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Balancing Simplification and Detail Preservation in Low Poly Image Abstraction through Edge-Preserved Seed Point Generation

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Abstract: Low poly image abstraction is an art form that has gained popularity in recent years, particularly in the digital art community. The process involves simplifying an image by reducing the number of polygons used to represent it while preserving its overall appearance and details. This paper proposes a new approach to low poly image abstraction that utilizes edge-preserved seed points to preserve important details while reducing triangle count. The proposed approach involves six steps. First, the input image is smoothed using an anisotropic diffusion filter. Second, the entropy of each pixel in the smoothed image is computed and stored in an entropy map. Third, seed points for Delaunay triangulation are selected by identifying pixels with maximum entropy values in the entropy map. Fourth, the Delaunay triangulation is generated using the seed points as input. Fifth, colors are assigned to the triangles in the Delaunay triangulation using a color selection module. Finally, the final low poly image is generated by rendering the colored Delaunay triangulation. The effectiveness of the proposed method was evaluated through qualitative and quantitative experiments, comparing its results with other comprehensive methods using a diverse range of images from a benchmark dataset. The results showed that the proposed method outperformed other methods in preserving image details while maintaining low polygon count. Additionally, the proposed method was found to be efficient and capable of producing visually appealing results.

Index Terms: Low Poly Image, Abstraction, Anisotropic Diffusion Filter, Entropy Map, Delaunay Triangulation, Seed Point Generation.

1. Introduction

Low poly image abstraction is a style that has been around for a while, but it has recently gained renewed popularity in the artist community, particularly in 2D illustration and graphics design. The style involves using adaptive polygons, typically triangles, to represent objects in an image. These polygons are arranged in such a way that they form a specific abstract visual effect. Many artists and designers are using this style to create unique and visually striking images. Modern graphics and artworks are trending towards a minimalist style, with vector images being a significant factor in this trend. Vector graphics use polygons to create images, making them easy to scale, edit, and animate. The resolution of the graphic is determined by the number of polygons per unit area, which is crucial for performance optimization. This technique has become increasingly popular in recent years, particularly in the fields of video game design and graphic design. Some examples of games that use low poly images are Don't Mess with Texas

[1], Superhot [2], Morphite [3], Astroneer [4], and Morbus [5]. Low poly abstraction has been used in everything from advertising campaigns to animated films, and it has become an important tool for artists and designers looking to create distinctive and eye-catching visuals.

The origins of low poly abstraction can be traced back to the early days of computer graphics, when limited processing power and memory made it difficult to create complex, high-resolution images. To overcome these limitations, early 3D artists began using simple polygonal shapes to represent objects in their virtual worlds. This technique not only allowed them to create more detailed environments and characters, but it also gave their creations a distinct aesthetic that set them apart from traditional animation and illustration. Today, low poly abstraction has evolved beyond its origins as a technical workaround and has become a popular artistic style in its own right. With the advent of more powerful computers and software tools, artists and designers are able to create intricate and detailed low poly images that push the boundaries of what was once possible.

One of the key challenges in creating successful low poly images is finding the right balance between simplification and detail preservation. This balance is crucial to ensure that the resulting image is both visually striking and accurately represents the subject. Too much simplification can result in a loss of important details, while too much detail preservation can result in an image that is no longer abstract.

There are several factors that can influence the balance between simplification and detail preservation in low poly image abstraction. These include the nature of the subject, the artistic style and intent, and the technical tools and processes used to create the image. The nature of the subject is an important consideration when creating a low poly image. Some subjects, such as organic forms or complex structures, may require a higher level of detail preservation in order to accurately convey their essential qualities. Other subjects, such as abstract concepts or simplified geometric shapes, may lend themselves more readily to simplification.

Artistic style and intent also play a critical role in determining the balance between simplification and detail preservation in low poly image abstraction. Some artists and designers may prefer a highly stylized and abstract look, in which case simplification may be the primary focus. Others may aim to create a more realistic or naturalistic interpretation of the subject, in which case detail preservation may be prioritized.

One important consideration when balancing simplification and detail preservation is the level of abstraction desired in the final image. Low poly image abstraction can range from highly stylized and abstract to more realistic and detailed. The level of abstraction will depend on the artist's intent, as well as the subject being represented. Abstraction and polygon reduction methods can be utilized to achieve various objectives at different levels of detail and fidelity. They enable the generation of diverse styles, topologies, and forms from original objects while considering geometric changes and maintaining desired levels of visual quality [6].

The suggested abstraction method's purpose is to provide edge-preserved low-poly image abstraction without losing image semantics. To do this, we used a mix of edge preserving smoothing and maximum entropy regions to produce seed points.

1.1 Objective and Contributions

The aim of this study is to accurately and precisely delineate low poly image abstraction from natural images. A Balancing Simplification and Detail Preservation in Low Poly Image Abstraction through Edge-Preserved Seed Point Generation method was developed for this purpose, which relies on anisotropic diffusion filter and entropy map. The key contributions of this paper are as follows:

- Anisotropic diffusion filter is studied and this filter can effectively remove noise and small details from images while preserving important features like edges and textures.
- The proposed algorithm suggests a novel approach to converting pixel images to low poly images, which balances the trade-off between simplification and detail preservation.
- The algorithm introduces the concept of edge-preserved seed point generation, which provides a more accurate representation of the edges in the low poly image.
- Demonstrating the effectiveness of the proposed method through a series of quantitative and qualitative evaluations, including comparison to state-of-the-art techniques and user studies.

The paper is organized as follows. Section 2 presents an overview of existing studies that explore various techniques for low-poly image abstraction. Thereafter in the Section 3, the proposed Low Poly Image Abstraction through Edge-Preserved Seed Point Generation method is designed. Quantitative and qualitative evaluations are presented in Section 4. Finally, the concluding remarks are provided in Section 5.

2. Literature Review

This section provides a thorough analysis of cutting-edge approaches for low-poly image abstraction techniques, which may be roughly classified as manual approach, web-based approach, and automated approach.

2.1 Manual approaches

In this approach, the low-poly image abstraction is created entirely by hand, with no automated tools or algorithms involved. To generate a low-poly image in Adobe Illustrator [7] by hand, trace the outlines of the shapes, divide them into polygons, fill them with colors, and add finishing touches. CorelDRAW [8] another vector graphics editor that can be used to manually create low-poly images. Like Adobe Illustrator, artists can trace over the original image and simplify it into a collection of flat, two-dimensional polygons, each with a color that reflects the general composition of the region. Sketch [9] is vector graphics editor, so the process for generating a low-poly image by hand in Sketch is similar to Adobe Illustrator and CorelDRAW. Although these methods can be time-consuming and labor-intensive, they offer a high degree of customization and control over the final output.

2.2 Web based approaches

Web based tools typically allow users to upload an image and then use a simple interface to adjust the size and shape of the triangles or other shapes used to create the low-poly effect. The resulting images can then be downloaded or shared directly from the tool's interface.

Delaunay [10] is widely recognized and allows users can drag and drop an image onto the canvas for generating low-poly images based on Delaunay triangulation. The tool offers various choices for modifying the point rate, maximum number of points, blur size, edge size, and pixel limit, allowing for a fine degree of control over the output to produce different results. Low Poly Art Generator [11] tool used to create geometric low poly art images based on Delaunay triangulation. It includes only a single control option, referred to as "cell size", which regulates the pixel measurements of the grid cells, varying from 10 to 100 pixels. Another tool, Polytomizator [12], that create low poly images from an input image based on Delaunay triangulation. Users can upload or drag and drop their desired input image and adjust settings such as different brushes, brush sizes, and densities. Triangulation low poly image generator [13] uses the Voronoi diagram technique to create low poly images. Users can upload their image, adjust the point size and randomness, and generate a unique low poly image. The Triangulator website [14] is known for its easy-to-use low-poly image generator based on Delaunay triangulation. It offers three different algorithms (YAPE, YAPE6, and Fast Corners) with sliders for adjusting triangle size and number (using the "Minieigen" slider) or making small tweaks (using the "Laplacian" slider). To create a triangulated image, users simply upload an image, choose one of the three algorithms, and specify the desired output resolution.

While web-based generators offer a simple and easy way to create low-poly images, they often have limited options for customization. Users may not be able to adjust certain parameters or have the ability to fine-tune the low-poly effect to their liking. Also web-based generators may not work well with more complex images and quality of the final result may vary depending on the quality of the algorithm used.

2.3 Automatic Approaches

Automatic low poly image abstraction is the process of generating low poly abstractions of images through algorithms and computer programs, eliminating the need for manual involvement.

Uasmith et al. [15] uses a bilateral filter that smoothes the input image while preserving the image's global edges. Then, seed points are generated using various algorithms such as K-means segmentation, contour extraction, and Ramer-Douglas-Peucker simplification. These seed points are then combined into a single cluster and a Delaunay triangulation is performed to create the low-poly image. Zhang et al. [16] proposes an automatic approach for low-poly style image and video processing, which uses a real-time triangulation method to synthesize images and videos into low-poly style. The method employs the use of edge and color information to select vertices for composing triangles and an anti-jittering method to eliminate abrupt changes in position and color of the triangles between adjacent frames in video low-poly stylization. M. Gai and G. Wang [17] introduce a new method for generating low poly rendering of images that is popular in the art design community. The method proposes important principles and mimics the creation process of artists. It uses feature edges to constrain vertices and produce clear boundaries, and the Voronoi diagram iteration guided by a feature flow field to reflect the feature structure of the local shape. The approach also includes salient region detection to achieve different mesh densities between foreground and background, and special color processing techniques to improve the artistic quality of the results. Instead of relying on edge detection for vertex placement, K. Lawonn and T. Günther [18] introduced an error function that measures the similarity between the colored triangulation and the original image, allowing for a more accurate determination of vertex placement. They then use gradient descent to move the vertices to places where the Delaunay triangulation minimizes a given error metric over the whole image. This method produces results which get very close to the original image, in contrast to other papers, which focus more on how to make a visually pleasing low-poly images. They also implemented low-poly video, where for each frame they use the vertex placement of the previous frame as an initial starting point to calculate gradient descent on. The paper presents an algorithm called Pic2Geom [19] for generating low poly geometric art in a fast and efficient manner. The algorithm employs edge detection, saliency detection, and face detection to generate seed points that are used for Delaunay triangulation. The extension of the algorithm, Pic2Geom, called Pic2PolyArt [20], which focuses on the subject and transforms a photograph into geometric art that is based on polygons. To achieve this, the algorithm employs saliency, edge, and face detection techniques to identify the main subject and crucial features of the image. The framework then creates a set of seed points and utilizes Delaunay Triangulation and Voronoi Tessellation to produce triangle-based and polygon-based geometric abstractions, respectively. A summary of existing studies on low poly image abstraction is given bellow

Table 1. Existing studies on low poly image abstraction

Studies	Methodologies and Algorithms	Evaluation Metrics
Uasmith et al. [15]	Seed point generation (Bilateral filter, K-means segmentation, contour extraction, and Ramer-Douglas-Peucker simplification.), Delaunay Triangulation	Subjective evaluation, Numerical evaluation- mean structural similarity index (MSSIM)
Zhang et al. [16]	Sobel edge-detecting, Delaunay Triangulation	Subjective evaluation
M. Gai and G. Wang [17]	Constrained edge feature, Douglas–Peucker algorithm, Saliency detection and constrained Delaunay Triangulation or Voronoi diagram	User study and two-sample t test
K. Lawonn and T. Günther [18]	Vertex Optimization, Incremental Refinement, Delaunay Triangulation.	Subjective and Parameter evaluation
Pic2Geom [19]	Seed point generation (edge detection, saliency detection and face detection) and Delaunay Triangulation	Quantitative user study and Qualitative user study
Pic2PolyArt [20]	Seed point generation (Canny edge detection, saliency detection and face detection) and Delaunay Triangulation / Voronoi diagram	Empirical user studies and Qualitative evaluation

In summary, most of the methods employ edge detection and saliency maps for seed point generation, followed by Delaunay triangulation for mesh creation. Each method differs in the specific techniques used for seed point generation, resulting in variations in the final low poly abstractions.

3. Methodology

In this section, an overview of the proposed low poly image abstraction framework is given in brief. Figure 1 shows the overall block diagram of prosed method

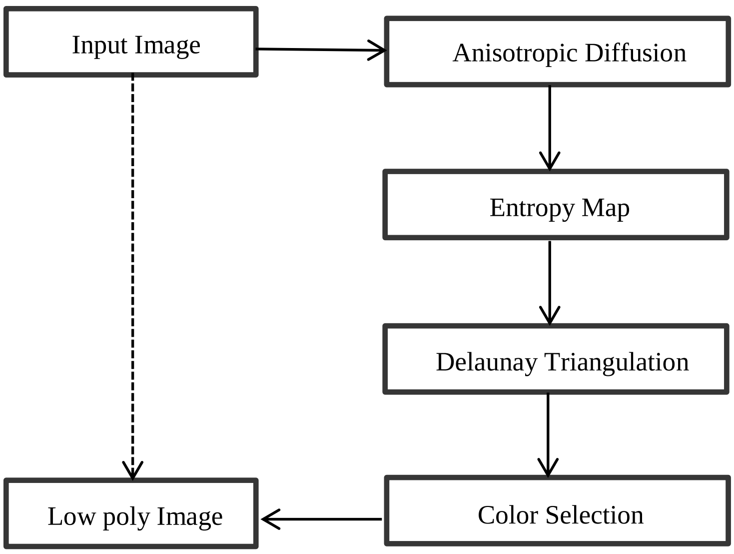


Fig. 1. Block diagram of low poly image abstraction framework.

The edge-preserved low poly image abstraction framework illustrated in Figure 1 consists of four key steps that are crucial for preserving the edge structure of the original image. The first step involves extracting the edges from the image and then distributing more points on these edges than on other regions. This approach ensures that the resulting low poly image retains the essential features of the original image and accurately represents the edges, which are often the most important aspects of an image. To further preserve the edge details, the input image is smoothed using the Anisotropic Diffusion filter before generating the seed points for Delaunay Triangulation. This filter selectively smooths out regions of the image while preserving the edge details, resulting in a smoothed image that maintains the essential edge features. The creation of an entropy map based on the local entropy of the smoothed image is a critical step in determining the locations of the seed points for the Delaunay Triangulation. The entropy map provides information about the information content in the image, with higher entropy values indicating more complex regions. The maximum entropy value pixels are selected as the seed points for the Delaunay Triangulation, which ensures that the resulting mesh accurately represents the complexity of the original image. Finally, each triangle in the Delaunay Triangulation is assigned a color based on average pixel values in the triangle, resulting in the final low poly image.

This approach provides a targeted reduction in the triangle count while preserving the essential features of the original image, making it an attractive option for use in various fields such as video game development, computer graphics, and data visualization. The four key steps are discussed in detail as follows:

3.1 Anisotropic Diffusion based image smoothing

Anisotropic diffusion smoothing is a well-known method for smoothing digital images with edge preservation. Perona and Malik [21] were the first to suggest anisotropic diffusion for image scale-space description and edge detection. Then anisotropic diffusion is defined as

$$\frac{\partial I}{\partial t} = div(C(x,y,t)\nabla I) = \nabla C.\nabla I + C(x,y,t)\Delta T \tag{1}$$

Where I is the input image, Δ denotes the Laplacian, ∇ denotes the gradient, $div\,(\ldots)$ is the divergence operator and $C(x,y,t)$ is the diffusion coefficient. The goal behind anisotropic diffusion is to pick $C(x,y,t)$ adaptively in different diffusion iterations such that intra-regions in an image remain smooth but inter-regional edges are preserved. Small intensity changes, such as noise or shading with low gradient levels, can thus be efficiently smoothed, whereas edges with high intensity transitions are efficiently preserved.

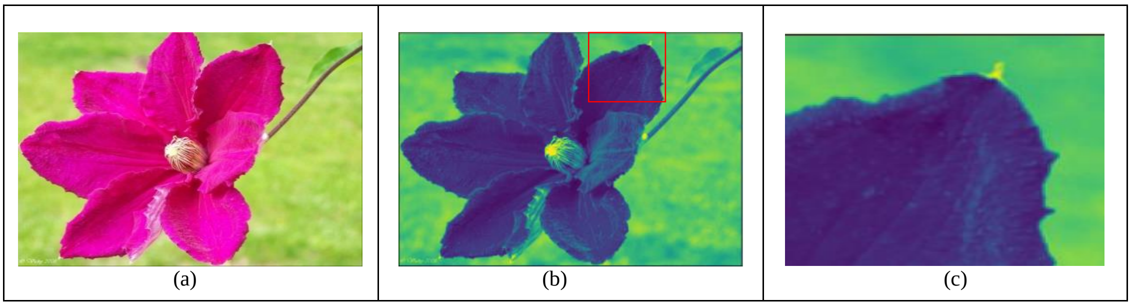


Fig. 2. (a) Original Image, (b) Smoothed image, (c) Enlarged portion.

In the above figure, 2(a) represents the original image and 2(b) represents the smoothed image obtained using Anisotropic Diffusion based image smoothing. 2(c) shows the enlarged portion of the red square region of figure 2(b). The details within a region, such as textures or patterns, are not lost during the smoothing process, while the edges between regions, such as the boundaries of objects or structures, remain intact. By applying the anisotropic diffusion filter, the method effectively suppresses high-frequency noise, texture, and minor variations in pixel intensities that can distract from the main geometric shapes. This smoothing process helps in achieving a more simplified and clean appearance in the final low poly abstraction.

3.2 Entropy Map

An entropy map is a useful representation of the entropy or randomness of a signal in a specific area or location of an image. In other words, it highlights the parts of an image where there are sudden changes or variations in pixel values. Entropy is a measure of the image's information content and represents the number of bits required to represent visual data in image processing. Shannon's entropy [22] is frequently used in various fields, including image analysis, to estimate the degree of information present in a set of data. Higher entropy values indicate a high quantity of information, while smaller values indicate little information. The concept of local entropy in an image is linked to the variety of

Algorithm 1: Calculating the Local Entropy

Input : Image: A gray scale image I and n: neighborhood_size :
Output : Entropy map
Steps 1: Initialize the entropy map with zeros
Steps 2 : For each pixel in the image:

- Extract the local neighborhood size n x n centered on the pixel
- Compute the histogram of gray values within the neighborhood using the specified number of gray levels
- Normalize the histogram so that the sum of all bins equals 1
- Compute the entropy of the histogram using the formula H = - sum(p * log2(p)), where p is the probability of each gray level in the histogram
- Assign the entropy value to the corresponding pixel in the entropy map

Steps 3: Return the entropy map

information that exists within a particular neighborhood, and the size of the neighborhood is usually defined by a structuring element. With the help of an entropy filter, even the slightest variations in the distribution of grey levels within the local area can be identified. To calculate the local entropy value, it is recommended to use a circular structuring element with a radius that is sufficient enough to cover the entire local area's grey level distribution. Local entropy maps are useful for identifying areas of interest in an image with high entropy or randomness, such as edges, corners, or textures, which are critical for object recognition or segmentation. An algorithm for calculating the local entropy of an image is given bellow

In figure 3(a), the output of the algorithm is an entropy map of the input image 2(a). The entropy map represents the local entropy values of each pixel in the image. The brighter colors in the map indicate regions with higher entropy values, which correspond to areas with more texture, detail, or irregularities. On the other hand, lighter colors indicate regions with lower entropy values, which correspond to smooth areas or regions with constant grey values. The edges of the image have high entropy values because they typically contain abrupt changes in intensity or texture, which are captured by the local entropy measure. Therefore, the algorithm is able to detect edges and other high-frequency features in the image by computing the local entropy values. The proposed method utilizes the entropy map to identify areas in the image that contain significant details or important features. By considering the entropy values, the algorithm can prioritize preserving these regions during the simplification process. This ensures that critical elements, such as salient edges or distinctive structures, are retained in the final low poly abstraction, while less significant areas are simplified or abstracted further.

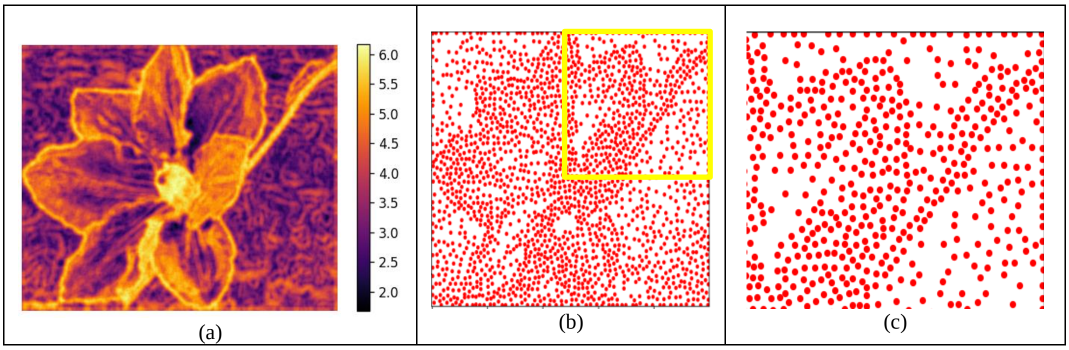


Fig. 3. (a) Local Entropy Map (b) Selected seed points (c) Enlarged portion .

To select seed points from an entropy map, the algorithm finds the pixels with the maximum entropy value, which corresponds to the regions with the highest information richness. The algorithm then marks those pixels as seed points, which can be used later for the low poly image abstraction. By repeating this process, the algorithm selects more seed points until it reaches the desired number (num_points) of seed points. Fig 3(b) shows the selected seed points.

3.3 Delaunay Triangulation

Delaunay Triangulation (DT) is a method of creating a triangle mesh from a set of points in a plane. The triangulation is constrained so that no circle that circumscribes any of the triangles contains any of the original points within its interior. In other words, the triangulation is a way of dividing the plane into smaller triangles, while ensuring that no triangle is "too skinny" or "too fat".

Delaunay Triangulation is a triangulation for a given set P of discrete points in a plane in which no point in P is inside the circumcircle of any triangle in DT. Delaunay Triangulation is the most often used algorithm for triangulation based geometric abstraction. Delaunay Triangulations optimize the minimum angle over all triangles in the triangulation, resulting in the fattest triangles possible. These fat triangles are typically utilized in existing low-poly image generators because they are more aesthetically appealing in low-poly art. Delaunay Triangulation ensures that the generated triangles are evenly distributed across the image. This property helps in achieving a balanced and visually pleasing arrangement of polygons, which is a key characteristic of low poly art.

To execute triangle-based simplification, the system utilizes the seed points generated by maximum entropy values, as P = {P1, P2,…… Pn}. The seed points are triangulated to generate a non-overlapping triangular mesh.

In Figure 4(a), the Delaunay Triangulation of the seed points is shown. This method connects the seed points together, forming a set of non-overlapping triangles. The Delaunay Triangulation ensures that no seed point lies within the circumcircle of any triangle formed by the seed points. Figure 4(b) depicts the resulting set of triangles obtained from the Delaunay Triangulation. These triangles collectively represent the low poly image abstraction.

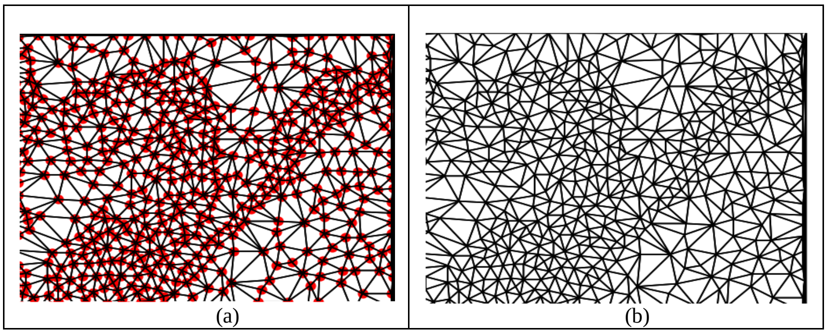


Fig. 4. (a) Delaunay Triangulation of seed points (b) Set of Triangles .

3.4 Color Selection

To fulfill the low poly image abstraction, colours each triangle with the average colour of all pixels within the triangle's boundary. Once the triangles are formed, the coloring process begins. To color each triangle, we first need to find all the pixels within the boundary of the triangle. Once we have all the pixels within the triangle, we can calculate the average color of all the pixels. This can be done by taking the RGB values of all the pixels and finding the average of each color component (R, G, B).Finally, we apply this average color to the triangle, filling it with the color that is the average of all the pixels within its boundaries. This process is repeated for all the triangles generated by Delaunay Triangulation, resulting in a fully-colored image. By calculating the average color of pixels within a triangle, intricate color details are smoothed out and simplified. This helps to create a more minimalist and stylized representation that aligns with the overall aesthetic of low poly art. Figure 5 demonstrates the transformation of the plain triangle structure into a visually appealing low poly image through the assignment of colors.

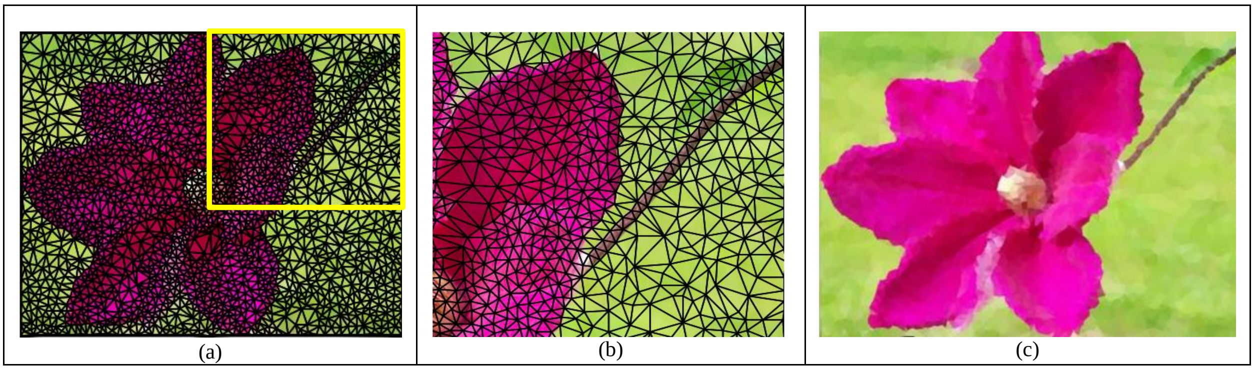


Fig. 5. (a) Assign Colors to Triangles (b) Enlarged portion (c) Low poly Image.

In Figure 5(a), the colors are assigned to each triangle in the low poly image. Each triangle is filled with an average color determined from the corresponding region in the original image. This step adds visual appeal and enhances the overall appearance of the low poly representation. Figure 5(b) provides an enlarged portion of the image, showcasing the individual colored triangles in greater detail. This close-up view allows for a better appreciation of the colorization

Algorithm 2: Low Poly Image Abstraction

Input: An image, *I*, and number of points for low poly image, *num_points*
Output: Generated low poly image , *low_poly_img*
Step 1. Smooth the input image, *I*, using an Anisotropic Diffusion filter.
Step 2. Compute the entropy of each pixel in the smoothed image using a sliding window and store the result in an entropy map.
Step 3. Select the seed points for Delaunay Triangulation.
- Find the maximum entropy value in the entropy map and mark the corresponding pixel as a seed point.
- Repeat the above step until the desired number (*num_points)* of seed points is reached.

Step 4. Generate the Delaunay Triangulation using the seed points as input.
Step 5. Assign colors to the triangles in the Delaunay Triangulation based on average color.
Step 6. Generate the final low poly image by rendering the colored Delaunay Triangulation**.**
Step 7. Return the low poly image, *low_poly_img*.

and the distinct polygons that make up the low poly image. Finally, Figure 5(c) presents the complete low poly image after the colorization process. The combination of the assigned colors to the triangles creates a visually captivating and stylized representation of the original image. The aforementioned steps are consolidated and summarized in Algorithm 2.

By smoothing out high-frequency variations and minor details, the anisotropic diffusion process contributes to achieving a cleaner and more simplified appearance in the final low poly abstraction. The entropy map helps guide the subsequent steps in identifying regions that should be preserved in greater detail to maintain the visual fidelity of the original image. Seed point generation ensures that the resulting polygons align with the essential features and structures, capturing the defining elements of the original image. Delaunay triangulation provides an efficient and visually pleasing way to connect the seed points while maintaining a balanced and evenly distributed polygonal structure. The color selection step contributes to the overall achievement of the desired low poly image abstraction by creating a simplified, cohesive, and visually appealing color representation. By combining these individual steps - anisotropic diffusion, entropy map creation, seed point generation, Delaunay triangulation and color selection - the proposed framework achieves a desirable low poly image abstraction.

4. Experiments and results

4.1 Qualitative evaluation on benchmark dataset

Mould and Rosin [23] developed a benchmark dataset specifically designed to assess the inherent quality of various stylization methods. Rather than aiming to directly compare algorithms and determine superiority, their primary objective was to offer insights into the characteristics and performance of each algorithm. The intention was to provide support in comprehending the behavior and outcomes associated with different stylization approaches. This dataset consists of 20 high-resolution images from Natural scenes, Architectural scenes, Objects, people and artistic scenes.

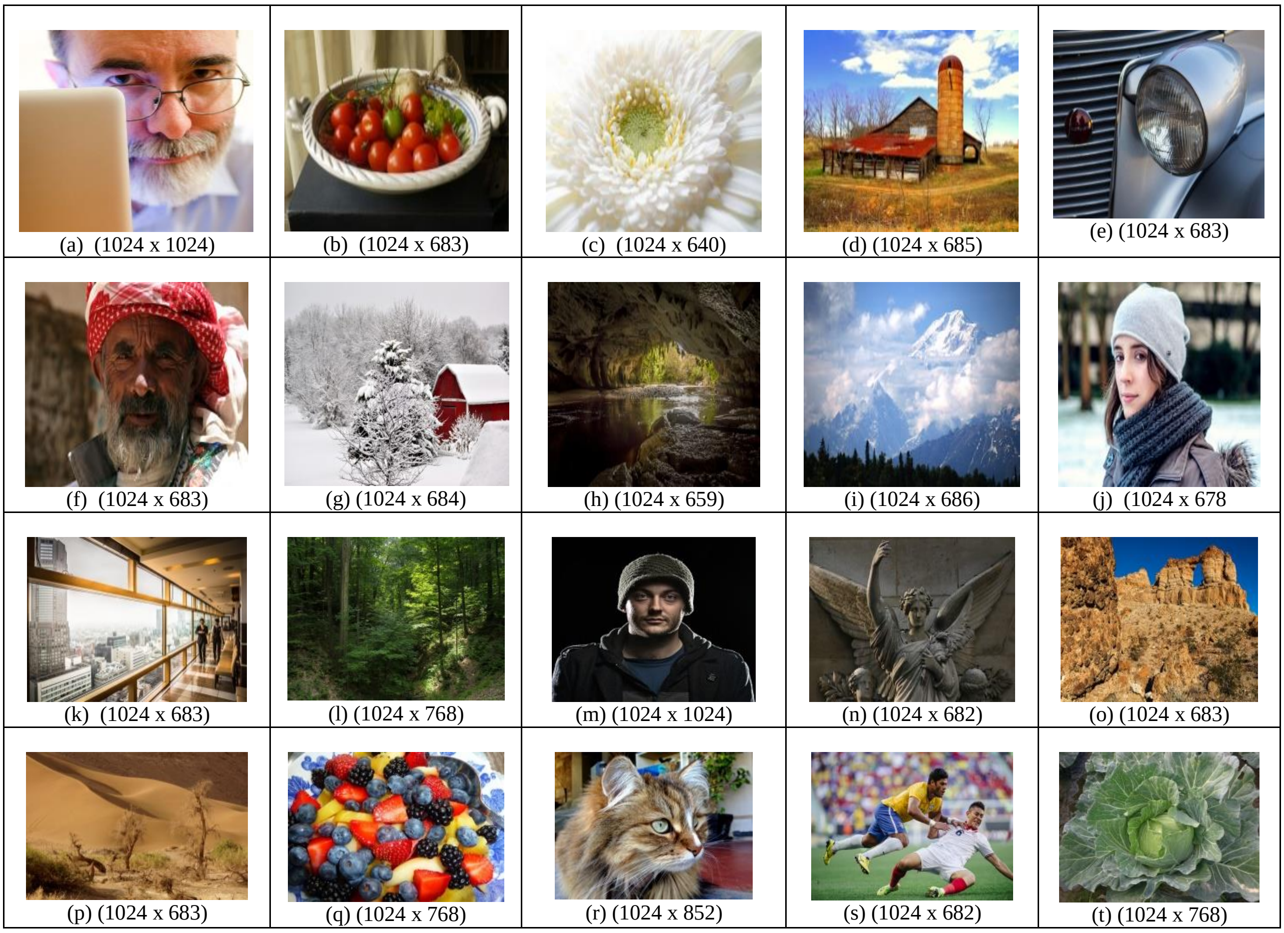


Fig. 6. Images from [24] (a) Mac, (b) Tomato, (c) Daisy, (d) Barn, (e) Headlight, (f) Yemeni, (g) Snow, (h) Oparara, (i) Mountains, (j) Toque, (k) City, (l) Darkwoods, (m) Rim, (n) Angel, (o) Arch, (p) Desert, (q) Berries, (r) Cat, (s) Athletes, (t) Cabbage.

Figure 6(a) to 6(t) showcases a collection of images from the benchmark dataset [23]. Each image is associated with its respective resolution mentioned above.

4.1.1 Performance Analysis of Simplified Representations by varying the number of points

The performance analysis of simplified representations, specifically low poly image abstractions, can be evaluated by qualitative measures such as visual inspection and subjective opinions. However, it is also important to consider quantitative measures to ensure that the simplified representation is visually appealing.

In the case of low poly image abstractions, one way to evaluate their performance is to compare the number of points used to represent the image. A lower number of points results in a more simplified representation, while a higher number of points results in a more detailed representation. Therefore, we can evaluate the performance of the simplified representation by varying the number of points and comparing the results.

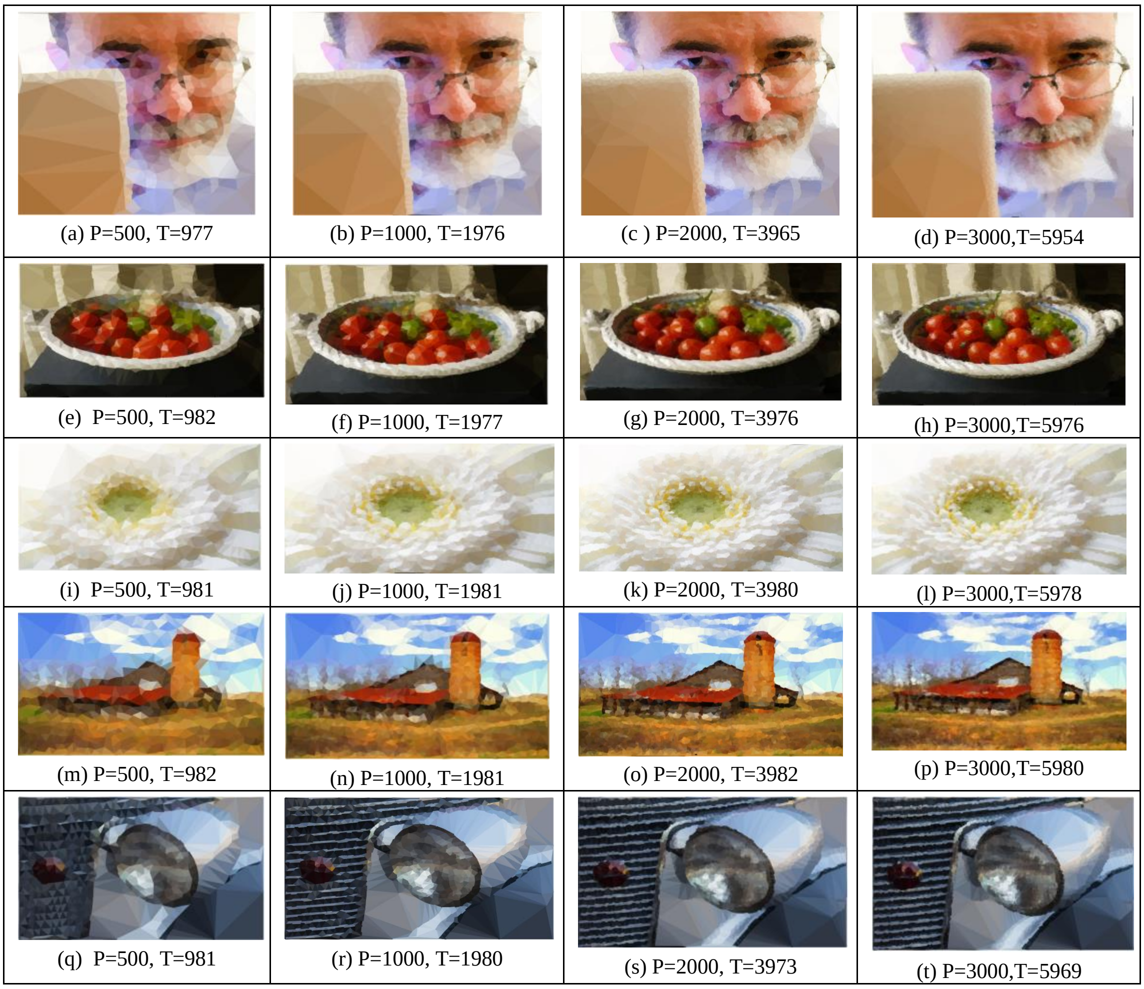
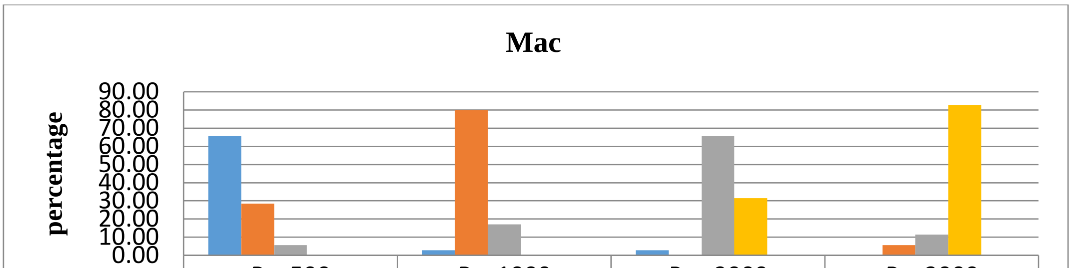


Fig. 7. Simplified Representations with varying number of points . P – Number of points, T – Number of triangles. (zoom in to observe the detailed abstraction).

To analyze the performance of various simplified representations of the proposed technique for low poly abstraction, a balance must be struck between simplification and detail preservation. This involves reducing the complexity of the original image while retaining its essential details. The simplified representations of the original images 6(a) to 6(e), with varying numbers of points and triangles, are shown in Figure 7. In the original image 6(a) of size (1024 x 1024) that contains 1048576 pixel , the proposed method generate low poly image abstractions 7(a) with 500 points and 977 triangles 7(b) with 1000 points and 1976 triangles, 7(c) with 2000 points and 3965 triangles 7(d) with 3000 points and 5954 triangles. Figure 7(e) to 7(h) display the simplified representation of the original image 6(b). Similarly, Figure 7(i) to 7(l) shows the simplified representation of the original image 6(c). Figure 7(m) to 7(p) exhibit the simplified representation of the original image 6(d). Lastly, Figure 7(q) to 7(t) portrays the simplified representation of the original image 6(e).

In order to assess the quality of the simplified representations, a Google Form was created. The form included the original image along with its four simplified representations. Participants were asked to rate each image on a scale of 1 to 5, with 1 being "Bad," 2 being "Poor," 3 being "Fair," 4 being "Good," and 5 being "Excellent." To ensure consistent understanding among participants, they were provided with clear instructions regarding the evaluation criteria. They were informed that overall image quality should be considered, taking into account various aspects such as color, edges, and detail. The participants were asked to evaluate how visually appealing the picture looked as a whole, considering the simplification achieved through the minimum number of points and triangles.



	P = 500	P = 1000	P = 2000	P = 3000
Bad	65.71	2.86	2.86	0.00
Poor	28.57	80.00	0.00	5.71
Fair	5.71	17.14	65.71	11.43
Good	0.00	0.00	31.43	82.86
Excellent	0.00	0.00	0.00	0.00

Fig. 8. Evaluation of Mac image fig 6(a) with user rating .

Figure 8 displays the evaluation of the Mac image 6(a) using different user ratings. It is evident that the simplified representations with 500 points received low ratings, with 65.71% of participants rating it as "Bad" and 28.57% rating it as "Poor". The 1000 points representation fared even worse, as 80% of participants rated it as "Poor". For the 2000 points representation, 65.71% of participants rated it as "Fair" and 31.43% rated it as "Good". The representation with 3000 points achieved the highest satisfaction, with 82% of participants giving it a "Good" rating.

The evaluation of the 20 images, from fig 6(a) to 6(t), using the proposed simplification algorithm reveals a consistent trend. The results suggest that the algorithm performs well when employing either 2000 points or 3000 points for the simplified representations.

The evaluation of the Mean Opinion Score (MOS) for the 20 images, represented in various numbers of points, provide additional insight into the performance of the proposed algorithm. Fig 9 presents the MOS values for the simplified images using 500 points, 1000 points, 2000 points, and 3000 points.

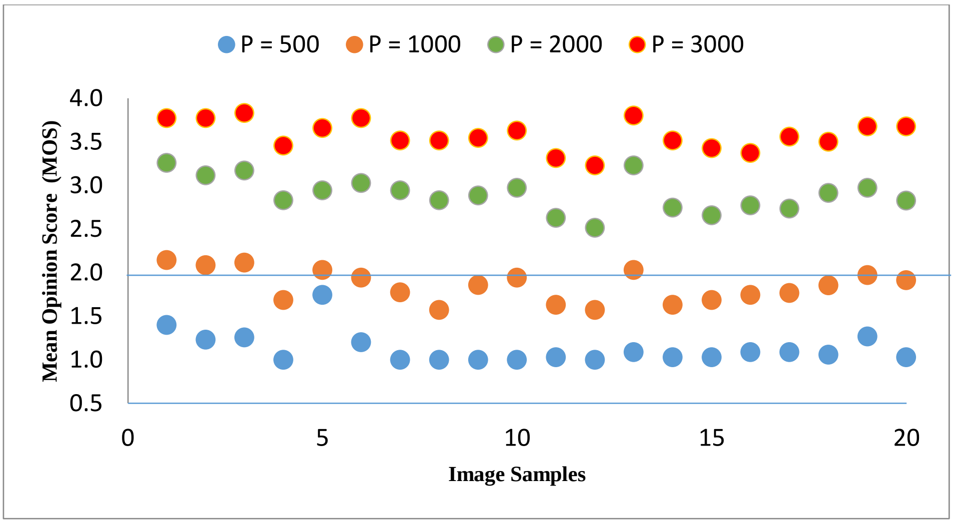


Fig. 9. Evaluation of 20 images fig. 6(a)- 6(e) with MOS.

Based on the MOS values, it is observed that the algorithm performs well when employing either 2000 points or 3000 points for the simplified representations. MOS values of 2.5 and above were obtained for the 2000 points and 3000 points representations, indicating a favorable level of quality and satisfaction among participants.

On the other hand, MOS values of 2.5 and below were obtained for the 500 points and 1000 points representations. This suggests that these lower densities of points were associated with lower perceived quality and satisfaction among participants.

These findings reinforce the notion that the algorithm achieves favorable results when using higher point densities, specifically 2000 points and 3000 points. These representations strike a balance between reducing complexity while retaining important visual elements, resulting in higher MOS values and greater participant satisfaction.

Additionally, the proposed simplified representations, which involve representing an image as a set of points and triangles, offer storage benefits compared to storing the full-resolution image. By only storing the points and color information of each triangle, storage requirements can be significantly reduced. The reconstructed image based on these simplified representations can provide an approximation of the original image, which can be visually satisfactory for many purposes.

4.1.2 Qualitative Analysis of various edge detection methods

The qualitative analysis involved comparing our proposed method with the Canny and Sobel edge detection algorithms. Fig 10(a) to 10(c) showcase the outcomes of low poly image abstraction using our method (10(a),10(d), 10(g), 10(j), 10(m)), the Canny method (10(b), 10(e), 10(h), 10(k), 10(n)), and the Sobel method (10(c), 10(f), 10(i), 10(l), 10(o)) of the original image 6(a)-6(e) respectively.

Fig. 10. Comparison of proposed method with canny and sobel edge detection methods. (zoom in to observe the detailed abstraction).

In our proposed method, seed points are generated based on the maximum entropy value in the entropy map. In contrast, the Canny method utilizes both Canny edge detection and Poisson disk sampling techniques to obtain seed points. Similarly, the Sobel method combines the Sobel edge detection algorithm with Poisson disk sampling for seed point generation.

During the analysis, our proposed method exhibited superior performance compared to the Canny and Sobel methods. This is primarily attributed to our method's ability to generate seed points more accurately in edges and other areas that contain significant information. By utilizing the maximum entropy value, our method gains a more comprehensive understanding of the image's information content.

Consequently, our method produces seed points that effectively capture the essential features and structures of the image, resulting in more precise and visually appealing low poly image abstractions.

4.2 Quantitative evaluation on Natural Image Dataset

The effectiveness of the proposed Edge Preserved Seed Point Generation for Low Poly Image Abstraction of Digital Images is investigated by comparing it with other notable algorithms, namely Polyvia [24], Generating Low-Poly Abstractions (GLA)[25], and Delaunay [10]. To conduct the analysis, a comprehensive Natural Images dataset [26] comprising 6,899 images from eight different classes, including airplane, car, cat, dog, flower, fruit, motorbike, and person, is utilized. Specifically, five distinct images are selected from each of the eight classes for evaluation and comparison purposes

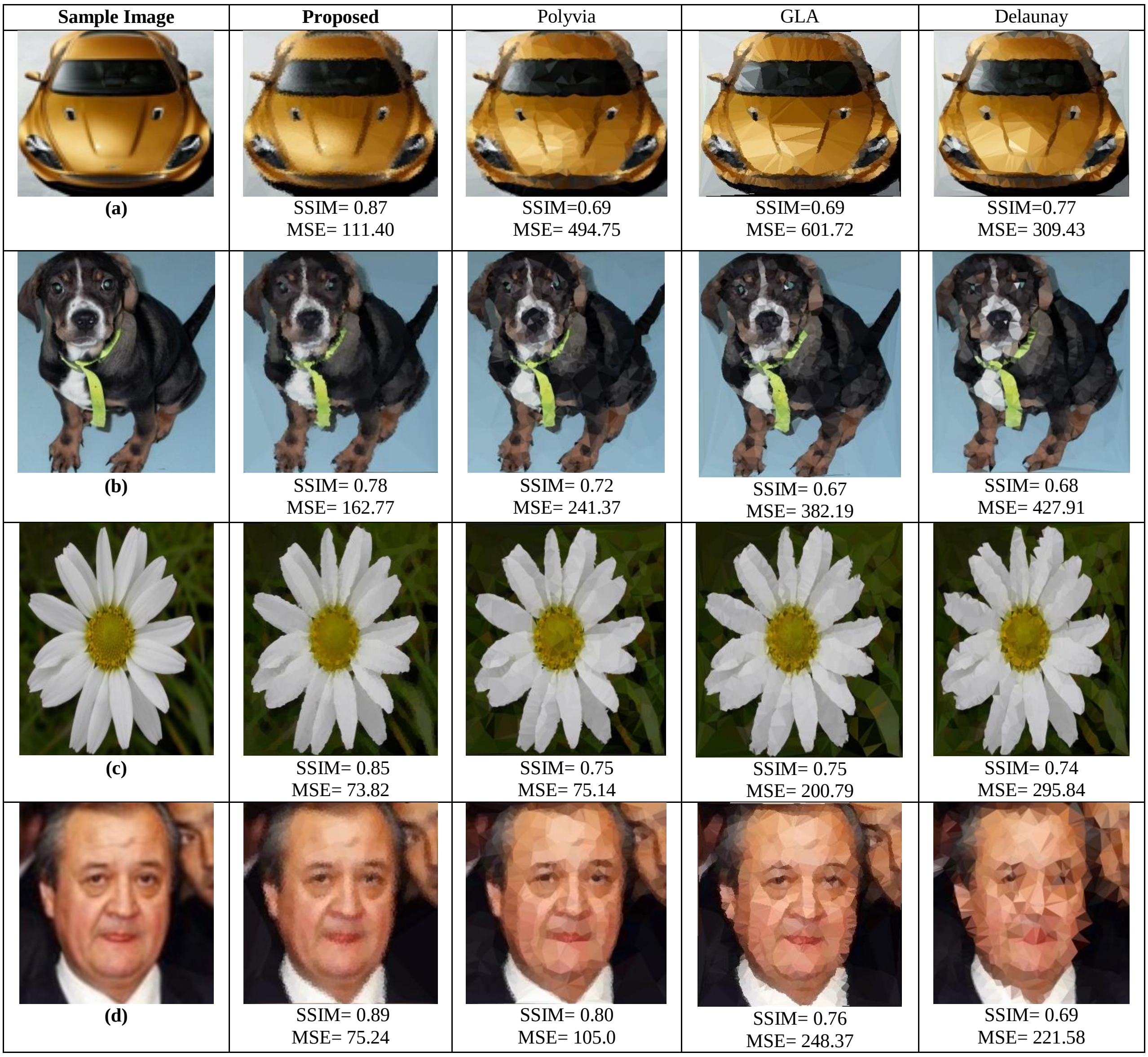


Fig.11. comparison of the proposed method with Polyvia, GLA, and Delaunay (zoom in to observe the detailed abstraction).

The quantitative evaluation in Figure 11 illustrates a comparison of the proposed method with Polyvia, GLA, and Delaunay. It is observed that the proposed algorithm can more accurately represent the main features of the image compared to Polyvia, GLA, and Delaunay. This conclusion is based on several metrics, including the Structural Similarity Index Measure (SSIM) and Mean Square Error (MSE) values.

The concept of structural information holds that pixels have high interdependencies, particularly when they are spatially adjacent to one another. Important details about the structure of the elements in the visual scene are carried by these relationships. SSIM value can vary between -1 and 1, where 1 indicates perfect similarity.

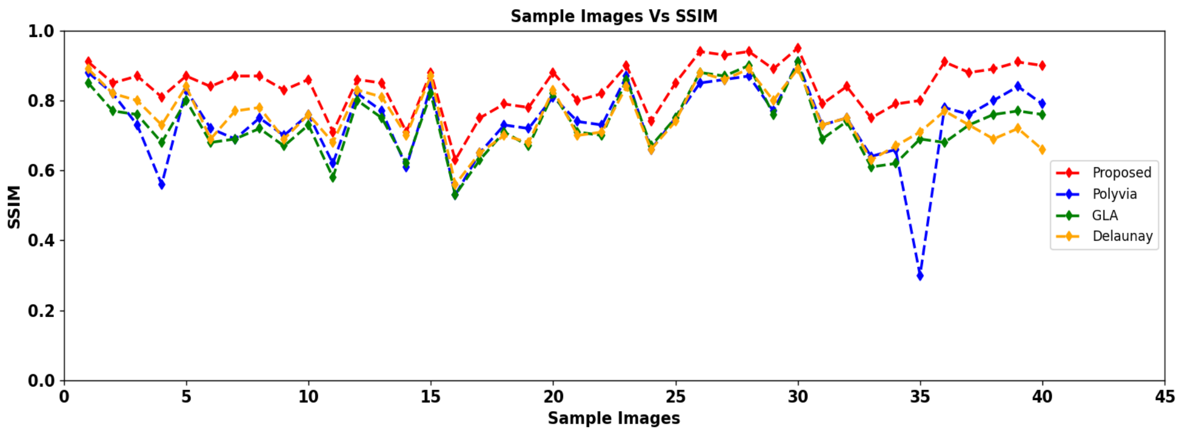


Fig. 12. Graphical representation of SSIM measure.

Figure 12 given above shows the SSIM with respect to 40 distinct numbers of natural images of varying sizes. A high SSIM value indicates that the proposed algorithm preserves the structural details and overall similarity between the original and simplified images to a greater extent. This suggests that the proposed method successfully captures and retains the essential features of the image.

MSE can also be used as a metric for evaluating the quality of compressed or reconstructed images. In this context, the MSE measures the average squared difference between the original image and reconstructed image. The formula for calculating MSE for images is similar to the formula for calculating MSE for regression models, but it is applied to each pixel in the images.

$$MSE = {}^{1}/_{(M * N)} * \sum\sum \left(I(x,y) - K(x,y)\right)^2 \tag{2}$$

Where M and N are the dimensions of the images, $I(x,y)$ is the intensity of the pixel at position (x,y) in the original image, $K(x,y)$ is the intensity of the pixel at position (x,y) in the reconstructed image. A lower MSE value indicates a better quality image reconstruction or restoration, as it means that the differences between the original and reconstructed/restored image are smaller

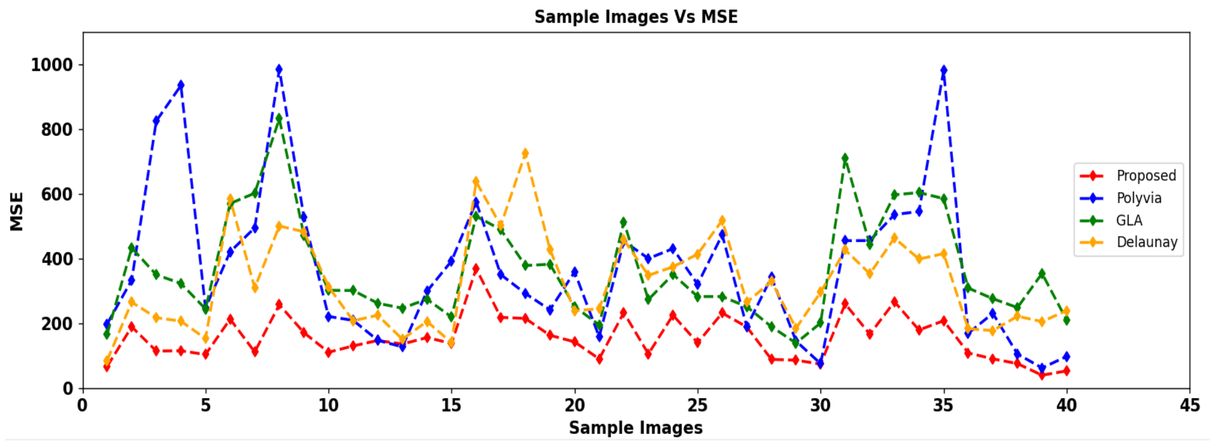


Fig. 13. Graphical representation of MSE measure.

Figure 13 given above shows the MSE with respect to 40 distinct numbers of natural images of varying sizes. A low MSE values indicate that the proposed algorithm exhibits minimal error or distortion when compared to the original image. This implies that the proposed method achieves a high level of fidelity in representing the image, with minimal loss of information or visual quality.

Taken together, the high SSIM values and low MSE values obtained by the proposed algorithm signify its effectiveness in accurately preserving the main features of the image. These results demonstrate the algorithm's capability to produce low poly image abstractions that closely resemble the original image while minimizing the introduction of artifacts or inaccuracies.

5. Conclusion

In this paper, we proposed a Balancing Simplification and Detail Preservation in Low Poly Image Abstraction through Edge-Preserved Seed Point Generation. The algorithm introduces edge-preserved seed points to generate a more accurate representation of edges in the low poly image. By preserving the important details of the edges, the final result is more visually appealing and conveys the original image's essential features. The edge-preserved seed points algorithm simplifies the representation of the original image without losing its essential features. The use of a simplified representation by reducing the triangle count can significantly improve the storage and reconstruction of the original image. Qualitative measures like visual inspection and mean opinion scores effectively evaluate the quality of simplified representations like low poly image abstractions. The algorithm performs well, delivering a desirable level of quality and participant satisfaction by balancing complexity reduction and retaining important visual elements. The proposed algorithm successfully generates visually pleasing and satisfying simplified representations. The quantitative evaluation of the proposed algorithm showcases its effectiveness in accurately preserving the main features of the image during the low poly image abstraction process. The high SSIM values and low MSE values indicate that the algorithm successfully maintains the fidelity of the original image while minimizing any introduced artifacts or inaccuracies. These findings affirm the algorithm's capability to generate high-quality low poly image abstractions that closely resemble the original images.

Additionally, reconstructing the original image from the triangle and color of each triangle is relatively easy and efficient, making it suitable for use in various applications. Overall, the reduction of the triangle count offers a valuable approach to simplifying image representation without sacrificing essential details, making it an attractive option for resource-constrained environments.

Future work on low poly image abstraction could involve exploring advanced algorithms and techniques for more efficient and optimized seed point generation, triangulation, and colorization processes. Additionally, incorporating user feedback and preferences through interactive interfaces or customization options can further enhance the user experience and satisfaction with the generated low poly abstractions.

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