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Sharpening enhancement technique for MR images to enhance the segmentation

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ABSTRACT

This study presents a sharpening image enhancement technique based on the Laplacian pyramid (LP) and singular value decomposition (SVD) to improve the visibility and segmentation of subtle organs. The technique utilizes the shape-invariant properties of LP and the SVD techniques to enhance the perceptual sharpness of an image. The sharpening enhancement of magnetic resonance images not only sharpens the edges, but also reduces the noise effect. The results are compared with state-of-art enhancement techniques. The performance measures like peak-signal-to noise (PSNR), mean structural similarity index (MSSIM), and absolute mean brightness error (AMBE) evaluates the improved performance of the proposed technique.

1. Introduction

Magnetic resonance imaging (MRI) is a non-invasive technique that helps radiologists to identify pathology or structural abnormalities of subtle tissues. Despite, the clinical use of MR imaging modality, they are hampered by noise either due to imperfection in the RF coils or due to the problems associated with image acquisition. Due to an inadequate contrast between the miniature structure and its background, human vision strains accomplish better focus and frail identification of sharp edges is felt as an absence of region-of-interest (ROI). However, the visual quality of MR images is mainly focused on perceptual sharpness and precision of edges. Sharpening enhancement can be elucidated as an inclusion of missing high-frequency components to enhance or detect the edges in an image.

The principle objective of image sharpening technique is to emphasize fine details or augment the blurred edges. Therefore, sharpening concentrates on augmenting characters in the high-frequency domain. Image sharpening enhances the contrast by adding the scaled edge information near the boundaries of objects [1]. Sharpening is a crucial pre-processing approach to increase the contrast between the bright and the dark regions to bring out edge features. It enhances the subtle elements already present and improves the steepness of the edges. Since, the edges of subtle tissues/organs are of higher perceptual importance this research is focused on edge enhancement of subtle tissues.

In the past, different image enhancement techniques have been proposed to enhance the visual quality and edge information in an image [2–5]. All these image enhancement techniques did image amplification, but these techniques have a drawback of producing undesirable artifacts at the boundary of the objects. Many research works have been presented on MR image enhancement for its contrast and identification of edge features. The most common MR image contrast enhancement methods are based on the morphological operation [6–8] and histogram equalization [9–11]. All these methods are able to address the issue of contrast enhancement, but they do not perform well at the edges of subtle tissues/organs. Multi-scale methods have also been applied for the contrast enhancement of medical images. Two types of multi-scale methods are commonly adopted: Wavelet methods [12–16] and the LP methods [17,18,20]. Recently, Wavelet and SVD-based technique was discussed by Iqbal et al. [19] to enhance the resolution of medical images. Wavelet-based methods are effective, but suffer from many shortcomings like ringing artifacts and Gibb's phenomenon at subtle edge structures. Furthermore, contrast amplification enhances the noise [18], so an efficient de-noising procedure [21] have been followed before sharpening of edges. This paper is focused on edge amplification of interested region rather than noise suppression or reduction. The LP decomposition has coarse sub-band to retain the boundaries along with textural information and difference sub-band to refine edge location and intensity details of the image. Also, the use of LP decomposition augments the high-frequency content of the image,

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using shape-invariant properties of edges across the scale. In addition, the SVD techniques enhance the contrast of edge pixels to bring out the boundary features. Thus, the LP decomposition of images with SVD technique allows a smooth enhancement of small details and avoids visible artifacts.

This paper presents a new sharpening enhancement method for MR images, using LPSVD approach that can enhance the subtle tissue edges. Multi-scale images are decomposed into coarse and difference sub-bands by LP. Since the coarse sub-bands are inclusions of fine structures, the weighted sum of a singular matrix and its GHE of coarse sub-band images increase the contrast. The rest of the paper is organized as follows: Section 2 gives the materials and methods of the proposed method. Section 3 gives the experimental results and discussion of the proposed technique, and Section 4 gives the conclusion of the proposed method.

2. Materials and methods

The more pleasing visual quality of an image is obtained by emphasizing the edges. The degree of low sharpness around the object boundaries are explored in the spatial domain or missing high-frequency components in the frequency domain. Thus, the LPSVD sharpening enhancement technique certainly helps to sharpen the edges around the objects.

2.1. Laplacian pyramid (LP)

The concept of LP on image decomposition was introduced by Burt and Adelson [22]. In LP decomposition, the multi-scaled image is firstly low pass filtered using the Gaussian filter and down-sampled. The subsequent layer of LP (difference sub-bands) are determined by subtracting layer of the Gaussian pyramid (coarse sub-bands). The process of decomposition is explained as:

$$\bar{X}_k = \downarrow (X\bar{k} - 1) \tag{1}$$

$$L_k = X_{k-1} - \uparrow (X_k) \tag{2}$$

where $\downarrow X$, $\uparrow X$ denotes the down and up sampling of image by a factor of 2. $\bar{X}_k$ is the filtered image of X_k and L_k is the successive layer of the LP.

2.2. Singular value decomposition (SVD)

The SVD is a technique employed for data reduction, feature extraction and typically for enhancement of images. The SVD decomposes the real and complex rectangular matrix A into a product of three matrices and is represented as $A = U\Sigma V^T$, where U and V are orthogonal matrices, and Σ contains singular values of matrix A. The singular values of the matrix contain the intensity information. Therefore, any changes in this matrix lead to changes in the input image. Image equalization through SVD technique depends on adjusting the singular value matrix [23]. The equalized SVD of A is written as:

$$A = U_A \Sigma_A V_A^T \tag{3}$$

where U_A, V_A are orthogonal square matrices called hanger and aligner respectively. Σ_A matrix represents the sorted singular values on its main diagonal.

If $\bar{\Sigma}_I$ is the new singular matrix of the equalized image and Σ_I is the singular value of input image then the correction factor is expressed as:

$$\xi = \frac{\max(\bar{\Sigma}_I)}{\max(\Sigma_I)} \tag{4}$$

The equalized image is given by the equation:

$$Equalized_A = U_A(\xi \Sigma_A)V_A^T \tag{5}$$

2.3. Proposed LPSVD technique

Edges are an important characteristic of image since they correspond to object boundaries. An ideal edge is a scale invariant in that no matter how much one increases the resolution the edge remains the same. LP consists of edge maps of the input image at different resolutions. Superimpose of LP (coarse sub-bands), and SVD techniques improve the sharpening by enhancing the contrast near object boundary, thus making the borders and edges visible better. The LP preserves the shape and phase of the edge maps across a scale. According to the proposed method, the edge map of the interested region is obtained through one level of LP. Then the edge details are sharpened by employing SVD techniques. One level of pyramid decomposition is employed in this proposed method because of loss of low frequency information at higher levels of the pyramid decomposition.

In the proposed LPSVD technique, the original image is decomposed into two different sub-bands C and D using one level of decomposition by LP as shown in Fig. 1(a). C is the coarse sub-band image of half size and D is the difference sub-band image of full size. Fig. 1(b) shows the proposed technique followed in coarse sub-band of LP. The low frequency coarse sub-band C and histogram equalized coarse image C_e are scaled by SVD as following as:

$$C = USV^T \tag{6}$$

$$C_e = U_e S_e V_e^T \tag{7}$$

The weighting factor ξ is calculated by the singular value of S and S_e using the equation

$$\xi = \frac{\max(S_e)}{\max(S)} \tag{8}$$

The new singular value with weight ξ is given as

$$S_\xi = \xi S \tag{9}$$

and the new enhanced coarse sub-band image is expressed as

$$C = U(S_\xi)V^T \tag{10}$$

For low contrast, MR images the scaling of singular values that would fail to produce better structural preservation when subjected to image segmentation. Due to the high value of ξ; the small edges, the contours of the region of interest cannot be distinguished from the background tissues. Therefore the new equalized coarse image is given by weighted sum of S_e and S as:

$$NewS = 0.2\left(\xi S + 1/\xi S_e\right) \tag{11}$$

$$NewC = U(NewS)V^T \tag{12}$$

Finally, the inverse LP is applied to produce enhanced medical images with sharper edges.

2.4. Evaluation metrics

In this article, LPSVD enhancement technique has been compared with GHE, Wavelet, SWTSVD techniques. The subjective assessment of the proposed enhancement technique is evaluated by the following parameters:

$$MSE = \frac{M, N[X(m,n) - Y(x,y)]^2}{MN} \tag{13}$$