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A Hybrid Model in Denoising Salt and Pepper Noise in Grey Images

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Abstract
Salt and pepper noise is a prevalent type of impulsive noise that often contaminates digital photographs, resulting in a decline in their quality and hindering subsequent image processing operations. This paper provides a comprehensive examination of a hybrid model (Fuzzy Logic and Genetic Algorithm) denoising methods that are specifically developed to handle salt and pepper noise in grayscale images. It tends to offer insights into their fundamental concepts, advantages, and constraints.

***Keywords**: Salt and Pepper noise, Fuzzy logic, Genetic Algorithm, Grey images.*

1. INTRODUCTION

Digital pictures may be distorted by several types of noise, including Gaussian noise, random noise with a normal distribution, salt and pepper noise, and black and white impulses on the image. Gaussian noise often arises from electrical noise in the camera, whereas salt and pepper noise is caused by malfunctioning or non-functional pixels in the camera sensor. Salt and Pepper noise is a form of picture distortion that introduces random black and white pixels into an image, creating a visual effect similar to grains of salt and pepper. Image degradation can occur due to noise, which is frequently encountered in real-world situations. Therefore, efficient noise reduction techniques are necessary [9]. Linear filters are commonly employed to attenuate noise due to their ease of design and implementation. Linear filters are effective for removing linear noise. When it comes to different types of noise, the effectiveness of these filters significantly diminishes, and particular denoising techniques must be employed.

.In the digital image processing field, dealing with noise in grey images is a common challenge that researchers and scientists face. One of the most challenging types of noise is salt and pepper noise, which manifests as random black or white pixels scattered throughout an image.

To address this issue, a hybrid model combining fuzzy logic and genetic algorithm has been proposed as an effective denoising method. Fuzzy logic is a mathematical framework that deals with reasoning and decision-making in situations where uncertainty is present, while genetic algorithms are optimization techniques inspired by the process of natural selection.

The hybrid model works by first using fuzzy logic to identify and classify noisy pixels in the image, assigning them a degree of membership to the categories of black or white noise. Then, the genetic algorithm is applied to optimize the denoising process by evolving a population of candidate solutions to find the best filter parameters for removing the noise.

Several techniques have been created in recent years to remove sudden and unpredictable noise. These approaches include the median filter, adaptive median filter, weighted median filter, centre weighted median filter, tri-state median filter, and noise adaptive soft-switching median filter.

Although non-linear filters are successful in reducing the effects of impulsive noise in images, they may have difficulty in differentiating between small details and the noise. Consequently, they remove both the undesirable noise and the complex details from the image.

Therefore, it is crucial to develop a filtering algorithm that can efficiently process ambiguous and unclear data in different aspects of the image. However, researchers have developed fuzzy rules based filtering techniques that has ability to vague and uncertain reasoning. The fuzzy filtering method effectively reduces noise in a clear manner by utilising expert knowledge. It is particularly useful for specialised applications in the analysis of complicated scenes and the recognition of objects.

Zadeh created fuzzy logic in 1965 as a mathematical method specifically designed to address situations involving ambiguity. This technique for soft computing is significant because it incorporates the concept of computing with words and provides a means to deal with imprecision and information granularity. In the context of fuzzy theory, language constructs such as "many," "low," "large," "dark," "bright," and others can be accurately depicted.

The genetic algorithm (GA) is recognized as one of the most popular metaheuristic algorithms, extensively utilized across various optimization, design, and application domains. As one of the earliest proposed population-based stochastic algorithms, GA includes selection, crossover, and mutation operations, similar to other evolutionary algorithms (EAs). Based on Darwin's theory of evolution, particularly the concept of survival of the fittest, GA simulates the fittest genes. The algorithm is population-based, where each solution corresponds to a chromosome and each parameter represents a gene. A fitness (objective) function evaluates the fitness of each individual in the population. To improve poor solutions, the best solutions are selected through mechanisms such as random selection, k-tournament, or roulette wheel. These mechanisms are more likely to choose the best solutions, as the probability of selection is proportional to fitness. Additionally, the probability of selecting poorer solutions helps avoid local optima by allowing trapped good solutions to be pulled out with other solutions [2].

The genetic algorithm (GA) is inspired by Darwin's theory of biological evolution, which is based on the principle of "survival of the fittest." In nature, fitter organisms have a higher chance of survival [10]. The mechanism of natural selection involves replication, selection, inheritance, recombination, and variation of individual traits. These processes allow selection to operate across generations, guiding the evolution of organisms in a favorable direction. This enables species to evolve and diversify, allowing for a wide range of organisms. Natural selection can lead to population diversification and the creation of new species. Genetic algorithms are advantageous over other search algorithms due to their simplicity, speed in finding targets, and robust coding capabilities, making them effective stochastic search algorithms with significant applications in numerous fields (Wang, 2022). GAs have been successfully applied in diverse domains, including engineering, finance, robotics, and biology.

The genetic algorithm optimizes the parameters of the fuzzy logic system by evolving them. It generates a population of candidate solutions, with each solution representing a set of fuzzy logic parameters. The fitness of each candidate solution is then evaluated using a fitness function that measures denoising performance. The fittest candidate solutions are selected as parents for the next generation. Through successive generations, the genetic algorithm applies crossover and mutation operations to explore the parameter space and enhance denoising performance. The optimized set of fuzzy logic parameters obtained at the end of the optimization process represents the optimal configuration for denoising salt and pepper noise in grayscale images.

By combining the strengths of both fuzzy logic and genetic algorithm, this hybrid model offers a powerful solution for denoising salt and pepper noise in grey images. It can effectively remove noise while preserving important image details and improving image quality.

Overall, the hybrid model presents a promising approach to tackling the challenging problem of salt and pepper noise in grey images, showcasing the potential of combining different techniques to achieve superior results in digital image processing applications.

2. Related Work

In the paper [1] introduced a novel method for restoring a picture that has been corrupted by salt and pepper noise (SPN) using a hybrid genetic algorithm (HGA) at all levels of noise density. This enhanced HGA is referred to as effective HGA (EHGA). The primary innovation of the suggested approach is in the integration of genetic algorithm with picture denoising techniques inside the population, resulting in rapid convergence. The concept involves gradually transforming a group of individuals across several cycles employing crossover and mutation operators. This method involves the development of a collection of photos rather than a collection of parameters derived from the filters. The experimental results from simulating various images using peak signal-to-noise ratio, structural similarity index metric, image enhancement factor, and Universal Quality Index indicate that the proposed algorithm surpasses other methods in both qualitative and quantitative removal of SPN, particularly when the noise density is moderate to high. EHGA also maintains crucial characteristics such as the texture and edges of the picture.

[9] presents a novel fuzzy impulse noise reduction technique as a viable solution. The efficacy of the proposed algorithms is evaluated by comparing their performance to several established noise reduction techniques. The findings are evaluated using objective metrics such as peak signal-to-noise ratio and mean square error. The results illustrate that the suggested algorithms achieve exceptional results in reducing noise and preserving picture details for a wide range of noise levels.

3. Methodology

For this study, a Constructive Research Methodology is chosen, together with the Object-Oriented Design Approach (OODA) for system structure development.

4. Dataset Description

The data used, is a salt and pepper noisy grey images.

5. System Design

The hybrid model will utilise the OODA (Observe, Orient, Decide, Act) framework in its design, where components will be conceptualised as objects. This unique construct will be assessed using both rigorous and comprehensive approaches to clearly establish its usefulness, thanks to its incorporation of both theoretical and practical aspects. The effectiveness of the model will be verified by cross-validation approaches.

The suggested system is a hybrid model that combines a fuzzy logic model with a genetic algorithm model. Each of these models has a distinct function in processing noisy visual data.

The first stage in preparing the noisy image includes using a fuzzy logic-based adaptive filter. This filter utilises the fuzzy inference system (FIS) to evaluate the amount of noise in each pixel and then carry out the appropriate denoising procedure. A fuzzy filter is employed to first decrease the level of noise in the noisy image. Fuzzy logic is employed to assess the degree of noise in individual pixels by taking into account the intensity and values of the neighbouring pixels. The categorization of pixels as noisy or noise-free is decided by fuzzy rules, which are developed based on their membership to several linguistic variables that represent varying degrees of noise, such as low, high, or medium. Once fuzzy inference is used to determine the noise level of each pixel, denoising algorithms are then employed to estimate the true intensity of the noisy pixels. These rules are developed based on professional knowledge and actual observations, allowing for accurate noise reduction while preserving the integrity of visual data.

The adaptive filter, utilising fuzzy logic, modifies its denoising approach by taking into account the characteristics of the input picture and the observed noise distribution. The filter's intrinsic versatility allows it to effectively handle various noise patterns and intensities seen in real-world scenarios.

The genetic algorithm model begins with the output generated by the fuzzy logic model. This model would be employed to optimise the membership function in order to get optimal solutions. The Genetic Algorithm model is employed as a tuning mechanism to optimise the fuzzy rules provided by the fuzzy logic model. Genetic algorithms provide exceptional performance in the field of global optimisation and exploration of search areas. When combined with fuzzy logic, evolutionary algorithms may systematically search across a broad spectrum of parameter configurations to identify an optimal or nearly ideal solution for denoising, taking into account the intricate nature of picture data. The Genetic algorithms model is used to optimise the parameters of the fuzzy logic system for denoising. This involves optimising membership functions, rule strengths, and other parameters to improve the efficiency of the denoising algorithm. It will enhance the resilience of the hybrid model by preventing it from becoming stuck in local minimums and enabling it to develop solutions that can be applied effectively to various pictures. It is essential to develop denoising models that can efficiently handle different picture kinds and noise patterns. It will utilise parallel processing, which is quite advantageous for accelerating the optimisation process. Within the realm of picture denoising, this will result in expedited and more effective attainment of ideal denoising parameters. Both fuzzy logic and evolutionary algorithms are proficient at managing non-linear connections. Salt and pepper noise causes non-linear distortions in pictures, and the hybrid model is more effective at capturing and reducing these distortions.

The hybrid model utilises the fuzzy system's capacity to manage uncertainty and intricate linkages, in conjunction with the global optimisation capabilities of genetic algorithms, by combining fuzzy logic with genetic algorithms. This collaboration leads to a strong and flexible method for efficiently managing salt and pepper noise in digital photographs.

Algorithm of the hybrid Model:

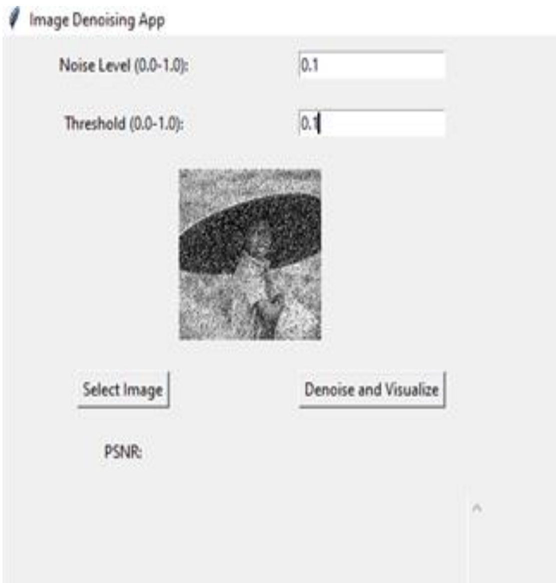
a) Add salt and pepper noise to the input image.
b) Define the fuzzy membership functions and rule base for the denoising process.
c) Initialize the genetic algorithm with a population of 10 individuals and run it for 10 generations.
d) The fitness function evaluates the performance of each individual (a 3x3 filter) by applying it to the noisy image and measuring the mean absolute difference between the denoised image and the original image.

After the genetic algorithm converges, the best individual (the 3x3 filter with the highest fitness) is used to denoise the noisy image.

The denoised image is returned as the output.

6. Result and Discussion

The salt and pepper noisy grey image is inputted into the hybrid model to be denoised. Threshold and noise level is randomly generated by the model, while the crossover value and mutation values are tuned manually to achieve optimal result. The performance matrix used in this study is the Peak Signal to Noise Ratio (PSNR).



An interface is designed to enable the user select and input a salt and pepper noisy grey image. The denoising of the image would be performed over 10 generations, with the aim to improve the fitness of the population over generations by selecting the fittest individuals to create offspring and potentially replacing less fit individuals with new, fitter ones. The goal is to evolve the population towards an optimal solution to the given problem.

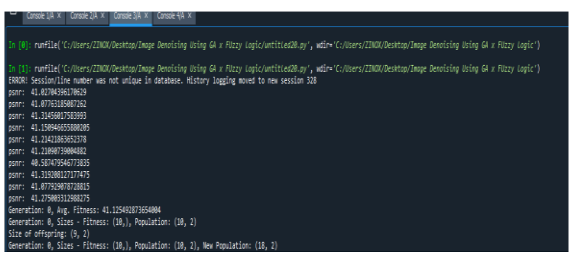
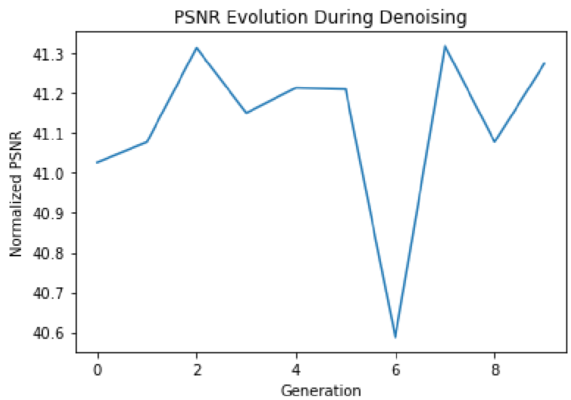
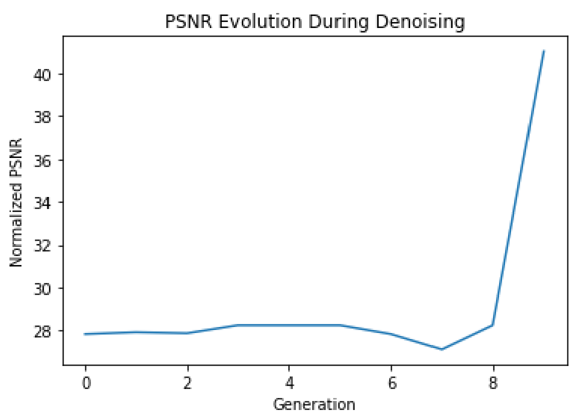


Figure 1: output of first generation.

Generation: 0, Avg. Fitness: 41.125492873654004
Generation: 0, Sizes - Fitness: (10,), Population: (10, 2)
Size of offspring: (9, 2)
Generation: 0, Sizes - Fitness: (10,), Population: (10, 2), New Population: (18, 2)
This simply means
In first generation, the population has 10 individuals with an average fitness of about 41.12. Everyone in the population has 2 parameters (genes which are threshold and noise level).9 new offspring are created, each also having 2 parameters. The new population size after combining the original population and the offspring is 18 individuals.


PSNR Evolution During Denoising
Normalized PSNR
Generation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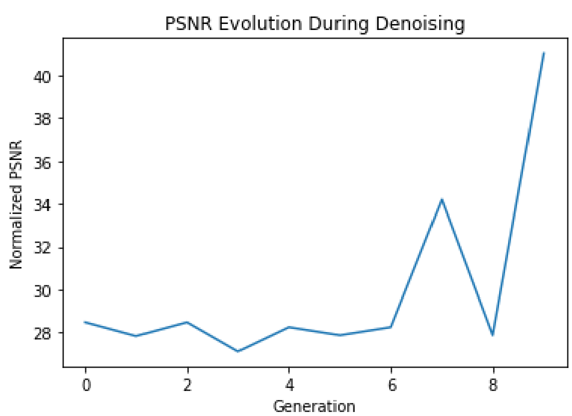
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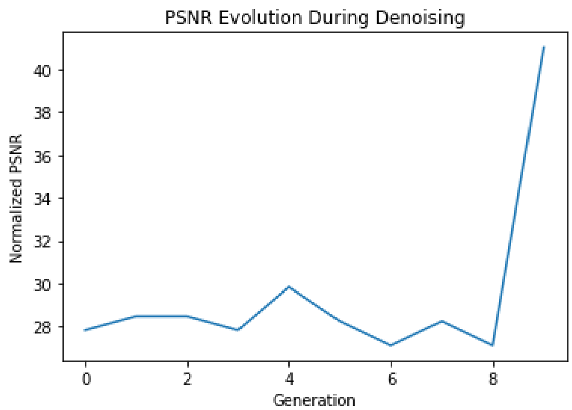
PSNR Evolution During Denoising
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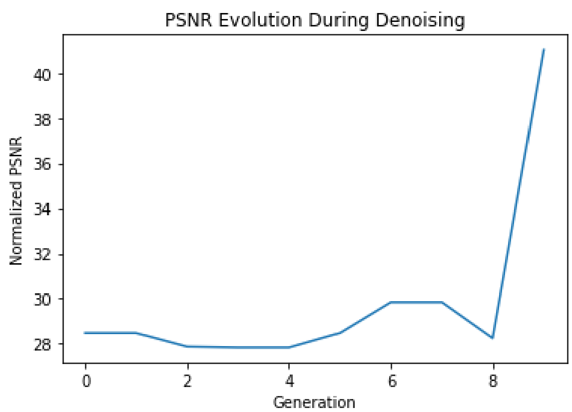
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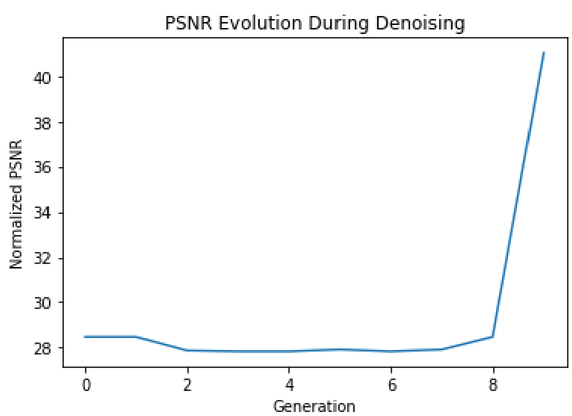
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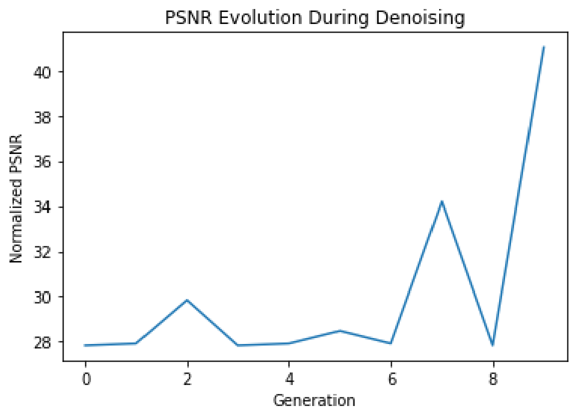
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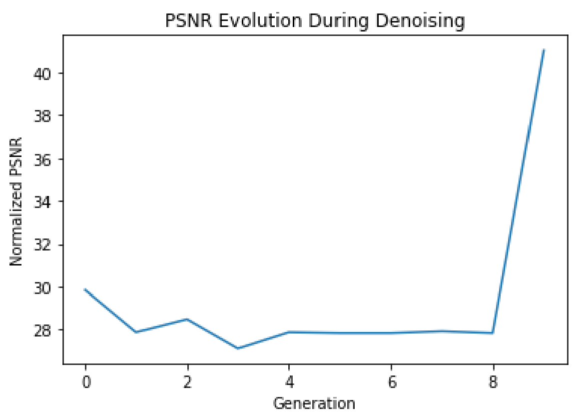
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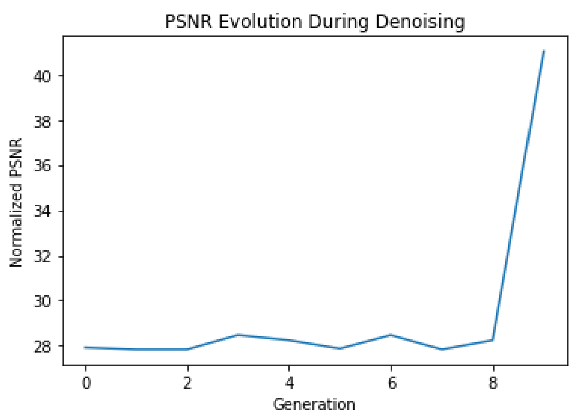
PSNR Evolution During Denoising
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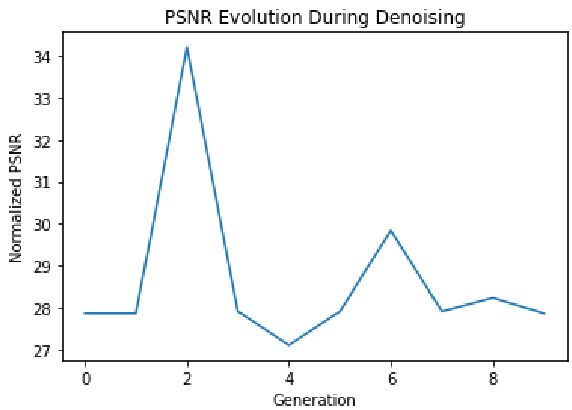

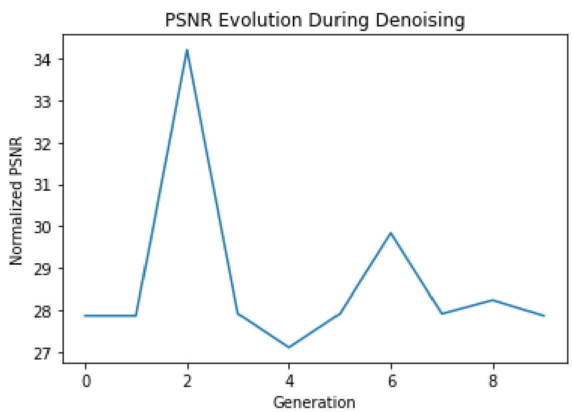

Result Summary

Table 1. Results

Number of Generations	Average Fitness (PSNR)	Size of Offspring	Fitness Size
0	44.47	6, 2	10
1	41.88	6, 2	10
2	51.98	6, 2	10
3	41.88	6, 2	10
4	51.93	6, 2	10
5	41.95	6, 2	10
6	59.86	6, 2	10
7	40.34	6, 2	10
8	50.96	6, 2	10
9	52.94	6, 2	10

Table 2. Evaluation Performance Matrix (PSNR)

Number of Generations	Average Fitness (PSNR)	Quality	Size of Offspring	Fitness Size
0	44.47	Excellent	6, 2	10
1	41.88	Excellent	6, 2	10
2	51.98	Excellent	6, 2	10
3	41.88	Excellent	6, 2	10
4	51.93	Excellent	6, 2	10
5	41.95	Excellent	6, 2	10
6	59.86	Excellent	6, 2	10
7	40.34	Excellent	6, 2	10
8	50.96	Excellent	6, 2	10
9	52.94	Excellent	6, 2	10

Key

Excellent = PSNR > 40dB
Good quality = 30dB< PSNR≤ 40dB
Fair Quality = 20dB < PSNR ≤ 30dB
Poor Quality = PSNR ≤ 20dB

The denoised image is visualized when the denoising process by the hybrid model is completed.

The Peak signal-to-noise ratio performance metrics was employed to determine the efficiency of our model. However, only 10 generations were used for the purpose of testing of the system. The formula for calculating the model's Peak Signal to Noise Ratio is given in the following equations:

$$PSNR = 10.\log_{10}(\frac{65025}{MSE}) \quad (1)$$

Performance Evaluation of the System

This hybrid model was evaluated using PSNR. The computed values of these metrics were captured in Table 1. The model achieved an accuracy and precision. Thus, it has actively demonstrated that it could serve as an efficiently denoising salt and pepper noise in grey images.

Conclusion

In summary, by presenting a hybrid model that combines fuzzy logic with evolutionary algorithms, this thesis makes a substantial contribution to the field of picture denoising. Significant advancements over current techniques are made by the suggested model, which not only achieves excellent noise reduction but also performs very well in maintaining important picture information. The methods and insights developed in this study provide significant information to the field of image processing and open the door to new developments and useful applications. The hybrid model has shown to be an effective tool for restoring high-quality images in a variety of technological and scientific disciplines, as evidenced by its ability to successfully tackle the problems presented by salt and pepper noise.

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