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A Novel Approach for Quaternion Algebra Based JSEG Color Texture Segmentation

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Abstract— In this work, a novel colour quantization approach has been applied to the JSEG colour texture segmentation using quaternion algebra. As a rule, the fundamental vectors of the colour space are derived by inverting the three RGB colour directions in the complex hyperplanes. In the proposed system, colour is represented as a quaternion because quaternion algebra provides a very intuitive means of working with homogeneous coordinates. This representation views a colour pixel as a point in the three-dimensional space. A novel quantization approach that makes use of projective geometry and level set methods has been produced as a consequence of the suggested model. The JSEG colour texture segmentation will use this technique. The new colour quantization approach utilises the binary quaternion moment preserving thresholding methodology, and is therefore a splintering clustering method. This method is used to segment the colour clusters found inside the RGB cube and the colour consistency throughout the spectrum and in the space are both considered. The results of the segmentation are compared with JSEG as well as with the most recent standard segmentation techniques. These comparisons show that the suggested quantization technique makes JSEG segmentation more robust.

Keywords: Quaternion, JSEG, Image Segmentation, Image Quantization

I. INTRODUCTION

Here we use a novel colour quantization method to JSEG colour texture segmentation. We reduced the number of dimensions of the colour space with the use of level set functions and Binary Quaternion Moment Preserving (BQMP) thresholding approach [1-3]. When using the BQMP thresholding method, the spectral bands are taken into account as a whole, such that each pixel in a given colour picture is treated as a point in a three-dimensional cube.

The suggested approach uses histogram equalisation to obtain a colour dataset with a normal distribution. The authors' concept presented in [4, 22, 25] is the basis for the suggested technique. The proposed method utilises the level set function [5, 8] and updates the level set function from the binary picture by means of the Heaviside function, as opposed to repeatedly slicing the polygon along a line and saving the local data to a file [6]. The tedious and resource-heavy polygon splitting process has been done away with, and the binary image is now being kept up-to-date through partitions in the level set routines [7]. In order to speed up the calculation, the level set functions are updated using elementary arithmetic operations [8]. Because the suggested method views the binary image as partitions, it produces a binary tree with fewer levels and a smaller number of final clusters [9-11]. At last, a colour map is built with a limited colour scheme that helps keep everything looking straight.

This novel colour quantization approach is used in the JSEG (J measure based SEGmentation) algorithm to produce a quantized picture [31-33]. In JSEG, a nonlinear filtering approach is used to generate a quantized class map, which was then used in conjunction with a spatial segmentation algorithm [12, 33]. The spatial segmentation process included the use of a homogeneity measure, J, to generate a J-image that would reflect the interiors and bounds of the segments. We then used the J-image to run an arbitrary class region growth and region merging method to create our segments [14, 30].

The first step of the JSEG segmentation algorithm is the primary focus of the proposed segmentation framework. In this second phase, we make a few minor adjustments to strengthen the segmentation in which the best number of clusters has been determined by computing the dispersion measures within-cluster and between-cluster [13].

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Recursively, the clusters with the shortest distance between them are merged into larger ones.

II. BACKGROUND AND RELATED WORK

Many scholars were drawn to JSEG since it is one of the most widely used and intuitive segmentation methods [14, 26]. JSEG used a spatial segmentation technique on a quantized classification map that is created using a nonlinear filtering approach. In spatial segmentation, a homogeneity measure, J was used to generate a J-image depicting the interiors and borders of the segments [34]. The J-image was then used as input to an arbitrary class region-growth and region-merging method [32] to carry out the segmentation. Several changes and comparisons have been made to JSEG in the previous decade due to the author's candid admission of the limitations of JSEG and suggestions for future development [15, 18, 27]. The first step of JSEG involves quantization, while the second level involves spatial segmentation. From a colour quantization outcome perspective, both [31] and [32] improved JSEG. In [9] authors created a new method called HSEG by modifying JSEG and including H measure into its spatial segmentation phase [28, 15].

In [33] authors demonstrated that H measure, like other gradient operators, is very sensitive to noise. In addition, they proposed and called a new measure J (B-JSEG) that incorporates directional operators into J measure. Since the colour quantization technique (based on vector quantization) significantly influences the final segmentation results of JSEG, while authors of [34] argued that a more robust colour quantization approach is necessary to further enhance the resilience of JSEG.

For the purposes of colour image processing, such as colour image compression, multi-class clustering of colour data, and subpixel colour-edge detection. In [28] authors have developed quaternion moment based operators using BQMP thresholding. They have also shown that the BQMP thresholding approach, a two-class classifier, produces results that are comparable to those of the best Bayes classifier for data sets with a normal distribution.

Authors in [29] developed the BSP tree, and each leaf node stands in for a polygonal area. They used the BQMP thresholding approach to convert the colour picture to a binary format, and then used the best-fit criteria to establish the partition lines inside the binary image. It was then possible to divide the area along the acquired partition lines. The BSP tree approach has the drawback of using line quantization, which lowers the system's accuracy, and requiring a large number of geometric operations and powerful calculations to find the optimal dividing line and divide the polygon. Accuracy improves as the BSP tree becomes deeper. That is why you have to compromise one for the other: speed or precision [16, 17, 19-20].

III. PROPOSED APPROACH

Ordinarily, in colour image processing, pixel colours are treated as vectors in a physical, Euclid colour space [21-25]. It is common practise to use the three RGB components as the basic vectors of the colour space. Due to the inherent convenience of quaternion algebra for working with homogeneous coordinates, the suggested system makes use of a colour quaternion representation that views a colour pixel as a point in a 3D cube. Important to this quantization process is that the RGB cube's colour pixels be evenly distributed. However, in the RGB space of pictures of the natural world, the R, G, and B components are closely connected. Since the complete range of colours that humans can see is not supported by the RGB colour mode, the RGB colour space also has the disadvantage of being non-uniform and difficult to visualise. It is thus challenging to judge the observed differences in colours based on distances. In order to fix this issue, a histogram equalisation approach is used to the initial RGB picture.

Representation of a colour image using Quaternions

Considering the importance of local correlation, we figured out for a formula that would allow us to generate a complete quaternion matrix out of six 2D real matrices that are strongly linked and so serve as a representation of a colour picture. In order to do this, we took into account an adjoining pair of pixels situated at the coordinates (i, j) and $(i, j + 1)$, where i and j stand for the position of a row and column of pixels, respectively. Since, we are aware that each pixel in the RGB space has three values in colour space, we can conclude that the pair of pixels situated at (i, j) and $(i, j + 1)$ will have a total of six values. In order to construct a model that turns each pair of pixels into four integers, which can form a complete quaternion, we employed a fully connected feedforward auto-encoder to determine values and biases for all these six subpixels. Because each pair of neighbouring pixels in RGB colour space at coordinates (i, j) and $(i, j + 1)$ is turned into one quaternion integer, we used this model to create a quaternion matrix with the same number of rows as the original picture but having half number of columns.

Histogram Equalization

Image quality can be enhanced for human viewing by using the histogram equalisation approach, which is categorized as global contrast modification. The literature in [14] examines

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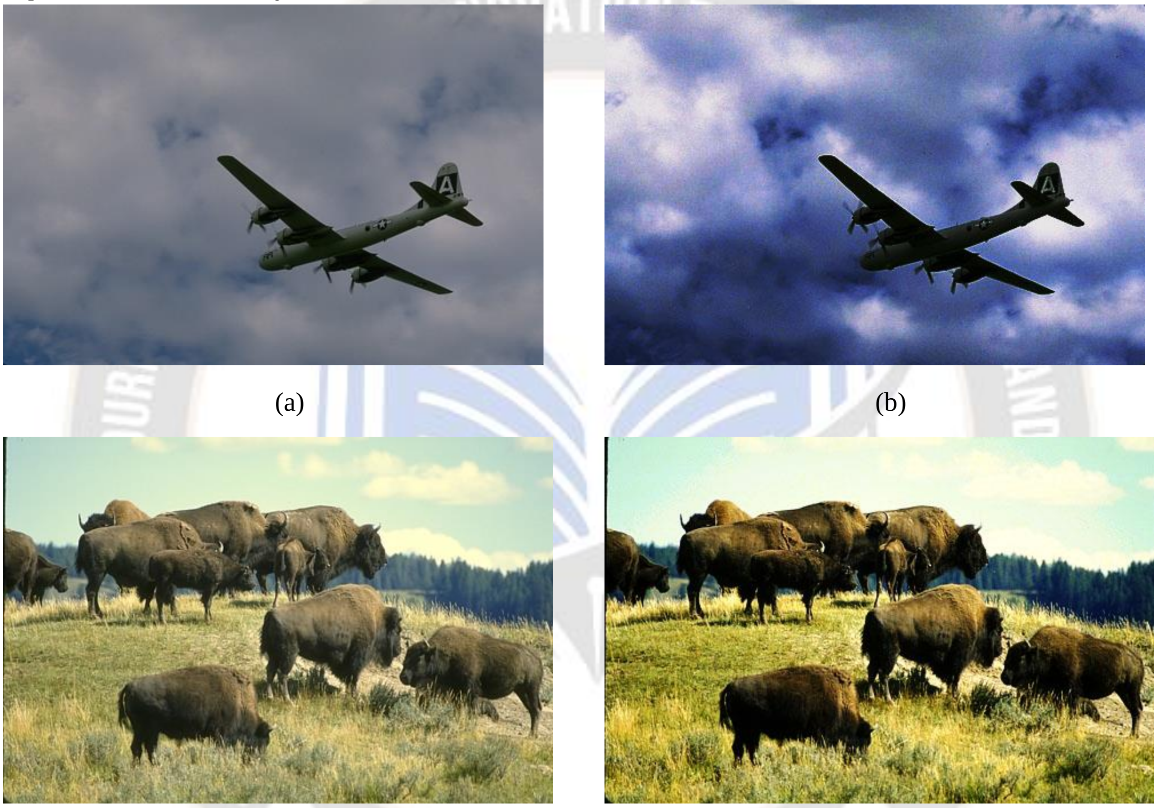
more advanced histogram equalisation methods. Our proposed setup also uses a colour histogram-equalisation technique to adjust the brightness and hue of the colours in the picture. First, a nonlinear HSI colour space is created from the RGB colour space. It is assumed that the HSI colour pixel is a uniformly distributed random vector $\vec{\vartheta} = (\vartheta_H, \vartheta_S, \vartheta_I)^T$ where $\vartheta_H, \vartheta_S, \vartheta_I$ are random vectors that are modelled for hue, saturation and intensity respectively. Hue is the most important aspect of colour, and changing it leads to unintended colour artefacts [15], hence it is kept unchanged in the proposed method. Using grayscale histogram equalisation, the intensity and saturation of each pixel are transformed into a uniformly distributed random vector so that they may be better analysed.

$$P[\vartheta \le \vartheta_n] = \sum_{i=0}^{n} f(\vartheta_i) \qquad \forall\, i = 0, 1, .., G-1 \tag{1}$$

Since we are working with 8-bit pictures, the maximum number of grayscales (G) is 256. In equation 1 the function $f(\vartheta_i)$ is the probability density function of ϑ. After the histogram equalization in the HSI colour space, the picture is converted to RGB colour space that depicts un-correlation.



(a) (b) (c) (d)

Figure 1: (a) and (c) are the original test images from the BSDS300 dataset of Berkeley where (b) and (d) are histogram equalized images.

Implementing the Multiclass Clustering Algorithm using a Level Set and the BQMP Thresholding Method

Every colour picture pixel is given a hyper-complex representation in quaternion form, as $Q = Q_0 + Q_1 i + Q_2 j + Q_3 k$. The hyper-complex co-ordinates i, j, and k operators are constrained by the rule $i^2 = j^2 = k^2 = -1$. Displaying an RGB colour pixel as a quaternion is done using the notation $Q_0 = 0, Q_1 = R, Q_2 = G \; and \; Q_3 = B$.

In a quaternion-valued pixel-set, the BQMP thresholding method chooses a hyperplane as a threshold, classifying all pixels below the threshold into class 1 (C_1) and all pixels above the threshold into class 2 (C_2). Every class does this procedure repeatedly until a target number of clusters (k) has been attained. Class variance can also be used as a termination criterion for this iterative procedure.

The suggested quantization strategy uses class variance as a cut-off condition. The provided image's attribute determines the class's threshold, which in turn determines the variance of the class. In this study, the number of colour divisions used in the quantization process is taken as the secondary stopping criterion, and the threshold for the variance of the class is set to 1/30 of the variance of the original picture. Key steps in the quantization process include developing a binary tree, formulating a level set, and putting it into action.

The sections that follow will elaborate on each of these parts.

Binary Tree Formulation

The suggested technique is based on a slicing clustering technique that results in a binary tree. The strategy of "divide and conquer" is a source of inspiration for divisive tactics. The divide-and-conquer strategy is effective for issues that can be subdivided recursively into simpler ones. Finding the underlying cause of the main issue requires solving a series of smaller, more manageable challenges and then merging their answers. The original, seed picture is used as the starting point for a divisive approach. The initial picture is then split in half. If a partition is split, the original partition's node is removed, and two new partitions, each containing their own area, are created. The process of division will continue until either M, the maximum number of leaf nodes, is achieved or the variances of all partitions remain below the threshold. Divisive algorithms are based on straightforward ideas, but need additional implementation details to work properly. How to choose which node should be divided and how to split it is the primary concern. Before dividing something into pieces, the algorithm must make a decision. When deciding which node to split, the suggested technique uses a BFS-style ordering. Number of pixels, node variance, and threshold all play a role in determining whether or not a node may be divided. In the suggested method, the node is divided using the BQMP thresholding technique. This section introduces the main and secondary level set functions that represent the node areas and partitions, respectively. Each pixel has to be allocated a cluster membership (or node number) at each stage of the division process. For the purpose of this assignment, the parent's membership status is taken into account. This membership data is what the node membership queue is made up of, and it is what is utilised to derive the node region from the main level set function.

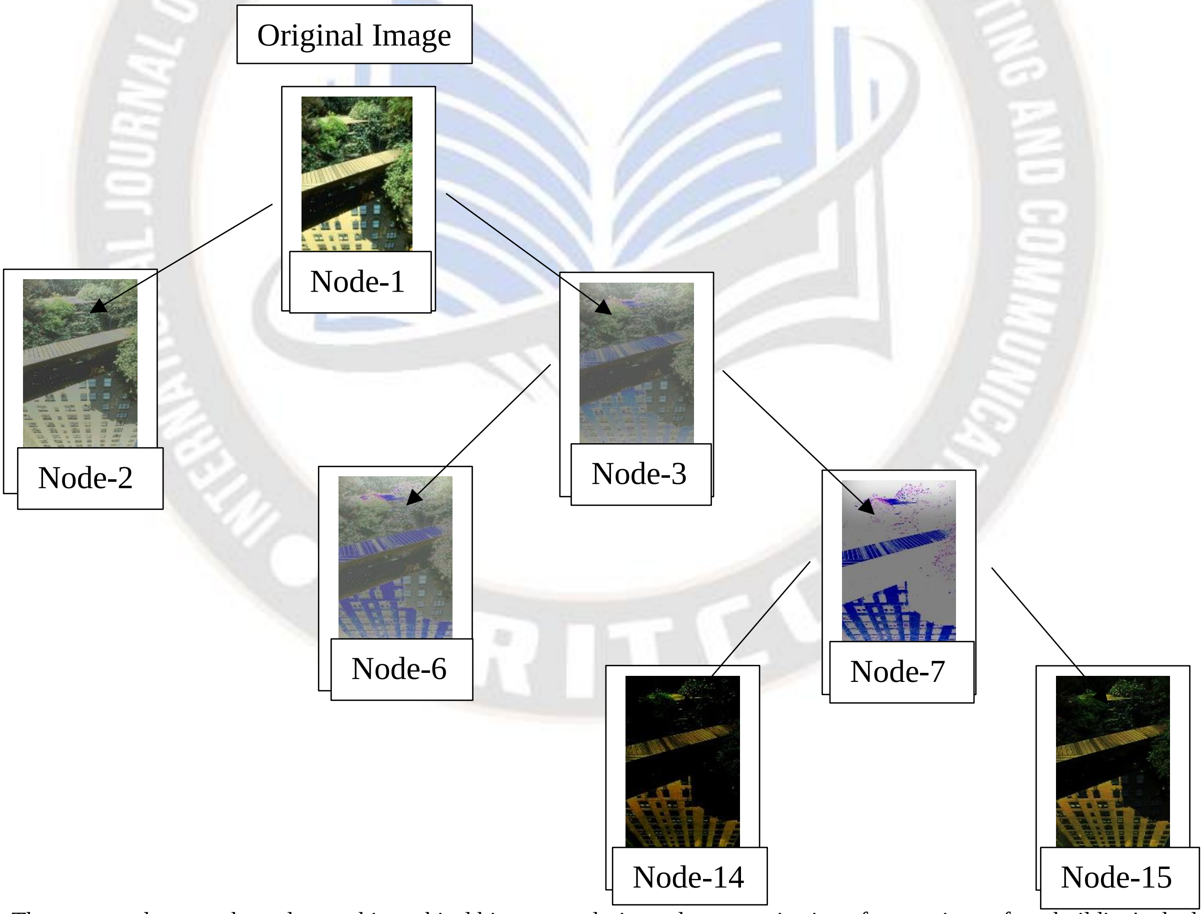


Figure 2: The suggested approach produces a hierarchical binary tree during colour quantization of a test picture for a building's shadow on a lake.

The building shadow in a lake picture obtained by the proposed approach is shown in a hierarchical binary tree structure with membership values given to each node, as shown in Figure 2. The first "node" is the original picture, while the second and third are the offspring of that image. The left child of the nth node is always 2n and the right child is always 2n+1. Each cluster is represented by a leaf node. The suggested clustering creates clusters at nodes 2, 6, 14, and 15.

Formulation of level set

An implicit function specified in a higher dimension, called the level set function, is used to express contours between two classes in level set techniques [14,15,16], and this function is then evolved using a Partial Differential Equation (PDE). The node areas are represented by level set functions in the proposed method.

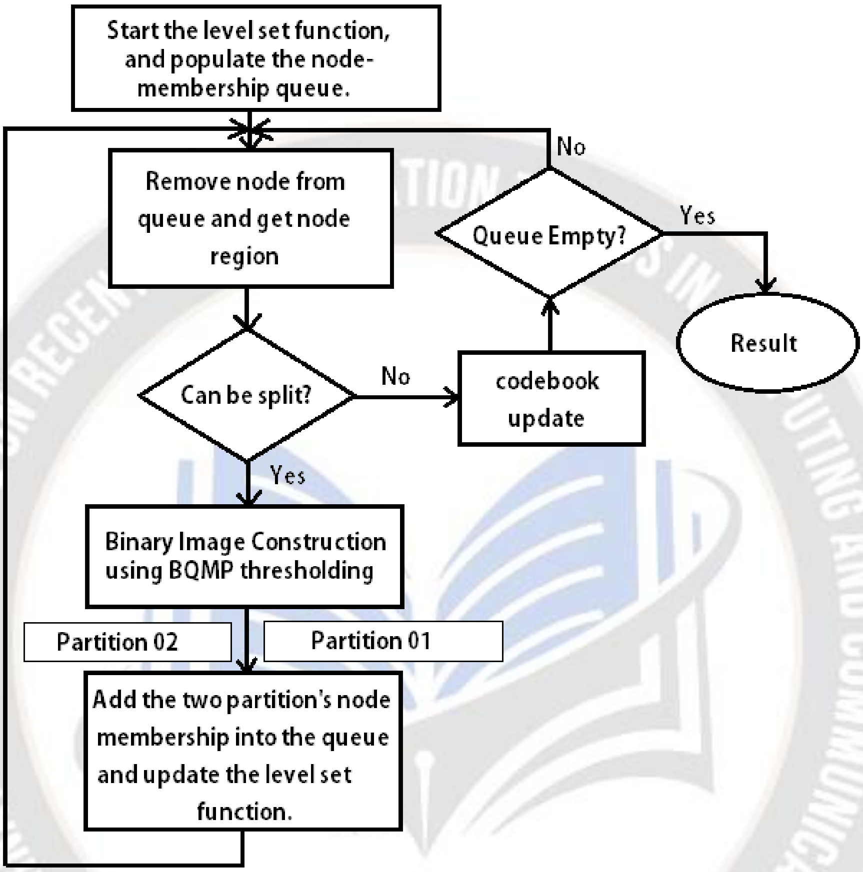


Figure 3: Diagrammatic representation of the level set formulation used in the proposed colour quantization method

The blocks used in level set formulation are shown in figure 3. Take into account an *mxn* pixel picture whose pixel's locations are depicted by (x, y). This level set formulation employs two major level set functions, α and β, of size *m*x*n*, and three supplementary level set functions, µ1, µ2 and µ3 also of size *mxn*. Pixel association values are stored in a numeric level set function called δ. If the association values are completed, the Ω function of the level set reflects this. The node area N and the two node divisions are defined by the secondary binary level set functions µ1, µ2, and µ3. Take the case of the N node area, for which the secondary level set functions required to construct the node region and its partitions are specified by the corresponding equations (2, 3, and 4).

$$\mu_1(x,y) = \begin{cases} 1 & if\ \mu_1(x,y) \in nodeN \\ 0 & otherwise \end{cases} \quad (2)$$

$$\mu_2(x,y) = \begin{cases} 1 & if\ Q(x,y) \in C_1\ and\ \mu_1(x,y) = 1 \\ 0 & otherwise \end{cases}$$

$$\mu_3(x,y) = \begin{cases} 1 & if\ Q(x,y) \in C_2\ and\ \mu_1(x,y) = 1 \\ 0 & otherwise \end{cases}$$

Where, C1 and C2 are the two classes we get after for the pixel Q(x,y) after BQMP thresholding process.

All primary level set functions are preserved during the quantization process. A short-term solution, supplementary level set functions are employed to refresh the main level set functions. Node area extraction, BQMP thresholding, partitions representation, and level set function updates are important features of every level set system. BQMP

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partitions are represented by μ_2 and μ_3, which are extracted from the secondary level set function μ_1 using the same notation. The node area µ1 is fed through the BQMP thresholding method, and the resulting partitions µ2 and µ3 are produced. Listed below is a description of the level set formulation used to extract node regions having membership value as N and portray them as partitions. Equation 5 provides the formula for determining the node area.

$$\mu_1(x,y) = \sim H_\varepsilon((\alpha(x,y) - (N+1)U)\beta(x,y))$$

Where, U is a equivalent unit matrix size to that of $\mu_1$and H_ε is a Heaviside function approximated by smoothing function which can be depicted as in equation 6.

$$H_\varepsilon(\beta) = 1 + \frac{2}{\pi} arctan\left(\frac{\beta}{\varepsilon}\right)$$

When, ε=1 then equation 6 reduces to equation 7

$$H(\beta(x,y)) = \begin{cases} 0 & \beta(x,y) < 0 \\ 1 & \beta(x,y) \geq 0 \end{cases}$$

The Heaviside operator returns a binary representation, where 1 represents a positive or zero input parameter and 0 represents a negative one. If it is determined that the present node may be divided into two, the main level set functions are revised accordingly. The result of the quantization process has been shown in figure 4 and we can see that the quality has not been degraded even after decreasing colour information several times.

Raw Image (20659 Colours) Quaternion (13 Colours)

Raw Image (45329 Colours) Quaternion (43 Colours)

Raw Image (33657 Colours) Quaternion (25 Colours)

Raw Image (22118 Colours) Quaternion (13 Colours)

Raw Image (39431 Colours) Quaternion (16 Colours)

Figure 4: The proposed Quaternion based image quantization approach has drastically reduced the number of colours to represent the raw images from the Berkeley image dataset.

Quaternion based JSEG Segmentation

Due to spatially variable lighting, which modifies both the intensity and chrominance components of the colour picture, the developers of the JSEG method have noted that their algorithm has an over-segmentation issue. To address these issues, the suggested segmentation framework proposes a two-stage process: first, the introduction of histogram equalisation and a quaternion-based divisive quantization approach; and second, the determination of the appropriate number of classes. Since it employs a quaternion-based quantization approach, the proposed full segmentation framework in this section is called Q-JSEG. Figure 5 shows a flowchart of such an inclusion in the original JSEG algorithm.

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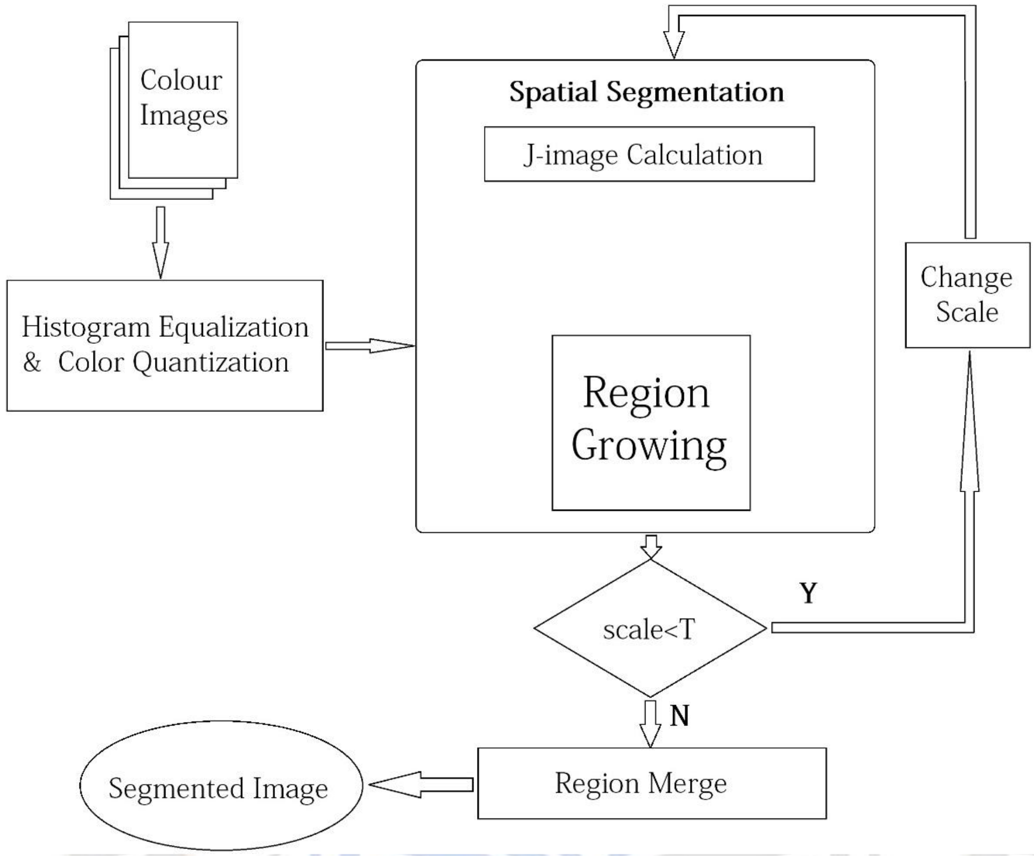

Figure 5: A flow diagram of Proposed Q-JSEG

Algorithm used in the proposed quantization technique is an iterative process makes use of the queue data structure. A binary tree as depicted in figure 2 is representing the segments of the provided colour picture is the result of this process. The algorithm for the proposed approach can be broken down into main parts as algorithm 1 and figure 5. The algorithm 1 deals with the quaternion based image quantization approach and the figure 5 involves integrating it into the JSEG colour segmentation approach.

Algorithm 1: Quaternion based image quantization approach

Input:

Output:

Start Store Image and Initialize Primary Level set functions and Membership Queue

Store Database of Image and Primary Level set function

1: **for** *every image in the database* **do**

2: *read membership value from the queue*

3: **if** *queue_empty* **do**

4: *Stop*

5: **Else**

6: *extract node region* τ_1

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```
            calculate number of pixels (P)
            calculate total number of pixels (T_P)
              if (P > T_P) do
                calculate Squared Error (SE)
                if (SE>T) do
                  split the node region using BQMP thresholding
                  calculate τ_2 and τ_3
                  update levelset function μ_1
                  compute membership values of 2 partitions
                  goto step 2
                Else
                  update levelset function and calculate average color
                   goto step 2
             else
                goto step 2
    end for
```

IV. RESULTS AND DISCUSSION

The photos in the Berkeley collection are taken in the wild and as such have irregular textures, blurry edges, and poor contrast. The longest side of the colour photos in this collection has been scaled to 192 pixels for optimal viewing experience. Q-JSEG and JSEG were tested in order to qualitatively compare their segmentation accuracy on this dataset. For the suggested Q-JSEG method to work, many crucial parameters, including the number of quantization divisions, the region growth scales, and the threshold set to the number of pixels in the area merging process, must be defined. This study quantizes the picture to around 16 colours by building a binary tree with 5 layers (15 divisions). In this experiment, we selected window sizes (scales) of 9x9, 5x5, and 3x3 due to the large (128x192 or 192x128) size of the images captured. Fifty pixels are required as the bare minimum for an area. The suggested system's main benefit is that the number of clusters is determined automatically based on the excellence factor. In Figure 6, we see how the segmentation results of the proposed Q-JSEG algorithm is compared to those of JSEG and FCR. The segmented results of FCR clearly show that it produces two boundary lines. Due to the fact that the FCR method employed a window of size 7x7 during the segmentation process, the thickness of the border line is around 7 pixels. Instead, it makes use of the benefits that come with using a variety of colour spaces and colour histograms.

It can be seen in figure 6 that the number of clusters that resulted from the suggested segmentation is lower, and that the segmentation itself provides better relevant findings in comparison to JSEG and FCR. The Q-JSEG boundary line is a single line, and the amount of boundary error has been drastically cut down. Figure 6 shows the segmentation results for the photos that have a lighted sky in the first, second, and fourth rows, respectively. Because the suggested structure makes use of an algorithm for sky correction, the sky pixels that have (spatially variable) various colour compositions have been grouped together into a single class.

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Proposed Q-JSEG **JSEG** **FCR**

Figure 6: A visual Comparison of results obtained from the compared three algorithms

Table 1: Performance in tabular format of the compared three algorithms with Q-JSEG

Algorithm	**Mean Performance Index**	**Standard Performance Index**
FCR	0.78	0.081
Q-JSEG	0.82	0.13
CTex	0.79	0.091
JSEG	0.76	0.11

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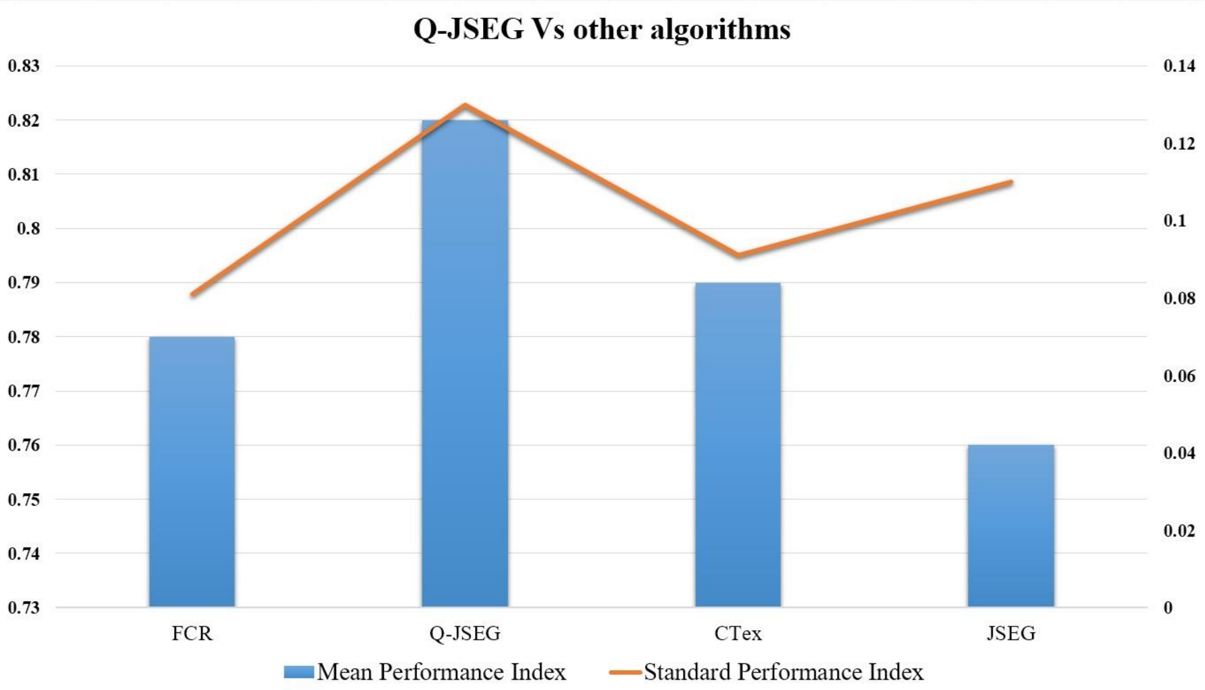

Figure 7: A graphical representation of the proposed Quaternion based JSEG image segmentation over other state-of-the-art algorithms.

V. CONCLUSION AND FUTURE WORK

In order to better segment JSEG colour textures, a novel quantization approach based on projective geometry and level set techniques has been created. The new colour quantization methodology is a partitioning clustering method that divides the RGB cube's colour clusters according to their spectral and spatial homogeneity. To increase the contrast between colours and normalise the RGB cube, histogram equalisation was used. In the suggested technique, each node of the binary tree stands in for a division. The internal nodes are purely logical and get no dedicated physical memory. The quantized colour data is only present in the leaf nodes. The level-set functions keep track of data about nodes and partitions. This makes the suggested divisive clustering technique more efficient in terms of both memory space and processing time. To further mitigate the excessive segmentation issue, the suggested quantization approach may be refined to take into account the angular characteristic of the hyper plane used in the colour division procedure. Better algorithm performance may be achieved by using advanced histogram equalisation methods. The following chapter provides a quantitative analysis of all the algorithms provided in this thesis and a comparison of the findings with the current state of algorithms.

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