

Super Ellipse Window Based Image Zooming Algorithm

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Submitted By
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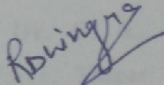
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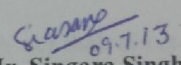
Certificate

I hereby certify that the work which is being presented in the thesis entitled, “**Super Ellipse Window Based Image Zooming Algorithm**”, in partial fulfillment of the requirements for the award of degree of Master of Technology in Computer Science and Applications submitted in School of Mathematics and Computer Applications(SMCA), Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Mr. Singara Singh** and refers other researcher’s work which are duly listed in the reference section.

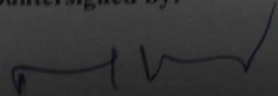
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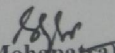

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Abstract

Image zooming deals with the enlargement of an image. While zooming an image, an image is magnified but it introduces certain artifacts. These artifacts are jaggies, blurring and ghosting. So while zooming an image these artifacts should be reduced.

In this thesis, Introduction gives a clear picture about the type of image processing, different formats of images along with the brief introduction about image zooming and its interpolation techniques. It also compares the interpolation techniques on the basis of visual and computational properties.

Literature survey gives the details of the category of algorithms i.e. adaptive algorithm and non-adaptive algorithm with detailed description of Pixel replication, Bilinear interpolation, Bicubic interpolation, Filtering methods, Learning based algorithms. It also describes the literature survey of the image zooming interpolation techniques.

Image causes a lot of problems when it is zoomed so in order to reduce these artifacts and produce sharp images an algorithm is proposed along with the details of two existing algorithms i.e. New Edge Directed Interpolation (NEDI) and Improved New Edge Directed Interpolation (iNEDI). The proposed algorithm provides an improvement over the existing algorithms which was visible through images and also through a quantitative measure known as Peak Signal to Noise Ratio (PSNR). The proposed algorithm provides maximum PSNR improvement of 0.8 dB over NEDI and 0.7 dB over iNEDI. But it provides 1dB less than MEDI.

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Abbreviations

BMP	Bitmap
EASE	Error Amended Sharp Edges
GIF	Graphic Interchange Format
HR	High Resolution
iNEDI	Improved New Edge Directed Interpolation
JPEG	Joint Photographic Expert Group
LAZ	Local Adaptive Zooming
LR	Low Resolution
MSE	Mean Square Error
MMSE	Minimum Mean Square Error
NEDI	New Edge Directed Interpolation
PICT	Picture
PNG	Portable Network Graphics
PSNR	Peak Signal to Noise Ratio
RS	Resolution Synthesis
TIFF	Tagged Image File Format

1.1 Introduction

An image may be defined as a two dimensional function $f(x, y)$ where x and y are spatial (plane) co-ordinates. The amplitude of 'f' at any pair of co-ordinate (x,y) is called the intensity or gray level of the image at that point. The elements of image are called pixels (short for **picture elements**), and they are arranged in a grid format with each pixel containing information about its colour or intensity [21]. There occurs a number of processes that can be performed on an image. These processes include image zooming, image segmentation and various others processes. The technique used for image zooming is interpolation. Image interpolation is the technique to find unknown pixel with the help of known pixels. When an image is zoomed by an image zooming algorithm an output image which is obtained is enlarged. Here the input given is an image which is passed through an image zooming algorithm and the output consist of an enlarged image. The output image obtained is detailed and is of high resolution. There are a number of image zooming algorithm ranging from traditional nearest neighbor interpolation to algorithm of image interpolation based on fuzzy logic. Every interpolation algorithm has its own pros and cons, some are faster while others produce a high quality enlarged image. Image processing is one of the fastest growing technologies. A lot of work is being done and also going on in this field. Basically there are two types of image processing:

Analog Image Processing: This process refers to the changes or amendment that is being made to an image by using electrical means like television imagery. Analog image processing is any image processing task conducted on two-dimensional analog signals by analog means.

Digital Image Processing: This type of image processing makes use of digital computers to process an image. In digital image processing we require either the full image or the part of image which is to be processed from the user's point of view like the radius of object etc. As digital system is in widely applied in various areas, producing digital images of good contrast and detail is strong in demand specially in

areas like vision, remote sensing, model identification and fault detection. There are various advantages of using digital image processing like preservation of original data accuracy, flexibility and repeatability. Digital image processing involves scaling as an important area. Scaling operation plays an important role in digital images. Scaling involves shrinking or zooming of a digital image. Shrinking or sub sampling refers to reduction of image pixels. Shrinking is basically used for compression and thumbnail view of images. In thumbnail view we require to resize the digital image in smaller size and for this we require to reduce the number of pixels from the original image. While performing sub sampling the number of pixels is reduced and this reduction of number of pixels is done by replacing the group of pixels by a chosen random pixel value in that group. Interpolation is the method which is used to find the new unknown pixel from the earlier known pixels. There is a large variety of interpolation techniques which are used to find the unknown pixels. Image zooming is among the fundamental image processing operations. Methods like Joint Photographic Experts Group (*JPEG*) are usually an acceptable standard while it is among lossy methods, but still has a good quality outcome. Zooming is related to resizing up of images to be able to see more detail, increased resolution using optics, printing techniques, or digital processing [21,5]. The applications of image interpolation range from the commonplace viewing of online images to the more sophisticated magnification of satellite images. With the rise of consumer-based digital photography, users expect to have a greater control over their digital images. Astronomical images from rovers and probes are received at an extremely low transmission rate (about 40 bytes per second), making the transmission of High Resolution (*HR*) data infeasible. In medical imaging, neurologists would like to have the ability to zoom in on specific parts of brain tomography images. Zooming can be used to resize a video frame to fit the field of view of a projection device, which may help to reduce blurring. Finally, the most obvious application of image zooming is to simply allow one to enjoy a larger version of a favorite image obtained from any commercially available digital imaging device such as a camera, camcorder or scanner.

1.1.1 Different Formats of Digital Images

The format use to save the image file will be determined by its intended use. Some formats are common for the web, others for presentation or print. Some of the most common are listed below:

PICT: Stands for 'Picture' and is used for storing 8-bit, 16-bit or 24-bit color or gray scale images. *PICT* files work well for the onscreen presentation of graphics.

TIFF: Stands for 'Tagged Image File Format' and is used to exchange files between applications and computer platforms. It is supported by virtually all paint, image editing, and page-layout applications.

GIF: Stands for 'Graphic Interchange Format' and is used for simple web images. Because *GIF* files are limited to 256 colors, it is suggested that you should not use this format for photographs or other images with high color ranges.

JPEG: Stands for 'Joint Photographic Experts Group'. *JPEG* is actually a standard method for compressing graphics by removing non-essential information. A *JPEG* file can be created from most file formats and is frequently used for web-based images because of its small file size.

BMP: Stand for 'Bitmap' and this format is used for Images that are simple black and white. Note that 'black and white' refers to those images that have only two tones, either black or white.

PNG: Stands for 'Portable Network Graphics, format, an open source substitute for *GIFs*. *PNGs* provide a high lossless compression rate than *GIFs*, and help to reduce cross-platform differences in image display quality, among other technical advantages.

For the purposes of sharing files, adding images to PowerPoint presentations and posting them to websites, the formats you will use are *JPG* and *GIF*. These files are almost universally readable by image editors, work well on websites, and offer small file sizes with reasonable quality levels [1,3, 4].

1.2 Image Zooming

Image zooming is the method of enlargement and magnification of images for the better view of digital images. In digital image processing, image zooming is the method of over sampling. In zooming new locations are created and on those new

locations we assign the new pixel value. A zooming algorithm takes an image as an input and creates a new larger image as output. For this various transformation are applied to the input image and the output is a detailed, enlarged image which is less noisy. However speed and efficiency are hard to balance while performing various transformations. Image zooming is among the fundamental image processing operations.

Traditional image zooming techniques use up-sampling by zero-insertion followed by one-dimensional filtering to interpolate the *HR* samples. The main drawback of this approach is that the frequency content of the high-resolution image is the same as the Low Resolution (*LR*) image. This is due to the fact that linear techniques are incapable of introducing new information into the image. The lack of new high frequency content results in a variety of undesirable image artifacts such as blocking, staircase edges and blurring.

1.2.1 Definition of Zooming

Magnification is the process of enlarging something only in appearance, not in physical size. This enlargement is quantified by a calculated number also called "magnification". When this number is less than one it is referred as reduction in size, sometimes called "minification" or "de-magnification".

Typically magnification is related to scaling up visuals or images to be able to see more details, increased resolution using microscope, printing techniques. In all cases, the magnification of the image does not change the perspective of the image.

- **Linear or transverse magnification:** For real images, such as images projected on a screen, *size* means a linear dimension (measured, for example, in millimeters or inches).
- **Angular magnification:** For optical instruments with an eyepiece, the linear dimension of the image seen in the eyepiece (virtual image in infinite distance) cannot be given, thus *size* means the angle subtended by the object at the focal point (angular size). Strictly speaking, one should take the tangent of that angle (in practice, this makes a difference only if the angle is larger than a few degrees).
-

1.3 Interpolation: A Method of Image Zooming

Image zooming is an important process in image processing. It is a process to recover image from distorted to its original image. The restoration of degraded images can be applied in many application areas that are needed to repair images. Image interpolation is one part of image restoration. Very often data is specified on a regular grid (values are written at the vertex position of a 2 Dimensional(D) or $3D$ grid) or on a line (in the $1D$ case) but the program needs to evaluate values at random position on that grid [1].

Interpolation (sometimes called resampling) is an imaging method to increase (or decrease) the number of pixels in a digital image [4]. It is applied in diverse areas ranging from computer graphics, rendering, editing, medical image reconstruction, to online image viewing. Interpolation is done by approximating the required function using simpler functions such as, polynomials. This permits input values to be evaluated at arbitrary positions in the input, not just those defined at the sample points. The goal of image interpolation is to produce acceptable images at different resolutions from a single LR image. The actual resolution of an image is defined as the number of pixels, but the effective resolution is a much harder quantity to define as it depends on subjective human judgment and perception.

The image quality highly depends on the used interpolation technique. Image interpolation works in two directions, and tries to achieve a best approximation of a pixel's color and intensity based on the values at surrounding pixels. The following example illustrates how resizing / enlargement works.

2D Interpolation →

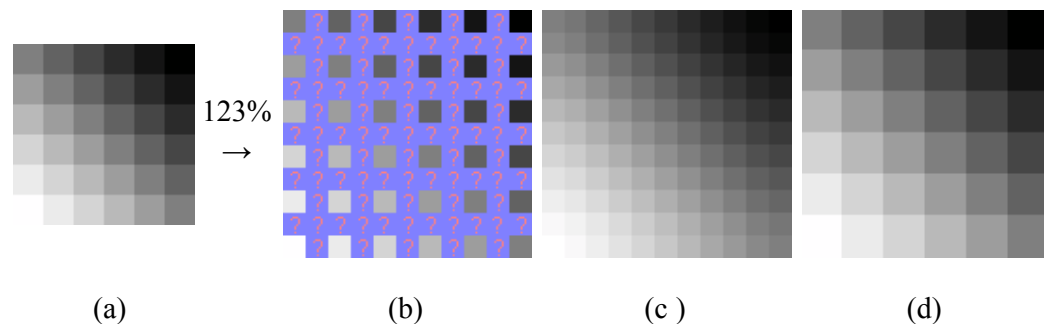


Figure 1.1 (a)Original image (b) Before interpolation (c) After interpolation
(d) No interpolation

Digital image interpolation is the recovery of a continuous intensity surface from discrete image data samples. For instance, *HR* cameras digitize scenes at a much finer scale and so contain more information than *LR* cameras. All pictures and images cannot be stored by *HR* due to equipment, memory, in the case of the Internet, bandwidth limitations. There are various techniques image zooming techniques which are as follows:

There are various zooming techniques. Some of them are given as follows:

- **Linear Techniques:** Linear techniques, [4]–[7], use linear space-invariant filters to interpolate the high-resolution samples. Common choices of interpolation filter are nearest neighbor, bilinear, bicubic, quadratic, Gaussian and various types of spline functions [4]. Since the theory behind linear interpolation is well established, most of the research in this approach is focused on finding new filters which reduce artifacts introduced by the traditional filters, as well as more efficient implementations. In [5], a modified version of the B-spline is used to obtain interpolation filters with better frequency responses, [6] proposes an *FIR* filter design method that attempts to account for the properties of human vision, and [7] develops non-separable cubic convolution kernels to replace the traditional separable cubic filter. Due to the relative simplicity and efficiency of linear interpolation techniques, they are the most common approach provided by commercial software packages such as Adobe PhotoShop and Matlab.
- **Non - Linear Techniques:** Non-linear techniques, [8]–[10], use non-linear optimization processes constrained by certain image features. In [8], a method which optimizes a convex cost function based on the approximation of the gradient of the high-resolution image from the low-resolution image is presented. This method attempts to preserve edges by adding constraints on their orientation. A different approach is taken by [9], in which the problem is viewed from a geometric perspective. In this method, an image is first linearly interpolated. Then spatial regions of constant intensity are wrapped such that level curves are smoothed, thereby sharpening boundaries between regions. In

[10], a regularized image interpolation method is proposed which focuses on the correct modeling of the image acquisition and display processes.

- **Transform Techniques:** Transform techniques, [11, 12], are primarily focused on the use of multi-resolution decomposition, followed by interpolation applied to each level of the decomposition and/or extrapolation of higher resolution levels. These approaches aim at synthesizing the high frequency components of the magnified image by adapting the interpolation to suit the frequency content contained at each level of decomposition. In [11], higher resolution levels of Laplacian pyramid decomposition are extrapolated from lower ones. Another approach, taken by [12], makes use of a filter bank which extracts edge directional components from the low resolution image and interpolates each sub-band in a directional specific way as to enhance the edges it contains.
- **Statistical Techniques :** Statistical techniques, [13, 14], attempt to estimate the high-resolution image based on the properties of the given low-resolution image. In [13], the high-resolution image is modeled by a Gibbs-Markov random field with specially selected clique potentials to classify the properties of each neighborhood. The chosen potentials allow the classification of pixels by degrees of smoothness or discontinuity, thereby being able to properly handle edges. Another approach creates a set of pixel classification gathered from the statistics of pixels in typical training images [14]. Once trained, the algorithm interpolates an image by estimating the best filter coefficients (in the mean-square sense) for each neighborhood. From these four categories, only the first is not an adaptive technique. Non-linear and statistical techniques seem to have found greater use in highly specialized applications such as super-resolution, where a sequence of video frames are combined to form a single, high-resolution image, and medical imaging, where the algorithms are tied to the underlying physics of the image-acquisition process or are highly constrained by prior knowledge of image features.

A need for *LR* images in interpolation algorithms gives end-users a magnified image of higher resolution for viewing, printing, editing, and creating.

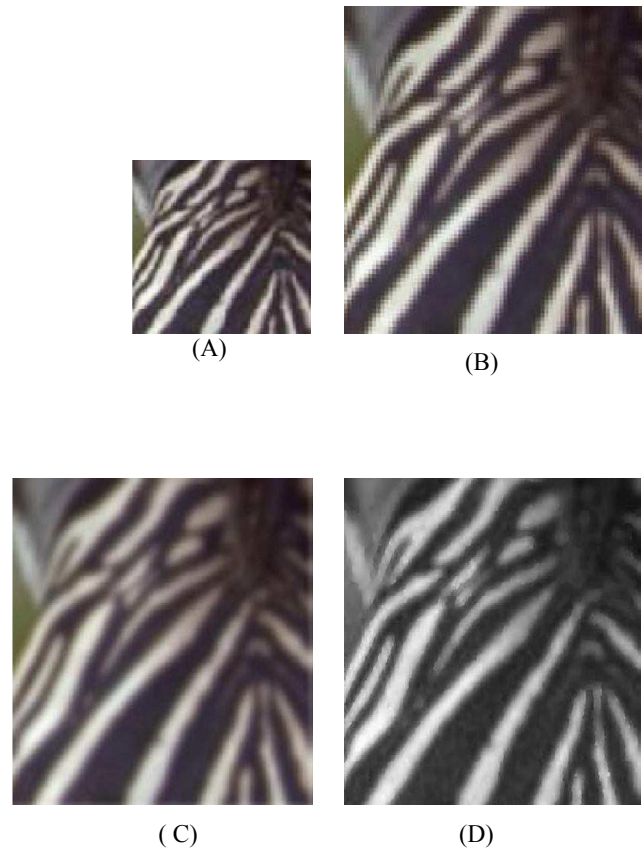


Figure 1.2 (A) Original Image (B) Jaggies in Image (C) Blurring in Image (D) Ghosting in Image

The above figure shows the three major artifacts while zooming an image. These artifacts are shown in Figure 1.2(a) jaggies are the blocks are formed due to replication of pixels, Figure 1.2 (b)blurring is the unclarity of the image, Figure 1.2(c) ghosting is the distortion of the image. The interpolation algorithms attempt to solve these artifacts in many ways. Some factors must be kept in mind while making an algorithm like speed (zooming should not take much time for enlarging an image) and memory requirement (the algorithm should not take much memory space) [2].

1.4 Algorithm Subdivision

Common interpolation algorithms can be grouped into two categories: adaptive and non-adaptive. Adaptive methods change depending on what they are interpolating, whereas

non-adaptive methods treat all pixels equally. So the image zooming depends on the type of algorithm an image is using for the enlargement purpose.

1.4.1 Non-Adaptive Algorithms

Non adaptive interpolation, interpolates by fixed pattern for all pixels has the advantage of easy to perform and low calculation cost [3]. Depending on their complexity, these use anywhere from 0 to 256 (or more) adjacent pixels when interpolating. The more adjacent pixels they include, the more accurate they become, but this comes at the expense of much longer processing time. These algorithms can be used to both distort and resize a photo. These are :

- Nearest Neighbor
- Bilinear
- Bicubic
- Lanczos
- Bilinear b/w blur

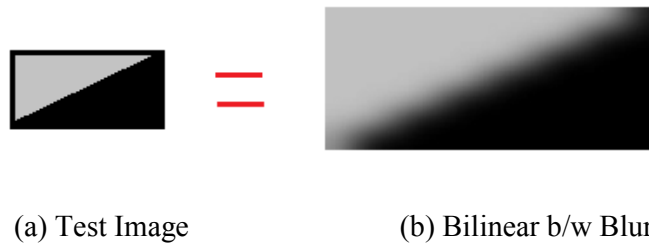


Figure 1.3 Enlarged Image using Non-Adaptive Algorithm

The zoomed image of Figure 1.3(a) using adaptive algorithm is shown in Figure 1.3(b).

1.4.2 Adaptive Algorithms

Adaptive interpolation estimates lost pixel values using feature of surround pixel[15]. However, it has a lot of calculations. Many of these apply a different version of their algorithm (on a pixel-by-pixel basis) when they detect the presence of an edge aiming to minimize unsightly interpolation artifacts in regions where they are most apparent. These algorithms are designed to maximizing the artifact-free detail in enlarged photos, so some cannot be used to distort or rotate an image. These are:

- Nearest Neighbor
- Bicubic
- Genuine Fractals
- Photo Zoom
- Smart Edge



(a) Test Image

(b) Smart Edge

Figure 1.4 Enlarged Image using Adaptive Algorithm

The zoomed image of Figure 1.4(a) using adaptive algorithm is shown in Figure 1.4(b).

1.5 Interpolation Methods

Interpolation is the process by which a small image is made larger. Software tools stretch the size of the image and generate pixels to fill in the blanks. Interpolation is the estimation of values in a function between known points. Interpolated images produce smoother lines and a better large print than if the original, small image was simply printed large. There are several basic function-fitting or interpolation methods, including pixel replication, bilinear interpolation, and bicubic interpolation.

1.5.1 Pixel Replication

Pixel replication is the simplest interpolation from a computational standpoint is the nearest neighbor, where each interpolated output pixel is assigned the value of the nearest sample point in the input image. This technique is also known as point shift algorithm and pixel replication. The interpolation kernel for the nearest neighbor algorithm is defined as The frequency response of the nearest neighbor kernel is

$$h(x) = \begin{cases} 1, & 0 \leq |x| < 0.5 \\ 0, & 0.5 \leq |x| \end{cases} \quad \dots (1.1)$$



Figure 1.5 (a) Down sampled image (b) 3× Pixel Replication image (c) Original Image

A type of up sampling of a digital image, effected by increasing the number of pixels in an image, but without adding any data or detail. In Figure 1.5, original image Figure 1.5(c) down sampled by a scale of three. Figure 1.5(a) then magnified 3 times using pixel replication. The new colored pixels are often interpolated using the original pixels. Image quality is not often very high when images are enlarged in this manner. As shown in Figure 1.5(b), images made with pixel replication are extremely jagged. Hence the higher resolution image is blocky and jagged, since the original pixels have grown by exactly the magnification scale.

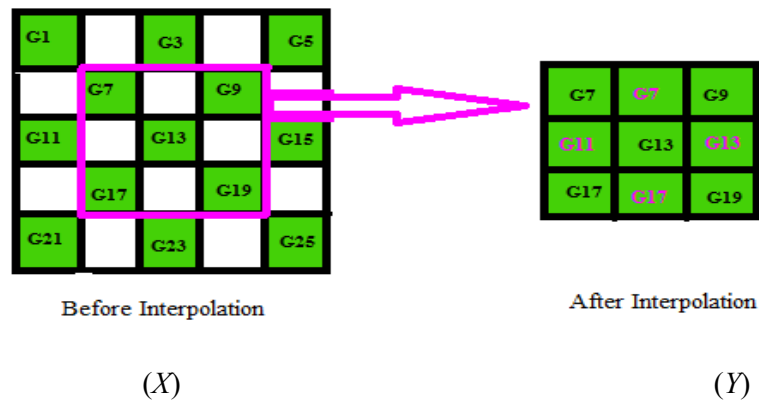


Figure 1.6 Pixel Replication Working(X) Before Interpolation(Y) After Interpolation

The above Figure 1.6 shows how pixel replication actually works. The X image is $2\times$ magnified and in the particular pattern and hence we got the image Y .

1.5.2 Bilinear Interpolation

In mathematics, bilinear interpolation is an extension of linear interpolation for interpolating functions of two variables (e.g., x and y) on a regular grid. The interpolated function should not use the term of x^2 and y^2 but xy , which is the bilinear form of x and y .

Bilinear interpolation considers the closest 2×2 neighborhood of known pixel values surrounding the unknown pixel. It then takes a weighted average of these 4 pixels to arrive at its final interpolated value.

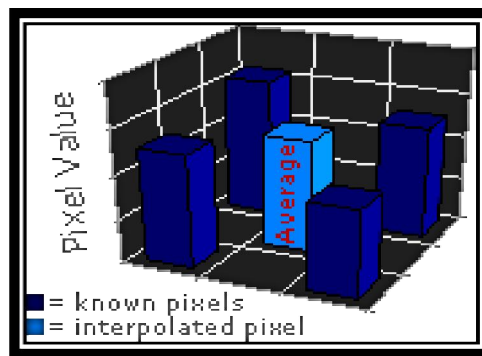


Figure 1.7 Bilinear Interpolation

This results in much smoother looking images than nearest neighbor.[16] Weight is determined by assigning weighted value of 4-nearest neighbor pixel (as shown in Figure 1.7) to generated output pixel. Each weighing value is proportional to distance from each existing pixel. This method has advantage of simple calculation. And output image using bilinear interpolation is better than nearest neighbor replication. However, blurring effect occurs by averaging surrounded pixels. Figure 1.8 gives an example of linear interpolation in one dimension. As can be seen from the figure, unknown pixel values in the high-resolution grid are estimated to exactly lie on the line that fits between two original pixel values.

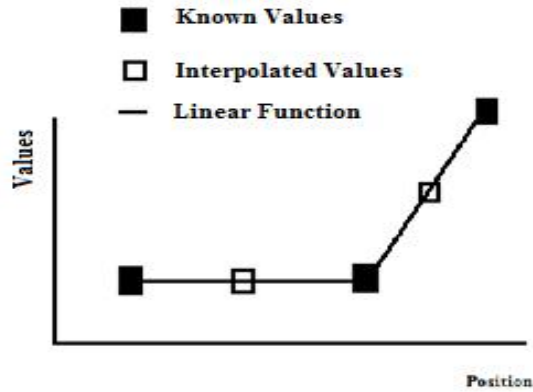


Figure 1.8 Linear Interpolation

A linear function is fit between known values and all interpolated values fall on the fitted line. For example, in 2 x magnification in one dimension, there would be only one unknown pixel between known pixel values. The pixel value would be calculated by taking half of the first known pixel plus half of the second known pixel. By this, interpolation is performed in one dimension. Linear interpolation extends easily into two dimensions.

Bilinear interpolation can be described as linear interpolation in one dimension followed by linear interpolation in the other. For example, if we are estimating a pixel between a block of four original values, then two temporary values are firstly created: a linear interpolation between the top pair of pixels; and the second, a linear interpolation between the bottom pair of pixels as shown in Figure 1.9. Lastly, a linear interpolation is performed between the two temporary values.

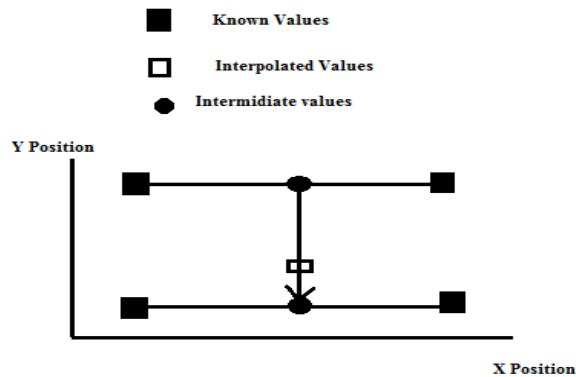


Figure 1.9 Bilinear Interpolation



(a) Down Sampled image



(b) Pixel replication image



(c) $3 \times$ Bilinear image



(d) Original image

Figure 1.10 Pixel Replication and Bilinear Interpolation.

In Figure 2.7, original image Figure 1.10(d) down sampled by a scale of three , Figure 1.10(a) then magnified $3 \times$ Bilinear interpolation, Figure 1.10(b). Bilinear interpolation results in much smoother looking images than nearest neighbor. This can be seen in Figure 1.10. Due to the interpolation process, the image becomes slightly blurred since pixel values are spread throughout the high-resolution grid.

1.5.3 Bicubic Interpolation

Bicubic interpolation is an extension of cubic interpolation for interpolating data points on a two dimensional regular grid. The interpolated surface is smoother than corresponding surfaces obtained by bilinear interpolation or nearest-neighbor interpolation.

Bicubic interpolation uses the information from an original pixel and sixteen of the surrounding pixels to determine the color of the new pixels are created from the original pixel. Bicubic interpolation is a big improvement over the previous two interpolation methods for two reasons the first is bicubic interpolation uses data from a larger number of pixels and secondly because bicubic interpolation uses a bicubic calculation that is more sophisticated than the calculations of the previous interpolation methods as shown in Figure.1.11. Bicubic interpolation is capable of producing photo quality results and is probably the most commonly used method.

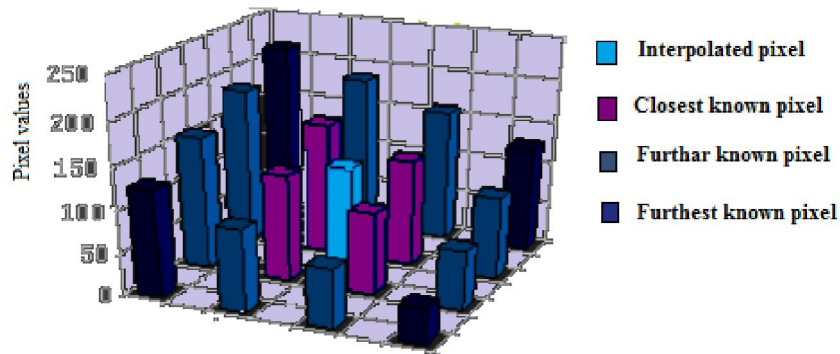


Figure 1.11 Bicubic Interpolation

Bicubic interpolation works same as bilinear interpolation, except using a cubic function instead of a linear function to estimate pixels between known values as in Figure 1.11. This is a high performance pixel interpolation that gives outstanding results, both in calculation speed and in quality of results. It is usually the best choice when not too radical downsampling operations are involved in geometrical transformations. This form of interpolation has advantages and drawbacks over bilinear interpolation. First, calculating the cubic polynomial in a specific area of the image is more computationally expensive than simple linear fits and also requires a larger neighbor to calculate the curve. A linear function fits straight lines between known points, and a cubic function fits cubic splines. On the other hand, jaggies are more distinguished since the image isn't blurred.

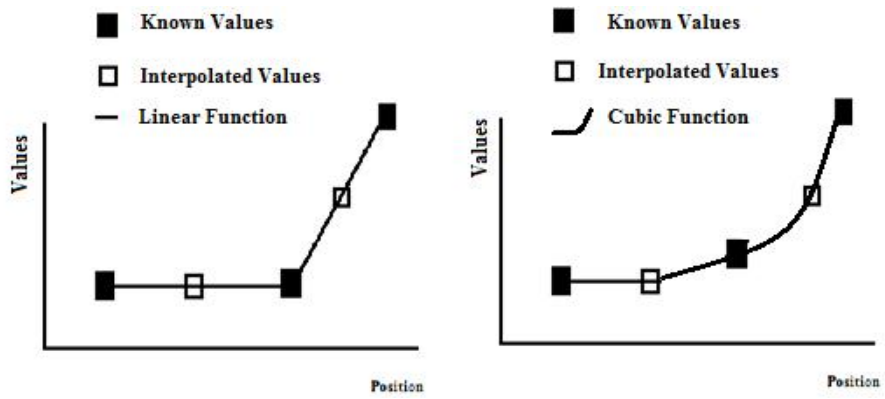


Figure 1.12 Linear vs Bicubic Interpolation



(a) Down sampled image



(b) 3x Bilinear image



(c) 3x Bicubic image



(d) Original image

Figure 1.13 Bilinear vs Bicubic Interpolation.

A comparison of bilinear and bicubic interpolation is shown in Figure 1.12. In Figure 1.13, original image Figure 1.13(d) down sampled by a scale of four as shown in Figure 1.13(a) then magnified $3 \times$ bicubic interpolations in Figure 1.13(c). Bicubic interpolation produces magnifications, which are sharper and more jagged (lena for example) than bilinear interpolation.

1.6 Filtering Methods

Another branch of magnification techniques uses filtering approaches to magnify low-resolution images. Filter-based methods use sampling theory to attempt to create perfect interpolation of images. A perfect reconstruction of sampled points is accomplished by convolving these points with a sinc function in the spatial domain. However, this is impossible due to the infinite extent of the sinc function. Filter-based methods overcome this by either truncating the sinc function, or even approximating a truncated sinc function with a cubic spline. Due to these approximations, errors are introduced into the interpolation of the data, causing both blurring, jaggies, and ringing. Another limiting factor with filter based methods is the increased computational cost. Even with a truncated sinc function, the kernel can be quite large. For instance, the Lanczos [15] filter's kernel is 16×16 , making the algorithm much more computationally expensive than Bicubic Interpolation.

1.7 Learning Based Algorithms

Another general area of interpolation methods is learning-based algorithms. These algorithms pull information from training data in order to aid in the interpolation and create high resolution data [16, 17, 18, 19, 20]. For example, “Optimal face reconstruction using training” by Muresan and Parks [17] uses pairs of low-resolution and high-resolution images of faces. This training data is then used to aid in the interpolation of low resolution face images. Data in the high resolution image is not simply interpolated but can also be “created” by analyzing similar areas of face pairs. This facet of data creation is unique to learning-based algorithms. Unfortunately, these algorithms also have several drawbacks. First, analyzing training data can be computationally expensive. Second, the training data can require large amounts of storage memory. Also, specific training data is required for images. For instance, to make the most accurate face magnification, you need a large collection of face images

to train with. Also, certain learning-based algorithms, such as Image Analogies [20], require extensive user interaction to identify regions in an image. These drawbacks hinder extensive use of learning-based algorithms for image magnification.



Figure 1.14 Optimal Face Reconstruction Example.

In Figure 1.14, original image (1.14a) is down sampled by a scale of four (1.14b) then magnified by 4 times using Optimal Face Reconstruction [17]. Learning-Based algorithms can reconstruct areas such as the eyes far better than algorithms such as Bicubic Interpolation, but Learning-Based algorithms require specific training data in order to produce quality results.

1.8 Characteristics of Image Zooming Techniques

Zooming is used for several purposes like image reconstruction, improving image display for humans, reducing artifacts, correcting geometrical distortion introduced by optical sub system, obtaining sub pixel accuracy and computing the new pixel position for rotation. There are following reasons that make image zooming an area for research:

Speed: Zooming operation requires an image to be enlarged at one click of button as slow zooming operation might irritate user.

Clarity: Sharpness of the image must be retained. When the image is zoomed certain areas get blurred or the image quality decreases so the quality of the new zoomed image should be same as the original image.

Smoothing: Neighboring pixels should have same continuity in color except for the edge pixels i.e. if there occurs mismatch in color combination than the quality of the image gets deteriorated.

Memory Requirement: Zooming operation requires a lot of memory for its processing to be done. So a large amount of memory is required in order to handle the zooming process effectively.

1.8.1 Comparative Study of Image Zooming Techniques

The image zooming techniques can be compared on the output of interpolated image that is generated. This comparison is based on two things i.e. visual properties and second is computational complexity.

i. Visual Properties:

- **Contrast Invariance:** The method should preserve the luminance values of objects that are present in image and maintain the high contrast of an image.
- **Geometric Invariance:** The method should preserve the geometric features, subjective matter and size of objects of an image.
- **Over-Smoothing:** The method should not give rise to blocky regions in an image.
- **Edge Preservation:** After applying the method the boundaries, sharpness and edges should be retained.
- **Noise:** The method should not produce noise in the resulted image. The method should work for noisy and noise free images also.
- **Application Awareness:** Different applications have different requirements like efficiency, clarity, quality, sharp edges. The method should serve the

purpose. For example some application demands high quality in resulted image like medical images.

ii. Computational Property:

- **Sensitivity to Parameters:** The method should be generalized enough such that its performance should not vary as the internal parameters of images vary. These methods range from replication [10], Fractal based [1], Nearest-neighborhood interpolation [2], Bilinear [3], Bicubic, Cubic-spline [4], curvature-interpolation [5], Sinc, b-spline [6, 7], Wavelet-based [8], LLE based [8], Fuzzy logic based [9].

Chapter 2 Literature Survey

2.1 Introduction

A lot of people have researched on image zooming interpolation techniques. Some have researched on the hybrid approach; some have tried to improve the existing algorithms. So in this chapter the literature survey of image zooming interpolation technique is discussed.

2.2 Literature Survey

Parker *et al.* [1] provides with a comparative study on various interpolating methods ranging from the simple nearest neighborhood method to the complex cubic spline interpolation method. The nearest neighborhood method is the fastest amongst the all method but the quality of the enlarged image is very poor whereas the cubic spline method compromises with the speed but the quality of the enlarged image is very high.

Kris *et al.* [2] proposes an algorithm based on a source model emphasizing the visual integrity of detected edges and incorporates a novel edge fitting operator, A small neighborhood about each pixel in the low resolution image is first mapped to best fit continuous space step edge. The resulted expanded image is of sharper edges.

Jan *et al.* [3] propose a method which occurs in two phases one is rendering and the other is correction. In the rendering phase a high resolution image is generated from a low resolution image by filtering and then piecewise linear interpolation is done. In correction phase the mesh values generated from the rendering phase are corrected using disparity generated from the values generated from sensor model and true low resolution data.

Dildier *et al.* [4] proposed various projection methods in which induction of an image on to a set of acceptable super-resolution were carried out. In this the logic of increasing image resolution is stated as an inverse of image reduction .A projection of an image onto this set of images provide the best possible result.

Bryan *et al.* [5] presents the idea of geometric based interpolation that smoothly fits the isophote contours at all points in the image rather at selected points

in the image. By using level set methods for curve evolution, no explicit extraction and representation is required. This algorithm uses the earlier methods and then iteratively constructs isophotes using constrained smoothing.

Atkins *et al.* [6] proposed a new approach called resolution synthesis (RS). In RS, the pixel being interpolated is first classified in the context of a window of neighboring pixels; and then the corresponding high resolution pixels are obtained by filtering with coefficients that depend on the classification. RS is based on the stochastic model which tend to give a min MMSE (Minimum Mean Square Error).

Qing *et al.* [7] proposed a new method for image expansion. In this method the fidelity and the sharpness of the expanded image was taken into consideration. For achieving this goal edge-directed interpolation and edge sharpening methods were applied. After applying the operations a more natural and sharp expanded image was obtained with very less computational cost.

Yujin *et al.* [8] proposed an adaptive edge-directed interpolation algorithm using multi-directional neighboring pixels. In this the missing pixel is calculated as the weighted sum of 12 neighboring pixels. In this method the interpolation region selection method is also proposed which help to reduce the computational complexity. This proposed method results in restoring major edges with several direction.

Li *et al.* [9] proposed an edge directed interpolation algorithm for natural images known as NEDI. In this algorithm local covariance coefficients are estimated from a low resolution image and then use this covariance estimates to adapt the interpolation at a higher resolution based on the geometric duality of low resolution and high resolution covariance. It proposes an hybrid approach of switching between bilinear interpolation and covariance-based adaptive interpolation which reduced the computational complexity of the algorithm.

Sheng *et al.* [10], presents a method for image zooming using Quasi Hermite interpolation spline, which provides a smaller interpolation error, and reasonable computing times. Moreover, the method can preserve the contours or edges of images by adjusting the corresponding local parameters. The theoretic analysis and the experimental results show that the interpolation effects by the proposed approach are slightly better than those by the existing interpolation approaches. Also the run-times of this method are evidently superior to the method by normal cubic interpolation spline.

Zhiwei *et al.* [11] proposed a new Mathematical Technique for Image Interpolation using the nearest neighbor interpolation and bilinear interpolation together for magnifying images based on relative colour difference of pixels. The method is more suitable for non word images than word images.

Youngjoon *et al.* [12] proposed an Error Amended Sharp Edges(EASE) scheme, which is a modified bilinear method. In order to remove artifacts from image it tries to amend the interpolation error by employing the classical interpolation error theorem in an edge adaptive fashion. The high resolution images recovered were more sharper and clearer for all synthetic and natural images.

Hajizadeh *et al.* [13] proposed a new method that uses least directional differences of neighbor pixels, based on bilinear and bicubic interpolation methods for images. This improves zooming results even for low resolution images in both qualitative and quantitative aspects.

Wong *et al.* [14] proposes an adaptive-directional window selection for edge directed interpolation. It makes use of a practical directional elliptic window which works according to the edge direction sliding along an edge and then subsequently chooses the best window evaluated by choosing the elliptic window which has the lowest MSE (Mean Square Error). It helps to solve the covariance mismatch problem.

Tam *et al.* [15] proposes a Modified Edge Directed Interpolation (MEDI) method that eliminates the prediction error accumulation problem by adopting a modified training window structure and extending the covariance matching into multiple direction. It helps to preserve edge smoothness and sharpness as compared to other algorithms.

Wang *et al.* [16] presented two algorithm in this paper. One combines the pixel replication and bilinear interpolation by making a choice between them through through the difference of adjacent pixels. The second one is based on Locally Adaptive Zooming (LAZ) which helps to improve cubic spline interpolation. These two methods have their own advantages as first one is fast and the second have a better quality.

Nicola *et al.* [17] proposes a method *iNEDI* for image upscaling and helps to preserve edge features and natural appearance. In this paper *NEDI* was improved in order to reduce numerical instability and making the region used to estimate the low

resolution covariance adaptive. Although the computation is heavy but the results obtained are certainly of high quality.

Shveta *et al.* [18] proposed broad categorization and comparison of image zooming techniques. In this paper a comparison based study has been made of all the interpolation techniques ranging from traditional interpolation techniques to fuzzy based interpolation. Later the paper presents performance of these techniques on the basis of *PSNR*.

3.1 Introduction

When an image is zoomed, new pixels are inserted into the image in zooming process. While Image zooming a lot of artifacts are introduced, this deteriorates the quality of the zoomed image obtained. These artifacts occur because new pixels are introduced when we zoom an image. So this chapter explains the existing algorithms along with the proposed algorithm which is discussed in detail.

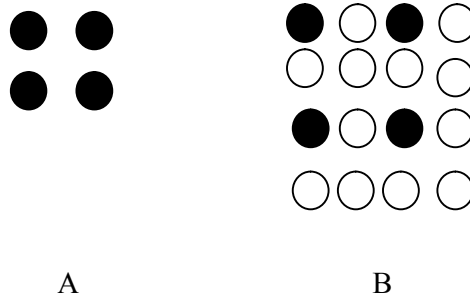


Figure 3.1 (A) Original Image (B) Zoomed Image

In Figure 3.1 the image A is magnified by 2 times to get image B. The white circles are the unknown pixel values and these are calculated using zooming technique. Now in Figure 3.1 image B has got 12 new pixels, so with the help of zooming technique, the value of these 12 pixels is calculated. There are various algorithms which are used to find the unknown pixels but the algorithms on which we focus are edge directed interpolation algorithms. These algorithms try to recover missing pixel information by assuming that there is a known relationship between a low resolution image and the high resolution image.

3.2 New Edge Directed Interpolation (NEDI)

Li *et al.* proposed *NEDI* [9] which is based on the assumption that the low

resolution covariance of pixel values in 5 pixels cross-like configurations is a good approximation of the high resolution covariance. The image is therefore approximately doubled in size by first putting original $N \times N$.

Pixels I_{LR} (the dashed window) in an enlarged $(2N - 1) \times (2N - 1)$ grid I (see Figure 3.2) and then filling in two steps the missing values as weighted averages of the four closest valued pixels. Figure 3.2 show the first step, inserting the new values in positions $(2i + 1), (2j + 1)$ using:

$$I_{2i+1,2j+1} = \alpha \cdot (I_{2i,2j}, I_{2i,2j+2}, I_{2i+2,2j}, I_{2i+2,2j+2}).$$

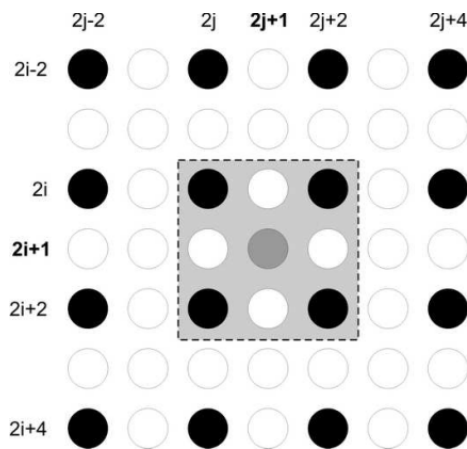


Figure 3.2 Original $N \times N$ pixel are placed in $(2N-1) \times (2N-1)$ grid.

The darker circles represent pixels from original LR grid, the white circles represent the pixels that are to be interpolated and the central circle is the pixel that is to be interpolated in the first step of interpolation. The value of α is calculated using:

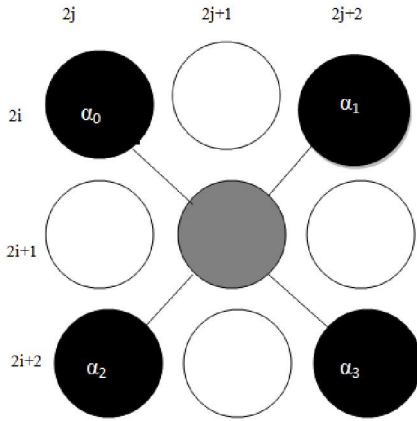


Figure 3.3 Calculation of α coefficients

The central point is calculated using fourth order interpolation algorithm that sums up the contribute of each diagonal neighbor multiplied by its alpha coefficients.

$$Y_{2i+1,2j+1} = \sum_{k=0}^1 \sum_{l=0}^1 \alpha_{2k+l} \cdot Y_{2(i+k),2(j+l)} \quad \dots(3.1)$$

NEDI estimates the alpha coefficients by solving by solving an unconstrained system of linear equations.

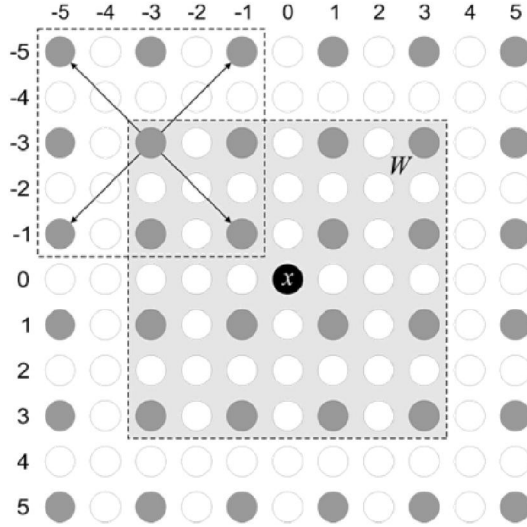


Figure 3.4 Square window W with its four diagonal neighbors

The system is obtained by assuming that the coefficients linking each pixel with its four diagonal neighbors do not change with scale and that they are constant in a squared window W centered in the pixel to interpolate.

$$MSE = \|\vec{y} - \vec{\alpha}C\|^2$$

$$\vec{y} = [\bar{x}_{-3,-3} \quad \bar{x}_{-3,-1} \quad \bar{x}_{-3,1} \quad \dots \quad \bar{x}_{3,3}]^T$$

$$C = \begin{bmatrix} \bar{x}_{-5,-5} & \bar{x}_{-5,-1} & \bar{x}_{-1,-5} & \bar{x}_{-1,-1} \\ \bar{x}_{-5,-3} & \bar{x}_{-5,1} & \bar{x}_{-1,-3} & \bar{x}_{-1,1} \\ \dots & \dots & \dots & \dots \\ \bar{x}_{1,1} & \bar{x}_{1,5} & \bar{x}_{5,1} & \bar{x}_{5,5} \end{bmatrix}$$

$$\frac{\partial(MSE)}{\partial \vec{\alpha}} = 0$$

$$-2\vec{y}C + 2\vec{\alpha}C^T = 0$$

$$\vec{\alpha} = (C^T C)^{-1} (C^T \vec{y})$$

The y vector consists of all the pixel values of the window W . The C matrix contains in each row the values of the four diagonal neighbors of each pixel listed in Y . C^T is the transpose of C . *NEDI* estimates the alpha coefficients by minimizing the Mean Square Error (*MSE*).

The second step fills the remaining gaps in the same way after a 45° rotation of the grid as shown in figure.3.5.

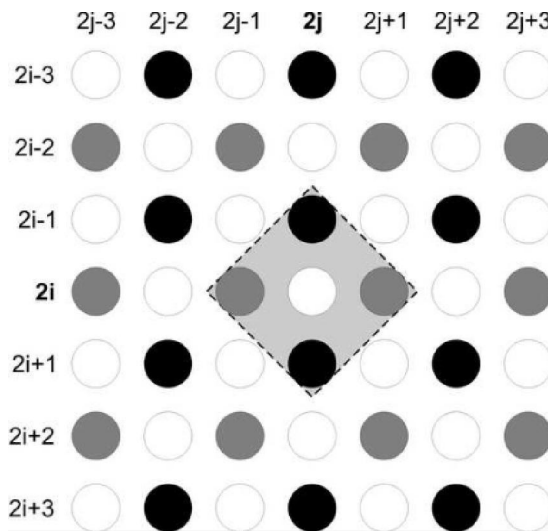


Figure 3.5 The remaining empty pixels are then filled after a 45° rotation

The black circle represent the pixel from the original *LR* image while the white pixels represent the pixels that are to be interpolated and the gray circle represent the pixels that were interpolated in the first step of *NEDI* using the equation 3.1.

Limitation of *NEDI*

- The assumption of local stationarity of the covariance (local regularity in curvature) is violated in several cases.
- Introduces several artifacts in high frequency regions.
- The system is often ill-conditioned. The use of larger windows improves the conditioning of the $C^T C$ matrix but produces the blurred images.
- Interpolated pixel values changes with global brightness.
- Very high computational complexity.

3.3 Improved New Edge Directed Interpolation(*iNEDI*)

iNEDI is the algorithm to fix or reduce the original *NEDI* problems and increase the interpolation accuracy of the zoomed image obtained as the output. The basic improvements include:

- **Non-edge Pixel Handling:** When the four pixels used to calculate the interpolated ones having similar gray level, there is no need to compute the *NEDI* coefficients . If the covariance is stationary, a small error causes a bad conditioning of the solution. If the local gray level variation is below a fixed threshold *iNEDI* uses the Bicubic interpolation. This choice gives better trade-off between edge direction preservation, accuracy and speed, using higher values of the threshold (only for strong edges).
- **Window Shape:** The square window W used by *NEDI* introduce some directional artifacts and is also non-isotropic. This problem was solved by using a circular window.

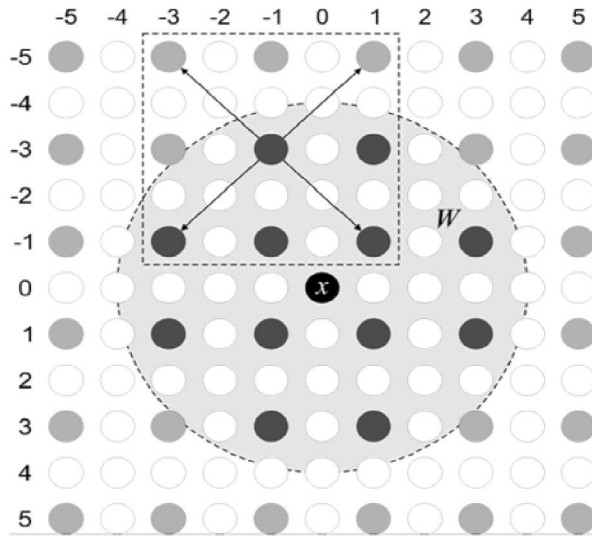


Figure 3.6 Circular window W to interpolate pixel

To account for various frequency regions *iNEDI* can dynamically change the radius from maximum to minimum radius.

- Edge Pixel Handling: *iNEDI* tried to exclude all the pixels from the circular window that are not the part of local edge and are not connected to the edge as shown in figure 4.7.

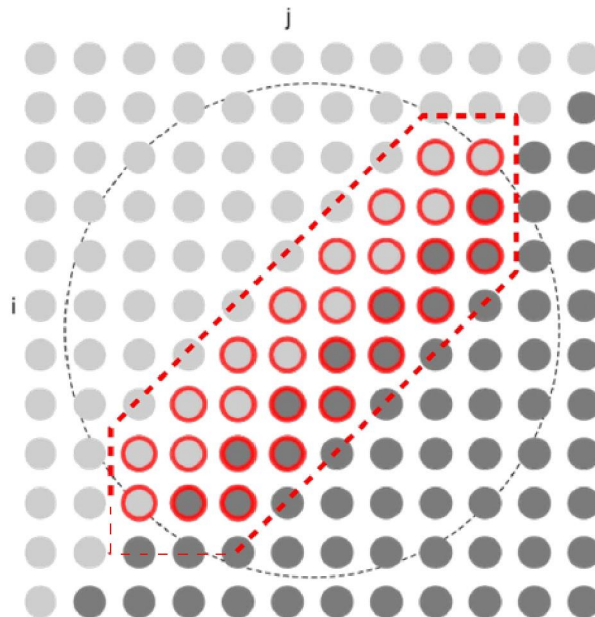


Figure 3.7 Image showing exclusion of non-local edge pixels

- Matrix Conditioning and Error Propagation: The over constrained system

$c\alpha=y$ is almost always ill-conditioned and a small error in y can produce a large error in the estimated value of α .

3.4 Problem Statement

After going through the literature survey it has been found that the performances of existing algorithms do not perform well for the images containing sharp edges and discontinuities. So there is the need to have an algorithm which can produce good quality images after zooming.

3.5 Proposed Algorithm

Shape of the window: In the proposed work, the shape of window is changed from a circle to a superellipse because the squared window can introduce directional artifacts and makes the algorithm non isotropic. These parameters can be reduced with the help of a superellipse window.

Pixel Handling : It is evident that when the four pixels used to calculate the interpolated ones have a similar gray level, there is no need to compute the *NEDI* coefficients, if the covariance is stationary, a small error causes a bad conditioning of the solution, even if, on the other hand the use of linear interpolation changes slightly the results. This problem is already handled in the original *NEDI* formulation, moving to bilinear interpolation if local gray level variation is above a fixed threshold *THR*. Bilinear approximation in low frequency regions is used. This choice, of course, does not give improvements in image quality when *THR* is low. It gives, however, the possibility of obtaining a good tradeoff between edge direction preservation, accuracy and speed using higher values of the threshold (i.e.using this algorithm only for strong edges).

Segmentation of edges : To segment the connected "edge region", we used a sort of region growing method defined as follows:

Start from 4 valued neighboring pixels of the central point and add iteratively neighbors (in the original grid) of these pixels with the following properties:

- The gray level between the maximum and the minimum value of the 4 neighbors is not lesser than *THR* (as in the central point).
- The gray levels of each pixel is not larger than the maximum value of the

gray level of the 4 neighbors of the central incremented by a threshold *MARGIN* and not lower than the minimum of the 4 neighbors of the central point decremented by the same *MARGIN*.

- The Euclidean distance between the pixel and the central point is less than r .
- Enlarge the "edge" region with the same rules by increasing r up to a maximum value R if the increment of the radius correspond to a decrement of the normalized residual of the least squares fit.

With this selective procedure and the control on the residual, we increase the probability of obtaining a good interpolation, but there is still the possibility of having unwanted high frequencies (that are not excluded by the constant covariance condition and may occur in case of a small number of samples in the fit). For this reason we put a further constraint by replacing any interpolated value outside the intensity range of the four neighbors with the closest of the values delimiting that range (i.e. maximum or minimum).

Global brightness Invariance : With the *NEDI* method, interpolated pixel values change with the global brightness, i.e. they do not depend only on differences between neighboring values, but also on the absolute value. This effect can be easily removed by changing the *NEDI* constraint by subtracting the average of the four neighbors intensities from the values inserted in C and y , i.e. replacing C with

$$\alpha = c^+ y$$

where $C^+ = (C^T C)^{-1} C^T$ is the Moore-Penrose pseudoinverse matrix, and find the minimum norm using the Singular value Decomposition. In this it helps to avoid the directed inversion of $C^T C$.

Steps of the Algorithm

Step 1: The image of size (H×K) is given as an input.

Step 2: In the second step the window chosen to be ellipsoid is used for the selection of y points. All pixel's distance from the central pixel is calculated and if this calculated distance is less than the maximum radius then these values are entered in

an array of Kernel Mask (KM).

Step 3: With each pixel intensity value, constant is added in order to have all the values far from zero. This help in reducing artifacts and wrong estimates.

Step 4: The image is expanded to the size of $(2H-1) \times (2K-1)$.

Step 5: In this step the image is padded so that it can store expanded image on a rotated matrix.

Step 6: Minimum and maximum values of 4 neighbors is calculated and if the difference between these values are less than or equal to a constant then Bicubic interpolation is used else this proposed algorithm is used.

Step 7: If proposed method is chosen then find only the connected pixels of the four neighbor of the pixel to be interpolated.

Step 8. Now since is bad conditioned therefore use the Moore-Penrose pseudoinverse matrix which is the generalization of the inverse matrix where $(C^T C)^{-1} (C^T \vec{y})$ is the Moore-Penrose pseudoinverse and find the minimum normal solution. In this way the $C^T C$ direct conversion is avoided.

Proposed algorithm is implemented in MATLAB and is applied on different images. Zoom factor is 2 and 4 and zoomed output images are shown in Figures 3.8,3.9 and 3.10. Proposed algorithm is compared with *NEDI* and *iNEDI* algorithms. This algorithm provides maximum 0.8 dB higher than *NEDI* and maximum 0.7 dB higher than *iNEDI*.

Table 3.1 PSNR of Different Images Zoomed by a Factor of 2

Image Name	NEDI	iNEDI	Proposed
Boat	25.0981	25.6871	26.1011
Pepper	26.0912	26.1350	26.6182
Bridge	21.6621	21.9812	22.3015
Zelda	29.6118	30.0912	30.3396
Sailboat	24.0765	25.0256	25.6280
Airplane	24.0612	24.2167	24.8267
Baboon	19.7431	20.1318	20.1907
Photo1	17.1012	17.3410	17.8523
City	23.3518	24.1982	24.3423
House	24.0121	24.0553	24.5094
Testimage	25.0625	25.1368	25.5343
Barbara	25.1432	25.3537	25.9977

Table 3.2 PSNR of Different Images Zoomed by a Factor of 4

Image Name	NEDI	iNEDI	Proposed
Boat	25.5981	25.6871	26.1011
Pepper	26.0912	26.1350	26.6182
Bridge	22.1621	22.2812	22.3015
Zelda	30.3118	30.0912	30.3396
Sailboat	24.0765	24.3613	25.6280
Airplane	24.1112	24.1167	24.8267
Baboon	19.5431	19.8318	20.1907
Photo1	17.1012	17.3410	17.8523
City	23.3518	23.7982	24.3423
House	24.0021	24.0553	24.5094
testimage	20.8158	20.8765	21.4112
Barbara	20.9892	21.1023	21.6960



(a)



(b)



(c)



(d)

Figure 3.8 (a)Original Boat Image (b) Boat Image 2 times Zoomed by NEDI (c) Boat Image 2 times Zoomed by iNEDI (d) Boat Image 2 times Zoomed by Proposed Algorithm



(a)



(b)

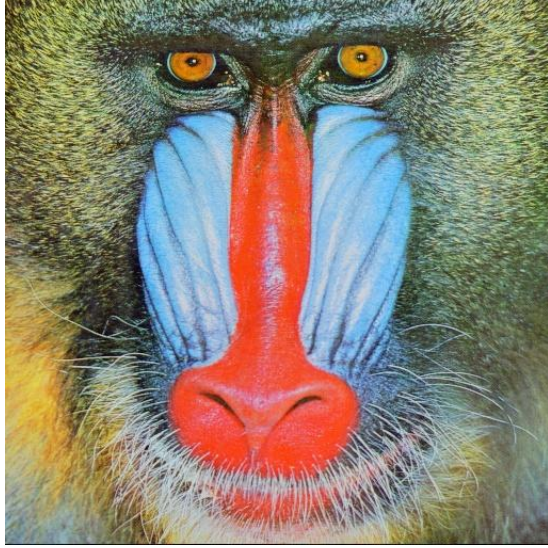


(c)

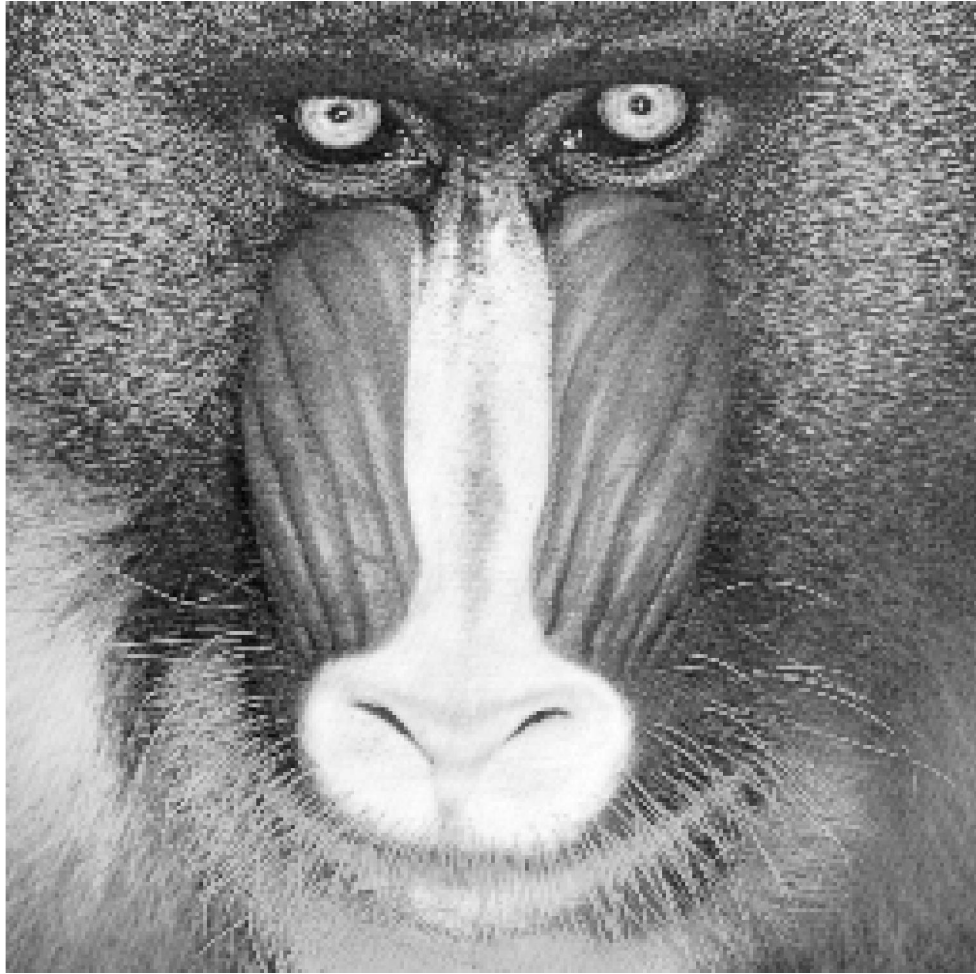


(d)

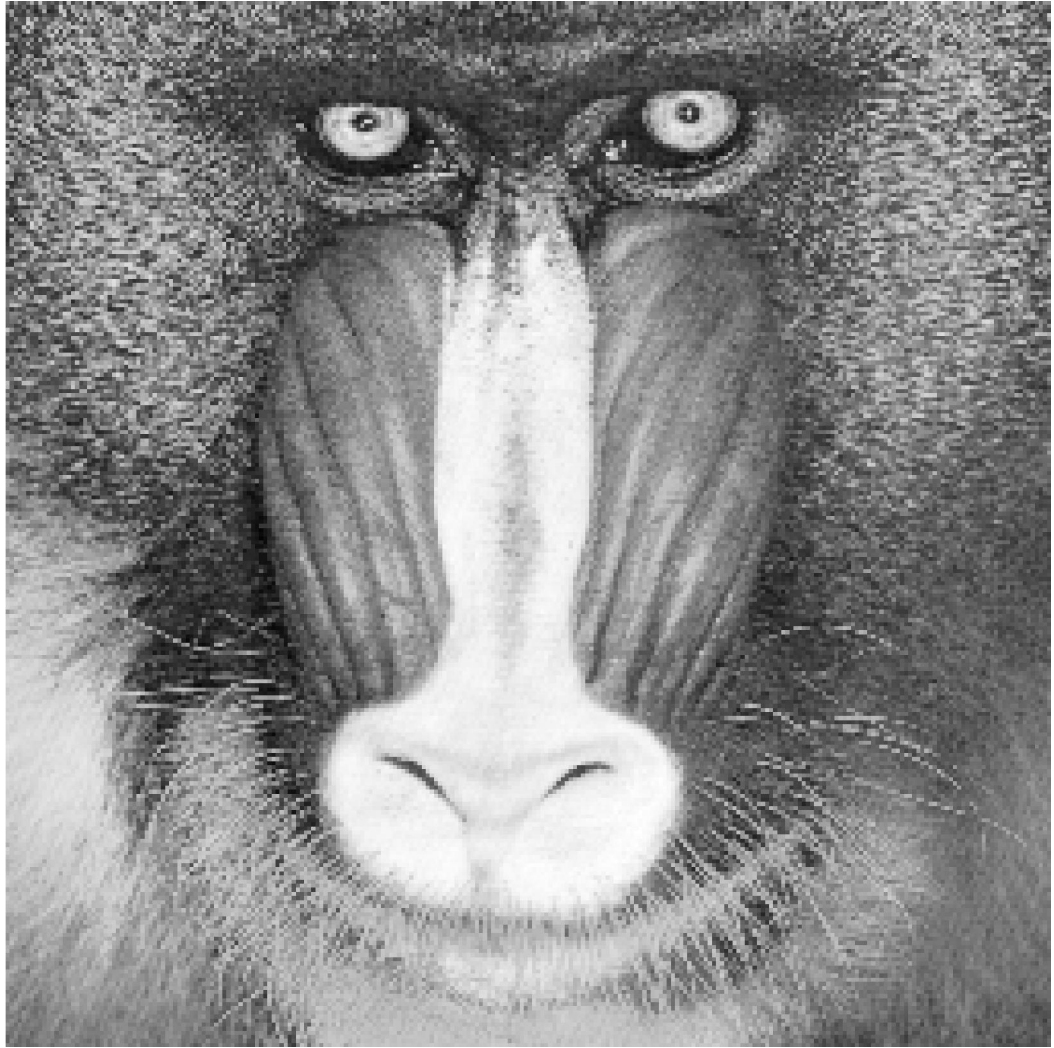
Figure 3.9 (a) Original Airplane Image (b) Airplane Image 4 times Zoomed by NEDI (c) Airplane Image 4 times Zoomed by iNEDI (d) Airplane Image 4 times Zoomed by Proposed Algorithm



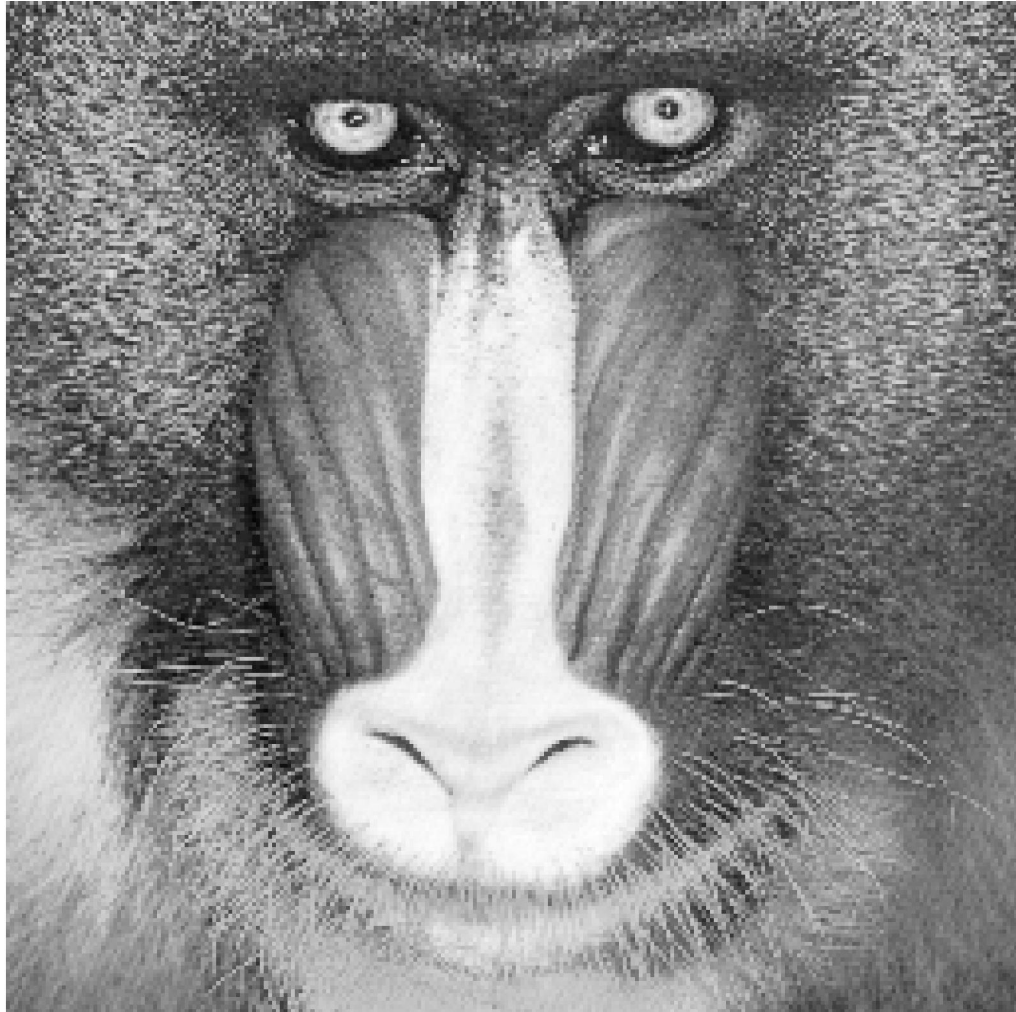
(a)



(b)



(c)



(d)

Figure 3.10 (a) Original Baboon Image (b) Baboon Image 4 times Zoomed by NEDI
(c) Baboon Image 4 times Zoomed by iNEDI (d) Baboon Image 4 times Zoomed by
Proposed Algorithm

Chapter 4 Conclusion and Future Work

Digital images are the part and parcel of our life nowadays. So processing them has also become the need of the hour. Digital image processing is used in editing, printing and is also used to interpret and analyse the sensitive digital data obtained from digital images. The thesis has proposed an algorithm which produces better magnified images in the output as compared to previous standard techniques.

The proposed algorithm works very well for the edges of the image and focus on removing the artifacts occurring on the image. It produces very good result whenever an image is magnified. The proposed algorithm provides maximum PSNR improvement of 0.8 dB over *NEDI* and 0.7 dB over *iNEDI*. But it provides 1 dB less than *MEDI*.

The algorithm attempts to minimize the artifacts that are present in standard magnification techniques. The proposed method concentrates on edges present in the image and works on changing the sharp intensity of the image. The proposed method provides better image quality than existing techniques.

The future work would involve the improvement of the proposed algorithm for the images containing continuous intensity variation. The proposed algorithm can be extended to have four windows like *MEDI* approach.

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