Image Enhancement Based on Discrete Cosine Transforms (DCT) and Discrete Wavelet Transform (DWT): A Review

Wan Azani Mustafa¹,a, Haniza Yazid²,b, Wan Khairunizam³,c, Mohd Aminuddin Jamlos¹,d, I Zunaidi³, Z M Razlan², A B Shahriman²

¹Faculty of Engineering Technology, Universiti Malaysia Perlis, UniCITI Alam Campus, Sungai Chuchuh, 02100 Padang Besar, Perlis, Malaysia
²Advanced Intelligent Computing and Sustainability (AICoS) Research Group, School of Mechatronics Engineering, Universiti Malaysia Perlis, 02600 Arau, Malaysia
³Faculty of Technology, University of Sunderland, St Peter's Campus, Sunderland, SR6 0DD, United Kingdom

a wanazani@unimap.edu.my, b hanizayazid@unimap.edu.my, c khairunizam@unimap.edu.my, d mohdaminuddin@unimap.edu.my

Abstract: Image enhancement is an important topic in image analysis in order to help humans and computer vision algorithms to obtain an accuracy information for analysis. The visual quality and certain image properties, such as brightness, contrast, signal to noise ratio, resolution, edge sharpness, and color accuracy were improved through the enhancement process. The goal of image enhancement is to improve the quality of an image to become more suitable for a particular application. Till today, numerous image enhancement methods have been proposed for various applications and efforts have been directed to further increase the quality of the enhancement results and minimize the computational complexity and memory usage. In this paper, an image enhancement method based on Discrete Cosine Transforms (DCT) and Discrete Wavelet Transform (DWT) was studied. This paper presents an exhaustive review of these studies and suggests a direction for future developments of image enhancement methods. Each method shows the owned advantages and drawbacks. In future, this work will give the direction to other researchers in order to propose new advanced enhancement techniques.

1. Introduction
The image enhancement technique is to make the digital picture more appealing to our eyes, for example, making the images smooth or sharp [1–4]. This is an important topic in digital image processing. It can help humans and computer vision algorithms obtaining accurate information from the enhanced images. The visual quality and certain image properties, such as brightness, contrast, signal-to-noise ratio, resolution, edge sharpness, and color accuracy were improved through the enhancement process [5–9]. Recently, many image enhancement methods have been developed based on various digital image processing techniques and applications. They can be developed in the spatial domain or spatial-frequency domain. The enhanced image provides useful information for post-processing, especially in segmentation stage. Several survey papers on image normalization and segmentation methods have been presented in the literature and can be found in [10–13].
In the recent decades, Fourier Transform (Discrete Cosine Transforms (DCT) & Discrete Wavelet Transforms (DWT)) has been one of the major interesting research to enhance the images [14,15]. The discrete cosine transform (DCT) helps separate the image into parts (or spectral sub-bands) of differing importance (with respect to the image's visual quality). The DCT is similar to the discrete Fourier transform: it transforms a signal or image from the spatial domain to the frequency domain [16]. The discrete wavelet transform (DWT) is an implementation of the wavelet transform using a discrete set of the wavelet scales and translations obeying some defined rules. In other words, this transform decomposes the image into a mutually orthogonal set of wavelets [17]. In this paper, a comprehensive review of DWT and DCT was studied. The objective of this study is to analyze the advantages and drawbacks of each proposed method based on DWT and DCT.

2. Discrete Cosine Transforms (DCT)

One of the most significant current discussions in image enhancement is the Discrete Cosine Transforms (DCT) method. A DCT is another popular technique used because it is fast and effective. The basic function of DCT is to transform signals from the spatial representation into the frequency representation. Starting from 2006, Chen et al. [18] suggested a slight modification on Discrete cosine transforms (DCT) algorithm to improve the result performance under large illumination variations. They found that by discarding low-frequency DCT coefficients in the logarithm domain, the method capable of reducing the illumination variations effect significantly. The advantages of this method are no modelling step and bootstrap sets are required. The approach is fast and easy to be implemented in a real-time face recognition system. However, it is essential to solving a shadowing and the specularity problems because they lie in the same frequency band as some facial features.

In summary, according to an investigation by [18], the advantages using the DCT techniques are:

1) The DCT is real-valued instead of complexity (i.e., it involves magnitude and phase) such that it is easier to be implemented.
2) The DCT is more efficient for illumination variation estimation than the DWT.
3) The DCT approach is similar to the homomorphic filtering, which has been used for contrast enhancement.

Similarly, Vishwakarma et al. [19] considered the correlation of DCT in low frequency coefficients as the main parameter. This approach involved two steps: first, by using histogram equalization function. The original image was stretched and second, the low frequency of DCT coefficients was re-scaled to a lower value to compensate the illumination variations. The benefit of this technique is, it does not require recalculation of the DC coefficient for another difference illumination original image. In order to improve the previous method, [20] proposed a combination of Adaptive Histogram Equalization and DCT. Adaptive Histogram Equalization was used to stretch the contrast of the original image before applying the logarithm transform. Next, [21] again reported a new method based on a fuzzy filter that has been applied to the low frequency DCT (LFDCT) coefficient. This experiment involved two main techniques: Histogram Equalization (HE) and Contrast Limiting Adaptive Histogram Equalization (CLAHE) to find the background normalization. Based on the result, this method was efficient and successful compared to [20] and [19] methods. All the above approaches are able to perform in the real-time face recognition systems.

However, interestingly, this is contrary to a study conducted by [22] where focuses on Balanced Discrete Cosine Transfer (BDCT) to reconstruct the background image. The unbalanced background condition and low contrast were normalized before performing the segmentation process. The aim of the research is to overcome the drawback of DCT where reconstructing the background image in horizontal or
vertical directions only. Based on the accuracy of segmentation result, the BDCT method achieved up to 25% better than the DCT method. Figure 1 shows the result of the BDCT method.

![Figure 1](image_url)

**Figure 1.** (a) and (c); The original ‘Mura defect’ image: (b) and (d); the resulting image after applying BDCT method [22].

In a different study, Lian, Er, & Li (2011) examined a low computational complexity illumination normalization method for face recognition application. Based on the noise estimation, the DCT coefficients were assumed as an illumination model to solve the background problem. The benefits of this approach are simple to implement and effective. However, in the future, the effect of the adaptive size selection of local area should be investigated. In a colour image, a new method for manipulating the DCT coefficients known as Multi Contrast Enhancement (MCE) was proposed by Xia, Panetta, & Agaian (2011). DCT was applied to produce an image with a few sub-bands based on the low and high frequency component. However, to improve the DCT function, alpha rooting and logarithmic enhancement function has been performed. The main advantage of this approach is simple, fast, and efficient for colour image application.

A study by Praveena & Venkatasrinu (2012) suggested a novel method of contrast enhancement for low contrast satellite images based on a combination of Singular Value Decomposition (SVD) and DCT. SVD was used to normalize the illumination and the output image was reconstructed using DCT. The technique was effective and produced a better performance compared to DWT-SVD technique [26], DWT technique, and Gamma Correction techniques. This finding is supported by [27] who proposed the technique using DCT and the Singular Value Decomposition (SVD). This technique process the image block by block. The DCT-SVD is not only robust but also effective in retaining the imperceptible property of the image.
In 2013, Goel et al. [28] presented low frequency DCT coefficients in order to remove the illumination variation. This approach also performed contrast limiting adaptive histogram equalization (CLAHE) for optimum contrast enhancement. The above findings contradict the study by [14,28]. They argued that a combination work of the regularized histogram equalization (HE) and the DCT is more effective and comprehensive especially for remote sensing image compared to CLAHE technique. The HE was used to generate the distribution function of the original image and produced a new image with improved global contrast. Moreover, the method has a satisfactory computation time, which is suitable for remote sensing and ordinary images enhancement. The comparison result of the enhancement methods is shown in Figure 2.

![Figure 2](image)

**Figure 2.** A comparisons on the Tank image: (a) Original image, (b) HE, (c) AGCWD [29], (d) DWT-SVD [26], and (e) Fu method [14].
3. Discrete Wavelet Transform (DWT)

Recently, wavelet transform technology has been widely applied in image processing and pattern recognition. Wavelet transforms can analyze an image in multi-resolution and detect small fluctuations at the multi-levels, they are good tools for contrast enhancement. A good contrast enhancement should be considered both a global and local information. An increasing amount of literature was discussed based on illumination normalization algorithms using wavelet-related methods were discussed, especially in face recognition application. In 2009, [30] published a paper which described a combination Multi-Scale Retinex (MSR) and DWT in order to enhance the colour images. The main purpose of MSR is to normalize the shadow effect and automatically improve the image quality. Finally, the DWT was used to fuse the sub-images into a single composite image that is more informative and suitable for visual perception.

In other research, [31] presented an improvement of wavelet algorithms. DWT was applied to get different band information and each band was processed separately. The low frequency was stretched using the HE and at the same time, the high frequency was denoised. In 2012, a 2D wavelet method was investigated by [32]. By focusing on low frequency components to find new coefficients, the result was good to normalize the shadows. In addition, this technique is simple and easy to be implemented in real-time face verification system. However, the weakness of this technique is a slow processing time.

In medical image application, [33] demonstrated a modification method of Undecimated Discrete Wavelet Transform (UDWT). The method used the hierarchical correlation of the coefficients of UDWT. The advantages of this approach are the algorithm is simple, fast, and produced better visual quality results. [34] found a significant relationship between Undecimated Wavelet Transform (UWT) and Wavelet Coefficient Mapping (WCM) technique to improve the previous method. UWT acted as a filtering to eliminate the noise in the original image and next, WCM was used to enhance the contrast. The method was tested on mammograms and chest radiograph images. Based on the assessment results, the approach is significantly superior, and faster compared to the Undecimated Discrete Wavelet Transform (UDWT) [33] and sigmoid-type mapping [35]. This technique can be used not only for improving the visual quality of medical images, however also as a pre-processing module for computer-aided detection/diagnosis systems to improve the performance of screening and detecting regions of interest. Table 1 shows the comparison result of previous research.

Table 1. Comparison of image processing methods in terms of 4 quantitative quality metrics for mammograms [34].

| Method            | Mean-To-Standard-Deviation (MSR) | Contrast Improvement Ratio (CIR) | Peak Signal-To-Noise Ratio (PSNR) |
|-------------------|----------------------------------|----------------------------------|-----------------------------------|
| Sigmoid [35]      | 6.09                             | 0.29                             | 36.39                             |
| UDWT [33]         | 5.80                             | 0.28                             | 38.35                             |
| UWT + WCM [34]    | 6.24                             | 0.67                             | 37.98                             |

A different opinion was expressed by [36] which suggested that a combination technique of Stationary Wavelet Transform (SWT), Singular Value Decomposition (SVD), and Discrete Wavelet Transform (DWT) in order to enhance the contrast. The original image was divided into four sub-bands to process separately before reconstructing a high-resolution image using IDWT (Inverse Discrete Wavelet Transforms). Based on PSNR, the result was superiority compared to the conventional techniques such as DWT, Bilinear, and Bicubic. Similar findings were reported by [37]. They proposed enhancement technique based on DWT and
Singular Value Decomposition (SVD) for fungus images application. The procedures almost similar to the method proposed by [36], however, this approach focuses on modification of low sub-bands coefficients. This approach produced a better result compared to HE, CLAHE, and AHE. The research by [37] was supported by [38] where a contrast enhancement method based on Discrete Wavelet Transform (DWT) and Singular Value Decomposition (SVD) was proposed. Therefore, they improved the wavelet function to become productive known as Dual-Tree Complex Wavelet Transform (DTCWT). The main purpose of DTCWT is to find the high frequency sub-bands, however, it introduces the new artefacts. The Non-Local Means (NLM) filter was applied in order to eliminate the artefacts. Finally, the Inverse DTCWT was used to merge all the sub-bands image. They also described a combination technique to enhance the contrast of the satellite image. The combination involved Resolution Enhancement (RE), Dual-Tree Complex Wavelet Transform (DTCWT) and Non-Local Means (NLM) [39]. The process and flow almost similar to the above method [38], however, this approach explained more on the Resolution enhancement (RE). The Lanczos interpolator used in order to interpolate the low-resolution image and high frequency sub-bands. The resulting performance of a few techniques is shown in Figure 3.

![Figure 3](image_url)

**Figure 3.** The comparison result: (a) Original image ‘Brain MRI’, (b) SWT-RE [40], (c) DWT-RE, (d) DTCWT-RE, (e) DTCWT-NLM-RE [39], (f) GHE, (g) SVD-based CE [41], and (h) DTCWT-NLM-SVD [38].
In 2011, [42] conducted numerical experiments on face images under different lighting conditions. A new novel method known as multi-scale dual-tree complex wavelet transform (DT-CWT) was proposed in order to reduce the halo artefacts in the non-uniform image. In a different study, [43] found a new method using knee transfer function and gamma correction based on Discrete Wavelet Transform (DWT). The procedure dealt with four frequency components which are Lowpass-Lowpass (LL), Lowpass-Highpass (LH), Highpass-Lowpass (HL), and Highpass-Highpass (HH). The outcome is effective to improve the image quality, especially for low contrast images.

In the pre-processing process, [44] demonstrated that illumination and contrast correction using DWT by applying a few steps: (1) the original image was decomposed into two components, which are low frequency and high frequency components, (2) the two components were processed separately through contrast enhancement to eliminate the effect of illumination variations and enhance the detailed of edge information, and (3) the normalized image was corrected using the Inverse Discrete Wavelet Transform (IDWT). Based on computation time results, this method performed faster compared to other methods such as Multi-Scale Retinex (MSR) [30], logarithm domain (LTV) [45], and anisotropic diffusion based smoothing technique [46].

4. Conclusion
One major area of digital image processing is image enhancement. The main objective of image enhancement is to improve the quality of images emphasize wanted features and make them less obscured. Generally, image enhancement can be divided into two categories which are spatial domain and frequency domain. This study discusses an overview of the background and related work in the area of image enhancement based frequency domain (DWT and DCT techniques). Based on the review, the frequency domain technique can analyze an image in multi-resolution and detect small fluctuations at the multi-levels, they are a good technique for contrast enhancement. However, the DWT technique shows a slow processing time and complex implementation. In addition, the DWT has a problem to deal with higher noise and badly non-uniform image. Besides, the DCT has a high computational cost and complicated in term of selecting suitable transfer functions or parameters. A serious drawback of this Fourier transforms approach is the algorithm does not perform perfectly to enhance the image in an extreme illumination and has a problem to deal with the high noise level.

5. Acknowledgment
This work was supported by Ministry of Higher Education Malaysia under the Fundamental Research Grant Scheme (FRGS/1/2018/SKK13/UNIMAP/02/1)

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