A Systematic Review on Image Enhancement Techniques

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Abstract Image enhancement is a very important process used for enhancing the quality of an image, and for this purpose, numerous techniques have been used and applied. This paper describes how to enhance an image using different techniques. Various techniques have been studied for image enhancement used in different research papers. Understanding and reviewing the techniques used for image enhancement are the main goal of this paper. Our review work leaves a lot of future scopes which can be extended further by researchers.

Keywords Image enhancement · Image quality · Digital image processing

1 Introduction

Image enhancement is a process by which we can improve the quality of the digital image which makes it easier for identifying features. This can be done by removing noise, sharpening, or brightening an image. The techniques identified in the paper to enhance an image are contrast stretching and image sharpening, nonlinear image enhancement technique, genetic algorithm, generalized fuzzy enhancement, wavelet transform technique, multi-scale and single-scale retinex improvement technique, etc. This paper is divided into four sections. Section 1 is an introduction about the image enhancement followed by review procedure in Sect. 2. Section 3 covers the detailed analysis of the selected papers. Finally, in conclusion, answers to the research questions as well as the future scope are discussed in Sect. 4.

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Table 1 Research questions identified

Research questions
RQ1: To identify the various techniques used in the image enhancement?
RQ2: To compare the traditional image enhancement techniques with the new image enhancement techniques?
RQ3: To identify the factors affecting the image quality?

2 Review Procedure

To study the image enhancement techniques, we have read around 150 research papers. We have adopted a similar approach taken by Singh et al. [1, 2, 3] and then identified the most suitable papers using the following steps: (i) we have downloaded the papers using the keywords: image enhancement techniques, (ii) we read the abstract, title, and conclusion, (iii) we have chosen the research papers which are related to our study based on the content of papers, (iv) we have chosen 30 most relevant papers out of 150 papers, (v) the findings have been reported after studying each paper thoroughly, (vi) finally, we made tables which categorize the major contribution of authors, and techniques used in various papers. Following are the research goals to study the image enhancement techniques (Table 1).

3 Related Work

In this section, various papers related to image enhancement have been taken into account for review and analysis.

In [4], Negi et al. discussed contrast stretching and image sharpening techniques. It is an approach that concurrently adjusts contrast and enhances boundaries of an image. On the gray-scale image contrast stretching is applied and then it proceeds to Laplacian mask, and finally, Laplacian image is appended to the original gray-scale image to obtain the desired sharpened image.

In [5], Wu et al. proposed image enhancement using wavelet-based contourlet transform with cycle translation. In this, wavelet transform is used for decreasing the redundancy occurring in the original method of contourlet transform. WBCT and cycle translation are merged. At last, to magnify the images, adaptive enhancement function is selected. The proposed method can efficiently magnify the images and decrease the flecked at the background region, the image edges.

In [6], Wang et al. discussed NIE (Nonlinear Image Enhancement). Simulation and identification processes are used along with the proposed NIE method. This process uses clipping and scaling parameters which are an appropriate combination of various images. This process enhances the quality of blurred image and a better quality is achieved, and PSNR (signal-to-noise ratio) performance is obtained than other nonlinear enhancement techniques.

In [7], Sree et al. implemented the FPGA-based retinal fundus image enhancement algorithms. The design was accomplished using Simulink, and the implementation was accomplished on the Spartan 3E Development Board. It was found out that hardware system performance through different experiments was more as compared to software version for complicated video inputs.

In [8], Yaping et al. discussed the stepwise refinement method. The main objective of this method is how to recognize and enhance the particular portion of a digital image, and maintaining other information of the object by keeping it unchanged. So stepwise refinement method is used to figure out the problem. It comprises of image pre-processing, recognition and enhancement.

In [9], Imtiaz et al. discussed a color image enhancement method. FICE algorithm is used to enhance the RGB endoscopic images. The color reproduction is carried out by transferring chrominance map from the source image to the enhanced gray-scale spectral image in the procedure of corresponding luminance and texture information. It throws light on some of the tissue characterization on the surface part of the base endoscopic image.

In [10], Premkumar et al. discussed the color image contrast enhancement technique. Firstly, RGB image is transformed to HSV (hue, saturation, and value) color space. Hue color channel is selected for DST decomposition. The lower directional sub band is used for reformation. By transforming HSV to RGB color space, the enhanced image is acquired. From proposed DST-based contrast image enhancement approach, the satisfactory result is attained.

In [11], Bhattacharya et al. proposed a fast algorithm for raising the contrast of an image locally by using singular value decomposition (SVD) approach. The contrast of a partially degraded image is magnified by using this approach. Under global and partial degradation, the method is carried out properly and a good perceptual quality after processing is achieved.

In [12], Teng et al. described the Laplacian and Gaussian methods and discovered an upgraded Laplacian pyramid image enhancement method. On the obtained threshold of the Laplacian pyramid improvements, there is a good solution for the color difference between the smaller image detail enhancement and for the large difference in the color image enhancement, the effect is very obvious.

In [13], Wang et al. proposed an improvement to the wavelet transform method, naming it the lifting wavelet transform method for image enhancement purposes. It contrasts the new method with the existing wavelet transform method. The lifting wavelet transform method accredits the image to have wide gray-scale scope and also the detail is clear.

In [14], Munteanu et al. proposed real-coded genetic algorithm method for automatic image enhancement named EVOLEHA. In order to attain better explorative behavior, the method applies a real-coded GA with significant modifications like PCA-mutation. Due to a more exploitative crossover and selection scheme, the search is well-balanced and durable. EVOLEHA attains a combined goal (e.g., efficiency, robustness, wide applicability) that is not achieved by any other known enhancement methods.

In [15], Sun et al. proposed a novel optical transfer function-based micro image enhancement algorithm. An optical transfer function is used by this method for image enhancement. The proposed algorithm was better to save edge information of the micro image and no distortion when it is compared with Butterworth high-pass filter algorithm.

In [16], Ehsani et al. proposed an adaptive and iterative histogram matching (AIHM) algorithm for chromosome contrast enhancement used in medical applications. To meet the different requirements and obtain the different results, some parameters in the presented model could be selected. The detailed simulations were accomplished using different sets of single chromosomes, indicating that the proposed method enhances the details adequately.

In [17], Xiao-guang et al. proposed a generalized fuzzy enhancement method. This method overcomes efficiently the problem of information of middle and low gray levels lost in the method put forward by S.K. Pal. The edge of processed image becomes distinguishable, and by using this method, better object information of low gray levels is kept. It gives highly enhanced image and improves contrast ratio.

In [18], Ke et al. proposed an innovative image enhancement framework consisting of BiTA and SWCE. The traditional gamma adjustment curve is modified using the BiTA algorithm. The adjustment of global luminance is done by BiTA. By analyzing and setting the parameter γ, it limited the contrast lost. The saliency map with a simple contrast enhancement method is integrated by SWCE. SWCE carries out more enhancements in the areas that humans pay larger attention to.

In [19], Tang et al. proposed a new image enhancement technology which is based on a multi-scale contrast measure in the wavelet domain for radiologists to screen the mammograms. It alters the contrast of an image directly, so the proposed image enhancement technology is a direct contrast enhancement technology.

In [20], Dong-liang et al. proposed the generalized fuzzy enhancement method that overcomes the limitations of the traditional fuzzy method of enhancement. The enhancement problem of the low contrast and the narrow gray range images is solved by this method. The improved label algorithm is used for image segmentation and recognition, which is helpful in understanding an image and in object recognition.

In [21], Choi et al. discussed image enhancement technique in which an input RGB color image is transformed into HSV color image. The H component remains unchanged. Firstly, illumination is evaluated using JND-based nonlinear low-pass filter, to enhance the V component. It is done in ratio to the enhanced ratio of V component image, to enhance the S component. Finally, the image is transformed back to RGB color image.

In [22], Hasikin et al. discussed fuzzy gray-scale enhancement technique. The fuzzy measures in the image are maximized by using this technique. By using power law transformation and saturation operator, the membership function is modified. The intensities are increased of the underexposed regions, and intensities are decreased of the overexposed region, which is why the dynamic range is maintained. Other methods use INT operator (the membership value is modified above and below the threshold value) and NINT operator.

In [23], Xianghong et al. discussed the enhancement algorithm for colored medical images. It includes two features: color space transform enhancement and wavelet analysis enhancement. By using wavelet analysis, the image is fragmented and improved. From RGB space, the color image is converted to IHS (intensity, hue, and saturation) space. The new saturation which is enhanced replaces the image saturation. The nonlinear transform adjusts the intensity of the image. The image is then reconverted from IHS space to RGB space, and finally, the image is enhanced.

In [24], Yang et al. discussed morphological reconstruction enhancement. A non-idempotent connected operator is explained in this method. Overall enhancement of simple connected zones of image is done. Finally, the connected zones and the relations of the connected zones of an image are defined which are reconstruction, choice and iteration times. To describe image's peak component, flat area regional maximum, and their relations, a tree structure is used.

In [25], Peng et al. discussed enhancement method of THz images. By using wavelet transform into low and high-frequency part, a THz image is fragmented. Approximation coefficients go through nonlinear enhancement technique. This method magnifies the target and represses the background. Detail coefficients go through histogram equalization but it also enhances noise as well. So firstly, to remove noise in high-frequency band wavelet, denoising is applied. In target identification, the proposed method has good application prospect.

In [26], Gorai et al. proposed an automatic color enhancement technique using particle swarm optimization. Parameters of objective function are made effective by particle swarm optimization. The intensity transformation uses local as well as global information. The objective function makes the use of entropy and edge information for measuring the quality of input image. To obtain the enhanced image, scaling (or sometimes rescaling in case of gamut problem arises) is done.

In [27], Verma et al. used genetic algorithm to enhance an image. GA enhances the image naturally as it measures the fitness of a particular by estimating the intensity of spatial edges comprised in the image. Image is broken into sub images. Transformation function is applied. Fitness function is used. One with higher fitness is selected using tournament selection. Crossover is done using an arithmetic crossover, and finally, PCA-mutation is done.

In [28], Khan et al. proposed fingerprint image enhancement using multi-scale DDFB-based diffusion filters and modified Hong filters. The major goal of a fingerprint image enhancement is to magnify the image in order to remove noise and magnify reliable minutiae points. To calculate orientation field of a fingerprint image, multi-scale DDFB is required. This shows that this technique is more reliable than any derivatives-based techniques.

In [29], Raju et al. proposed a new fuzzy logic and histogram-based algorithm for magnifying low contrast color image. In this method, there are two parameters: K and M, where K is contrast identification parameter and M is image's average intensity parameter. The RGB image is transformed to HSV color space. Under the control of parameter M, V component is strained in order to magnify the image. The visual quality is modified by this method.

Table 2 Analysis of research papers related to various image enhancement techniques

Paper ID	Technique(s) identified
[1], [9]	Laplacian Method (Mask and Pyramid)
[2], [10], [16], [20], [22], [29]	Wavelet transform-based techniques
[3], [8]	Nonlinear image enhancement methods
[13], [26], [30]	Histogram-based techniques
[11], [24]	Genetic algorithm-based enhancement
[14], [17], [19]	Fuzzy-based enhancement
[21], [25], [27]	Multi-scale methods for enhancement
[4], [5], [6], [7], [12], [15], [18], [23], [28]	Other methods (HSV, DoG, PSO, shearlet transform, FPGA, optical method, BiTA and SWCE, FICE, etc.)

In [30], Lin et al. proposed retinex improvement for nighttime image enhancement. In case of low light images, this method can be applied to preserve normal or intensive lighting areas and reduce noise in highly low light areas.

In [31], Samantaray et al. focus on improving fingerprints using a proposed difference of Gaussian method. For that, histogram equalization is used and the proposed method is compared with other approaches also. Separate algorithms for contrast enhancement and detail enhancement are proposed so that fingerprints can be analyzed correctly.

In [32], Chouhan et al. propose a dynamic stochastic resonance-based technique which is used to improve the quality of dark contrast images so that they can be easily identified. For this method to be implemented, image must be in discrete wavelet transform (DWT) domain. For the purpose of contrast enhancement, internal noise of the image is used instead of external noise which improves the performance of enhancement.

In [33], Akila et al. compare various contrast enhancement techniques for images used in breast cancer detection (mammographic image enhancement). Techniques used are HE, CLAHE, BBHE, MMBEBHE, and RMSHE. According to the analysis, HE changes brightness of the image so the details cannot be viewed clearly. BBHE and MMBEBHE provide noise removal from images. Out of CLAHE and RMSHE, which both provide significant contrast enhancement, RMSHE is proved to be better.

4 Conclusion

In this paper, from Sect. 3 and Table 2, research questions proposed earlier in Table 1, i.e., RQ1, RQ2, and RQ3 are identified and answered. The main goal of this systematic review is to identify and analyze various image enhancement techniques which are used to enhance the quality of an image, including noise,

contrast, brightness, etc. These techniques help researchers compare various enhancement algorithms and choose the best of them as per the required purpose.

Answer to RQ1
Various techniques that are identified from our review work are listed as follows:

1. **Laplacian method:** mask and pyramid.
2. **Wavelet-based Enhancement:** wavelet transform, lifting wavelet transform, multi-scale contrast feature in wavelet domain, wavelet and color space transform, wavelet-based enhancement using DSR.
3. **Nonlinear Image Enhancement Methods:** singular value decomposition (SVD).
4. **Histogram-based methods:** HE, CLAHE, BBHE, MMBEBHE, and RMSHE, adaptive and iterative histogram matching (AIHM), fuzzy logic and histogram-based image enhancement.
5. **Genetic Algorithm-based evolutionary enhancement** (EVOLEHA).
6. **Fuzzy-based enhancement:** fuzzy-based iterative image enhancement, generalized fuzzy-based image enhancement.
7. **Multi-scale methods:** multi-scale morphological reconstruction, multi-scale retinex improvement, multi-scale DDFB-based diffusion filters and modified Hong filter.
8. **Other techniques:** field programmable gate array, stepwise refinement method, FICE algorithm, discrete shearlet transform, optical transfer function-based image enhancement, BiTA and SWCE, HSV Transform, particle swarm optimization, difference of Gaussian.

Answer to RQ2:
The most common algorithm traditionally used for image enhancement is histogram equalization. Other algorithms were also used but they were somehow an extension or modification of histogram equalization only.

As the technology advanced, various new methods were developed for the enhancement of images. As expected, new techniques were better than the traditional image enhancement techniques. As studied from various papers, we found out that wavelet transform- and soft computing-based methods (GA and fuzzy) were better than the traditional histogram equalization methods.

Answer to RQ3
As analyzed, there are various factors which can affect image quality. Some of them are noise, sharpness, distortion, contrast, color accuracy, dynamic range, exposure accuracy, lens flare, etc. These factors must be kept in mind while choosing or designing any image enhancement algorithm.

Finally, we can conclude that main techniques identified are histogram equalization, wavelet processing and transform, genetic algorithms, fuzzy enhancement techniques, Laplacian and Gaussian techniques, etc.

In future, this review can be used to compare various image enhancement algorithms and their feasibility can also be determined. Also, a specific area can be

chosen and further review and research work can be carried out. The proposed studies may be used to do comparative analysis, and further improvement may be applied by proposing new image enhancement techniques. Further, proposed image enhancement techniques may increase the quality of images.

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