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A Novel Algorithm for Removal of Herringbone Artifact in Brain MR Images Using FFT and Canny Edge Detector

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ABSTRACT: *Magnetic Resonance Images of Brain often contain herringbone artifact in the form of stripes spread in either frequency or phase encoding directions throughout the image. These artifacts create a problem in image enhancement and segmentation process and they have to be removed for accurate segmentation of region of interest. This paper presents a novel algorithm to remove herringbone artifact using frequency domain technique which preserves image details and sharpness of edges. The algorithm is developed using Fast Fourier Transform and Canny Edge detector. Filter is created using Canny Edge detector to pick the bright spots created by herringbone artifact. Frequency spectrum of artifact image is multiplied with this filter to zero out the frequencies of artifact. Final image is restored by taking the inverse Fast Fourier Transform. Accuracy of the image restoration is jeopardized at minimal degree in the case where pixels are falsely picked up as artifact. The quality of the processed image is evaluated using signal to noise ratio and energy loss metrics. The results shows that there is a greater improvement in signal to noise ratio and negligible energy loss in the processed image and suggests that the novel algorithm presented in this paper is suitable in processing and removing herringbone artifact in brain MR images.*

Keywords:*Magnetic Resonance Imaging (MRI); Herringbone Artifact; Fast Fourier Transform(FFT);Canny Edge Detector; Filter;Inverse Fast Fourier Transform; Signal to noise ratio(SNR); Energy loss.*

I. INTRODUCTION

Now a day's Magnetic Resonance Imaging (MRI) is a powerful medical imaging technique used in radiology to investigate the anatomy and physiology of the human brain in both health and disease. A wide variety of artifacts are commonly being encountered during MR image acquisition. An artifact is any undesirable feature that appears in an image which is not present in the original imaged object.The presence of artifacts in the image may be confused with pathology or just reduce the quality of examinations. To detect any abnormality in the brain like tumor or lesion, the artifact must be removed or minimized [1]. Artifacts create a problem in the enhancement process and affect segmentation accuracy. Artifacts have some spurious features appeared in the original image. Artifacts are classified as patient related and system related depending on their origin of the cause. Several artifacts occur in MRI [1] but in this paper, system related artifact, the herringbone is considered for removal.

The herringbone artifact is an MRI artifact and appears as a fabric or herring bone throughout the image. It is also called as crisscross artifact or corduroy artifact. The artifact is scattered all over the image in the form of stripes in a single slice or multiple slices in either frequency or phase encoding direction of the image. The herringbone artifact is a term used in MRI for stripe noise or artifact found in other images. The reasons to cause herringbone artifact are,

- Electromagnetic spikes by gradient coils,
- Fluctuating power supply and
- RF pulse discrepancy.

The possible solution to remove this artifact can be done by the technician or service engineer of the MRI scanner. However the artifact can be removed in technical ways by developing image processing techniques. The novel algorithm proposed in this paper completely removes the herringbone artifact in brain MR images.

In general an artifact image can be functionally represented as

$$f(r,c) = x(r,c) + n(r,c) \tag{1}$$

Where, $f(r,c)$ = the artifact image

x(r,c) = the prior image
n(r,c) = the noise artifact
Where r = 0,1,2,………. M-1 rows and c=0,1,2,…………N-1columns of discrete image matrix of size MxN.

There are usually two ways to reduce the noise or artifact. One is the spatial domain technique and other is the frequency domain technique. In frequency domain, the image frequency spectrum can express the characteristics of the image noise. The Fourier Transform is applied to obtain frequency spectrum of the image to analyze the artifact.Traditional Fourier Transformation uses low pass or high pass filter to reduce certain frequency signal, and then reduces the artifact. This process works well in some conditions, but if the artifact is mixed with image detail, then details of the image is also removed. The overall image is smoother while the image quality is further reduced [2].
Several different filters are available to minimize or remove the artifact in MR images, such as moving average filter, histogram matching, interpolation method, frequency filtering with Fast Fourier Transform as well as wavelets [4]-[11]. Although different methods give satisfactory results for different images, the basic idea of removal of artifact is that artifact should be known before processing.
From the above discussion it is understood that there is no specific algorithm which can completely tackle the herringbone artifact problem in the MR image. In the proposed method, Canny edge detector is used to remove the "bright spots" in frequency spectrum of the image created by herringbone artifact and then used as filter. In general, a smoothing procedure applied in the image spatial domain can be exactly used in frequency domain(e.g. a median filter) [12]. Frequency domain is a better approach than spatial domain so that edge sharpness can be preserved.

II. METHODOLOGY

2.1 Fourier Transform

Suppose in$f(r,c)$ with r=0,1, 2,…… M-1 andc= 0,1,2,……. N-1 specifies the raw image of size M x N. The two-dimensional Fourier Transform is given as F(u,v) is obtained from the equation (2)

$$F(u,v) = \sum_{r=0}^{M-1} \sum_{c=0}^{N-1} f(r,c)\, e^{-j\omega(\frac{ur}{M}+\frac{vc}{N})} \quad (2)$$

For all u = 0,1,2,………..M-1 and v = 0,1,2,…………N-1.
In fact the frequency domain is the coordinate system that is determined by F(u,v) and the frequency variables uand v. This domain is comparable with the spatial domain (the coordinate system defined by the spatial variables r and c). The rectangular M × N area defined by u = 0,1,2,..,..M-1 and v = 0,1,2, ..,.. N-1 can be considered as a rectangular frequency. Clearly rectangular frequency has the same size of the input image[3].

2.2 Inverse Fourier Transform

The Inverse Fourier transform of the image is obtained from equation (3),

$$f(r,c) = \frac{1}{MxN} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u,v)\, e^{j\omega(\frac{ur}{M}+\frac{vc}{N})} \quad (3)$$

for all r = 0,1,2,…............M-1 and c = 0,1,2,…………….N-1.
The values in equation(2) are also called the Fourier series coefficients. The value of the Fourier transform in the center of the rectangular frequency F(0,0) is called dc component of Fourier transform which represents the complete image detail [2].The general method for visual examination of the Fourier transform is to calculate Fourier spectrum F(u,v)and represent that as an image[3].

2.3 Canny Edge Detector

In this paper, Canny edge detector is applied to the frequency spectrum of the original image to detect the 'bright spots' which are revealed as artifact. Canny edge is also based on the first derivative coupled with noise cleaning. The detection of abrupt changes of the frequencies in the frequency spectrum is influenced by the presence of artifact. Hence the smoothing of these frequencies improves the detection of 'bright spots'. The Canny edge detector performs better than Sobel or Prewitt edge detectors[13]. Canny edge detector tries to achieve an optimal trade-off between the two by approximating the first order derivative of the Gaussian. The Gaussian function for 1-D is given by the equation (4).

$$G = \frac{1}{\sqrt{2\pi}\sigma} e^{-\left(\frac{x2}{2\sigma2}\right)} \quad (4)$$

Gaussian first order derivative is used to calculate the gradient in horizontal and vertical direction. Fig.1 shows the Gaussian function in 1-D and its first order derivative.

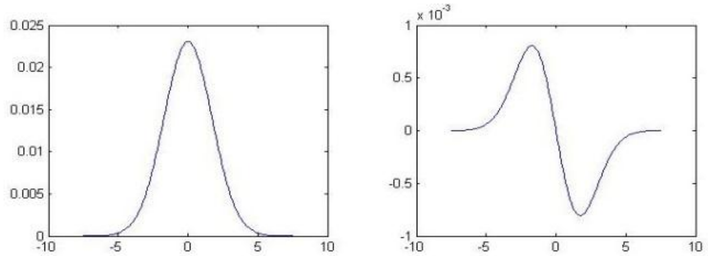


Figure 1: Gaussian function and its first order derivative.

Sigma value is used to set the width of the Gaussian function. Canny edge detector provides a good detection, localization and uni-response to a true edge [13].

2.4 Implementation

The steps involved in the implementation of the proposed algorithm for removal of herringbone artifact in brain MR images are shown in the block diagram of fig.2. The MR image database is created by taking herringbone artifact image from open source internet[Courtesy:http//radiopaedia.org/articles/herringbone artifact] and also from the radiologists. The DICOM images taken from the radiologists are converted to jpeg format suitable for processing by the proposed algorithm.

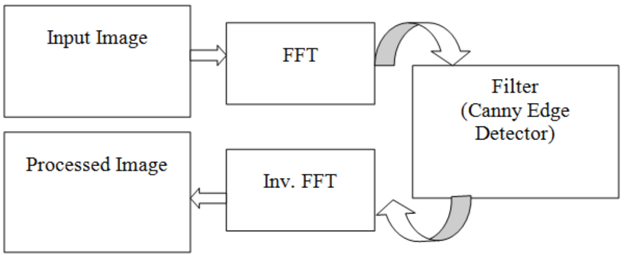


Figure 2: Implementation of the proposed method.

2.5 Steps of herringbone artifact removal algorithm.

1. Read the Herringbone artifact brain image from database
2. Apply Fast Fourier Transform on the image to obtain frequency spectrum
3. Create a filter using Canny edge detector by calculating sigma value for width of the Gaussian function using equation(5)

$$\sigma = \sqrt{\frac{\sum_{u,v}[F(u,v)-F_{mean}]^2}{MxN}} \qquad (5)$$

Where,

$F_{\text{mean}} = \frac{1}{MxN}\sum_{u,v} F(u,v)$

for all u,v. where u = 0,1,2..,…..M-1 and v = 0,1,2...,…..N-1.

4. Calculate the threshold value using half of this sigma value and use these threshold and sigma values to apply canny edge detector.
5. Fill the holes in canny edge detector result.
6. Complement the generated image.
7. Filter is now created which in turn acts as a notch filter and multiply this with the frequency spectrum (LogF) of the original artifact image
8. Apply the Inverse Fast Fourier Transform in order to restore the image
9. Display the image

2.6 Assessment of filter quality

For reliable validation of the filter quality, both qualitative and quantitative aspects are decisive. Qualitatively, the artifact removed images need to be free from artifact, while all other image details have to be preserved. Quantitatively, local mean values of the filtered image away from herringbone artifact must be maintained which is an important requirement for quantitative image analysis [12] [17].

The well-known qualitative method in signal processing is the signal to noise ratio (SNR) for images which is given by equation (6)

$$\text{SNR} = 10\log_{10}\left(\frac{Signal\ Power}{Noise\ Power}\right) \tag{6}$$

The signal power is defined by equation (7) for input image

$$\text{Signal Power} = \sum_{r=0}^{M-1}\sum_{c=0}^{N-1} f(r,c)^2 \tag{7}$$

And noise power is defined by equation (8) for processed image

$$\text{Noise Power} = \frac{1}{MxN}\sum_{r=0}^{M-1}\sum_{c=0}^{N-1}[f(r,c) - f'(r,c)]^2 \tag{8}$$

Where M and N are rows and columns of image matrix. Original image is $f(r,c)$ and processed image is $f'(r,c)$. Equation (8) is also called as Mean Square Error (MSE).

Quantitative evaluation of the results is the total energy of a signal. The loss of the energy can be expressed by the energy of the difference of the original image $f(r,c)$ and the filtered image $f'(r,c)$, relative to the original one, resulting in the relative mean square error ε_r given by equation(9) [12].

$$\varepsilon_r = \frac{\sum[f(r,c) - f'(r,c)]^2}{\sum f(r,c)^2} \tag{9}$$

III. RESULTS AND DISCUSSION

To illustrate the performance of the proposed algorithm, we have considered two groups of MR images of brain, namely images downloaded from open source [Courtesy:Radiopaedia] and images collected from the radiologists. The results are discussed in detail for one image with herringbone artifact using the algorithm. For images taken from radiologists, the herringbone artifact is simulated over the images and processing is done using the algorithm.

Original herringbone artifact brain MR Image is shown in fig.3 (a). The frequency spectrum of original image displayed in amplitude scale is shown in fig.3 (b) which alone cannot reveal the artifact; in fact it cannot be seen through the human eye because dc component is too high compared to noise spikes, hence convert it to logarithmic scale of the FFT image which is represented as LogF shown in fig.3(c).Arrow marks show the bright spots created by artifact.In general, an edge detection procedure is applied in the image spatial domain can be exactly used in frequency domain. For the result shown infig.3 (d), take the complement in order to create a filter which removes the bright spots created by artifact. Created filter shown infig.3 (e) is multiplied with LogF image fig.3(c) to eliminate the bright spots. The result is displayed infig.3 (f). Finally, Inverse Fourier Transform is applied to restore the image without herringbone artifact. The artifact free image is shown in fig.4.

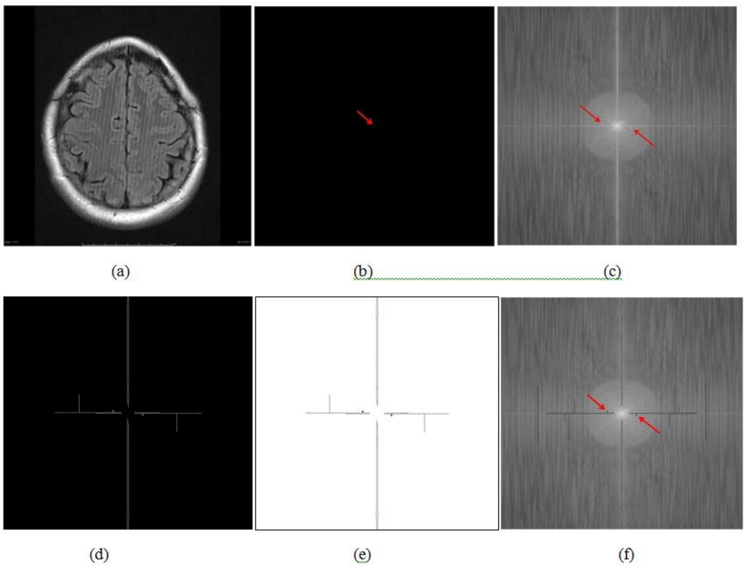


Figure 3: (a) Original herringbone artifact image (b) Frequency spectrum of original image in amplitude scale (c) Frequency spectrum in Logarithmic scale (d) Canny Edge detector result of original herringbone artifact mage (e) Complement of Canny edge detector, this image is multiplied with the image frequency spectrum of image (c) and the resulting image with removed bright spots shown in (f).

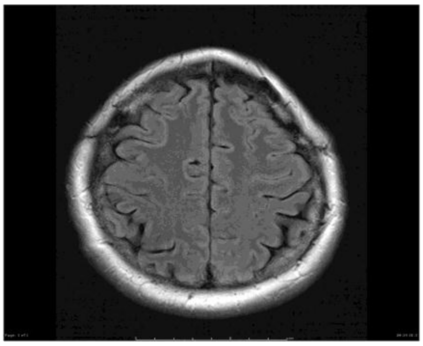
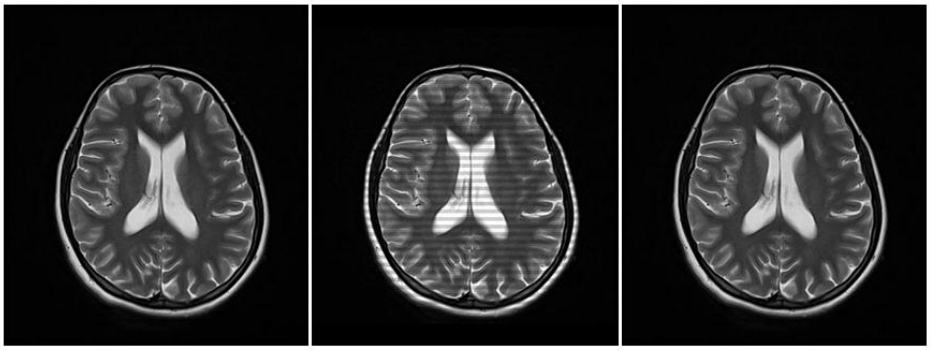


Figure 4: Restored image without herringbone artifact

Qualitatively evaluated the result of the restored image using SNR whichgives a value of 87.94179 dB for the input image shown in fig.3 (a), and quantitatively evaluated using energy loss which gives 0.16843% for the restored image shown in fig.4.

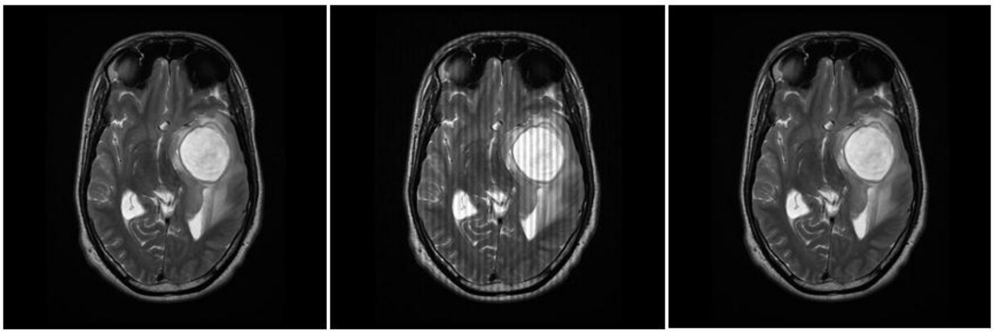
The table 1 shows the values of SNR and Energy Loss for simulated herringbone artifact images. The image1 shown in fig.5 (a) is of normal brain and after adding herringbone artifact in horizontal direction shows the SNR value of 67.73391 dB and after removal of artifact using proposed algorithm, the SNR value has increased to 113.9654 dB. The energy loss of image1 after adding artifact is 2.9444% and after removal of artifact the energy loss is almost zero percent.



(a) (b) (c)

Figure 5: (a) Original MR Image of normal brain without herringbone artifact collected from Radiologists
(b) Simulated herringbone artifact on original image along horizontal direction (c) Restored image with removed artifact using proposed algorithm.

Similarly image2 shown fig.6 (a) is of tumor brain and after adding herringbone artifact in vertical direction shows the SNR value of 70.28518 dB and after removal of artifact using proposed algorithm, the SNR value has increased to 84.5712 dB. The energy loss of image2 after adding artifact is 2.4548% and after removal of artifact the energy loss is almost zero percent.



(a) (b) (c)

Figure 6: (a) Original MR Image of tumor brainwithout herringbone artifact collected from Radiologists
(b) Simulated herringbone artifact on original image along vertical direction (c) Restored image with removed artifact using proposed algorithm.

Table 1 SNR and Energy Loss values for simulated herringbone artifact images.

Images	SNR in dB		Energy Loss in %	
	Before	After	Before	After
Image1(normal)	67.73391	113.96540	2.94409	0.00007
Image2(tumor)	70.28518	84.57126	2.45483	0.09150

IV. CONCLUSION

The proposed algorithm for removal of herringbone artifact in MR images of brain using FFT and Canny edge detector is a powerful approach in spectral domain. It is designed for wide range of herringbone or stripe artifact removal in MR images.The proposed algorithm is implemented on MATLAB platform and tested on various herringbone artifact brain MR Images taken from open source and also from the radiologists. The images are analyzed both qualitatively and quantitatively using signal to noise ratio and energy loss metrics for original artifact image taken from open source. The table 1 shows the values of SNR and energy loss for images taken from the radiologists but herringbone artifact is simulated over image and tested with the proposed algorithm.It is observed that there is a greater improvement in SNR of processed image with minimal loss of energy. The frequency domain technique preserves all the image details. The experimental results suggests that the proposed algorithm is efficient and suitable to remove herringbone artifact which occurs in either frequency encoding or phase encoding direction on brain MR Images.

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