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FINAL REPORT

Image Enhancement Through Quilting, Synthesis, And Transfer Using the Improved Efros-Freeman Algorithm

Kerem ÖZTÜRK
190711002
ELECTRICAL-ELECTRONICS ENGINEERING
MALTEPE UNIVERSITY

Selim GEDİKLİ
200711008
ELECTRICAL-ELECTRONICS ENGINEERING
MALTEPE UNIVERSITY

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2 Introduction

2.1 Project Overview

In the evolving area of digital image processing, the enhancement of images through innovative techniques remains a cornerstone for various applications. This project, titled "Image Enhancement through Image Quilting and Texture Transfer using the Improved Efros-Freeman Algorithm[1]," focuses on improving the area texture synthesis and transfer. Image quilting and texture transfer are important techniques used in the world of digital image processing to enhance image aesthetics, realism, and utility; implement texture generation with the aim of efficiency and system design.

2.2 Motivation

As students that are passionate about digital imaging and its potential, we were drawn to the complexities and creative possibilities within the world of image enhancement. The choice of this project topic came from a curiosity about how digital images can be manipulated and enhanced to achieve more realistic and aesthetically pleasing results. The challenge of improving an existing algorithm like Efros-Freeman was particularly interesting, offering a hands-on opportunity to contribute to an area that's not only technically intriguing but also widely applicable in fields ranging from graphic design to augmented reality and game industry. This project presented a unique opportunity to apply classroom learning to real-world problems, challenging us to think critically and creatively in engineering solutions.

3 Related Work

3.1 Existing Techniques

The area of image enhancement is rich with various techniques, among which the Efros-Freeman algorithm[2] has been an important contributor since its development date which is 2001. Originally developed for texture synthesis, this algorithm made the groundwork for some advancements in the field. However, despite its effectiveness, it presents limitations in handling complex textures and scalability and especially naturality.

3.2 Differences and Originality

This project distinguishes itself by introducing an improved variant of the Efros-Freeman algorithm. The modifications implemented touch to the non-effective parts of the original algorithm, primarily focusing on enhancing the detail preservation in textures and improving the overall efficiency of the texture transfer process. These improvements are designed to make more realistic and visually appealing results, especially in scenarios involving hard textures[3].

[1] Research on Improved version of Efros-Freeman Algorithm by Jeremy Long and David Mould that is included in References section.
[2] The paper that explains Efros-Freeman algorithm written by Alexei Efros and William T. Freeman is included in References section.
[3] Hard textures can be defined as textures that do not include patterns.

3.3 Contribution to Literature

Contributions of this project is its aim to improve a developed algorithm. By optimizing the core processes of image quilting and texture transfer, the project not only advances the technical capabilities in image enhancement but also broadens the scope of its applicability in various digital imaging contexts.

4 Methodology

4.1 Technical Details Introduction

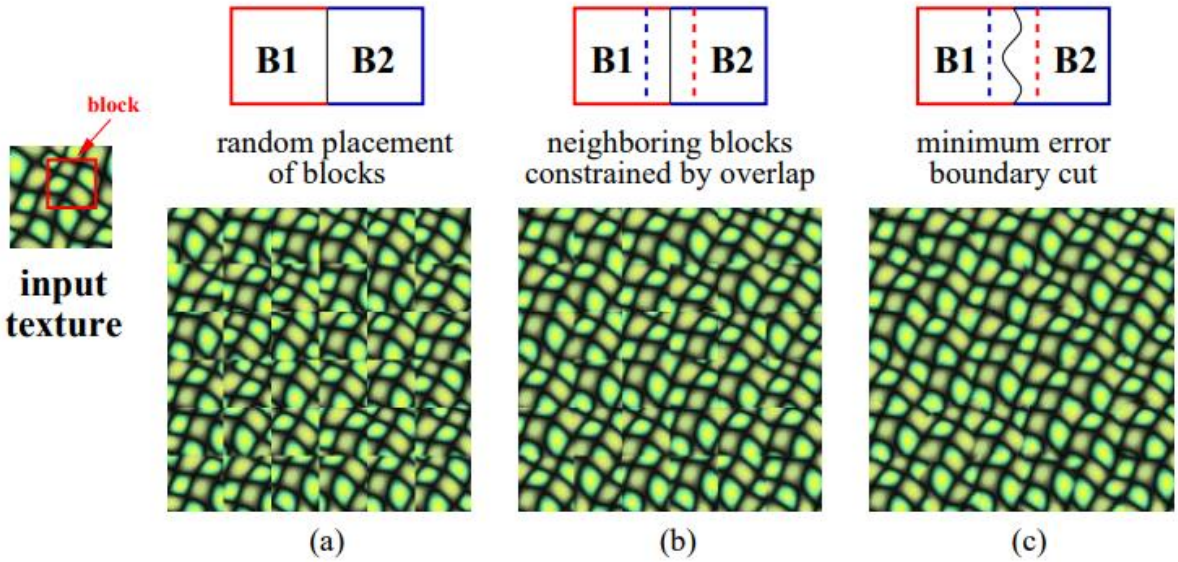
The project is about an enhanced version of the Efros-Freeman algorithm, which can be considered as non-efficient due to a specific approach it includes. Key modifications include improvements in the algorithm's ability to handle texture gradients and transitions by implementing a different boundary selection approach, aiming a more natural transition of textures. To address this, we need to understand the algorithm’s nature.

4.2 Efros-Freeman Algorithm

The Efros-Freeman algorithm, introduced in this context, presents an elegantly simple solution to the texture synthesis challenge. The core concept of their algorithm is the synthesis of new textures by selecting and seamlessly stitching together patches from existing textures. This method, while straightforward, proved effective in generating cohesive and visually appealing textures but not effective as time and computation.

Furthermore, Efros and Freeman extended their methodology to include texture transfer, a process that enables the application of texture from one object to another, allowing cutting and pasting material properties onto random objects. This capability significantly enhances the versatile and applicable side of the algorithm in image enhancement applications.

There can be considered three ways to choose as a boundary when making chunks in a texture.



Method (a) and its static approach may seem not natural but for many stochastic textures, it gives results that can be considered good. However, for generalizing the approach to less stochastic and static textures, method (b) can be used. But what if we want to select boundaries in images that are not so paternal. **Computational efficiency got worse**. Method (c) to reduce blockings the boundary between blocks is computed as a minimum cost path through the error surface at the overlap.

4.3 Algorithm Enhancement

Significant improvements were made to overcome the current limitations of the Efros-Freeman algorithm. Our primary goal was to ensure that the algorithm could handle texture gradients and transitions more naturally. For this, we modified the boundary selection approach during tissue synthesis and designed a more efficient tissue transfer process. We also developed a new analysis method to improve the computational efficiency of the algorithm.

We specifically encouraged the avoidance of high-cost areas by applying the **non-scalar metric** algorithm. This alternative metric, unlike traditional shortest path algorithms, prefers long and winding paths, reducing noticeable errors in the synthesized tissue.

"

```
partialNonscalarCompare(p1, p2):
   if p1.maxEdgeCost equals p2.maxEdgeCost:
      return min(p1.distance, p2.distance)
   else:
      return min(p1.maxEdgeCost, p2.maxEdgeCost)
```

"

Pseudo code[4] for the comparison between paths for the partial non-scalar metric is shown above. It returns the 'shorter' path by first comparing the maximum edge values in each, and using cumulative distance only to break ties.

4.4 Implementation Procedure

Implementation of the improved algorithm was carried out using MATLAB, which has multiple resources for image processing. The development process included forking existing GitHub repositories, modifying, organizing elements (helper files and directory system) coding and testing with various textures. In particular, the challenges of optimizing the balance of quality and efficiency have been overcome by a combination of algorithmic and parametric adjustments. During this process, experiments were done on various texture images to test and validate the performance of the algorithm. Image Quilting, Texture Synthesis and Transfer algorithms were completed successfully.

You can access the final organized code from the GitHub link:
https://github.com/Teo00/Improved-Efros-Freeman.

[4] Pseudo code is a descriptive text expressing the outline of algorithms, independent of any programming language.

5 Results

5.1 Presentation of Results

The results achieved by the project significantly demonstrate the advances made in image enhancement. The results show a significant improvement in detail preservation and number of apparent overlaps, especially in complex texture scenarios.

a) Quilting (Texture Synthesis) Results

i. Texture synthesis using the non-scalar metric method by taking textures from **small plums** image.

Figure 1 – The Texture

Figure 2 – The Quilted Image

ii. Texture synthesis using the non-scalar metric method by taking textures from **disabled walking path** image.

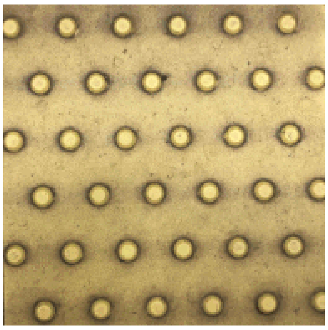


Figure 3 – The Texture

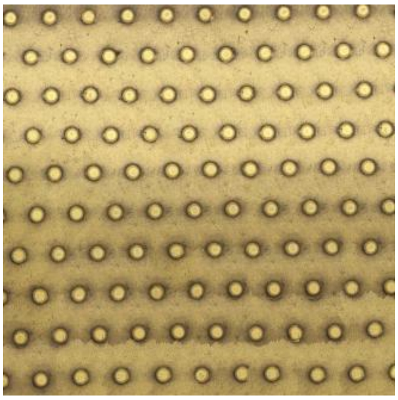


Figure 4 – The Quilted Image

iii. Texture synthesis using the non-scalar metric method by taking textures from **small cloth** image.

Figure 5 – The texture

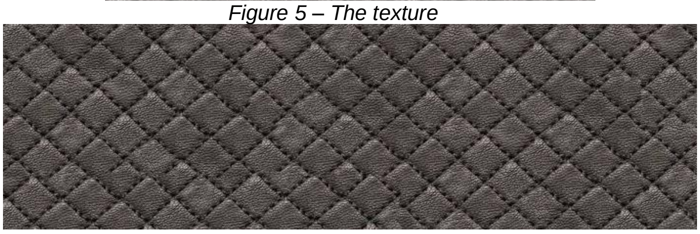


Figure 6 – The Quilted Image

iv. Texture synthesis using the non-scalar metric method by takin textures from a **chipboard** image.

Figure 7 – The Texture

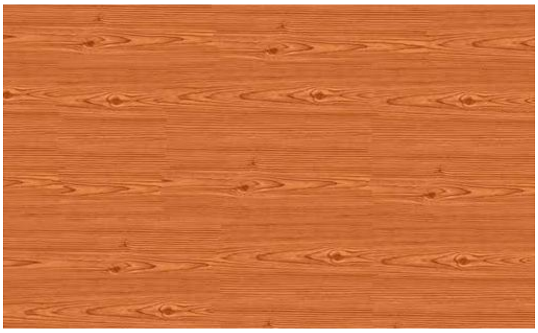


Figure 8 – The Quilted Image

b) Texture Transfer Results

Figure 9 – The Source Texture

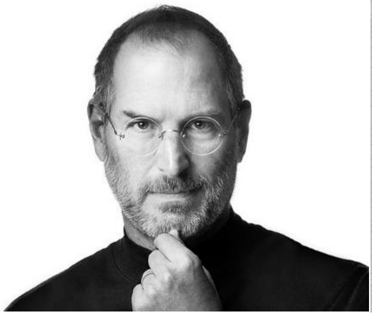


Figure 10 – The Target Image

Figure 11 – The Synthesized Image

Figure 12 – The Source Texture

Figure 13 – The Target Image

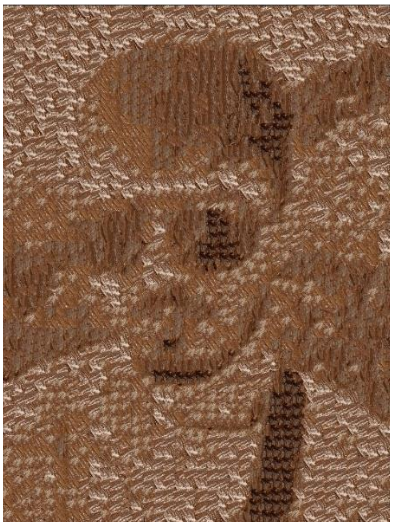


Figure 14 – The Synthesized Image

Figure 15 – The Source Texture

Figure 16 – The Target Image

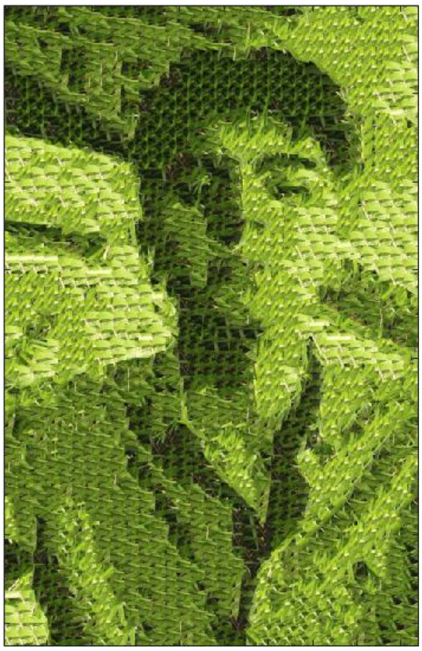


Figure 17 – The Synthesized Image

Figure 18 – MATLAB output of Texture Transfer on a target image

Experiments have shown that the improved Efros-Freeman algorithm is superior to the original version, especially when working with difficult textures. The results reveal that it provides more natural and seamless transitions in tissue synthesis and transfer. Additionally, significant improvements were achieved in terms of the algorithm's processing time and computational efficiency. The overall improvement in the quality of the thumbnails and the seamlessness of the patch integrations are testament to this success. The desired results were also achieved in the Texture Transfer stages, which is an application of this.

5.2 Comparison with Existing Work

Compared with the results of the Improved Efros-Freeman algorithm and the Conventional Efros-Freeman algorithm and other contemporary image enhancement techniques, the improvements are obvious. The improved algorithm not only achieves a higher degree of realism in the representation of textures, but also achieves this with greater computational efficiency. This comparison is supported by quantitative metrics such as rendering time and includes qualitative assessments such as smoothness and integration of textures.

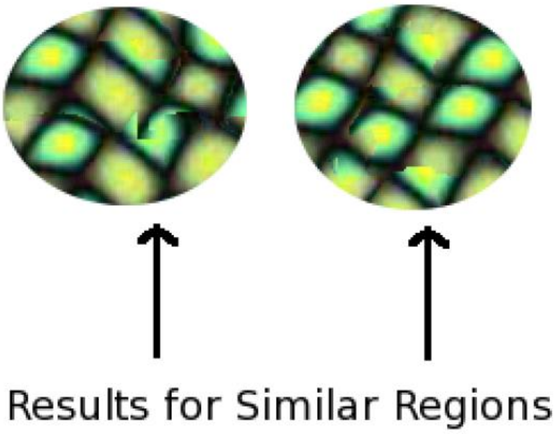


Figure 19 – Shows that comparison of two algorithm on similar region [5]

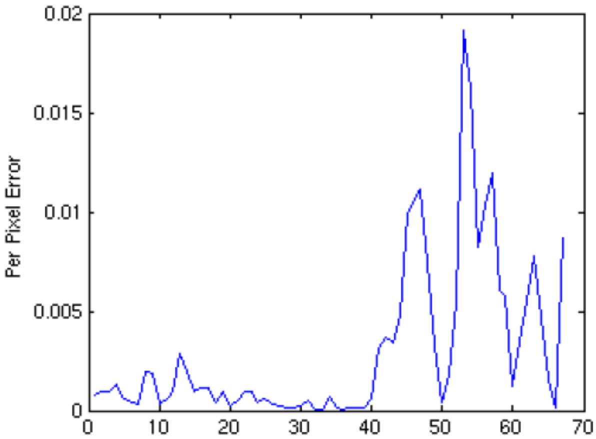


Figure 20 – Per pixel error in conventional methods that minimum error boundary cut. [5]

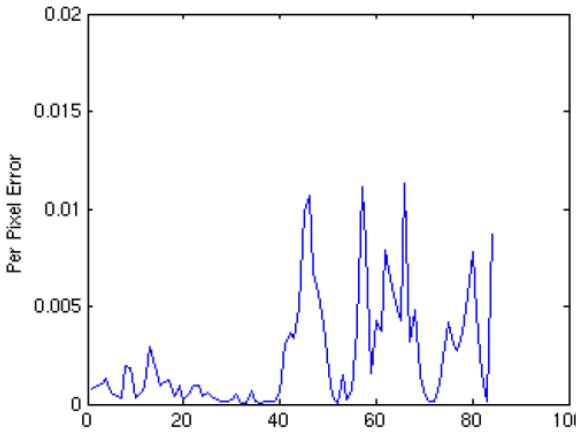


Figure 21 – Per pixel error in improved method minimum error boundary cut methods. [5]

By closely examining the error profiles of two patches being cut with identical constraints along the overlaps, we can see that the partial non-scalar metric features a noticeably lower peak, as seen on Figure 21, the Figure 20 shows the conventional metric. Checking around the peak in the error map causes the non-scalar metric to generate a longer path, but this allows it to avoid the high error areas that the conventional metric cuts right through. In essence, the non-scalar metric spreads the error out over a long distance, making it less sharp and apparent. In contrast, the traditional distance metric tries to take a short, compact route, even when that means travelling over an error peak.

[5] Images with courtesy to [1]


Figure 22 – The Source Texture


Figure 23 – Image Quilting Output


Figure 24 – Improved Image Quilting Output

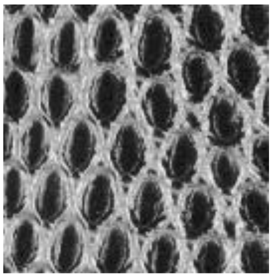


Figure 25 – The Source Texture

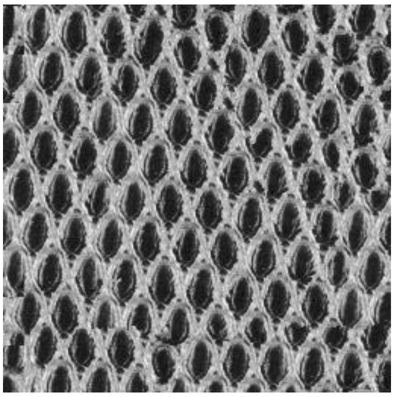


Figure 26 – Image Quilting Output

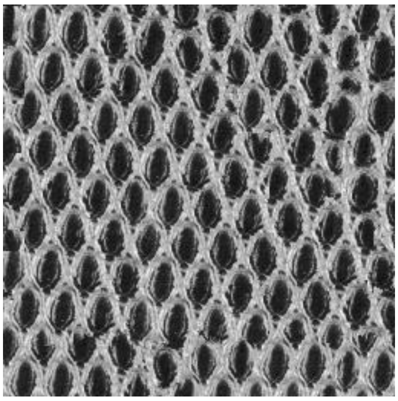


Figure 27 – Improved Image Quilting Output


Figure 28 – The Source Texture


Figure 29 – Image Quilting Output


Figure 30 – Improved Image Quilting Output


Figure 31 – The Source Texture


Figure 32 – Image Quilting Output


Figure 33 – Improved Image Quilting Output

Both outputs were generated with the same patch size and same overlap size.

6 Conclusion

6.1 Performance Analysis

Project; has showed its strengths in producing high-quality, realistic textures and rendering efficiency. However, like anything in this area, it has limitations where there is possibility for further improvement, especially with highly complex or noisy textures. The improved version comes to front with its success, especially when processing difficult and complex textures. However, detailed tests on larger texture datasets need to be performed and the algorithm needs to be further optimized.

6.2 Future Directions

The improved algorithm can be applied to a wider variety of textures, and we can see how it performs under different situations. Another idea is to integrate artificial intelligence and machine learning methods to make the developed algorithm even smarter. This could both increase the efficiency of the algorithm and improve its ability to deal with more complex textures.

The improved algorithm can be used in graphic design, game development or virtual reality fields. Such applications provide the opportunity to test what has been learned in practice and provide solutions to real-world problems.

6.3 Final Thoughts

This project represents an important step in the field of image enhancement. Through the improved Efros-Freeman algorithm, it not only contributes to academic discussions but also offers practical solutions to real-world problems in the field of digital imaging.

As we approach the end, we can say that this experience has been incredibly valuable in terms of having the opportunity to apply our theoretical knowledge in practice. As Electrical and Electronics Engineering students, we applied the complex concepts we learned in textbooks to real-world problems. The challenges and obstacles we encounter have improved our problem-solving abilities and developed our ability to think flexibly. Each mistake, each failed attempt, led us to a better solution.

In conclusion, the most important thing this project taught us was the importance of being patient and overcoming difficulties. Every challenge was a new learning opportunity for us, and completing this project not only gave us technical skills but also helped us become more determined and motivated engineers.

7 References

[1] D. M. Jeremy Long, "Improved Image Quilting," Proceedings of Graphics Interface 2007, Montréal, Québec, Canada, 2007.

[2] W. T. F. Alexei A. Efros, "Image Quilting for Texture Synthesis and Transfer," California, Berkeley, 2001.