ENHANCEMENT OF IMAGE CONTRAST USING COMPUTATIONAL INTELLIGENCE ALGORITHMS

Synopsis submitted

By

SAORABH KUMAR MONDAL

Doctor of Philosophy (Engineering)

DEPARTMENT OF PRINTING ENGINEERING
FACULTY COUNCIL OF ENGINEERING AND TECHNOLOGY
JADAVPUR UNIVERSITY
KOLKATA 700032, INDIA

2023

1. Introduction

Image contrast is an important characteristic that drives the visual appearance as well as the feature detection tasks for many computer vision applications [1]. Due to several natural and hardware limitations of the image capturing devices low image contrast is resulted. Therefore, image contrast enhancement is a prominent research topic. Global histogram equalization (GHE) [2] is a common way to improve image contrast which probabilistically remaps the existing image intensity levels to the available intensity levels.

Despite simplicity, GHE frequently offers artifacts like false contouring and artificial appearance. Brightness preserving bi-histogram equalization (BBHE) [3] and dual sub-image histogram equalization (DSIHE) [4] are examples of improved statistical methods of GHE. In these two methods, the statistical histogram of an image is divided into two sub-histograms based on mean and median intensity respectively followed by equalizing each division individually. Adaptive histogram equalization (AHE) [5] and its further development contrast limited adaptive histogram equalization (CLAHE) [5] have also shown significant improvement of contrast while addressing the limitations of conventional algorithms. Here the adaptive methods basically performs several histograms and use them to redistribute the image lightness value. Hence, these methods also suitable for local contrast enhancement as well as enhancing the edges of all the region of image. One of the major limitations of these algorithms is noise amplification which can result poor enhancement sometimes. Adaptive gamma correction (AGC) [6] and their modified version adaptive gamma correction weighted distribution (AGCWD) [6] optimize the gamma parameter based on the weighted distribution function with the help of probability distribution function (pdf) and cumulative distribution function (cdf). Dynamic histogram equalization (DHE) [7] and its modified version dynamic fuzzy histogram equalization (DFHE) [7] are also the improved methods for enhancing the image contrast over conventional techniques. These techniques separate the statistical histogram of an image based on local minima and each sub histograms are assigned with a specific gray level ranges before equalizing them. Spatial entropy-based contrast enhancement in DCT (SECEDCT) [8] was proposed by T. Celik is one of the recent image enhancement techniques, which is the modification of SECE [8] technique in DCT domain. SECE algorithm performs the distribution of spatial location of pixel gray-levels to compute the spatial entropy for global contrast enhancement. SECEDCT performs both the global and local contrast enhancement by using DCT coefficients scaling process along with SECE method.

Very recently another few modified HE based methods have been developed, for example, fuzzy dissimilarity adaptive histogram equalization with gamma correction (FDAHE-GC) [9] where an intensity mapping function is developed from fuzzy dissimilarity histogram (FDH) for the purpose of image contrast enhancement and the gamma correction is applied to enhance the dark regions, contrast-limited adaptive histogram equalization with dual gamma correction (CLAHE-DGC) [10] where the contrast has been enhanced by boosting its luminance value in addition of CLAHE technique, adaptive gamma correction with weighted histogram distribution (AGCWHD) [11] where a new adaptive gamma correction method is implemented to enhance the contrast, while a weighted histogram distribution is employed for natural color and detail preservation are implemented to enhance the contrast of an image. These recently developed techniques are considerably efficient to enhance the image contrast but sometimes there will be a lack of proper balance in between visual output and feature retention. That opens the room for further developments which can provide not only visually pleasant contrast enhanced images but retention of image features as well.

Computational intelligence (CI) algorithms can be a possible solution to address these problems and generate contrast enhanced image preserving the desired original image characteristics. The applications of different computational intelligence algorithms have as well been reported for image enhancement. Biological behavior inspired optimization techniques have shown significant potential in solving engineering problems with better results than traditional complex mathematical approaches. Genetic algorithm (GA) [12] is an example of such techniques. It was introduced by John Holland in 1975 and is still popular for its adaptability and flexibility which in turn result in better search dynamics to find global optima avoiding the local optima. Swarm intelligence techniques are one of the subset of computational intelligence algorithms where the algorithms mimic the behaviors of natural swarms. Particle swarm optimization (PSO) [13], artificial bee colony optimization (ABC) [14], ant colony optimization (ACO) [15], bacteria colony optimization (BCO) [16], grey wolf optimizer (GWO) [17], bat algorithm (BA) [18], etc are popular algorithms that have been employed for contrast enhancement. These optimization techniques basically search an optimal solution which will enhance the image contrast as well as preserve the other image characteristics of the tested images to provide better result.

The main target of this thesis work is to enhance the image contrast while maintaining the other features such as brightness, sharpness, color, etc using computational intelligence algorithms that have not been well explored for this problem yet. Most of the contrast enhancement techniques fail to retain the image characteristics as well as the performance of image quality assessment (IQA) metrics become poor. So, this work is focused on mathematical development of objective functions based on contrast interpretation as well as imaging model and subjecting these objective functions to enhance the image contrast using computational intelligence (CI) algorithms.

2. Research objectives and scope of the work

Image contrast is an important characteristic that drives the visual appearance as well as the feature detection tasks for many computer vision applications. Due to several natural and hardware limitations of the image capturing devices low image contrast is resulted. Therefore, image contrast enhancement is a prominent research field. Broadly, the different algorithms for contrast enhancement can be divided into two categories; spatial domain and frequency domain operations. The former one is performed on the intensity values using different statistical parameters of the images. Different established methodologies under this category succeed to improve the image contrast but most of the techniques provide some undesired results including alteration of mean brightness, over enhancement, false contouring and erroneous color representations. Image brightness is defined as the measure of acquired image intensity or the intensity of those images which are converted from analog to digital. It is also known as luminous brightness. In case of over-enhancement, the images are suffered from edges loss, important texture change and mostly the images are look unnatural. When the grey level resolution of a digital image become degraded, then false contouring occur. The main reason of false contouring is insufficient number of gray levels present in a digital image. For erroneous color representation, false color is the main issue. A false-color image is that type of color image, which is totally different from original color image. Human cannot normally see the different wavelengths color in this type of image but for true color image, it is clearly visible. In this thesis, some presented techniques have been represented to overcome such limitations and to provide better contrast image maintaining other image futures to improve the overall quality of an image. The objectives of the thesis work can be summarized as follows:

A) A thorough literature survey to find the commonly used contrast enhancement techniques.

B) To find the limitations of such commonly used techniques.

C) To represent the recent advance techniques where such limitations are minimized.

D) To establish the frequency domain algorithms, that has shown better performance over spatial domain approaches in many cases since transform domains provide better control over local image characteristics which in turn provides improved feature retention.

E) To explore the potential of comparatively less explored computational intelligence algorithms for enhancing the image contrast with maintaining other image futures.

F) To develop objective functions driven by image characteristics and frequency domain interpretation of contrast for optimizing through the chosen CI algorithms.

G) To evaluate the results of CI algorithms against results of different state-of-art contrast enhancement algorithms in both subjective and objective manner.

3. Organizations of the chapters

The thesis is divided into six chapters. The brief descriptions of the chapters are given below:

Chapter 1, ***“Introduction and scope of the thesis”*** elucidates the importance of contrast enhancement of an image in the field of image processing and outlines the objectives of this thesis work. A brief literature survey has been highlighted. The chapter finally concludes with scope of the thesis and some clearly framed research questions to answer at the end of the thesis work.

Chapter 2, ***“Objective functions formulation and data analysis techniques”*** presents formulation of two different objective functions based on frequency domain analysis and imaging characteristics. The chapter also presents the detail about different evaluation methods that have been used in this thesis and the images that have been consistently used throughout the thesis.

Chapter 3, ***"Image contrast enhancement using bacteria colony optimization (BCO)"*** presents a new contrast enhancement technique using bacteria colony optimization (BCO). The brief description of algorithm and parameter setting for presented work has been emphasized in this chapter. Both of the formulated objective functions have been subjected to BCO and results have been analyzed in comparative manner to draw the conclusion in terms of potential of BCO for contrast enhancement.

Chapter 4, ***"Image contrast enhancement using grey wolf optimizer (GWO)"*** presents a contrast enhancement technique using gray wolf optimizer (GWO) which optimizes the formulated objective functions. This chapter includes a brief description of GWO algorithm and the parameter settings involved in the presented work. The visual and objective comparisons between the output of GWO and established methods have been included to show the potential of the GWO based contrast enhancement.

Chapter 5, ***"Image contrast enhancement using bat algorithm (BA)"*** presents another image contrast enhancement technique using bat algorithm (BA). This chapter includes the brief description of BA and the required parameter settings. Like previous chapters, in this case also both the objective functions have been subjected to BA and the results obtained with different objective functions have been presented in comparative manner against subjective and objective evaluation metrics.

Chapter 6, ***"Concluding remarks***" finally represents the overall comparison between the presented techniques and an overall summary of the work carried under this thesis. It also highlights the major findings and observations noted in the course of this thesis. The answers to all the previously framed research questions have as well been presented in this chapter. The chapter also draws the possible future directions of the presented work.

4. Summary of the results

Three different optimization techniques have been applied to optimize the objective functions and to provide better enhance output. These techniques are bacteria colony optimization (BCO), grey wolf optimizer (GWO) and bat algorithm (BA). All the techniques were realized using Matlab® software in Windows PC and all the images have been reproduced at 300 dpi resolutions. Both the gray images and the color images are chosen for verify the potential of the presented techniques. All the input images are taken from standard databases, namely, SIPI [19], TID [20] and CSIQ [21]. Among different techniques, 8 techniques have been considered for comparison purpose in this thesis work. These techniques cover different paradigms of algorithms in both spatial and frequency domains. These techniques are global histogram equalization (GHE), dynamic fuzzy histogram equalization (DFHE), multi-scale Retinex (MSR), spatial entropy based contrast enhancement in DCT (SECEDCT), genetic algorithm (GA), artificial bee colony (ABC), contrast-limited adaptive histogram equalization with dual gamma correction (CLAHE-DGC) and fuzzy dissimilarity adaptive histogram equalization with gamma correction (FDAHE-GC). The results are presented in comparative manner where the outputs of all the presented techniques have been included both visual comparison as well as objective comparison.

The objective evaluations against the image quality assessment (IQA) metrics are very important assessment to judge the quality of an image. Among many IQA metrics 4 full reference (FR) [22] and 1 no reference (NR) [23] metrics have been considered in this work. The FR metrics include the ground truth images for evaluation and in this thesis entropy [24], patch-based contrast quality index (PCQI) [25], contrast enhancement factor (CEF) [9], and colorfulness (C) [26] metrics have been used. The NR metric does not include the ground truth for evaluation but it measures overall naturalness in enhanced images. Natural image quality evaluator (NIQE) [23] is considered here as NR metric for this purpose. Local entropy is a popular metric which indicates better information containment by higher values. PCQI is a very important measure particularly for contrast. This metric not only provides value but also provides a binary image (PCQI<1) which shows the amount of contrast distortions present in the processed image. A higher mean-PCQI value indicates better result as well. NIQE is a no-reference metric that vouch the naturalness of processed image and lower values of NIQE indicates better naturalness. CEF indicates the contrast level of output images and higher value of CEF indicates better enhance of image contrast. Colorfulness is also very important image quality metric where the level of color retention can be computed. Higher value of C indicates better color balance and visualization.

From the analysis of presented techniques, it is observed that, all the three presented techniques are very much efficient to retain the image characteristics while enhancing the image contrast. The visual outputs in compare with other techniques showed inspiring potential of the presented techniques in image contrast enhancement. The objective evaluation against entropy, PCQI, NIQE, CEF and colorfulness with test images from three standard databases show that the presented methods can result in values up to 7.8, 1.5, 3.2, 1.3 and 20.7 respectively, for the stated metrics which are competitive to the reported conventional and improved techniques.

5. Contribution of the thesis

This thesis work has focused to enhance the image contrast while preserving the other image characteristics. The work can be considered contributory since it provides two new objective functions that are different in their nature reflecting image contrast from different aspects while addressing the feature loss limitation of the existing algorithms. The objective functions also consider the generalization potential of the presented method so that those can be used across different fields of image processing applications. The work also elaborates the possibility of three comparatively new computational intelligence algorithms namely, bacteria colony optimization (BCO), grey wolf optimizer (GWO) and bat algorithm (BA) for contrast enhancement as their application to the problem domain in this thesis is not well reported yet to the best of our knowledge. The thesis as well presents a very detailed evaluation of the results including both subjective and objective parameters.

References

1. Gonzalez R. C. & Woods R. E. (2009) Digital Image Processing (third ed.). Pearson. New Delhi, India.
2. Wan A. M. et al. (2018) A review of histogram equalization techniques in image enhancement application. *J. Phys.: Conf. Ser.*1019 012026. doi: 10.1088/1742-6596/1019/1/012026.
3. Kim Y.-T. (1997) Contrast enhancement using brightness preserving bi-histogram equalization. *IEEE Trans. Consum. Electron.* 43(1):1–8.
4. Wang Y., Chen Q. & Zhang B. (1999) Image enhancement based on equal area dualistic sub-image histogram equalization method. IEEE Trans. Consum. Electron. 45(1):68–75.
5. Reza A. M. (2004) Realization of the contrast limited adaptive histogram equalization (CLAHE) for real-time image enhancement. Journal of VLSI Signal Processing Systems for Signal, Image and Video Technology. 38(1): 35–44.
6. Huang S.-C., Cheng F.-C. & Chiu Y.-S. (2013) Efficient contrast enhancement using adaptive gamma correction with weighting distribution. Image Process. IEEE Trans. 22(3):1032–1041.
7. Sheet D. et al. (2010) Brightness preserving dynamic fuzzy histogram equalization. IEEE Transactions on Consumer Electronics. 56(4): 2475 – 2480.
8. Celik T. (2014) Spatial entropy-based global and local image contrast enhancement. IEEE Transactions on Image Processing. 23(12):1-10.
9. Veluchamy M. & Subramani B. (2020) Fuzzy dissimilarity color histogram equalization for contrast enhancement and color correction. Applied Soft Computing Journal. 89:106077.
10. Chang Y. et al. (2018) Automatic contrast-limited adaptive histogram equalization with dual gamma correction. IEEE Access 6. 11782–11792.
11. Subramani B. & Veluchamy M. (2019) Image contrast and color enhancement using adaptive gamma correction and histogram equalization. Optik Journal. 183:329-337.
12. Munteaunu C. & Rosa A. (2000) Towards automatic image enhancement using genetic algorithms. In Proc. Congress on Evolutionary Computation. 1535–1542.

13. Gorai A. & Ghosh A. (2009) Gray-level image enhancement by particle swarm optimization. In: Proc. of 2009 World Congress on Nature & Biologically Inspired Computing (NaBIC). 72–77.

14. Draa A. & Bouaziz A. (2014) An artificial bee colony algorithm for image contrast enhancement. Swarm and Evolutionary Computation. 16: 69–84.

15. Haldenbilen S., Baskan O. & Ozan C. (2013) An Ant Colony Optimization Algorithm for Area Traffic Control. Journal of Itechopen. DOI: 10.5772/51695.

16. Chen H. et al. (2014) Bacterial colony foraging optimization. Neurocomputing 137: 268–284.

17. Mirjali S. et al. (2014) Grey wolf optimizer. Advances in Engineering Software**.** 69:46–61.

18. Asokan A. et al. (2020) Bat algorithm based non-linear contrast stretching for satellite image enhancement. Geo sciences. 10. 78. 2020.10.3390/geosciences10020078.

19. SIPI Image Database for gray scale images. (2017) http://www.sipi.usc.edu/database

20. Ponomarenko N. et al. (2009) TID2008 - A database for evaluation of full-reference visual quality assessment metrics. Advances of Modern Radio electronics 10:30-45.

21. CSIQ Database for color images. http://vision.eng.shizuoka.ac.jp

22. Pedersen Marius & Hardeberg, Jon. (2012) Full-Reference Image Quality Metrics: Classification and Evaluation. Foundations and Trends® in Computer Graphics and Vision. 10.1561/0600000037. 7:1-80.

23. Fu Yan & Wang Shengchun. (2016). A No Reference Image Quality Assessment Metric Based on Visual Perception. Algorithms. 9. 10.3390/a9040087.

24. Glasner Eli & Ye Xiangdong. (2009) Local entropy theory. Ergodic Theory and Dynamical Systems - ERGOD THEOR DYN SYST. 29. 10.1017/S0143385708080309.

25. Wang Shiqi, Ma Kede, Yeganeh Hojatollah, Wang Zhou & Lin Weisi. (2015) A Patch-Structure Representation Method for Quality Assessment of Contrast Changed Images. Signal Processing Letters, IEEE. 10.1109/LSP.2015.2487369. 22:2387-2390.

26. Hasler David & Suesstrunk Sabine. (2003) Measuring Colourfulness in Natural Images. Proceedings of SPIE - The International Society for Optical Engineering. 10.1117/12.477378. 5007:87-95.

List of publications

Contributions in the form of publication in international journals:

1) S. K. Mondal, A. Chatterjee, B. Tudu, "Image contrast enhancement using histogram equalization: a bacteria colony optimization approach", J. Print Media Technol. Res. – Vol. 10 No. 2 (2021), June 2021, ISSN 2414-6250.

2) S. K. Mondal, A. Chatterjee, B. Tudu, "DCT Coefficients Weighting (DCTCW)-Based Gray Wolf Optimization (GWO) for Brightness Preserving Image Contrast Enhancement", International Journal of Image and Graphics (2022), 2350018 (29 pages), © World Scientific Publishing Company DOI: 10.1142/S0219467823500183.

3) S. K. Mondal, A. Chatterjee, B. Tudu, "Image contrast enhancement by optimization of color channel difference using bat algorithm", J. Print Media Technol. Res. Article in Press.

Conference papers

4) S. K. Mondal, A. Chatterjee, B. Tudu, "Image contrast enhancement using a crossover-included hybrid artificial bee colony optimization", Computer, Communication and Electrical Technology – Guha, Chakraborty & Dutta (Eds) © 2017 Taylor & Francis Group, ISBN 978-1-138-03157-9.

5) S. K. Mondal, A. Chatterjee, B. Tudu, "A Hybrid Particle Swarm Optimization and Artificial Bee Colony Algorithm for Image Contrast Enhancement", *Proceedings of the International Conference on Computing and Communication Systems*, Lecture Notes in Networks and Systems, Chapter- 26, pp.: 277-285.

6) S. K. Mondal, A. Chatterjee, B. Tudu, "Image Contrast Enhancement Using Histogram Equalization-Based Grey Wolf Optimizer (GWO)", *Proceedings of the International Conference on Communication, Devices and Networking*, Lecture Notes in Electrical Engineering, Chapter-23, pp.: 207-214.

Saorabh Kumar Mondal