Biomedical Signal Processing and Control 39 (2018) 271–283

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

A fully customized enhancement scheme for controlling brightness error and contrast in magnetic resonance images

Justin Joseph*, R. Periyasamy

Department of Biomedical Engineering, National Institute of Technology, Raipur, Chhattisgarh 492010, India

ARTICLE INFO

Article history:
Received 16 January 2017
Received in revised form 10 July 2017
Accepted 1 August 2017
Available online 18 August 2017

Keywords:
Contrast enhancement
Histogram equalization
Clip-limit
Contrast metric

ABSTRACT

Enhancement schemes are said to be ideal when they produce images with maximum contrast and minimum brightness error. But these are two conflicting objectives. Their relative significance is always application dependent. No mechanism is available in the conventional histogram equalization to control contrast and brightness error. Even though methods like Contrast Limited Adaptive Histogram Equalization (CLAHE) and Weighted Threshold Histogram Equalization (WTHE) have such provisions, tuning their multiple operational parameters simultaneously is laborious. A global contrast mapping scheme for Magnetic Resonance (MR) images which equip the user to customize its performance based on the application is proposed in this paper. In this scheme, the histogram is clipped with respect to a threshold between the mean and maximum probability density values in it, determined by the arbitrary clip-limit, 'α', $0 \leq \alpha \leq 1$. The clipped or residue pixels are reallocated to the histogram bins according to the relative vacancy in them. Prior to the equalization, the Cumulative Probability Density (CPD) computed from the re-normalized histogram is expanded to increase the dynamic range of the enhanced image. In terms of Relative Enhancement in Contrast (REC), Absolute Mean Brightness Error (AMBE), Structural Similarity Index Metric (SSIM) and Saturation Evaluation Index (SEI), the proposed method is observed to be superior to Brightness Preserving Bi-histogram Equalization, WTHE and CLAHE on 30 sets of MR images.

1. Introduction

Human perception is more responsive to contrast than absolute luminance [1]. The term 'contrast' collectively reflects the pixel intensity difference between distinct objects and structures in an image. In a good contrast image, an object or Region of Interest (ROI) would be easily perceivable. Along with the developments in digital image computing, numerous techniques have also emerged for improving image contrast. Some of them are contrast stretching, contrast transformation, gamma correction, Histogram Equalization (HE) and their extensions [2].

The conventional techniques for contrast enhancement have serious constraints. Contrast stretching is not applicable for images which already occupy the full dynamic range. In contrast transformation, it is tedious to design a transformation function, equally suitable for multiple images which differ in their information content and histogram statistics. The grey level range enhanced in gamma correction greatly depends on the value of the power, 'gamma', used in its Power Law Transformation (PLT). The optimum value of gamma could be image dependent and gamma correction does not have the capability to selectively enhance most informative grey level regions. The straight forward method which can adaptively or selectively enhance the informative regions in the image is HE, usually termed as Global Histogram Equalization (GHE). In GHE, the contrast enhanced intensity 's_k', corresponding to the original intensity, 'r_k', is directly proportional to its Cumulative Probability Density (CPD) as shown in (1),

$$s_k = T(r_k) = C_k(L-1),\ \text{where}\ \ C_k = \sum_{j=0}^{k} P_k,\ \text{Given},\ P_k = \frac{n_k}{MN} \tag{1}$$

where, 'L-1′ is the maximum limit of the grey level. For a uint8 image, the value of 'L' is equal to 2^8. 'C_k', 'P_k' and 'n_k', respectively are the CPD, discrete probability density and number of occurrence of the k^{th} intensity. M*N is the gross amount of pixels present in the image. 'n_k' is generally termed as the 'histogram' and 'P_k' as the normalized 'histogram'. Consequently, from (1),

$$s_k = \frac{(L\text{-}1)}{MN}\sum_{j=0}^{k} n_j \qquad k = 0,1,2,\ldots\ldots, L\text{-}1 \tag{2}$$

---

* Corresponding author.
E-mail addresses: josephjusti@gmail.com, justmanimala@yahoo.com (J. Joseph).

http://dx.doi.org/10.1016/j.bspc.2017.08.003
1746-8094/© 2017 Elsevier Ltd. All rights reserved.

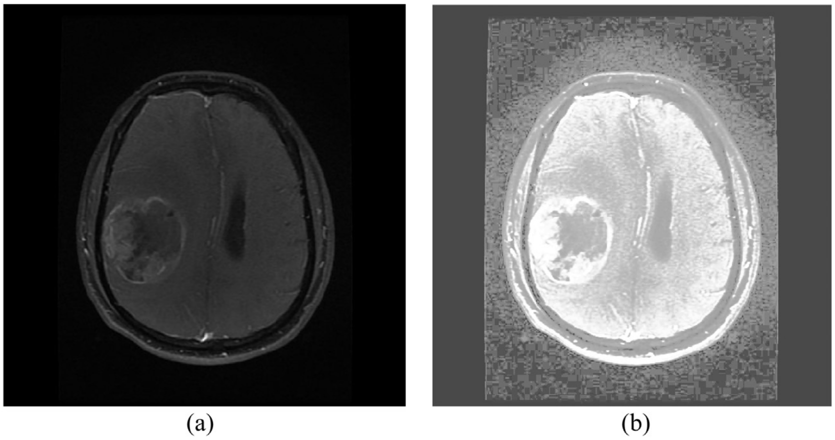
(a) (b)

Fig. 1. (a) Original image (b) Contrast enhanced image with GHE.

The slope of the transformation at a grey level 'r_k' is proportional to the histogram height 'P_k', at that grey level, as apparent in (1) and (2). So that the contrast mapping function in HE will have larger slope at the most frequent grey levels in the image. This makes GHE capable of selectively enhancing the most frequent grey levels or the most informative grey level region of the image. According to (1), the enhanced image will have an offset intensity equal to $(L\text{-}1)P_0$ if $P_0 >> 0$. In this context, the dynamic range of the enhanced image gets compressed to $(L\text{-}1)P_0 - (L\text{-}1)$ instead of occupying the full dynamic range from 0 to (L-1). The shrinking of the dynamic range is not appreciable as far as an enhancement scheme is concerned. This effect is termed as Offset Intensity Artefact (OIA), in this paper. OIA will have critical importance if the background region occupies relatively larger portion of the image size, especially for medical images like Magnetic Resonance Images (MRI) or Ultra Sound (US). An MRI and its equalized version are shown in Fig. 1. It can be noticed in the enhanced image (Fig. 1(b)) that, abruptly dark background in the original image (Fig. 1(a)) gets transformed to significantly larger grey levels due to OIA.

In addition to OIA, predominantly frequent grey levels may get over enhanced in GHE. In some cases, the mean brightness of the equalized image would be intolerably different from that of the original image. The enhanced image may appear 'washed out' or 'saturated'. In medical images the brightness characteristics may have some diagnostic significance. GHE alters the natural histogram statistics of the image and amplify noise. Different from natural or panoramic images, captured with high resolution cameras, the problem of noise amplification is more troublesome in imaging modalities like MRI. Moreover, no mechanism is available in GHE to control the level of enhancement and brightness error.

Numerous strategies, meant to improve the overall performance of GHE are available in literature. As an attempt to incorporate the brightness preserving characteristics into HE, Atta et al. [3] formulated a scheme in which the enhanced image was reconstructed from a vector formed by averaging the singular value matrices of the contrast enhanced image obtained from GHE and the original image. Averaging Histogram Equalization (AVHEQ) [4], is a similar approach in which the histogram had been averaged with a fraction of the maximum probability density value in the histogram. The value of this fraction which offers minimum brightness error was selected. Unlike AVHEQ, in Background Brightness Preserving Histogram Equalization (BBPHE) [5], the histogram had been segregated into foreground and background segments and the segments were equalized individually. The technique was based on the assumption that the grey levels exhibiting higher probability density values correspond to the background.

In Bi-Histogram Equalization with a Plateau Limit (BHEPL) [6], the histogram had been bisected with respect to the mean intensity in the image. The histogram segments were clipped with respect to the mean probability density of the individual segments, before equalization. In Dynamic Quadrants Histogram Equalization Plateau Limit (DQHEPL) [7] the histogram had been segmented into four, with respect to quartile grey levels in the image and each segment was clipped against their respective mean probability density. The range of each sub-histogram was stretched before equalization. In Range Limited Double Threshold Multi Histogram Equalization (RLDTMHE) [8], the image histogram had been segmented into three, with respect to Otsu's double threshold and the sub-histograms were equalized individually. The range of the grey levels in the equalized image was reduced to bring the minimum brightness error down. Thien et al. [9] also employed Otsu's threshold to bisect the histogram. In the technique put forth by S.C. Huang and C.H. Yeh [10], the histogram had been segmented into multiple sub-histograms. These sub-histograms were transformed individually. Maximum Peak Signal to Noise Ratio (PSNR) between the original and enhanced image was used as the objective criterion to determine the apt number of sub-histograms to which the original histogram has to be decomposed.

In Adaptive Image Enhancement based on Bi-Histogram Equalization (AIEBHE) [11], the sub-histograms obtained by segmenting the original histogram with respect to the median grey level, were clipped against individual thresholds before equalizing them. The threshold against which each sub-histogram had been clipped was the minimum value out of the minimum, median and mean of the probability density values in it. Median-Mean Based Sub-Image-Clipped Histogram Equalization (MMSICHE) [12], followed a different hierarchy in which the histogram had been clipped with respect to its median probability density and clipped histogram was bisected against the median grey level of the image. Each histogram segment had been sub-segmented with respect to the mean of grey levels in the segment and equalized individually. The clip-limit was adaptively computed from the objective criterion of minimum brightness error in Gain Controllable Clipped Histogram Equalization (GCCHE) [13].

The primary step in Segment Selective Dynamic Histogram Equalization (SSDHE) [14,15], was decomposition of the image histogram into multiple segments with respect to quartile grey levels. In the second stage, dynamic range of the histogram segments with relatively higher bin contents were expanded and equalized, while the segments with negligible bin contents had been left intact. Eventually, the segments which had been left intact and the equalized segments were normalized individually and fused together to form the enhanced image.