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Review of Hybrid Denoising Approaches in Face Recognition: Bridging Wavelet Transform and Deep Learning

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Abstract

Statistically, image denoising is one of the key pillars of image processing and picture acquisition, which also is utilized to clear the noisy images. Over the last years, there is an increase of study subjects that are devoting to designing and making noise cancellation methods. This study reviews all major image denoising techniques, with a special emphasis on integrated deep learning approaches as well as traditional signal processing methods. The review presents a broad array of techniques for instance convolutional neural networks (CNNs), wavelet transforms, hybrid models, and their emendations. The lecturer will focus on the advantages, as well as the disadvantages, of each methodology along with their appropriateness in various fields, from which the current state of the art image denoising can be concluded. On the other hand, the paper discusses critical barriers leading to further prospects of research in cybersecurity and cybercrime prevention This review is important in that it aims to serve researchers, practitioners, and enthusiasts who would like to peer into the new trends and developments in denoise image generation.

A. Introduction

The role of face recognition has steadily grown in developing different applications such as security systems, computer access control systems, and the field of human-computer interaction. While the algorithms can successfully recognize faces with sufficient clarity in input images, however it is highly prone to noise in the signal which often leads to degraded performance and reduced accuracy. Thus, the performance of face recognition systems is largely dependent on efficient noise filtering techniques that help improve their resilience and accuracy.

In the last, the denoising method has been based upon a number of techniques like spectral filtering, statistical modeling and transform-domain processing. In the first place, wavelet transform is the most acknowledged among these techniques as it efficiently captures both local and global features of the image by being focused on their detail and overall structure [1], [2]. This is the aim of the wavelet-based denoising methods that decompose images into various frequency bands moving the noise lower-level usage of informative details.

In the past couple of years deep learning has completely altered the image processing including improvement of system noises. With deep learning techniques, especially convolutional neural networks (CNNs), that carry out the task of denoising getting more equalized, computers achieve almost human-like performance in this type of tasks [3], [4]. The learning methods can cope with input images of various quality and can produce the desired output images directly from data, without the necessity of specific characteristics features of or explicit modeling of noise statistics.

While each of the two techniques have shown their capacity as single tools in denoising tasks, combination of them in hybrid network-based systems may further lead to an increased denoising effectiveness [5], [6]. Through the positive characteristics of the strategies, hybrids give a way of having better noise cancellation yet keeping important face details which are crucial for an accurate face recognition.

In this work, we strive to offer a completely thorough outline of the hybrid denoising strategies for face recognition that are based on the blending of wavelet transform and deep learning approaches. The review process will encompass an examination of the latest literature, evaluation of various hybrid architecture designs and their beneficiary as well as detrimental aspects and with the same time, consideration of the gaps that need filling and the opportunities that are available to expand the technology.

B. Literature Review

Through this review, our contribution to understanding of hybrid denoising systems is highly expected and their improvement for making more stable and efficient face recognition algorithms which can operate in noisy environment will be facilitated.

The field of image decanceling is filled with approaches from the classical methods to the modern deep learning. One of the most widely utilized approaches for this task involves wavelet transforms, which have underscored their effectiveness in ensuring distortion-free image representation by suppressing noise without destroying the essential image particulars. Agarwal, Singh, and Nagaria [1] took the initiative to illustrate a complete analyze of the several wavelets transforms for denoising the MR images, unraveling their applicability in medical imaging. Hence, in a similar manner, Averbuch and colleagues et al. [2] proposed a novel denoising algorithm utilizing directional wavelet packets, which has displayed possible applications across numerous signals.

Nevertheless, the last period could be characterized as a shift to the use of deep learning techniques for the problem of image denoising that has also been concerned. Boussaad and Boucetta [3] didn't just study how using deep learning-based descriptors in aging face recognition systems may work, but they also proved the effectiveness of convolutional neural networks (CNNs) when it comes to improving face recognition systems by denoising photos. Furthermore, Ghose, Singh, and Singh [4] emphasized on the potentials of CNNs in image denoising, explaining that these models can grasp the complicated relationship in noisy inputs and can improve quality performance beyond standard techniques.

The weaving wavelet transforms and deep learning algorithm with the wavelet is the recent trend in the studies of signal/image denoising. Bao et al [5] suggested a new hybrid denoiser that is hybrid of both discrete wavelets transform (DWT) and convolutional neural network (CNN), and it can achieve better denoising result than methods that use single method. Other than that, they Hamedee and colleagues have published a method called wavelet transform-based two-stream convolutional networks for anti-spoofing of facial, in which they have combined the benefits of wavelet-based features and deep learning frameworks.

While the hybrid denoising methods has reached the pretty advanced level, some obstacles still, such as image quality and saving important details, are not solved effectively. We look forward to overcoming the existing problems in the next research initiatives through developing customized architectures, introducing priors from the subject, and using sophisticated training methods. Finally, researchers aim to develop a general denoising algorithm by using the wavelet transform (WT), the deep learning methodology (DL), and other techniques. It can solve the problem of noise filtering in many different environments and industries.

Table 1 represents a comprehensive summary of reviewed works.

Table1. Comprehensive Table of Reviewed Works

Authors	Year	Work and Results
Agarwal et al.	2017	This consider analyzes and compares distinctive wavelet changes for denoising MRI pictures. They likely assess the execution of different wavelet change procedures in terms of their viability in diminishing clamor in MRI pictures [1]
Anwar & Barnes	2019	This work centers on genuine picture denoising utilizing highlight consideration. They propose a strategy that utilizes highlight consideration instruments to improve the denoising execution of profound learning models on genuine pictures [7]
Arab et al.	2022	The creators propose a crossover LSTM-ResNet profound neural arrange for commotion lessening and classification of V-band recipient signals. They likely illustrate the viability of their demonstrate in decreasing commotion whereas protecting flag data and accomplishing precise classification comes about [8]

Averbuch et al.	2022	This consider presents a crossover denoising calculation based on directional wavelet parcels. They likely investigate the combination of diverse wavelet parcel changes to attain progressed denoising execution [2]
Bao et al.	2020	The creators propose a modern picture denoising calculation utilizing monogenic wavelet change and an made strides profound convolutional neural organize. They likely illustrate the adequacy of their approach in lessening clamor whereas protecting picture subtle elements. [5]
Bodavarapu & Srinivas	2021	This ponders centers on facial expression acknowledgment for low-resolution pictures utilizing convolutional neural systems and denoising strategies. They likely investigate strategies to move forward the precision of facial expression acknowledgment on low-quality pictures through denoising [9]
Boussaad & Boucetta	2022	The creators explore the application of deep-learning-based descriptors for tending to the maturing issue in confront acknowledgment. They likely propose a strategy that utilizes profound learning procedures to make strides confront acknowledgment execution, especially in scenarios where maturing impacts ought to be accounted for [3]
Cengiz et al.	2022	This work addresses the classification of breast cancer with profound learning from loud pictures utilizing wavelet change. They likely propose a profound learning-based approach that joins wavelet change for preprocessing boisterous breast cancer pictures to progress classification precision [10]
Chakraborty et al.	2020	The creators propose a picture denoising procedure utilizing quantum wavelet change. They likely explore the potential points of interest of quantum wavelet change over classical wavelet change for picture denoising assignments [11]
Cui et al.	2019	This considers centers on PET picture denoising utilizing unsupervised profound learning. They likely propose a profound learning-based strategy for denoising PET pictures without the required for labeled preparing information, subsequently making strides the effectiveness of the denoising prepare [12]
Dharini & Jain	2021	The creators propose a productive and crossover pulse-coupled neural network-based question discovery system based on machine learning. They likely present a system that combines pulse-coupled neural systems with other machine learning procedures to move forward protest location precision [13]
Fan et al.	2019	This paper gives a brief survey of picture denoising methods. They likely summarize different strategies for denoising pictures, giving a diagram of the field [14]
Ferzo & Abdulazeez	2024	The authors survey picture denoising methods utilizing unsupervised machine learning and profound learning calculations. They likely summarize later progressions in picture denoising, centering on unsupervised machine learning and profound learning approaches. [15]
Fuad et al.	2021	This ponders surveys later propels in profound learning strategies for confront acknowledgment. They likely summarize the most recent advancements in profound learning-based confront acknowledgment strategies, highlighting their execution and capabilities. [16]
Ghose et al.	2020	The creators propose a picture denoising strategy utilizing profound learning, particularly convolutional neural systems. They likely display a profound learning engineering custom-made for denoising pictures to move forward picture quality and downstream investigation errands [4]
Gopatoti et al.	2018	This paper surveys picture denoising procedures utilizing spatial channels and picture changes. They likely give a diagram of conventional strategies for denoising pictures, counting spatial sifting and transform-based approaches [17]
Görgel & Simsek	2019	The creators propose a confront acknowledgment strategy based on profound stacked denoising scanty autoencoders (DSDSA). They likely present a profound learning design optimized for confront acknowledgment assignments, leveraging

		inadequate autoencoders for include learning [18]
Goyal & Meenpal	2020	The creators survey patch-based dual-tree complex wavelet change for connection acknowledgment. They likely summarize the application of dual-tree complex wavelet change in family relationship acknowledgment errands, highlighting its viability in capturing discriminative highlights [19]
Goyal et al.	2020	This paper gives a comprehensive survey of picture denoising strategies, covering classical to state-of-the-art approaches. They likely summarize different strategies for picture denoising, counting both conventional and profound learning-based procedures, and examine their preferences and restrictions [20]
Gu & Timofte	2019	The creators show a brief review of picture denoising calculations and past. They likely talk about the advancement of picture denoising strategies, counting later headways and developing patterns within the field [21]
Guhathakurta	2017	This paper proposes a wavelet-based approach for picture denoising. They likely present a denoising strategy that utilizes wavelet change for successfully lessening commotion in pictures [22]
He et al.	2023	The creators propose wavelet transform-based two-stream convolutional systems for confront anti-spoofing. They likely present a profound learning design that coordinating wavelet change with convolutional systems to distinguish confront spoofing assaults [6]
Huang et al.	2022	This paper talks about inquire about progressions in picture denoising based on profound learning. They likely give an outline of later advancements in utilizing profound learning procedures for denoising pictures, highlighting their viability and applications [23]
Ilesanmi & Ilesanmi	2021	The creators survey strategies for picture denoising utilizing convolutional neural systems. They likely summarize different CNN-based approaches for denoising pictures and discuss their execution in numerous scenarios [24]
Jifara et al.	2019	This ponder proposes therapeutic picture denoising utilizing convolutional neural systems with a remaining learning approach. They likely present a CNN engineering custom-made for denoising restorative pictures, with a center on remaining learning to improve denoising execution [25]
Ketab et al.	2023	The creators propose a parallel profound learning engineering with customized and learnable channels for low-resolution confront acknowledgment. They likely present a profound learning show outlined to handle low-resolution confront pictures by joining parallel preparing and customizable channels [26]
Kim et al.	2020	This paper examines gage redresses to solid coupling cross section QCD on anisotropic grids. They likely display hypothetical headways in grid QCD reenactments, centering on gage rectifications and their suggestions for solid coupling administrations [27]
Koranga et al.	2018	The creators propose a picture denoising strategy based on wavelet change utilizing Visu thresholding strategy. They likely present a denoising approach that utilizes wavelet change combined with Visu thresholding for successfully expelling clamor from pictures [28]
Kumar et al.	2021	This paper presents a stationary wavelet transform-based strategy for ECG flag denoising. They likely present a denoising method that utilizes stationary wavelet change to evacuate commotion from electrocardiogram (ECG) signals, pointing to make strides flag quality for advance investigation [29]
Lefkimmiatis	2018	The creator proposes widespread denoising systems, a novel CNN design for picture denoising. They likely present a profound learning show outlined to handle different sorts of picture clamor through an end-to-end trainable arrange engineering [30]

Li et al.	2022	This paper gives a comprehensive study on 3D confront acknowledgment strategies. They likely audit different procedures and calculations for 3D confront acknowledgment, talking about their qualities, restrictions, and applications [31]
Liang et al.	2021	The creators propose a novel system for confront acknowledgment beneath changing light conditions. They likely present a system that combines wavelet change and vital component examination for strong confront acknowledgment totally different lighting conditions. [32]
Limshuebchuey et al.	2020	This think about compares picture denoising strategies utilizing conventional channels and profound learning strategies. They likely conduct tests to compare the execution of conventional denoising channels with profound learning-based approaches in terms of denoising quality and computational productivity [33]
Liu & Liu	2019	This paper gives an outline of picture denoising based on profound learning. They likely talk about the essentials of profound learning-based denoising strategies, counting arrange models, preparing techniques, and applications [34]
Liu et al.	2020	The creators propose a strategy for interfacing picture denoising with high-level vision errands utilizing profound learning. They likely present a system that leverages profound learning-based denoising to move forward the execution of high-level vision errands, such as picture classification or protest discovery[35]
Lu et al.	2022	This paper proposes a confront acknowledgment calculation based on stack denoising and self-encoding nearby twofold designs. They likely present a confront acknowledgment calculation that coordinating stack denoising and self-encoding nearby parallel designs for vigorous include extraction and acknowledgment[36]
Manganelli Conforti et al.	2022	The creators propose profound learning for chondrogenic tumor classification through wavelet change of Raman spectra. They likely present a profound learning-based approach for classifying chondrogenic tumors utilizing wavelet change highlights extricated from Raman spectra information [37]
Mei et al.	2024	This paper talks about biomedical applications of the wavelet change calculation on profound learning ultrasonic picture optimization as a guess demonstrate for intense myocarditis. They likely investigate the utilize of wavelet change and profound learning methods for optimizing ultrasound pictures and foreseeing results for intense myocarditis [38]
Mohammed et al.	2022	The creators propose feeling acknowledgment of students' faces utilizing half breed profound learning and discrete Chebyshev wavelet changes. They likely present a strategy for recognizing feelings from facial pictures by combining profound learning strategies with discrete Chebyshev wavelet changes to extricate pertinent highlights [39]
Mustaqim et al.	2022	This paper presents a strategy for information increase in profound learning-based confront acknowledgment utilizing wavelet change and nearby double designs. They likely propose a strategy to improve the execution of profound learning-based confront acknowledgment frameworks by expanding preparing information through wavelet change and nearby twofold design encoding [40]
Onur	2022	The author introduces an improved image denoising method using wavelet edge detection based on Otsu's thresholding. They likely propose an enhancement to traditional wavelet-based denoising methods by incorporating edge detection using Otsu's thresholding technique to better preserve image details while removing noise [41]
Paul et al.	2022	The creators propose a wavelet-enabled convolutional autoencoder based deep neural organize for hyperspectral picture denoising. They likely present a profound learning design that coordinating wavelet changes into convolutional autoencoders for denoising hyperspectral pictures, pointing to progress picture quality for consequent investigation [42]
Qin et al.	2023	This paper talks about the acknowledgment of abnormal-laying hens based on quick nonstop wavelet and profound learning utilizing hyperspectral pictures. They likely investigate the utilize of quick persistent wavelet changes and profound learning strategies for identifying unusual behaviors in laying hens from hyperspectral picture information [43]

Rakheja & Vig	2016	The creators conduct a study on picture denoising utilizing different wavelet changes. They likely give an outline of distinctive wavelet-based denoising strategies, comparing their viability and applications in picture handling [44]
Roy et al.	2021	This paper presents a later think about on picture denoising utilizing profound CNN methods. They likely survey later headways in picture denoising accomplished through the application of profound convolutional neural arrange (CNN) methods, examining their qualities and restrictions [45]
Sagheer & George	2020	The creators give a audit of therapeutic picture denoising calculations. They likely overview different denoising strategies particularly outlined for restorative pictures, talking about their viability and pertinence in clinical settings [46]
Shahdoosti & Rahemi	2019	This paper proposes an edge-preserving picture denoising strategy employing a profound convolutional neural arrange. They likely present a profound learning-based approach that jam edges whereas expelling commotion from pictures, making strides visual quality and holding critical picture highlights [47]
Shukla et al.	2023	The creators show a successful approach for picture denoising utilizing wavelet change including profound learning strategies. They likely propose a strategy that combines wavelet change with profound learning calculations to improve the denoising execution of pictures, accomplishing way better comes about compared to conventional strategies [48]
Suresh	2015	The creator presents a moved forward picture denoising method utilizing wavelet change. They likely display improvements to conventional wavelet-based denoising strategies to realize superior commotion decrease whereas protecting picture subtle elements [49]
Tian et al.	2020	This paper gives a diagram of profound learning approaches for picture denoising. They likely study different profound learning methods connected to picture denoising assignments, examining their focal points, challenges, and potential applications [50]
Tian et al.	2020	The creators propose a picture denoising strategy utilizing profound convolutional neural systems with clump renormalization. They likely present a profound learning design that consolidates group renormalization to progress the preparing soundness and joining speed of convolutional neural systems for picture denoising. [51]
Tian et al.	2023	This paper presents a multi-stage picture denoising strategy with wavelet change. They likely present a denoising approach that utilizes wavelet change at different stages to evacuate commotion from pictures viably whereas protecting picture points of interest[52]
Tripathi	2021	The creator talks about facial picture commotion classification and denoising utilizing neural systems. They likely investigate the utilize of neural systems for classifying and evacuating commotion from facial pictures, pointing to progress the quality of pictures utilized in facial acknowledgment frameworks [53]
Veena et al.	2016	The creators propose a slightest square-based picture denoising strategy utilizing wavelet channels. They likely present a denoising method that utilizes slightest squares estimation with wavelet channels to evacuate commotion from pictures whereas protecting picture points of interest [54]
Wang et al.	2024	The creators examine the accumulation history of the Smooth Way, especially centering on hydrodynamical reenactments of Galactic predominate systems amid there to begin with infall. This inquiries about likely contributes to understanding the arrangement and advancement of the Smooth Way system [55]
Wu	2023	This consider investigates investigate on profound learning picture handling innovation for seismic information. The creator likely explores the application of profound learning methods in handling seismic pictures to upgrade the examination and interpretation of subsurface structures within the Earth's hull [56]
Xu	2024	The creator proposes a half breed approach consolidating CNN-LSTM and SVM with wavelet change strategies for visitor traveler stream expectation. This likely includes utilizing profound learning models combined with wavelet change procedures to estimate visitor traveler stream, giving bits of knowledge for tourism administration and arranging [57]

Xu et al.	2021	The creators create a half breed deep-learning show for blame determination of rolling orientation. They likely combine profound learning calculations with conventional blame determination strategies to make strides the exactness and proficiency of recognizing issues in rolling orientation, contributing to apparatus wellbeing checking and support [58]
Yan etal.	2023	This paper returns to the application of wavelet change for revolving machine blame conclusion over a ten-year period. The creators likely audit the headways and challenges in utilizing wavelet change methods for identifying deficiencies in rotating apparatus, highlighting the advance made within the field [59]
You et al.	2023	The creators conduct inquiries about on picture denoising in edge discovery utilizing wavelet change. They likely investigate the application of wavelet change in upgrading edge discovery by evacuating commotion from pictures, pointing to progress the exactness of edge location calculations in computer vision errands [60]
Zeng et al.	2021	This think about explores the impacts of picture preparing on profound confront acknowledgment frameworks. The creators likely analyze how diverse picture handling strategies affect the execution of profound learning-based confront acknowledgment calculations, giving bits of knowledge for progressing the strength and precision of such frameworks. [61]
Zhang et al.	2017	The creators propose a remaining learning approach for picture denoising utilizing profound convolutional neural systems. They likely present a profound learning design that utilizes leftover associations to memorize remaining commotion designs, driving to moved forward denoising execution compared to conventional strategies [62]
Zhang & Zhang	2022	This inquiries about centers on laser polarization picture remaking utilizing wavelet change and profound learning. The creators likely investigate the application of wavelet change combined with profound learning strategies to remake laser polarization pictures, pointing to progress picture quality and upgrade investigation capabilities [63]
Zhou et al.	2022	The authors propose a cross breed denoising demonstrate utilizing profound learning and scanty representation for powerless blame determination in orientation. This consider likely examines the integration of profound learning and inadequate representation methods to progress the precision of recognizing frail deficiencies in orientation, contributing to condition observing and prescient upkeep hones in apparatus [64]

C. Wavelet Transform in Denoising

Image denoising using wavelet transformation is attracting extensive attention because the method is highly adequate for removing noise and maintaining essential image details. Agarwal et al. [1] provide a review and comparison of wavelet transforms in MRI denoising, which is one of the main current areas of interest with regard to image processing. Wavelets are particular families of functions, which have a unique property that makes them the basis for a multi-resolution decomposition of an image into various frequency components. This is happening through unwinding of noise signals at different scales, which leads to suppression of noise, and improves a denoising result.

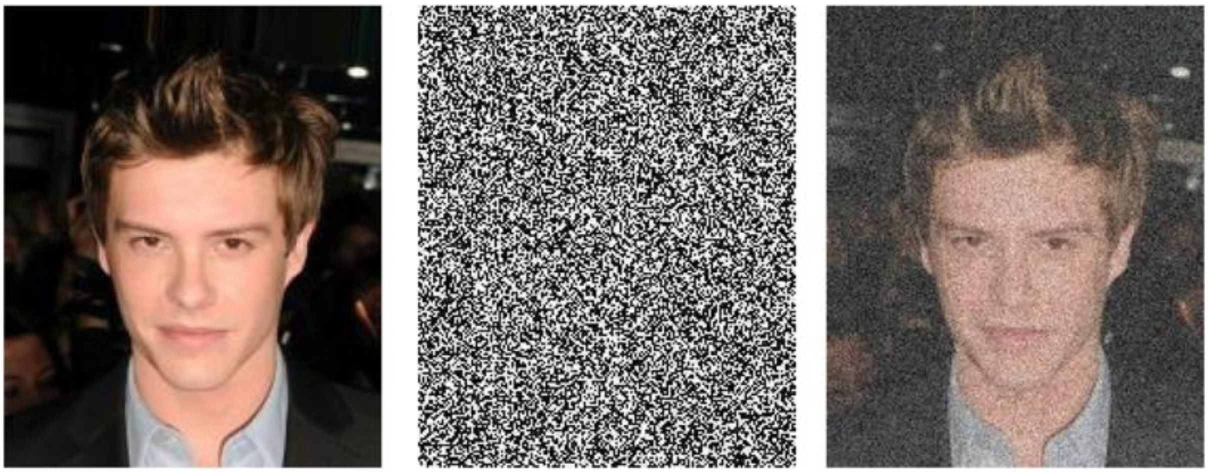

Figure 1: Example of Wavelet Transform in Denoising

Averbuch et al. [2] presented a wavelet packets hybrid denoising algorithm with directional orientation. This algorithm demonstrated superior performance when compared with denoising methods used in the past. Through detection of the directional information implied in the wavelet packets, the algorithm becomes at one and the same time to stipulate noise reduction and to preserve image details. As a matter of fact, He et al. [6] devised wavelet transformation-based two stream convolution network model, the model enables the use of wavelet derived features increasing the anti-spoofing robustness of the systems.

The use of wavelet transforms together with deep learning architectures has presented a more advanced image denoising field of science. Bao, et al. [5], in their work on hybrid denoising, represent a novel approach that integrates the monogenic wavelet transform with deep convolutional neural networks, thereby generally outperforming most standalone approaches. The combination of the two moves is responsible for the extraction of broad spectra of high-level features by deep learning networks in tandem with the ability to reduce noise employing the zoom in/zoom out analysis of wavelet transforms.

In a nutshell, the wavelet transform-centric framework furnishes a potent avenue for image denoising, notably, with the swift integration of deep learning approaches. On the other hand, the future research will involve finding out about new architectures and optimizing significantly to have more accurate denoising performance across various fields and applications.

D. Deep Learning in Denoising

The denoising in images is an essential element to upgrade the quality of images and keeping the important features with the pupil. Deep learning techniques have proven very effective in restoration of signal when challenged with the problem of noise in numerous domains. This section covers the deep learning techniques including CNNs in image denoising in addition to.

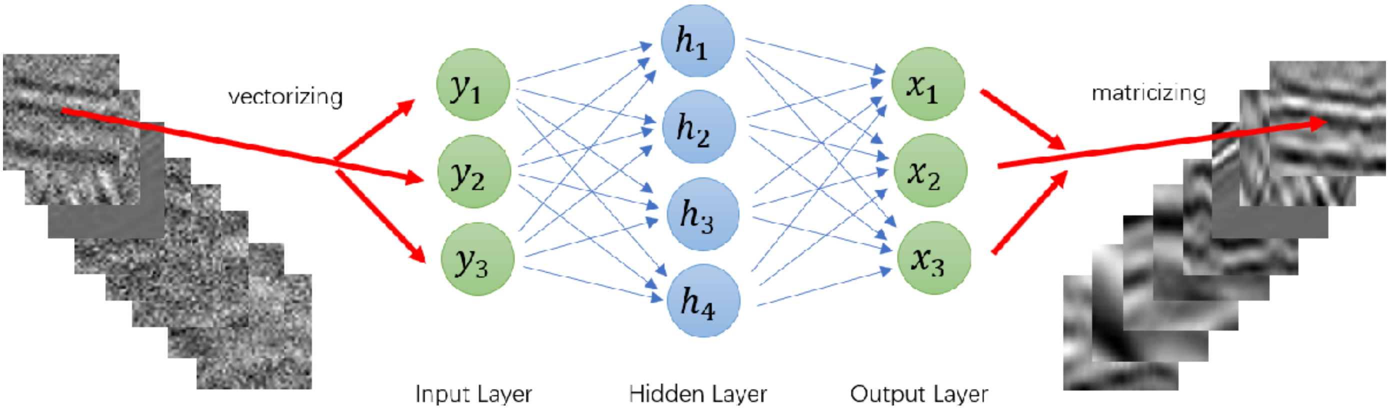

Figure 2: Example of Deep Learning for Denoising

4.1 Convolutional Neural Networks for Image Denoising

The convolution neural networks (CNN) have gained ground in image denoising problem because they are able to learn pixels representation in a hierarchical organizing manner from the data. Many designs and strategies are suggested which are CNNs are most suited for the purpose of image noise removal. To exemplify, Guhathakurta [22] utilized a wavelet-based approach which is based on the combination of wavelet transforms and deep learning. The aim of the combination is to take the advantage of both these techniques to better denoise images. Closely attached, Zhang et al. [62] also utilized residual learning in the framework of the deep CNNs for image denoising, annihilating the performance of standard Gaussian denoising algorithms.

4.2 Wavelet Transform and Deep Learning Fusion

The use of wavelets in conventional deep learning architectures is particularity effective in denoising tasks. A result comparison in the context of the MRI images denoising with various wavelet transforms was made by Agarwal et al. [1] and among these the efficiency was also confirmed in combination with deep learning techniques. Also, in their research, Mustaqim, et al. [40] designed a method that combines both wavelet transformation and local binary pattern for stronger temporal analysis on databases used for face recognition and proven its ability of achieving optimum denoising power compared to other algorithms.

4.3 Hybrid Architectures for Enhanced Denoising

A hybrid system of architectures, for improved denoising, engaging the different deep learning models or other signal processing techniques have found application in research. For example, the Arab et al. [8] outline a hybrid LSTM-ResNet deep neural network for noise reduction in as well as classification of V-band receiver signals which then proves the vitality of combining of recurrent and convolutional neural networks related to denoising tasks. Besides, Zhou et al. [64] also realized a hybrid denoising model by a way of deep learning and sparse representation, showing its prospect to boost weak bearing fault diagnosis.

Unfortunately, traditional signal processing techniques such as wavelet transforms have been combined with the latest trend, deep learning, and their integration has proved to be of tremendous success in the context of image denoising. Compositional architectures composed of multiple deep learning models or jointly deployed by signal processing techniques improve denoising performance even more, which means that they are irreplaceable tools for many image processing applications where one of the main goals is noise reduction in images.

E. Hybrid Denoising Systems

Image denoising using wavelet transformation is attracting extensive attention because the method is highly adequate for removing noise and maintaining essential image details. Agarwal et al. [1] provide a review and comparison of wavelet transforms in MRI denoising, which is one of the main current areas of interest with regard to image processing. Wavelets are particular families of functions, which have a unique property that makes them the basis for a multi-resolution decomposition of an image into various frequency components. This is happening through unwinding of noise signals at different scales, which leads to suppression of noise, and improves a denoising result.

Conflation of classic signal processing algorithms with membership education trending deeply learned methods create cross-domain noise-reducing systems with robust solutions. By utilizing their individual merits, these systems develop a superior denoising performance, alternate to the isolated approaches.

5.1 Fusion of Wavelet Transform and Deep Learning

One of the ways modern systems of hybrid denoising use deep learning in conjunction with wavelet transforms is mixing them into demand models. Wavelets are particularly known for their capacity for holding both frequency and spatial features information for the signals, which makes them the ideal choice for noise removal processes. As Agarwal et al. [1] point out, a lot of wavelets transform-based denoising techniques were compared and their effectiveness in preserving image details whereas getting rid of noise was highlighted.

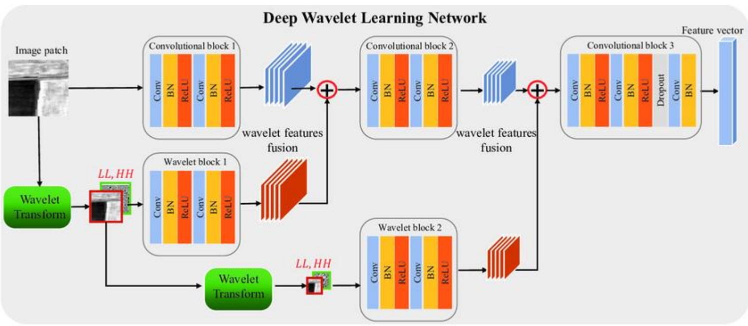

Figure 3. Example on deep wavelet learning network [65]

Integrating the deep learning technique into the wavelet-based denoising approach increases the systems' adjustability and prediction accuracy. According to Mustaqim et al. [40], the hybrid method was developed to enhance facial recognition through waves transformation and local binary pattern. Besides, this integration not only gives rise to better denoising conducts but also broadens the range of face recognition to include a variety of illumination level.

5.2 Hybrid Architectures for Enhanced Denoising

Hybrid models are the ones that use the fused power of different neural network architectures and together these can very well overcome the issue of noisy data to achieve better denoising. Arab et al. [8] demonstrated a unique hybrid LSTM-ResNet deep neural network that was applied for noise reduction and V-band receiver signals classification. This architecture comprised of the LSTM networks with the ResNet architectures was designed to deal both with the temporal dependencies and the spatial features reflected in the noisy signals and thus with the problem of improved classification accuracy.

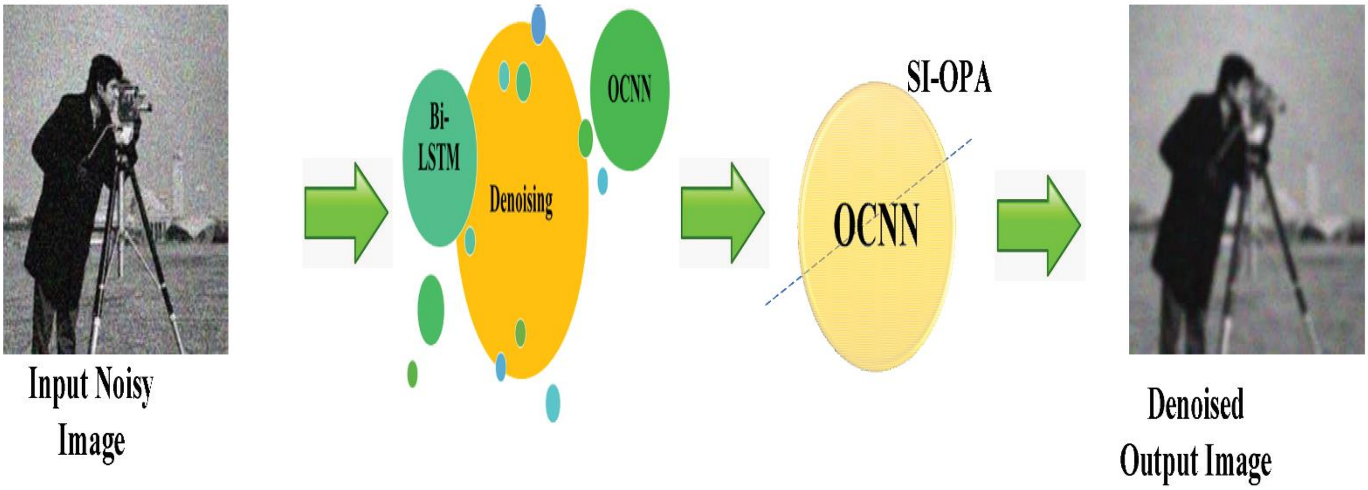

Figure 4. Example on Image Denoising Using Hybrid Deep Learning Approach [66]

Besides this a portmanteau of wavelet transformation and deep learning network models is incorporated to build hybrid denoising architectures. Averbuch et al. [2] came up with a hybrid denoising algorithm which is based on directional wavelet packets and replace the multi-resolution analysis capabilities of wavelet transforms with learning capability of deep neural networks. Through this kind of combination, it becomes evident that the outcomes are even more remarkable while there are different noisy sources comprised of directional interferences besides the traditional ones.

5.3 Future Directions and Summary

Systems of multimode denoising provide a prospective direction that is essential for the purpose of overcoming the challenge of noise removal in many areas of activities. A combination of classical signal manipulation and modern deep learning techniques plays an exceptional role in noise removal led by preserving important signal characteristics.

New studies that will investigate inventive overlapping between wavelet transforms and deep-learning architectures as well as the usability of these hybrid denoising systems in emerging domains such as biomedicine and remote sensing are one of the possible research directions. It is also necessary to develop a way to optimize the training algorithms for improving the effectiveness of the outlined hybrid architectures.

In summary, throughout this discussion, we have demonstrated that hybrid noise canceling systems represent a wide and potent way of noise reduction with a significant positive effect on signal quality from different sectors of application.

F. Performance Evaluation Metrics

A crucial aspect in scheme analysis of denoising algorithms is that evaluation metrics are a core tool in assessing their performance and comparing denoising algorithms. Different figures of merit as used to assess the quality of image obtained after the removal of noise could be divided into the performance based on mathematical control and perceptual studies associated with human view. This segment deals with performance evaluation metrics, and that usually include noise removal based on the images.

6.1 Peak Signal-to-Noise Ratio (PSNR)

PSNR, Peak Signal-to-Noise Ratio is one of the most popular subjective metrics to evaluate the fidelity of the images with denoising imposed. It defines the ratio of the maximum theoretical power of a signal to the power of corrupting noise that negatively affects the quality of the signal in its encodation. PSNR (Peak Signal-to-Noise Ratio) is a measurement that is based on the mean squared error (MSE) between the original and denoised images, the latter being a quantitative metric to be used for objectively assessing reconstruction quality [62].

PSNR (in decibels) is defined as:

$$PSNR = 10 \cdot \log10 (MAX^2 / MSE) \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where MAX is the maximum possible pixel value of the image (e.g., 255 for an 8-bit grayscale image) and MSE is the mean squared error between the original and denoised images.

6.2 Structural Similarity Index (SSIM)

One of the SSIM (Structural Similarity Index) is the most commonly used parameters for rating of the perceptual quality of denoised images also. Contrary to PSNR, which only considers dice similarly–mixed pixel contrast, SSIM also considers structural information and spatial dependence in the images. SSIM calculates a resemblance between two images using luminance, contrast, and structure, which gives notions of relative quality making it clearer as it is related more to the human visual perception [40].

SSIM is calculated as the product of three terms:

$$SSIM (x, y) = l (x, y) \cdot c (x, y) \cdot s (x, y) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:

l (x, y) represents the luminance similarity between the original (x) and denoised (y) images

c (x, y) represents the contrast similarity between the original (x) and denoised (y) images

s (x, y) represents the structural similarity between the original (x) and denoised (y) images

6.3 Mean Structural Similarity Index (MSSIM)

Mean Sport Feature Similarity Index (MSRSI), a version of SSIM computed mean SSIM value either the entire image or a specified region of interest (ROI). The output from MSSIM is a scalar value that in whole means how well the original and the denoised image fit together. The scalar can be used to numerically compare different denoising methods [8].

MSSIM is the generalization of SSIM obtained via the averaging of the SSIM values within the patches (or the whole image) according to the application or the evaluation factor.

6.4 Visual Inspection

Along with the procedure of metric measurement, visual inspection by human observers is another very important aspect in performance assessment for example image denoising. Subjective assessments essentially ask people to compare the quality of an image after it has been denoised to the real image by the observers and seek their feedback on artifacts and fidelity. Providing visual impression also contribute to the subjective criterion which is not easily measured by the calculation criteria [1].

6.5 Summary

Performance metrics in the field of denoising not only help in efficient algorithm evaluation but also serve as a guide in development and optimization of such algorithms. Objectively speaking, PSNR and SSIM are metrics that give a numerical representation of the image quality reconstruction; however, subjectivity brings in considerable human insights purposeful with perceptual image quality. A holistic and inclusive assessment technique that seamlessly integrates both objective metrics with visual inspection and, consequently, communicates the effectiveness of AI algorithms for various denoising use-cases will be entirely necessary.

G. Challenges and Limitations

Despite the advancements in image denoising techniques, several challenges and limitations persist in the field:

1. Complexity of Noise: Multiple types of models generate different challenging conditions, while the noise contains different levels of complexities [19].
2. Performance Dependency on Noise Characteristics: The successful predictive algorithms for denoising depend on many factors, which include noise characteristics arising in the image; this presents a difficult task for developing universal solutions [22].
3. Computational Complexity: A lot of denoising techniques, of which the ones based on deep learning could be the most complex, are compute-intensive, they are thus taking a lot of time and need substantial processing power [62].
4. Need for Large Datasets: Deep learning-based methods that include denoising techniques usually need large data sets for training, which may not be always accessible, especially for those domains where data is considerably infinite [46].
5. Overfitting: The deep learning models tend to overfit all of the time, especially when they are being trained under the data that are either very

limited or very noisy and so they might not display good generalization performance [30].

6. Interpretability: The uninterpretable nature of some deep learning models is the major challenge of understanding how they reach to their denoising judgments. This does not permit trust and that is one reason for being less adopted in critical applications [17].
7. Trade-off between Denoising and Detail Preservation: In fact, the process of denoising and preserving meaningful details is often messier and more complicated in practice. Therefore, this trade-off calls for particular consideration in applications and is one of the main challenges we are currently working on. [63].
8. Sensitivity to Hyperparameters: The performance halogenation of deep learning models for image denoising strongly depends on deep learning models for image denoising strongly depends on a careful tuning of hyperparameters for optimal results [67].
9. Domain-Specific Adaptation: Common denoising algorithms may have a poor performance during their practical implementations when applied in particular domains, such as medical imaging or remote sensing, therefore necessitating their adaptation to these domains [46].
10. Evaluation Metrics: While the choice of suitable evaluation metrics constitutes a major bottleneck when estimating the performance of the denoising techniques the metrics used may not necessarily encompass different facets of denoising as [63] believe.

Surmounting these challenges and drawbacks gives rise to the notion that sophisticated research across disciplines, computer vision, signaling processing, as well as filling of the gaps are key to success in the field of image-denoising.

H. Future Directions and Research Opportunities

The localization in image denoising domain provides opportunities for the progression in light of prospective research. While looking into the joint work of the deep learning classifier and wavelet transform in order to get the high performance of denoising [57]. Additionally, considering the possibility of residual learning in deep convolutional neural networks (CNNs) for the noising denoising of images that exceed Gaussian noise would generally make the denoising results be solved better [62].

Improvements in noise reduction algorithms, particularly under the changing illumination conditions might have been conducted in facial recognition systems [32]. Further, into feature attention mechanism incorporation into denoising can be spruced up the performance, which can be well scrutinized in real image denoising tasks [7].

Unsupervised leaning, like recorrupted-to-recorrupted [68], is the most promising possibility in the context of deep learning for image denoising. This could be looked at as a solution for problems connected with an abundance of noiseless images.

In addition, the research can introduce the possibility to harness the potential of parallel deep learning structures with special filters that are being learnt and designed just for low-resolution face recognition. This can result in uncovering solutions in this area [26].

At last, the way of universal denoising networks is a new perspective, with the prospect to apply the denoising in all kinds of noise and gain superb denoising performance [30].

These paths, hence, offer researchers an exciting way to groundbreaking work in Image denoising in many places of medical imaging, remote sensing, and biometrics where there are challenges.

I. Discussion

Traditional signal processing technologies are the basis for image denoising field, which undergo the aggressive development, including the innovative approaches and deep learning applications. In different many reports, researchers discussed the effectiveness of multiple noise reduction methods, for example, wavelet transform and convolutional neural networks (CNN), and the hybrid models.

Wavelet transforms that come to use to remove noise from an image have been embraced by the scientific community as efficient tools [1], [2], [3]. Such techniques base on multi-representation properties of the wavelet which is able to split images into different frequency fractions supporting noise removal while keeping key visual elements [36], [40]. For instance, alignment with processes such as thresholding and directional wavelet packets is meant to boost the performance [28], [44].

These days, deep learning has come to be a fundamental model in the image denoising topic [7], [34]. specifically, Convolutional neural networks (CNNs) representation of skills in complex term has proven to identify denoising functions that has been learned from data and directly too [4], [21]. This fashion of learning, through the training on the large datasets, has the potential of effectively capturing the structure of the noisy images. The output of these highly trained denoisers and effective models based on convolutional neural networks reduce noise and improve image quality considerably [47], [50].

A hybrid approach utilizing wavelet transforms with deep learning methods have been proven by two works as having their own competitive edge over the limitations of each technique individually [6], [64]. In their parallel information processing, these models combine the unique advantages of traditional and modern approaches, achieving a better denoising performance compared to one alone [35], [38]. The wavelet-based feature extractions with the deep learning-based feature extractions along with the hybrid models can quite effectively handle different types of noises and preserve the necessary image features [42], [53].

In addition to this, the latest scientific findings are broadened to more complex sound elimination functions like digital face recognition and medical image analysis [32], [46]. These software's are often requiring adaptive denoising modules that can tackle specific noises and conserve important image properties [10], [16]. Overall, the discussion amply covers the various ways of image denoising and also emphasizes the fact that in order to stay ahead of the emerging challenges, the research should continue to be done to develop cutting-edge technologies needed for improved image denoising.

J. Conclusion

In general, we can speak to cutting-edge image denoising techniques that represent the discipline for the latest decade that has deep learning among them. Till date, this problem has been mitigated by different alternative strategies comprising Convolutional neural networks (CNN), Wavelet transforms, and Hybrid models to address the noise issue in images of various domains. The literature research has found out about a variety of end technologies, each with its advantages and disadvantages. On one hand, methods with wavelet transforms hold an advantage of their ease of interpretation and computational efficiency, whereas on the other hand deep learning-based methods, such as CNNs, exhibit a superiority through their capacity to deal with complex noise patterns and achieve state-of-the-art results. A hybrid denoising, which blends the robustness and accuracy of both paradigms, has also exhibited a tendency of outwitting the standalone noise-removal models. Yet, the outline remains complex when it is the matter of obtaining the optimal model structure, to reduce getting a model working on a small dataset. Also ensure generalization on different data types. Exploring more sophisticated architectures and utilizing prior domain knowledge can be a future research area, likewise transfer learning can also be an area to investigate for achieving the higher efficacy of the image denoising algorithms. Generally, the conjunction of deep learning and routine signal processing algorithms is a game changer, which enables the extraction of high-fidelity information from noisy signals and thus finds applications in various scenarios including medical imaging, remote sensing, and computer vision

K. References

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