ISSN 2348-375X

Unique Journal of Engineering and Advanced Sciences

Available online: www.ujconline.net

Research Article

RESOLUTION ENHANCEMENT IN MRI VIDEO SEQUENCE USING MODIFIED CUBIC SPLINE INTERPOLATION

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Received: 27-12-2013; Revised: 24-01-2014; Accepted: 23-02-2014

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ABSTRACT

With the advent of digital imaging technologies in medical field, there is a great demand for the quality of medical images or video sequences for the accurate diagnosis of diseases. Magnetic Resonance Imaging (MRI) can only acquire images and video sequence with low resolution. High resolution is of great importance for the better classification of regions, zooming of a specific area of interest or helping the visual analysis. A number of interpolation techniques have been applied to enhance the resolution of images, but these classical approaches results in noise such as jagged edge distortion and blurring of images. In this paper a modified cubic spline interpolation technique for the resolution enhancement of MRI frames is proposed. The performance of proposed technique is evaluated using Peak Signal to Noise Ratio (PSNR).

Keywords: Interpolation, Magnetic Resonance Imaging, Resolution Enhancement.

INTRODUCTION

In many digital imaging systems, high resolution images are of great importance for pattern recognition, visual analysis, and zooming of a specific area. Owing to the inherent resolution limitations of physical sensors, the imaging system often produces images with low resolution, thus limiting the processes based on them. Resolution enhancement technologies are thus essential for many applications such as in medical imaging and satellite imaging where diagnosis and analysis from low resolution images are extremely difficult. The images or video sequences generated from medical equipments such as Magnetic Resonance Imaging (MRI), Computed Tomography (CT) or Mammogram are of low resolution due to the limitations of the imaging modality. A high resolution image allows better classification of regions and zooming of a specific region of interest in the image. Thus it is highly desirable to generate high resolution images in medical imaging applications where quality of the image in terms of its resolution is the major parameter for the accurate diagnosis of diseases.

The images obtained from MRI are the most common tool for diagnosis in Medical field. Magnetic resonance imaging (MRI), is a procedure to scan patients and obtaining very detailed images of organs and tissues throughout the body without the need for x-rays or "ionizing" radiation. Instead, MRI uses a powerful magnets and radio waves to create detailed images of the body that show whether or not there is an injury, disease process, or abnormal condition present. For this test, the patient is placed in the MRI scanner which is a large tunnel or doughnut-shaped tube surrounded by a giant circular magnet. The magnet creates a strong magnetic field that aligns atomic particles called protons that are present in most of the body's tissues, which are then exposed to a beam of radio waves. The applied radio waves then cause these particles to produce signals that are picked up by the receiver portion of the MRI scanner. The receiver information is processed by a computer, and an image is produced. Images from an MRI scan are digital images that can be saved and stored on a computer for more study. The image and resolution produced by MRI is quite detailed and can detect tiny changes of structures within the body. The MRI machine can also be used to produce 3-D images that may be viewed from many different angles. Magnetic resonance imaging (MRI) is done to find problems such as tumors, bleeding, injury, blood vessel diseases, or infection.

Magnetic resonance imaging (MRI) data is normally corrupted by noise, especially for fast scanning sequence. It generally tends to reduce the resolution and contrast and hence degrade the diagnostic accuracy of this modality. High resolution magnetic resonance images can directly enhance the readability and improve diagnosis accuracy[6]. In order to solve the problem of limited resolution in imaging devices, several super resolution (SR) approaches have been developed[1,11]. The idea of super resolution is to reconstruct a high resolution image from a set of low resolution images. There have been several techniques for constructing a high resolution image; these are categorized as single image super-resolution and super-resolution from several frames. In the first case, no other information is available to enhance the resolution. So, the resolution enhancement algorithms are based on smoothing and interpolation techniques. Most of the SR algorithms are based on the reconstruction of multiple low resolution images using the sub-pixel motion shifts and non-uniform to uniform sampling techniques.

The super-resolution techniques can be typically classified as frequency-domain approaches[4], learning-based approaches[2,3,7], iterative HR image reconstruction techniques[5,14], and interpolation-based approaches[10]. Multiframe SR reconstruction was first proposed by Tsai and Huang[4] in the frequency domain for registering a set of aliased LR images with application to SR. However, due to the lack of some prior knowledge in the spatial domain, and being constrained by global translational motion as well as linear space invariant blur[5], these frequency-domain approaches do not perform well in practical applications.

The general idea of learning-based approaches is to learn a set of image features from the learning example images and use them for the reconstruction of a high-resolution image. Learning based super resolution proposed in[8] reconstructed a high-resolution image using a single low resolution image with pair matching. Freeman *et al.*[8] learn a feature set of image patches that encode the relationships among different spatial frequencies from a large training set and use it as prior information for reconstructing higher frequencies for resolution enhancement. The performance of these learning based approaches largely depends on the learning examples. The method proposed in[4] based on the sparse association between input and example patches solve this problem. Moreover, the increase in resolution in the learning-based approaches is limited by the resolution of learning examples. There are certain cases for instance in the case of MRI images, due to economic or health reasons, a patient is scanned only once over a period of time. In such situations only a single low resolution image is available while some super-resolution methods attempt to exploit the information of several low resolution images. The most popular iterative HR image reconstruction techniques are the projection on convex sets algorithm[16], the maximum *a posteriori* (MAP) estimation, and their variations. The main advantage of them is that it is convenient to add image priors.

Another commonly used techniques for image resolution enhancement is Interpolation based approaches[10]. The conventional interpolation techniques used are nearest neighbor interpolation, bilinear interpolation, and bicubic interpolation. Nearest neighbor interpolation is the most basic interpolation technique. This interpolation algorithm considers pixel closest to the interpolated point and no other pixels are considered and thus results in least processing time. But it results in jagged artifacts, where some information at the edges is lost. In bilinear interpolation the output pixel value is the weighted average of the closest 2x2 neighborhood. It results in smoother images than nearest neighbor method but produces more blurred images. Bilinear interpolation considers the nearest 4x4 neighborhood of known pixels, the closer pixels are given a higher weighting in the calculation. It produces noticeably sharper images than nearest neighbor and bilinear methods. Thus these interpolation-based SR methods perform well in smooth (low-frequency) areas but poorly in edge (high-frequency) areas in that they are prone to blurring and jaggy artifacts along edges.

In this paper, we propose a modified cubic spline interpolation technique for the resolution enhancement of images. It provides a smooth interpolant and is more accurate than other interpolation methods. Since magnetic resonance images are normally affected by random noise, modified median filtering is used to suppress the noise. The performance of the proposed algorithm is evaluated using PSNR (Peak Signal to Noise Ratio). The rest of the paper is organized as follows: In section II, the proposed method for resolution enhancement is presented. Experimental results and performance comparison are discussed in section III. Finally, conclusions are presented in section IV.

PROPOSED METHOD

In this paper, we propose an algorithm for the resolution enhancement of images or video sequence using cubic spline interpolation. The proposed resolution enhancement algorithm is applied to all the frames of the noisy low resolution video. Median filtering is done to remove the noise present in the MRI frames. Apply cubic spline interpolation separately for each row and column on filtered image to obtain a high resolution image and finally compose it into video. The flow chart of the proposed method is shown in fig.1.

A.Denoising Using Modified Median Filter

Image denoising in digital image processing aims to remove the noise which may corrupt an image, while preserving its edges. Magnetic Resonance (MR) images are normally affected by random noise during the image acquisition process. The presence of noise not only produces undesirable visual quality but also lowers the visibility of low contrast objects. Noise removal is thus essential in medical imaging applications in order to enhance and recover fine details of an image. The medical images should be sharp, clear and free from noise and artifacts[6] to achieve the best diagnosis of diseases.

Median filter is a nonlinear filter which easily removes the noise while preserving its edges[15]. The basic idea of median filter is that for each pixel of the image, looks at its neighborhood and pick up the element which is most similar to others. The median is calculated by first sorting all the pixel values from the surrounding neighborhood into numerical order and then replacing the pixel being considered with the middle pixel value. Since the median filter cannot distinguish fine detail from noise, the proposed method applies modified median filtering. In Modified median filter, median filter is applied on input image along each row and column separately.

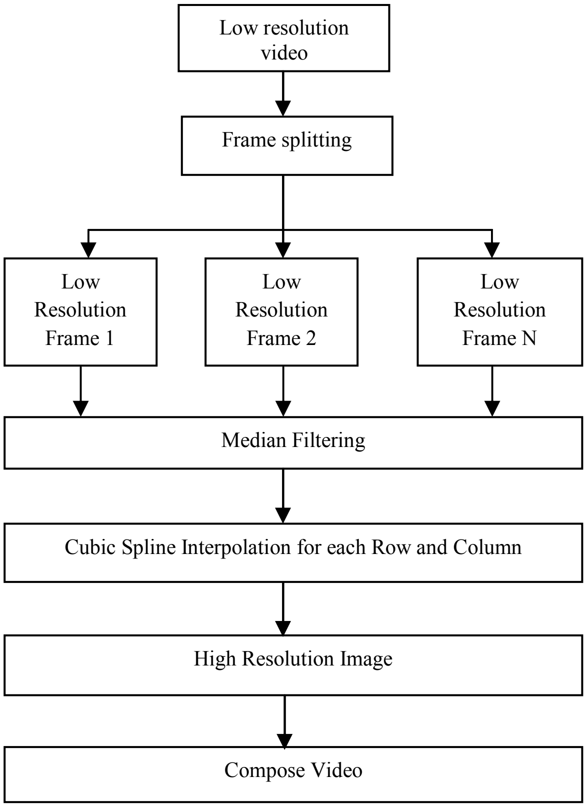

Fig.1. Proposed Resolution Enhancement Model

B. Cubic Spline Interpolation

Cubic spline interpolation is a form of interpolation where the interpolant is a cubic spline which is a spline constructed of piecewise polynomials that pass through a number of data points[13]. In cubic spline interpolation, a series of unique cubic polynomials are fitted between each of the data points, thus obtaining continuous and smooth spline curves. These cubic splines can then be used to determine rates of change and cumulative change over an interval. The basic idea behind cubic spline interpolation is to draw smooth curves called splines through a number of points[9,12]. This spline consists of weights attached to the points that are to be connected. Smooth curves are obtained by bending a flexible strip across each of these weights. The mathematical spline is similar in principle. In this case, the points are numerical data. The weights are the coefficients of the cubic polynomials which are used to interpolate the data. These coefficients 'bend' the line so that it passes through each of the data points without any erratic behavior or breaks in continuity.

The goal of cubic spline interpolation is to obtain an interpolation formula that is smooth in the first derivative, and continuous in the second derivative, both within an interval and at its boundaries. For a data set {xi} of n+1 points, we can construct a cubic spline with n piecewise cubic polynomials between the data points. If

$$S(x) = \begin{cases} s_0(x), x \in [x_0, x_1] \\ s_1(x), x \in [x_1, x_2] \\ s_{n-1}(x), x \in [x_{n-1}, x_n] \end{cases} \quad (1)$$

where s_i is a third degree polynomial defined by

$$s_i(x) = a_i(x-x_i)^3 + b_i(x-x_i)^2 + c_i(x-x_i) + d_i \quad (2)$$

for $i = 1, 2, \ldots. n-1$.

The first and second derivatives of these $n-1$ equations are

$$s_i'(x) = 3a_i(x-x_i)^2 + 2b_i(x-x_i) + c_i \quad (3)$$

$$s_i''(x) = 6a_i(x-x_i) + 2b_i \quad (4)$$

for $i = 1, 2, \ldots. n-1$.

S(x) represents the splines function interpolating the function f, with the interpolating property, $S(x_i) = f(x_i)$, i=1,2,…,n-1.

For the curve S(x) to be continuous across its entire interval, each sub-function must join at the data points, so $S_{i-1}(x_i) = S_i(x_i)$, i = 1,2,...,n-1.

For the n cubic polynomials, we need to determine 4n conditions (since for one polynomial of degree three, there are four conditions on choosing the curve).

This cubic spline interpolant should satisfy the following conditions.

1. The piecewise function $S(x)$ should interpolate all data points.
2. $S(x)$ must be continuous on the interval $[x_{1,} x_n]$
3. $S''(x)$ must be continuous on the interval $[x_{1,} x_n]$
4. $S''(x)$ must be continuous on the interval $[x_{1,} x_n]$

The advantage of cubic spline interpolation lies in the smoothness of the approximation, that is cubic spline interpolants are twice continuously differentiable.

EXPERIMENTAL RESULTS

To evaluate the performance of the proposed resolution enhancement method, we use different MRI test images. The proposed method can be applied to both MRI images as well as natural images. The test is conducted on images of different sizes. Fig.2 shows four consecutive frames of MRI brain images used to evaluate the performance of our work. The proposed algorithm is compared with two other methods namely Bilinear interpolation,and Bicubic interpolation.

The performance is evaluated using the quality measure, Peak Signal to Noise Ratio (PSNR). In this work resolution of an image is measured in terms of PSNR. PSNR values are used to measure the quality of an image. Peak signal-to-noise ratios (PSNR) have been implemented in order to obtain some quantitative results for comparison. PSNR is usually expressed in terms of logarithmic decibel value. The PSNR can be calculated as

$$\text{PSNR} = 10 \log_{10} \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} 255^2}{\sum_{i=1}^{M} \sum_{j=1}^{N} \left(f(i,j) - \hat{f}(i,j) \right)^2} \quad (5)$$

Where f is the original image and $\hat{f}$ is the enhanced image. A higher PSNR generally indicates that the reconstruction is of higher quality.

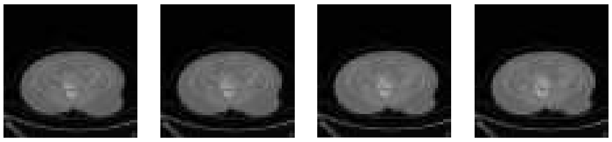

Figure 2: Four consecutive frames of MRI video sequence

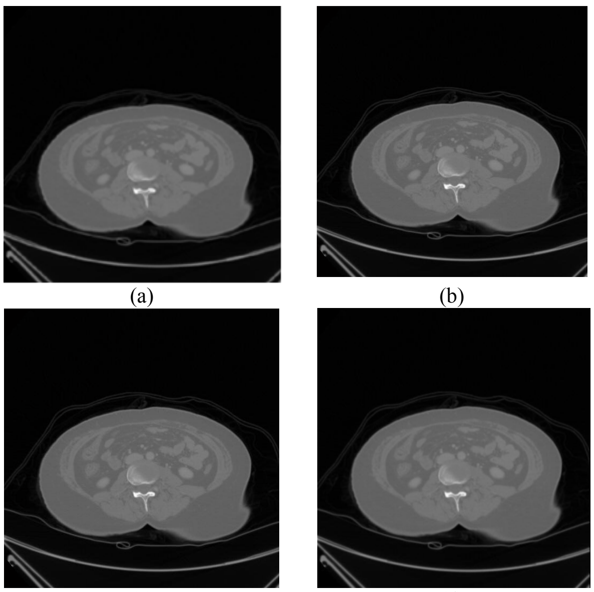

Figure 3: Interpolated images of a typical MRI frame (512x512) (a) Original image (b) Bilinear (c) Bicubic (d) Proposed method

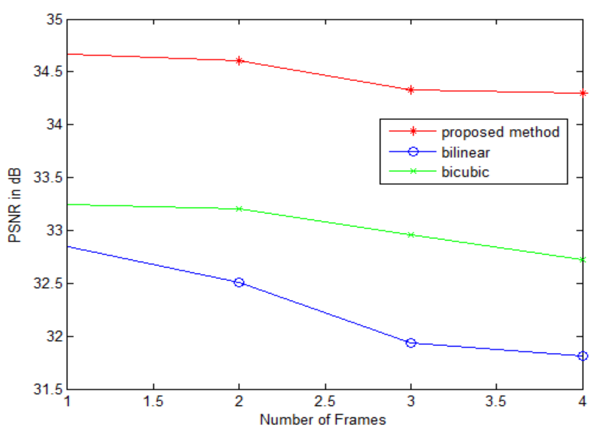

Figure 4: The effect of number of frames on PSNR of different resolution enhanced images of MRI video sequence.

Fig.3 shows the resolution enhanced images of different interpolation methods. We can observe that more jagged edges or blurring are produced in the interpolated images obtained by the bilinear interpolation and bicubic interpolation. It clearly shows that proposed method gives a sharper image. Fig.4 indicates the variation of PSNR along the number of frames. The performance of the proposed algorithm is superior compared with other interpolation methods. Fig.5 shows interpolating images of Lena using various interpolation methods. Table I shows that the proposed method has a higher PSNR compared to all other methods and the higher PSNR indicates a good quality image.

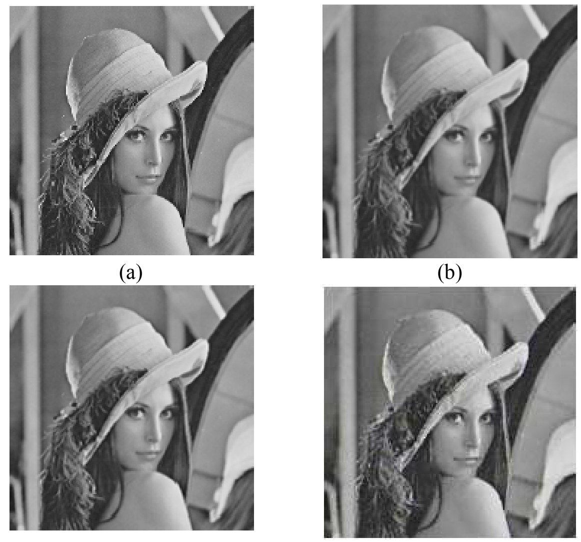

Figure 5: Interpolated lena image (256x256) (a) Original image (b) Bilinear (c) Bicubic (d) Proposed method

Table I: PSNR Comparison of Different Resolution Enhancement Methods

Method	MRI Image	Lena Image
Bilinear	32.843	27.325
Bicubic	33.2465	27.814
Proposed Method	34.6669	29.46

CONCLUSION

In most of the digital imaging applications, especially in medical imaging, high resolution is of great importance for the accurate analysis and diagnosis of diseases. In this paper, we present an efficient technique for the resolution enhancement of MRI video sequence using modified cubic spline interpolation method. The objective quality measure, Peak Signal to Ratio (PSNR) is used to evaluate the performance of the proposed method with other interpolation methods such as bilinear and bicubic interpolation. The visual and the quantitative analysis of the experimental results show that the proposed method have good PSNR values and is superior to other resolution enhancement techniques.

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Source of support: Nil, Conflict of interest: None Declared