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Investigating Polynomial Interpolation Functions for Zooming Low Resolution Digital Medical Images

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***Abstract*—**Medical digital images usually have low resolution because of nature of their acquisition. Therefore, this paper focuses on zooming these images to obtain better level of information, required for the purpose of medical diagnosis. For this purpose, a strategy for selecting pixels in zooming operation is proposed. It is based on the principle of analog clock and utilizes a combination of point and neighborhood image processing. In this approach, the hour hand of clock covers the portion of image to be processed. For alignment, the center of clock points at middle pixel of the selected portion of image. The minute hand is longer in length, and is used to gain information about pixels of the surrounding area. This area is called neighborhood pixels region. This information is used to zoom the selected portion of the image. The proposed algorithm is implemented and its performance is evaluated for many medical images obtained from various sources such as X-ray, Computerized Tomography (CT) scan and Magnetic Resonance Imaging (MRI). However, for illustration and simplicity, the results obtained from a CT scanned image of head is presented. The performance of algorithm is evaluated in comparison to various traditional algorithms in terms of Peak signal-to-noise ratio (PSNR), maximum error, SSIM index, mutual information and processing time. From the results, the proposed algorithm is found to give better performance than traditional algorithms.

***Keywords*—**Zooming, interpolation, medical images, resolution.

I. Introduction

THIS paper presents an algorithm for zooming low resolution digital medical images. Medical imaging refers to taking images of various parts (inside or outside) of a body using various methods such as radiography. These images aid doctors and surgeons for better medical diagnosis. However, digital medical images usually have low resolution because of nature of their acquisition [1]-[8]. Some typical examples of digital medical images are shown in Fig. 1. It is difficult to gain high quality information (e.g. shape and size of tumor or fracture) from these low resolution images. Therefore, this paper is focused on zooming (using interpolation) these images. The image zoomed using interpolation functions will have more number of pixels. This will help to improve the quality of these images; and thus can provide better level of information for the purpose of medical diagnosis. Interpolation has been widely used in many image processing applications such as facial reconstruction, multiple description coding, and super resolution [6]-[10].

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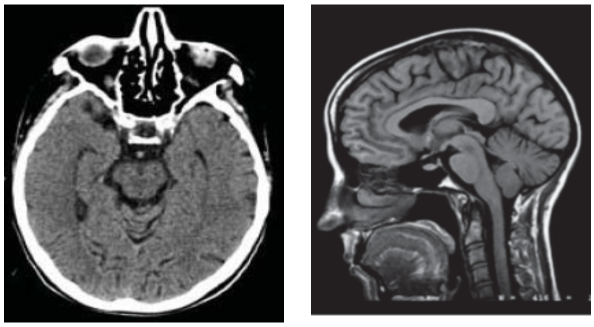

(a) (b)

Fig. 1 An example of (a) CT scan and (b) MRI digital image

By definition, zooming is the process of transforming a discrete image defined at one set of coordinate locations to a new set of coordinate points [11], [12]. Zooming can be divided into two processes: interpolation of the discrete image to a continuous image, and then sampling the interpolated image [12]. It uses the interpolation functions to find the values of pixels at new coordinates. Thus, its performance depends on the method used to select pixels and the interpolation functions used to calculate the value of pixels at new locations [11]-[17]. There are many types of interpolation functions developed to date. A review of key interpolation methods is given in [10], [18], [19]. The interpolation functions are also called polynomial based interpolation functions. These functions can be both linear and non-linear [11]-[17]. Some typical examples of most commonly used polynomial interpolation functions are: nearest-neighbor, bilinear and bicubic interpolation [11]-[17]. These are in use for last several decades; with their initial evident in early 1970s [13]. Since then, several researchers, engineers, professionals and organizations have used these functions in various image processing operations and research studies [11]-[23]. The nearest neighbor and bilinear interpolation methods are the simplest functions and they use just four nearest pixels to create an intermediate pixel. Bicubic interpolation is another popular function and uses the nearest 16 pixels to create an intermediate pixel. It produces better quality images than nearest-neighbor and bilinear interpolation [11]-[17]. However, the nearest-neighbor and bilinear interpolation exhibit computational simplicity at the cost of severe blurring problems particularly in edge regions. For medical images, ideally, the image interpolation algorithm should preserve the qualitative characteristics of the output image. Therefore, this paper presents an algorithm for performing zooming operation on low resolution medical images. The bicubic interpolation is

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used as its basis.

The rest of the paper is organized as follows. Section II presents the analytical model of proposed algorithm. Section III implements and evaluates its performance with Section IV leading to conclusions.

II. Proposed Algorithm

This section first explains image zooming using the bicubic interpolation function. It is shown in Fig. 2, in which the new pixel value at coordinates (i', j') is computed using bicubic interpolation function [11]-[17], as:

$$f_{i',j'} = [W_{-1}(D_y)\ W_0(D_y)\ W_1(D_y)\ W_2(D_y)][F]\begin{bmatrix}W_{-1}(D_x)\\W_0(D_x)\\W_1(D_x)\\W_2(D_x)\end{bmatrix} \quad (1)$$

where, $[F]$ is given by:

$$F = \begin{bmatrix} f_{i-1,j-1} & f_{i,j-1} & f_{i+1,j-1} & f_{i+2,j-1} \\ f_{i-1,j} & f_{i,j} & f_{i+1,j} & f_{i+2,j} \\ f_{i-1,j+1} & f_{i,j+1} & f_{i+1,j+1} & f_{i+2,j+1} \\ f_{i-1,j+2} & f_{i,j+2} & f_{i+1,j+2} & f_{i+2,j+2} \end{bmatrix} \quad (2)$$

and, the weights are given by:

$$W_{-1}(D) = 0.5 * (-D^3 + 2D^2 - D)$$

$$W_0(D) = 0.5 * (3D^3 - 5D^2 + 2)$$

$$W_1(D) = 0.5 * (-3D^3 + 4D^2 + D)$$

$$W_2(D) = 0.5 * (D^3 - D^2) \quad (3)$$

From (1)-(3), it is evident that the bicubic interpolation is linear and can be computed in parallel. This is why it is widely used in interpolation based image processing applications. However, it ignores the image local features and often result in image blurring. But, the medical images have local gradient features. So, a new algorithm is introduced to consider the local gradient features of an image during interpolation processing. It is based on the principle of analog clock and uses a combination of point and neighborhood processing, as shown in Fig. 3.

In Fig. 3, the center of clock points at the center of portion of image to be processed. The area covered by hour hand is the portion of image to be processed. The minute hand is longer in length. So, it is used to gain information about the pixels surrounding the portion of image, selected to be zoomed. This area is called neighborhood pixels region. The minute hand gains information about the area under processing and the surrounding area. The small hour hand uses this information to process the selected portion of the image. This area can be limited to a single pixel. In this way, the pixel-by-pixel image processing can be achieved by gaining information from surrounding area. The information processing of this algorithm is based on modified bicubic interpolation method.

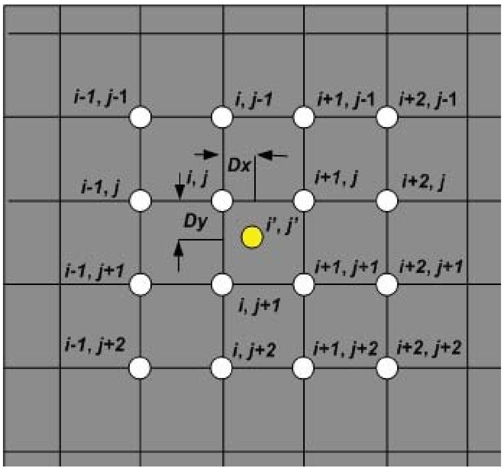

Fig. 2 Analytical model of Bicubic Interpolation

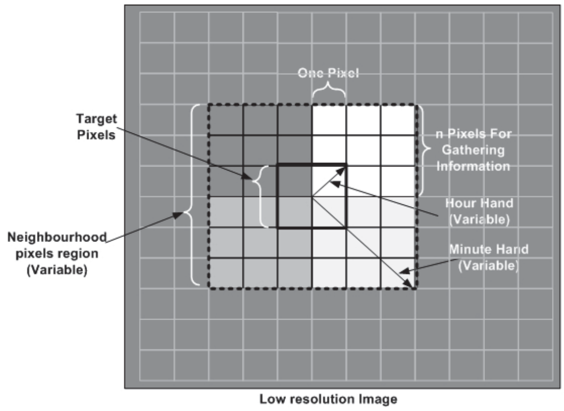

Fig. 3 Proposed algorithm based on neighborhood approach

The local gradient features are introduced in proposed algorithm using the gradient and neighborhood processing, as shown in Fig. 4. For this purpose, a set of four weights in four directions (top, bottom, left and right) are applied. In addition, the weights also cover information from the two sharing adjoining pixels. So, a single weight is calculated using 8 pixels instead of 4 corner pixels used in traditional bicubic method.

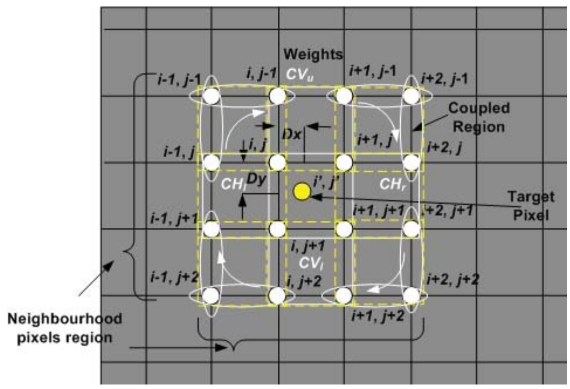

Fig. 4 Weights selection in proposed algorithm

Similar to (1)-(3), the equations for proposed algorithm is applied as:

$$f^{c}{}_{i',j'} = [W^c_{-1}(D_y)\ W^c_0(D_y)\ W^c_1(D_y)\ W^c_2(D_y)][F]\begin{bmatrix} W^c_{-1}(D_x) \\ W^c_0(D_x) \\ W^c_1(D_x) \\ W^c_2(D_x) \end{bmatrix} \quad (4)$$

where, the four multiplying weights in y direction to targeted pixels is given as:

$$W^c_{-1}(D_y) = W_{-1}(D_y)/CV(D_y)$$

$$W^c_0(D_y) = CV_u W_0(D_y)/CV(D_y)$$

$$W^c_1(D_y) = CV_l W_1(D_y)/CV(D_y)$$

$$W^c_2(D_y) = W_2(D_y)/CV(D_y) \quad (5)$$

where, $CV(D_y)$ is the vertical weight and further consists of upper and lower weights as shown in Fig. 4. It is expressed as:

$$CV(D_y) = W_{-1}(D_y) + CV_u W_0(D_y) + CV_l W_1(D_y) + W_2(D_y) \quad (6)$$

The interpolated surface can then be written as:

$$CV_u = (1 + 0.5 * (f_1))^{-1/2} \quad (7)$$

where,

$$f_1 = |f_{i,j} - f_{i,j-1}| + |f_{i+1,j} - f_{i+1,j-1}| + |f_{i-1,j} - f_{i-1,j-1}| + |f_{i+2,j} - f_{i+2,j-1}| \quad (8)$$

Similarly,

$$CV_l = (1 + 0.5 * (f_2))^{-1/2} \quad (9)$$

and,

$$f_2 = |f_{i,j+1} - f_{i,j+2}| + |f_{i+1,j+1} - f_{i+1,j+2}| + |f_{i-1,j+1} - f_{i-1,j+2}| + |f_{i+2,j+1} - f_{i+2,j+2}| \quad (10)$$

Similarly, the four multiplying weights in x direction to targeted pixel is given as

$$W^c_{-1}(D_x) = W_{-1}(D_x)/CH(D_x)$$

$$W^c_0(D_x) = CH_l W_0(D_x)/CH(D_x)$$

$$W^c_1(D_x) = CH_r W_1(D_x)/CH(D_x)$$

$$W^c_2(D_x) = W_2(D_x)/CH(D_x) \quad (11)$$

and, the corresponding weights will be given as:

$$CV(D_x) = W_{-1}(D_x) + CH_l W_0(D_x) + CH_r W_1(D_x) + W_2(D_x) \quad (12)$$

and, the left and right weights in horizontal direction is given as:

$$CH_l = (1 + 0.5 * (f_3))^{-1/2} \quad (13)$$

where,

$$f_3 = |f_{i,j} - f_{i-1,j}| + |f_{i,j+1} - f_{i-1,j+1}| + |f_{i,j-1} - f_{i-1,j-1}| + |f_{i,j+2} - f_{i-1,j+2}| \quad (14)$$

Similarly,

$$CH_r = (1 + 0.5 * (f_4))^{-1/2} \quad (15)$$

and,

$$f_4 = |f_{i+1,j} - f_{i+2,j}| + |f_{i+1,j+1} - f_{i+2,j+1}| + |f_{i+1,j-1} - f_{i+2,j-1}| + |f_{i+1,j+2} - f_{i+2,j+2}| \quad (16)$$

From the above expressions, it is clear that the proposed algorithm focuses on the local gradient features. Its performance is investigated in next section.

TABLE I
VALUES OF VARIOUS IMAGE QUALITY ASSESSMENT PARAMETERS FOR ZOOMING IMAGE OF HEAD BY A FACTOR OF 2

Algorithm	Time Taken (Seconds)	PSNR (dB)	SNR (dB)	MSE	Max. Error	Mutual Information
Nearest Neighbor	0.0493	21.4887	8.2899	461.5425	244	4.2854
Bilinear	0.0208	23.2518	8.0332	307.5412	183	3.6636
Bicubic	0.0113	23.176	8.216	312.9563	206	3.655
Lancoz	0.0098	23.1666	8.1503	313.6288	207	3.6249
Lagrange	5.5779	24.1048	9.7373	252.6989	225	4.7567
DWTSR	0.4762	22.9069	7.3199	332.9565	208	2.2894
DWTSWT	0.2062	22.9069	7.3199	332.9565	208	2.2894
DTCWT	0.2739	24.3822	8.2983	237.0591	201	2.5787
ICBI	274.5408	25.6859	9.924	175.5846	225	4.3283
INEDI	737.2068	26.4257	9.5212	148.0854	197	4.1621
EGII	31.9706	26.3047	9.8968	152.268	189	4.4378
DCC	9.6729	27.2627	10.1221	122.1279	197	4.3526
NEDI	37.768	26.367	9.4359	50.0989	208	4.4201
Proposed	0.0128	29.9367	11.1829	49.9189	165	5.2497

III. RESULTS & DISCUSSION

The proposed algorithm is implemented in MATLAB and its performance is evaluated for various low resolution medical images obtained from various sources such as Computed Tomography scan and Magnetic Resonance Imaging. However, for illustration and simplicity, the results obtained for a CT scan image of head (Fig. 5) are presented in this paper. To evaluate the performance of this algorithm, the image (256 x 256 pixels) is first reduced (down sized) to half. And then, the proposed algorithm is applied to zoom the reduced image by a factor of 2 so that it matches its original image size. The zoomed image is then compared to its original version, both quantitatively and qualitatively. The performance of the proposed algorithm is compared with the traditional algorithm, edge detection based interpolation (EDI) methods [24]-[30] and wavelet based image enlargement methods [31]-[37]. The EDI methods used are ICBI, NEDI, EGII, DCC & INEDI and their details are given in [24]-[30]. The wavelet based methods are DWTSR, DWTSWT & DTCWT and their details are given in [31]-[37]. The results obtained for quantitative parameters are mentioned in Table I. The key observations made are as follows.

A. Visual Appearance

The visual assessment is done based on the visual appealing of the images and the sharpness of edges produced. This is a subjective quality assessment method and its accuracy changes with an individual perception. From Fig. 5, the head image processed by nearest neighbor method is found to give poor visual appearance compared to other methods. It is because of the low interaction with nearby pixels, while computing the target pixel. This causes appearance of jaggies, staircases and non-uniform brightness. Bilinear, Bicubic and Lancoz have nearly the same performance in visual appearance. Similarly, images produced by Lagrange, DWTSR and DWTST are also nearly the same. However, all these methods have better performance than nearest neighbor. The images produced by these algorithms do not have sharp edges and have poor contrast; which makes most regions of image difficult to analyze. Among the results obtained for the EDI techniques, the ICBI & EGII has comparatively poor visual appealing than NEDI, INEDI and DCC. The images obtained by INEDI & DCC is found to have more sharp edges than DCC.

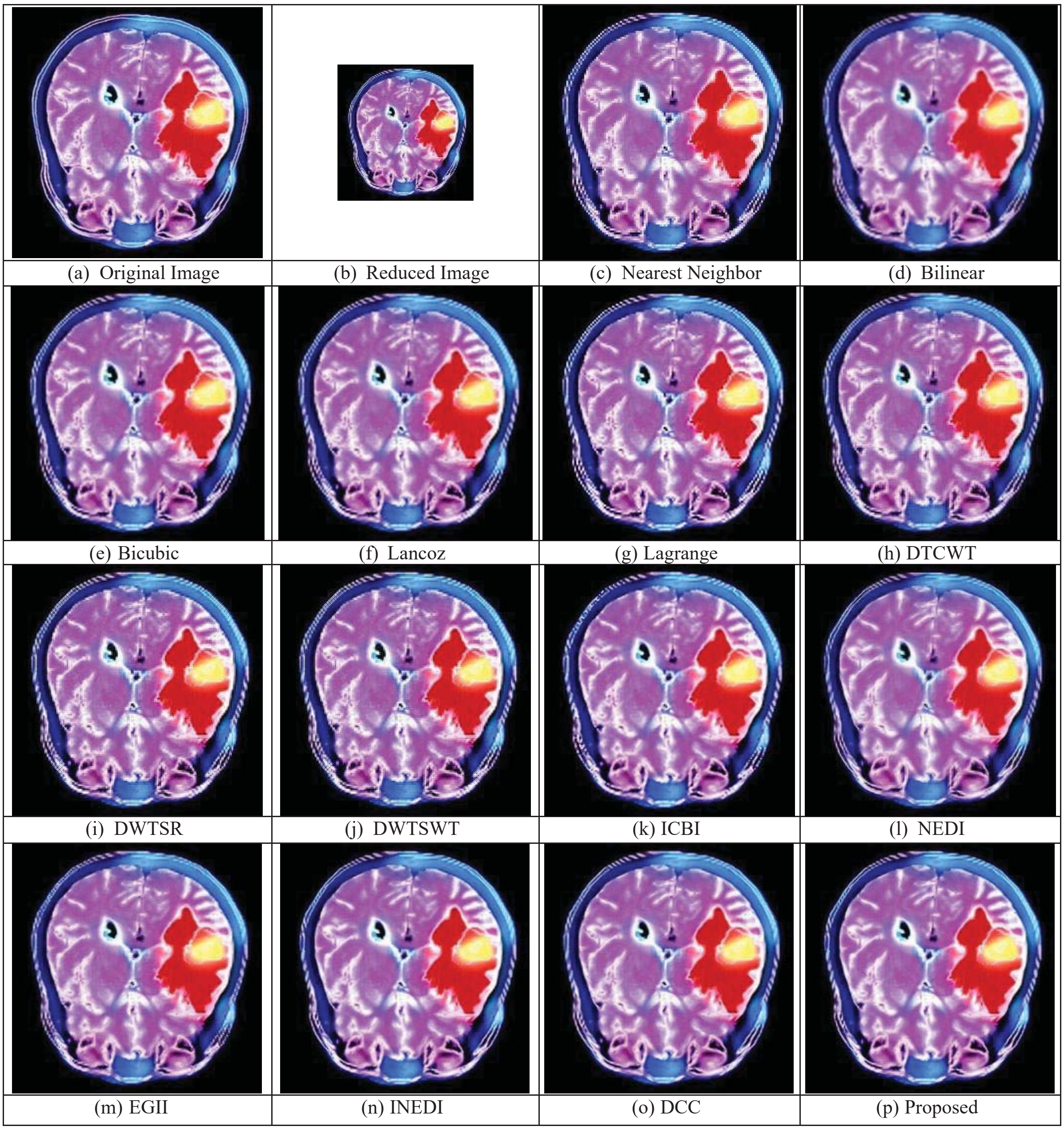

Fig. 5 Results of zooming the image (a, b) of head by a factor of 2 using (c) Nearest Neighbor, (d) Bilinear, (e) Bicubic, (f) Lancoz, (g) Lagrange, (h) DWTCWT, (i) DWTSR, (j) DWTSWT, (k) ICBI, (l) NEDI, (m) EGII, (n) INEDI, (o) DCC and (p) Proposed method

Image produced by proposed algorithm has more pleasant visual appealing results compared to all other methods. In addition, it has also sharp edges. This is because of the high interaction with nearby pixels, while computing the target pixel.

B. Processing Time

The processing time refers to time taken by the interpolation method to process (zooming in this case) an image. It is very important to determine the computation speed and complexity of the method. From the results in Table I & Fig. 6, INEDI is found to be the slowest method taking over 500 seconds to process (zooming in this case) an image of 128 by128 pixels. The next slowest method is ICBI, which is found to be taking around 400 seconds. Wavelet based methods are found to be faster than edge directed interpolation techniques. However, these are slower than traditional interpolation techniques. Lancoz is found to be the fastest method, with Bicubic and the proposed algorithm next to it. The proposed algorithm took a slightly higher time than Bicubic algorithm because of added computations to it. However, it is found to be fast enough to use in real time processing of medical images; compared to edge detection and wavelet domain methods.

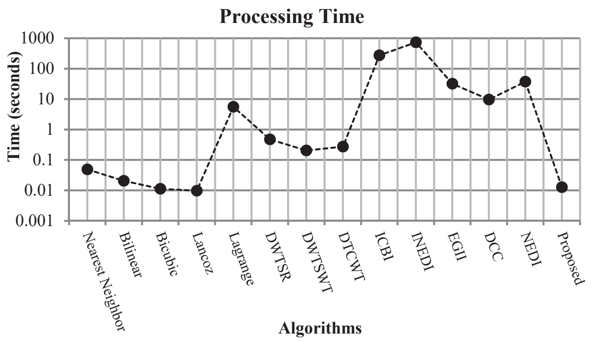

Fig. 6 Time taken by various methods for zooming image of head by a factor of 2

C. PSNR, SNR, MSE & Maximum Error

PSNR is an expression for the ratio between the maximum possible value (power) of a signal and the power of distorting noise. The constraint is that the higher the PSNR, the better the image has been reconstructed with respect to the original image. The PSNR & SNR results are tabulated in Table I & Fig. 7; whereas, the MSE & maximum error values are reported in Fig. 8.

From the results, the PSNR is found to be minimum and error is maximum for nearest neighbor algorithm. This is because this method only interacts with the four nearest pixels for computing the value of any unknown pixel. It just replaces the unknown pixel with the nearest pixel. Therefore, the error is high and PSNR is low in this case. The maximum value of PSNR is obtained for the proposed method; with the second next to it is DCC and then NEDI. This is because the proposed method has better interaction with corner neighboring pixels when computing the value of intermediate pixel. EDI methods performs better in terms of PSNR and SNR than the traditional algorithms (such as Bilinear and Lancoz). Among the five traditional algorithms investigated, Lagrange is found to have highest PSNR and SNR. In Fig. 8, the nearest neighbor is found to have highest MSE and maximum error. On the contrary, the proposed method is found to give lowest values of MSE and maximum error. This is because this method has better interaction with corner neighboring pixels when computing the value of any unknown pixel.

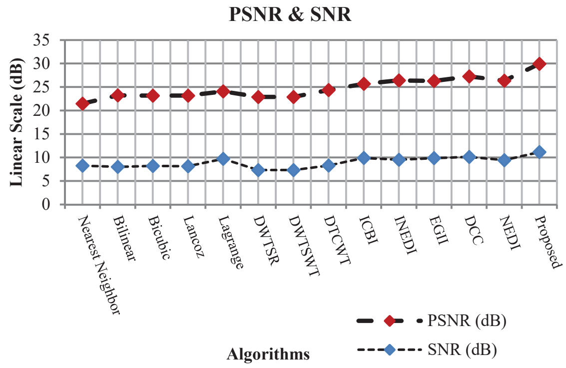

Fig. 7 PSNR & SNR values of the head image obtained by zooming using various methods

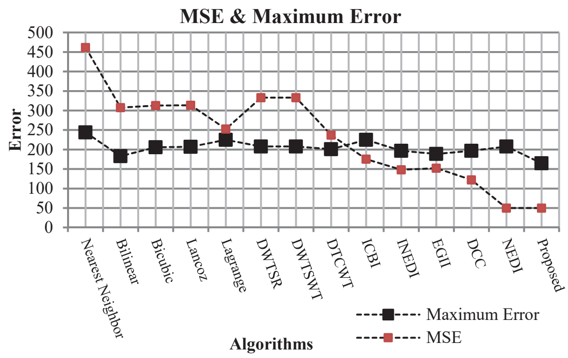

Fig. 8 MSE & maximum error values of the head image obtained by zooming using various methods

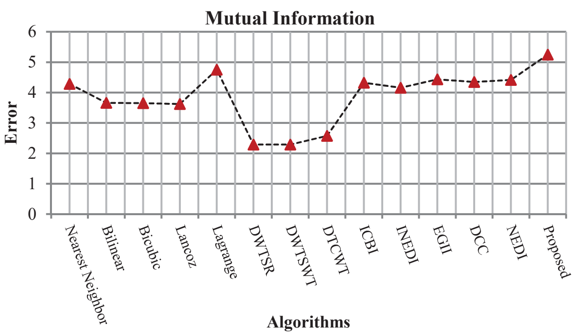

Fig. 9 Mutual information values of the head image obtained by zooming using various methods

D.Mutual Information

The mutual information for the image of head is reported in Table I, Figs. 9 and 10. A narrow pattern observed in mutual information pattern gives the high degree of relatedness between the images. Ideally, this narrow pattern should be a diagonal line. Mutual information depends upon the content of images. For the head image, the proposed method is found to give much narrow pattern than other algorithms. Among the traditional interpolation methods, the Lagrange method gives highest value of mutual information. In edge directed interpolation methods, the NEDI method gives the high degree of mutual information. But all the methods have less degree of mutual information than the proposed method. In summary from the results and discussion presented, it is concluded that the proposed method is capable of zooming low resolution medical images and is suitable to use in real time.

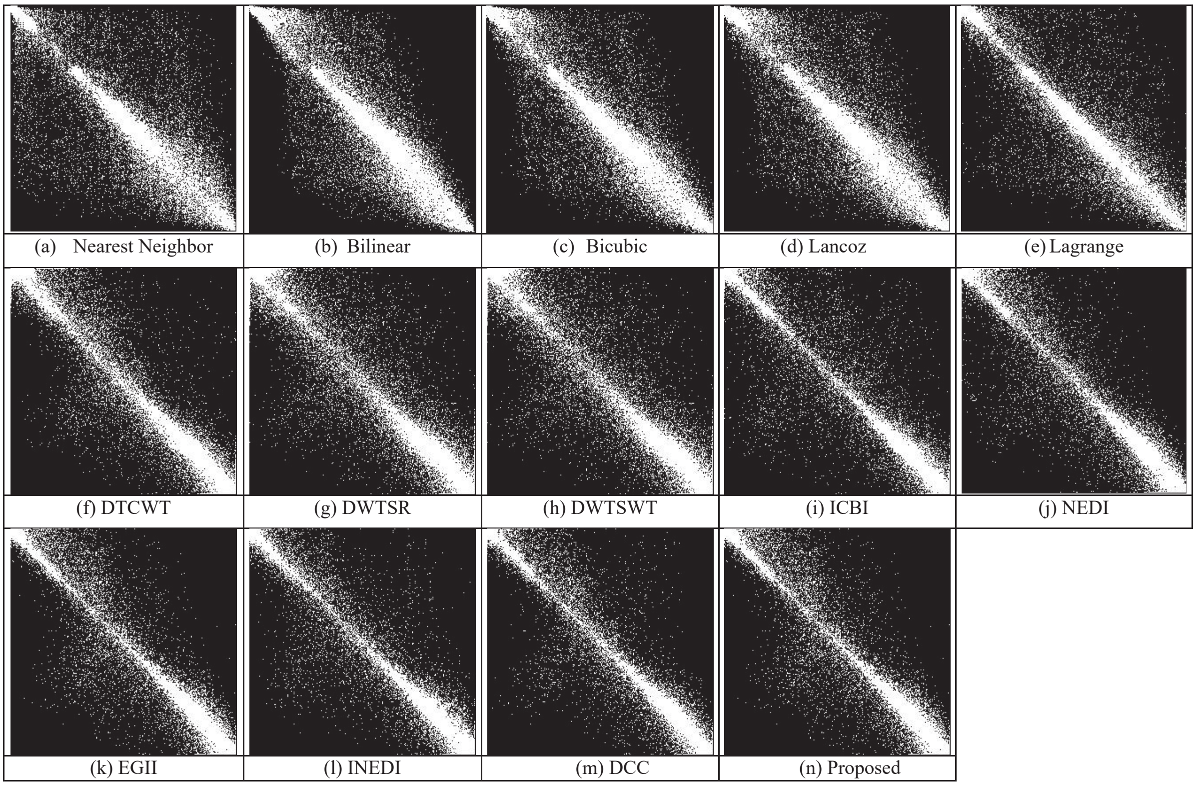

Fig. 10 Mutual Information results of zooming the image of head by a factor of 2 using (a) Nearest Neighbor, (b) Bilinear, (c) Bicubic, (d) Lancoz, (e) Lagrange, (f) DWTCWT, (g) DWTSR, (h) DWTSWT, (i) ICBI, (j) NEDI, (k) EGII, (l) INEDI, (m) DCC and (n) Proposed method

IV. Conclusions

This paper is focused on zooming low resolution digital medical images. A model to gain information related to pixels from a selected area and its surrounding area in an image is presented. The algorithm is implemented in Mat lab and its performance is analyzed for various low resolution medical digital images. However, for illustration and simplicity, the results obtained for a CT scan image of head is presented in this paper. Both the quantitative and qualitative parameters are used for evaluating the performance of this algorithm. Various EDI methods and wavelet based image zooming methods are also evaluated. The performance of proposed algorithm is also compared with various other traditional algorithms. From the results, the nearest-neighbor method is found to be most efficient from the computation point of view. However, at the cost of poor quality, with appearance of jaggies, staircases and non-uniform brightness. This is because of the low interaction with nearby pixels, while computing the target pixel. Bilinear, Bicubic and Lancoz interpolation methods have nearly the same visual appealing results; whereas, Lagrange, DWTSR and DWTST methods have nearly same performance in visual appearance. However, the edges in images produced by all these methods are not sharp. For EDI techniques, the ICBI & EGII has comparatively poor visual appealing than the NEDI, INEDI and DCC. From the results obtained, INEDI & DCC is found to have sharper edges than the DCC. However, the proposed algorithm has sharp edges than all other methods. Thus, the proposed algorithm produced better visual appearance of zoomed medical images.

Lancoz is found to be the fastest method, with Bicubic next to it. The proposed method slightly more time than Bicubic because of added computations to it. In summary, from all the results obtained it is concluded that the proposed method performs better than other mentioned methods; and is suitable for real time processing. In future, this algorithm will be implemented on real time devices and further work will be done to increase its speed.

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