Penerbit Akademia Baru

Journal of Advanced Research in Applied Mechanics

Journal homepage: www.akademiabaru.com/aram.html
ISSN: 2289-7895

Advanced Research in Applied Mechanics

Open Access

A systematic review: Contrast enhancement based on spatial and frequency domain

Wan Azani Mustafa [1,2,*], Haniza Yazid [1], Mastura Jaafar [1]

[1] School of Mechatronic Engineering, University Malaysia Perlis, 02600 Ulu Pauh, Arau, Perlis, Malaysia
[2] School of Engineering Technology, Kampus Sg. Chuchuh, Universiti Malaysia Perlis, 02100 Padang Besar, Perlis

ARTICLE INFO

Article history:
Received 15 December 2016
Received in revised form 20 December 2016
Accepted 24 December 2016
Available online 25 December 2016

Keywords:
Enhancement, Contrast, Spatial, Frequency, Review

ABSTRACT

Contrast enhancement is a fundamental step in image segmentation, and plays an important role in image processing, pattern recognition, and computer vision. Contrast enhancement can sharpen the edges of objects in an image, making it easier to extract objects and attain more information from the enhanced image. This is very useful for image analysis. This paper presents a comprehensive review of contrast enhancement methods based on two categorized which is spatial domain and frequency domain. The goal of image contrast enhancement is to improve the quality of an image to become more suitable for a particular application. Hopefully, the implications of this survey give future research directions for the researchers.

1. Introduction

One major area of digital image processing is image enhancement. Image enhancement deals with improving the quality of images, where the goal is to emphasize wanted features and make them less obscured [1–6]. Sometimes this is done at an expense of degrading the quality of other details. The area of digital image enhancement is very appealing, where many fundamental image enhancement techniques are built on very simple concepts [7–8]. A popular example of image enhancement is the enhancement of contrast [9–11]. In psychology, contrast is defined as the ratio of the difference between the luminance of an object and its surrounding background to the luminance of the surrounding background [12].

In this paper, a few selected enhancement methods were presented by two categorized: (1) the spatial domain approach and (2) the frequency domain approach. The spatial domain such as contrast stretching [13], histogram equalization [12] and unsharp masking [14]. Besides, some methods are derived from those classical approaches, such as contrast-limited adaptive histogram equalization (CLAHE) [15], adaptive neighborhood histogram equalization (ANHE) [15] and adaptive unsharp

[*] *Corresponding author.*
E-mail address: azani.mustafa@gmail.com (Wan Azani Mustafa)

masking [14]. The enhancement methods based on frequency domain such as Tang's method [16], which operates in the discrete cosine transform (DCT) domain and wavelet-based approaches, such as Jin's method [17], which applies LAHE to individual frequency bands. In addition, there are also methods based on multi-scale decompositions. These include Toet's method [18] that uses a ratio of the low-pass pyramid, and a method by Mukhopadhyay and Chanda [19], which uses morphological top-hat transformations.

The objective of this review is to study and explored the enhancement technique based on spatial domain and frequency domain in term of the methods, advantages, and drawbacks. The organization of this paper is as follows: Section 2 discussed an overview of the literature review. Section 2.1 and section 2.2 explained details about the methods using spatial and frequency domain. A few applications of image enhancement were presented in section 3.0 and finally section 4.0 described the conclusion of this research.

2. Literature review

There are several contrast enhancement methods. Some methods are implemented in the spatial domain, and some in the frequency domain. Also, contrast enhancement approaches can be local or global, as well as direct or indirect. In addition, some methods are based on a single scale processing, while others process multi-scale image representations.

2.1. Spatial domain

Histogram equalization (HE) is a commonly used global contrast enhancement technique for both colour and greyscale images. HE spreads out and flattens the histogram of the number of image pixels at each grey level value, thus stretching the intensity values in the image over more of the available dynamic range of grey levels and increasing the apparent contrast in the image. The classical contrast enhancement methods include contrast stretching, global and local (LAHE) histogram equalization/modification and linear unsharp masking. Methods based on LAHE include CLAHE, which limits the enhanced contrast, and ANHE, which uses adaptive regions of arbitrary shapes. Methods based on unsharp masking include the method by De Vries [20], which uses and adaptive filter to reduce over-enhancement, and also an adaptive unsharp masking method, which emphasizes medium-contrast details. An easy example of Histogram equalization results as shown in Fig. 1.

In a different study, Hall [22] proposed a method by equalizing the grey-level density of pixels, demonstrated that by modifying the histogram of an image, the perceptiveness of detail can often be increased very significantly.The basic assumption made in histogram modification is to at the information contained in an image is related to the probability of occurrence of each grey level. The information content of the image is often easier to perceive when the probability of occurrence of each grey level is uniformly distributed. A uniform distribution of grey levels tends to make equal use of each quantization level and to enhance low detail information due to range compression. The histogram equalization technique attempts to obtain this uniform distribution. The above findings contradict the study by Frei. Frei suggested the histogram hyperbolization method, which addresses the fact the at the response of the human visual system to stimuli is approximately logarithmic [23]. This method of histogram modification redistributes the information in the image hyperbolically.

The full-frame, or global histogram methods pointed out by Paranjape et al. [15]. This technique modifies the global histogram of the complete image. These methods are simple to implement, require no interaction from the user, and provide significant visual enhancement of the image. The main problem with these methods is the at small, relatively uniform regions may be lost as their grey values are combined with the values of their background. This takes place because the corresponding pixel values, due to their low occurrence, are considered to have low information content.

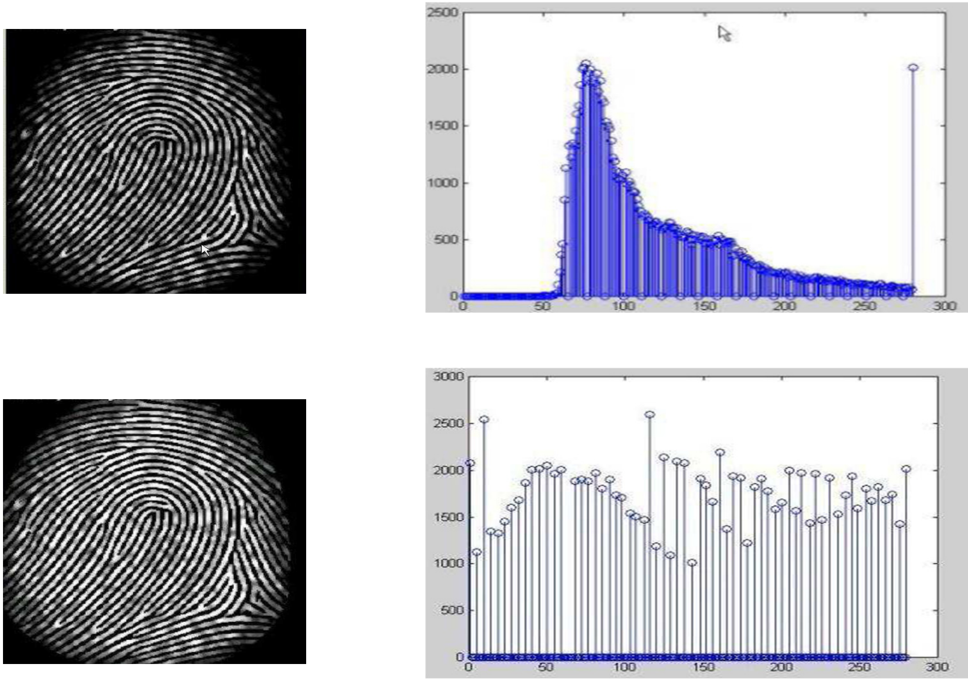

Fig. 1. The resulting image of histogram equalization; (above) original input image and (below) the enhanced image [21].

Unsharp masking is a contrast enhancement technique widely used in photography for over sixty years. It works by making an inverted blurred photographic mask of the original image on a piece of photographic film. The classic digital unsharp masking is based on adding a high-pass filtered, intensity scaled version of the input image to itself, thus emphasizing the high-frequency components of the original image. A filter (also called mask, kernel, template or window) is a small (e.g. 3 x 3) two-dimensional array of coefficients whose values determine the e nature of the operation performed such as blurring or sharpening [12]. The linear unsharp masking suffers from two main drawbacks: it is extremely sensitive to noise, and it enhances high-contrast areas much more than low contrast ones. A method to at addresses these problems are proposed by De Vries [20], In this method, sharpening is controlled by an adaptive filter, measuring the input contrast. As a result, the low-contrast areas are enhanced more that the high-contrast ones. This approach still suffers from noise over-enhancement when there is no mismatch between the target and the input dynamic ranges.

Polesel et al. [14] introduce an adaptive unsharp masking method. The objective of this method is to emphasize the medium-contrast details more than large-contrast details. Additionally, the filter does not perform the sharpening operation in smooth areas, making the system more robust to the presence of noise in the input images than traditional approaches. The adaptiveness of the unsharp masking is achieved using a Gauss-Newton adaptation strategy to reduce the squared error between the desired local dynamics and the actual local dynamics.

In 2011, Zhou et al. were published a paper in which they described the novel method called as Nonlinear Unsharp Masking (NLUM) [24]. This process was involved a few steps: (1) the input image was filtered using a nonlinear filter, (2) a few arithmetic operations were used for fusion the image, and (3) the enhanced process by using the proposed algorithm. The NLUM has been shown to provide more design flexibility that makes it possible to meet more specific and complex requirements in real-world applications. Based on the result, the NLUM more effective and efficient compared to conventional methods. Fig. 2 illustrates the comparison result of mammogram images.

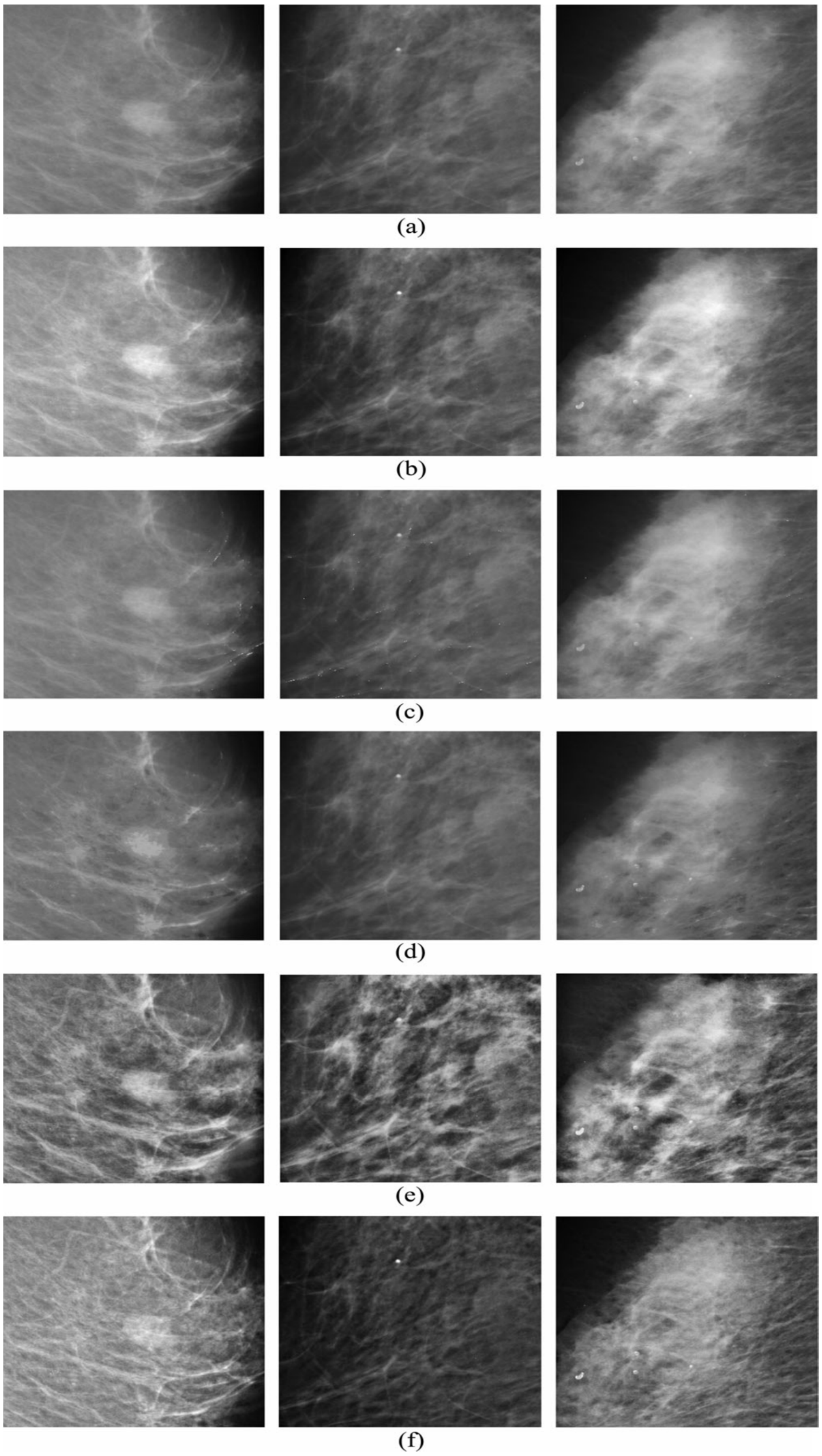

Fig. 2. Comparison of mammogram enhancement using different algorithms. (a) Original mammograms: Mam_1 to Mam_3. (b) Enhanced results by the NLUM [24]. (c) Enhanced results by the RUM [25]. (d) Enhanced results by the ANCE [15]. (e) Enhanced results by the CLAHE [26]. (f) Enhanced results by the DICE [27].

2.2. Frequency domain

Other approaches to contrast enhancement include the use of the frequency domain and multi-scale decompositions. Tang et al. [16] propose a contrast enhancement method using a contrast measure in the Discrete Cosine Transform (DCT) domain. DCT is used in the JPEG image compression format [28]. In this domain, the image is divided up into 8 x 8 blocks, and 64 DCT coefficients are derived for each block, corresponding to different frequencies of the signal within that block. In this contrast enhancement algorithm, those coefficients are grouped into 15 frequency bands. The frequency bands are arranged from lowest to highest frequencies.

In multi-scale contrast enhancement, an image is separated (or decomposed) into a number of components, where each component corresponds to a different scale. The actual decomposition method varies, but the choice of it affects how the different features in the image are decomposed. Multi-scale decomposition allows for enhancing of each scale separately, and thus to control the amount of enhancement (or de-enhancement) for each component of the scale. In direct multi-scale methods, a contrast measure can be defined as a relationship of a foreground feature (e.g. a pixel or a small foreground region) to the contextual background region. This contrast measure in a multi-scale representation can be computed using a foreground feature from a finer scale and a background feature from a coarser scale. Furthermore, the multi-scale representation allows for the contrast measure to be computed for different scales, which allows direct enhancement of individual scales. Also, if a multi-scale representation preserves locality information, the contrast measure can be computed locally for an individual pixel location, thus allowing an algorithm to be local or adaptive. Peli and Lim [29] propose an adaptive contrast enhancement algorithm, which separates the image into high and low spatial frequency components, using a low-pass filter [30]. It is an adaptive filter, which modifies the contrast locally. The low-pass component determines how much the high-pass component is enhanced. The low-pass component is then modified by a non-linearity, which controls the dynamic range of the image. Both components are then recombined to produce the enhanced image. Toet [18] proposes an adaptive multi-scale contrast enhancement technique based on the recombination of a non-linear ratio of low-pass (RoLP) pyramid. The information present at different levels of the pyramid corresponds to different scales of the original image. This allows for selective enhancement of details at different spatial scales. Each level of the pyramid can be adaptively enhanced using its contextual information from the other levels.

Recently, wavelet transform technology has been widely applied in image processing and pattern recognition [31–33]. There are many wavelet transforms that have been developed, and each has its own features. Another multi-scale approach to contrast enhancement is in using wavelets. In wavelet-based methods, the image is decomposed into a number of discrete frequency bands. Each of these bands can be referred to as scales (thus yielding a multi-scale structure). The advantage of this decomposition is a spatial and frequency representation with multi-scale structure and locality information preserved. Locality allows local/adaptive processing and multi-scale allows scale-based processing. The multi-scale decomposition, if properly chosen, can allow for separation of desired features or objects from noise. In the multi-scale approach, each scale can be processed separately allowing for the different amount of enhancement or different parameters for each scale.

An example of enhancement using wavelet method proposed by Jin et al. [17]. In this method over-complete dyadic spline wavelets are used, where the image is decomposed into 2 frequency bands (2 levels) with high frequency and low frequency. A local histogram equalization (LAHE) is performed in each frequency band with a different size of the local histogram window. The advantage of this method comes from combining the local enhancement capability of LAHE, and the selectivity of spatial-frequency components. A multi-scale morphological approach to local contrast enhancement is proposed by Mukhopadhyay and Chanda [19]. In this method, the scale-space decomposition is obtained via a series of top-hat transformations, varying the size of the structuring element. A tophat transformation decomposes an image into a base image and a feature image by applying either morphological opening (white top-hat transformation) or morphological closing (black top-hat transformation).

In 2013, the image enhancement using Dual-Tree Complex Wavelet Transform and Nonlocal Means (DT-CWT-NLM) was proposed by Iqbal et al. [34]. The main function of dual-tree complex wavelet transform (DT-CWT) to determine the high-frequency sub- bands and processed independently. Besides, the Lanczos interpolator was applied in order to interpolate the high-frequency subbands and the low-resolution (LR) of the input image.In case, to avoid the losing of high-frequency components, they suggest using the resolution enhancement (RE). The result and a few comparison methods were demonstrated in Table 1.

Table 1
The comparison result of different enhancement methods [34].

Algorithm	MSE	PSNR (dB)
SWT-RE [35]	0.0464	13.3332
DWT-RE [36]	0.0419	13.7802
SWT-DWT-RE [35]	0.0335	14.7528
VVIR-PDE-RE [37]	0.0269	15.6970
DT-CWT-RE [38]	0.0242	16.1576
DT-CWT-NLM-RE [34]	0.0174	17.5895

3. Application image enhancement

Medical photograph Enhancement: Medical image enhancement is very important to help the doctor/physician to analyze the patient's condition in a right way. Normally, medical cases associated with complex regions such as a brain, retinal eye, and heart contain an extensive enhancement procedure to analyze even a minute detail.

Satellite Image Enhancement: Satellite images are helpful in navigation to get information about numerous natural resources like gas, coal, and diamonds. Mostly, when a satellite captures an image of the earth from the outer space, the image was degraded and low quality caused by noise such as dust, fog, mist, etc. Satellite image enhancement is expensive and complicated compared to other enhancement methods.

Forensic Image Enhancement: Normally, the forensic image appears in poor condition like low-resolution images and blur images, whereas the image should be good contrast and sharpness of the image to help a doctor's analysis a details information. Two of the best image enhancement methods available are white balancing and contrast enhancement

Security Image Enhancement: As we all know that iris recognition is one of the widely used security applications for authorizing the employees to access confidential information. A better image quality is important to increase the detection process time.

4. Conclusion

In this paper, we present an overview of the background and related work in the area of contrast enhancement. Contrast enhancement is used in pre-processing images to improve their quality for specific applications, which can be for the human vision, or for further machine processing. Contrast enhancement algorithms can be implemented in the frequency domain or spatial domain. Spatial domain algorithms can be global or local (adaptive), where local image statistics are used. Also, contrast enhancement algorithms can be direct, which define and evaluate a contrast measure, or indirect. In addition, the algorithms can be performed in single-scale or multi-scale image representations. The main target of the literature review was to find and explore the benefits of image enhancement algorithms and also to find the shortcomings in existing algorithms and techniques. In conclusion, many researchers agreed that it is very difficult and impossible to construct a perfect mathematical algorithm to solve the illumination and contrast problem at the same time. This study was done to find the gaps in the existing research and possible solutions to overcome these gaps in the future.

Acknowledgment
This work was supported by Ministry of Higher Education Malaysia under the Fundamental Research Grant Scheme (9003-00517), Bumiputera Academic Training Scheme (SLAB) (890909035027), and Fellow Scheme from University Malaysia Perlis, Malaysia.

References
[1] Gayathri, S., N. Mohanapriya, and B. Kalaavathi. "Survey on Contrast Enhancement Techniques”." *International Journal of Advanced Research in Computer and Communication Engineering* 2, no. 11 (2013): 4176-4180.
[2] Ghabousian, R., Allahbakhshi, N. "Survey of Contrast Enhancement Techniques based on Histogram Equalization." International Journal of Review in Life Sciences 5, (2015): 901–908.
[3] Kaur, Er Mandeep, Er Kiran Jain, and Er Virender Lather. "Study of Image Enhancement Techniques: A Review." *International journal of advanced research in computer science and software engineering* 3, no. 4 (2013): 846–848.
[4] Singh, Kuldeep, and Rajiv Kapoor. "Image enhancement using exposure based sub image histogram equalization." *Pattern Recognition Letters* 36 (2014): 10-14.
[5] Singh, Sandeep, and Sandeep Sharma. "A Survey of Image Enhancement Techniques." *IPASJ International Journal of Computer Science* 2, no. 5 (2014): 1–5.
[6] Parveen, R., M. Nabi, F. A. Memon, S. Zaman, and M. Ali. "A Review and Survey of Artificial Neural Network in Medical Science." *Journal of Advanced Review on Scientific Research* 3 (2016) 8–17.
[7] Mustafa, Wan Azani, Haniza Yazid, and Sazali Bin Yaacob. "Illumination correction of retinal images using superimpose low pass and Gaussian filtering." In *Biomedical Engineering (ICoBE), 2015 2nd International Conference on*, pp. 1-4. IEEE, 2015.
[8] Mustafa, Wan Azani, Haniza Yazid, and Sazali Bin Yaacob. "Illumination normalization of non-uniform images based on double mean filtering." In *Control System, Computing and Engineering (ICCSCE), 2014 IEEE International Conference on*, pp. 366-371. IEEE, 2014.
[9] Mustafa, Wan Azani, Haniza Yazid, and Sazali Bin Yaacob. "A review: Comparison between different type of filtering methods on the contrast variation retinal images." In *Control System, Computing and Engineering (ICCSCE), 2014 IEEE International Conference on*, pp. 542-546. IEEE, 2014.
[10] Mustafa, Wan Azani, and Haniza Yazid. "Illumination and Contrast Correction Strategy using Bilateral Filtering and Binarization Comparison." *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)* 8, no. 1 (2016): 67-73.
[11] Kahani, M., A. Kamali-asl, H. Ghadiri, and S. Hashemi. "A method for material decomposition in dual-energy contrast enhancement digital mammography." *Measurement* 88 (2016): 87-95.
[12] Gonzalez, Rafael C., and Richard E. Woods. "Image processing." *Digital image processing* 3 (2008).
[13] Gonzalez, R.afael C., and Richard E. Woods. Digital Image Processing. Second, Prentice Hall, Upper Saddle River, NJ, USA, 2002.
[14] Polesel, Andrea, Giovanni Ramponi, and V. John Mathews. "Image enhancement via adaptive unsharp masking." *IEEE transactions on image processing* 9, no. 3 (2000): 505-510.
[15] Paranjape, Raman B., William M. Morrow, and Rangaraj M. Rangayyan. "Adaptive-neighborhood histogram equalization for image enhancement." *CVGIP: Graphical Models and Image Processing* 54, no. 3 (1992): 259-267.
[16] Tang, Jinshan, Eli Peli, and Scott Acton. "Image enhancement using a contrast measure in the compressed domain." *IEEE Signal Processing Letters* 10, no. 10 (2003): 289-292.
[17] Jin, Yinpeng, Laura M. Fayad, and Andrew F. Laine. "Contrast enhancement by multiscale adaptive histogram

equalization." In *International Symposium on Optical Science and Technology*, pp. 206-213. International Society for Optics and Photonics, 2001.
[18] Toet, Alexander. "Adaptive multi-scale contrast enhancement through non-linear pyramid recombination." *Pattern Recognition Letters* 11, no. 11 (1990): 735-742.
[19] Mukhopadhyay, Susanta, and Bhabatosh Chanda. "A multiscale morphological approach to local contrast enhancement." *Signal Processing* 80, no. 4 (2000): 685-696.
[20] De Vries, FP Ph. "Automatic, adaptive, brightness independent contrast enhancement." *Signal Processing* 21, no. 2 (1990): 169-182.
[21] Jaiswal, Rahul, A. G. Rao, and H. P. Shukla. "Image Enhancement Techniques Based on Histogram Equalization." *International Journal of Electrical and Electronics Engineering* 1 (2010) 69–78.
[22] Hall, E. L. "Almost uniform distributions for computer image enhancement." *IEEE Transactions on Computers* 100, no. 2 (1974): 207-208.
[23] Frei, Werner. "Image enhancement by histogram hyperbolization." *Computer Graphics and Image Processing* 6, no. 3 (1977): 286-294.
[24] Panetta, Karen, Yicong Zhou, Sos Agaian, and Hongwei Jia. "Nonlinear unsharp masking for mammogram enhancement." *IEEE Transactions on Information Technology in Biomedicine* 15, no. 6 (2011): 918-928.
[25] Ramponi, Giovanni, and Andrea Polesel. "Rational unsharp masking technique." *Journal of Electronic Imaging* 7, no. 2 (1998): 333-338.
[26] Pizer, Stephen M., E. Philip Amburn, John D. Austin, Robert Cromartie, Ari Geselowitz, Trey Greer, Bart ter Haar Romeny, John B. Zimmerman, and Karel Zuiderveld. "Adaptive histogram equalization and its variations." *Computer vision, graphics, and image processing* 39, no. 3 (1987): 355-368.
[27] Tang, Jinshan, Xiaoming Liu, and Qingling Sun. "A direct image contrast enhancement algorithm in the wavelet domain for screening mammograms." *IEEE Journal of Selected Topics in Signal Processing* 3, no. 1 (2009): 74-80.
[28] Wallace, Gregory K. "The JPEG still picture compression standard." *IEEE transactions on consumer electronics* 38, no. 1 (1992): xviii-xxxiv.
[29] Peli, Tamar, and Jae S. Lim. "Adaptive filtering for image enhancement." *Optical Engineering* 21, no. 1 (1982): 211108-211108.
[30] Porle, R. R., N. S. Ruslan, N. M. Ghani, N. A. Arif, S. R. Ismail, N. Parimon, and M. Mamat. "A Survey of Filter Design for Audio Noise Reduction." Journal of Advanced Review on Scientific Research 12 (2015) 26–44.
[31] Pei, W., and Y. Y. Zhu. "Wavelet transform-based edge detection of non-uniform illumination image." In *Geoinformatics 2008 and Joint Conference on GIS and Built environment: Advanced Spatial Data Models and Analyses*, pp. 71461I-71461I. International Society for Optics and Photonics, 2009.
[32] Fan, Chun-Nian, Hai-bin Wang, and Fu-Yan Zhang. "Improved Wavelet-Based Illumination Normalization Algorithm for Face Recognition." In *2009 First International Conference on Information Science and Engineering*, pp. 583-586. IEEE, 2009.
[33] Matsuyama, Eri, Du-Yih Tsai, Yongbum Lee, Masaki Tsurumaki, Noriyuki Takahashi, Haruyuki Watanabe, and Hsian-Min Chen. "A modified undecimated discrete wavelet transform based approach to mammographic image denoising." *Journal of digital imaging* 26, no. 4 (2013): 748-758.
[34] Iqbal, Muhammad Zafar, Abdul Ghafoor, and Adil Masood Siddiqui. "Satellite image resolution enhancement using dual-tree complex wavelet transform and nonlocal means." *IEEE geoscience and remote sensing letters* 10, no. 3 (2013): 451-455.
[35] Demirel, Hasan, and Gholamreza Anbarjafari. "Image resolution enhancement by using discrete and stationary wavelet decomposition." *IEEE transactions on image processing* 20, no. 5 (2011): 1458-1460.
[36] Demirel, Hasan, and Gholamreza Anbarjafari. "Discrete wavelet transform-based satellite image resolution enhancement." *IEEE transactions on geoscience and remote sensing* 49, no. 6 (2011): 1997-2004.
[37] Tschumperle, David, and Rachid Deriche. "Vector-valued image regularization with PDEs: A common framework for different applications." *IEEE Transactions on Pattern Analysis and Machine Intelligence* 27, no. 4 (2005): 506-517.
[38] Demirel, Hasan, Cagri Ozcinar, and Gholamreza Anbarjafari. "Satellite image contrast enhancement using discrete wavelet transform and singular value decomposition." *IEEE Geoscience and remote sensing letters* 7, no. 2 (2010): 333-337.