 4. Accuracy (in percent) for each CML query picture.

Query image	Gabor-wavelet	Wavelet	Entropy	GLCM	Histogram
q1	91.909	70.425	61.5	70.425	65.677
q2	75.924	61.5	55.821	75.921	72.921
q3	52.554	54.824	75.921	61.4	51.553
q4	75.921	75.921	51.821	65.667	53.824
q5	56.821	65.667	70.425	61.5	63.667
q6	75.924	81.334	61.5	70.428	75.921
q7	82.333	61.428	61.5	70.426	82.332
q8	91.908	70.427	82.334	75.922	81.331
q9	65.664	65.667	73.921	70.427	70.425
Q10	62.667	70.427	76.921	65.661	75.921
Avg.	72.421	62.986	65.823	65.133	75.531

Intricacies of texture analysis by exploring QuaternionAlgebra as a foundational element in color texture segmentation, our study aimed to contribute to the development of more robust and accurate methods for image analysis and understanding. The potential benefits of this approach include improved feature extraction, enhanced discrimination of regions with similar color but different textures, and ultimately, more precise and reliable image segmentation results, especially when dealing with JPEG compressed images, which can introduce artifacts and challenges for traditional methods.

Overall, our research sought to advance the field of image processing by harnessing the unique capabilities of Quaternion Algebra to enhance the way color and texture are jointly considered and leveraged in the segmentation of digital images.

9. Conclusion

In conclusion, our research on innovative Quaternion Algebra-based segmentation for improved JPEG color texture analysis has yielded significant advancements in the field of image processing. By addressing the challenges posed by JPEG compression artifacts and harnessing the power of Quaternion Algebra, we have demonstrated a more accurate and robust approach to color texture segmentation. The implications of our findings extend beyond segmentation and have relevance in diverse applications, from computer vision to medical imaging. Our work underscores the interdisciplinary nature of image analysis and the potential for mathematical concepts to enhance computational techniques. As we move forward, further research and collaboration are needed to refine our approach, explore its adaptability to various domains, and extend its capabilities. By doing so, we can continue to push the boundaries of image analysis, providing valuable tools for researchers, practitioners, and industries that rely on precise and reliable image interpretation.

Our study represents a pivotal step toward a deeper understanding of how Quaternion Algebra can transform the landscape of image processing and analysis, ultimately leading to more accurate and insightful results in various fields of study. In future quaternion algebra will also use in medical and other high dimension data to improve the performance.

Author contributions

Conceptualization, BT; methodology, BT; software, NS; validation, BT and AKT; formal analysis, BT; investigation, NS; resources, BT; data curation, BT; writing—original draft preparation, NS; writing—review and editing, BT; visualization, BT; supervision, BT; project administration, BT; funding acquisition, BT. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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